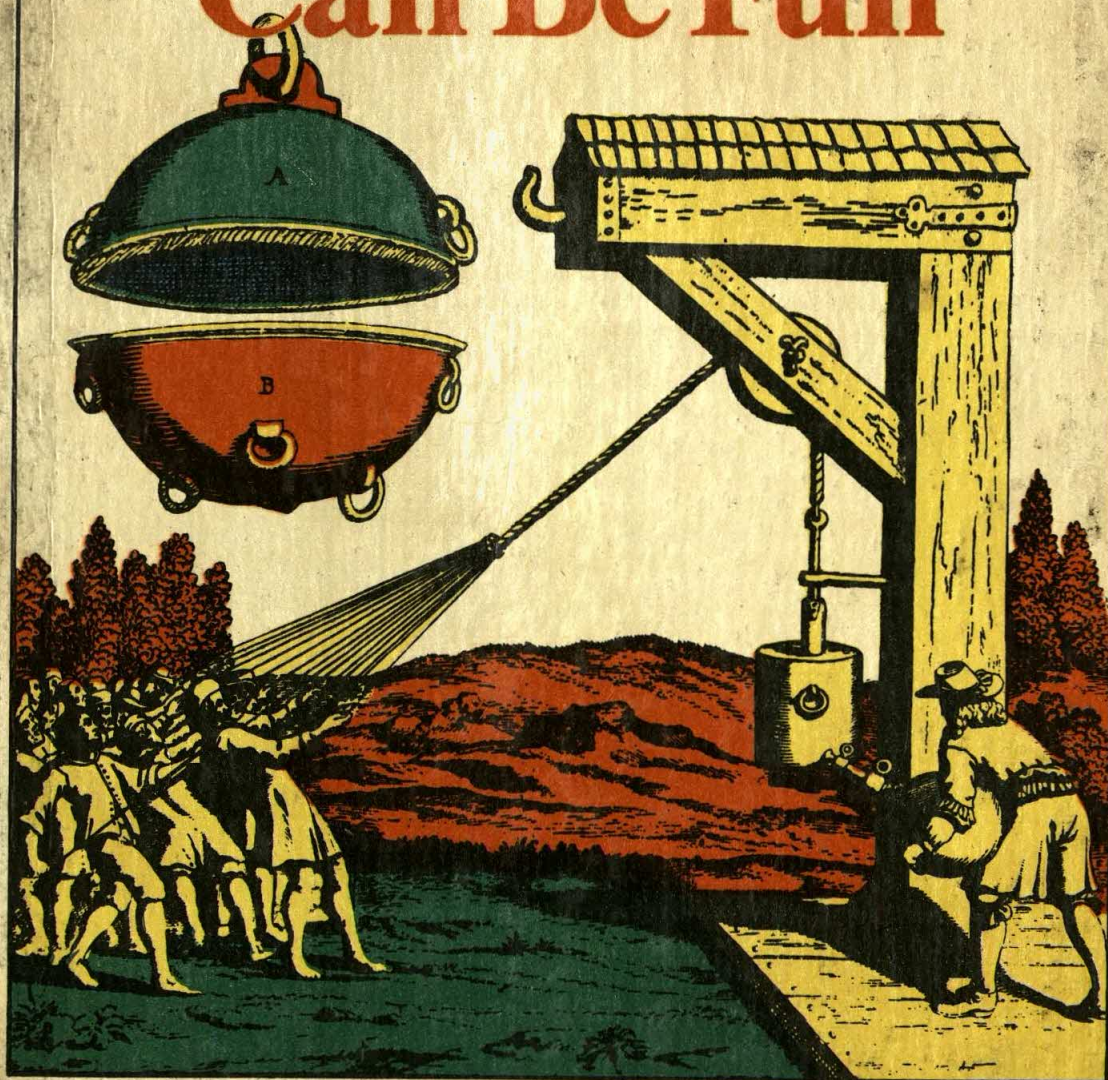


Y. Perelman

Physics Can Be Fun



Y. PERELMAN

Physics
Can Be Fun

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Y. PERELMAN

In 1913 in Russian bookshops appeared a book by the outstanding educationalist Yakov Isidorovich Perelman entitled *Physics for Entertainment*. It struck the fancy of the young who found in it the answers to many of the questions that interested them.

Physics for Entertainment not only had an interesting layout, it was also immensely instructive.

In the preface to the 11th edition Perelman wrote: "The main objective of *Physics for Entertainment* is to arouse the activity of scientific imagination, to teach the reader to think in the spirit of the science of physics and to create in his mind a wide variety of associations of physical knowledge with the widely differing facts of life, with all that he normally comes in contact with." *Physics for Entertainment* was a best seller.

Y. I. Perelman was born in 1882 in the town of Byelostok (now in Poland). In 1909 he obtained a diploma of forester from the St.

Petersburg Forestry Institute. After the success of *Physics for Entertainment* Perelman set out to produce other books, in which he showed himself to be an imaginative popularizer of science. Especially popular were *Arithmetics for Entertainment*, *Mechanics for Entertainment*, *Geometry for Entertainment*, *Astronomy for Entertainment*, *Figures for Fun*, *Physics Everywhere*, and *Tricks and Amusements*. Today these books are known to every educated person in the Soviet Union.

He has also written several books on interplanetary travel (*Interplanetary Journeys*, *On a Rocket to Stars*, *World Expanses*, etc.). The great scientist K. E. Tsiolkovsky thought highly of the talent and creative genius of Perelman. He wrote of him in the preface to *Interplanetary Journeys*: "The author has long been known by his popular, witty and quite scientific works on physics, astronomy and mathematics, which are moreover

Y. Perelman

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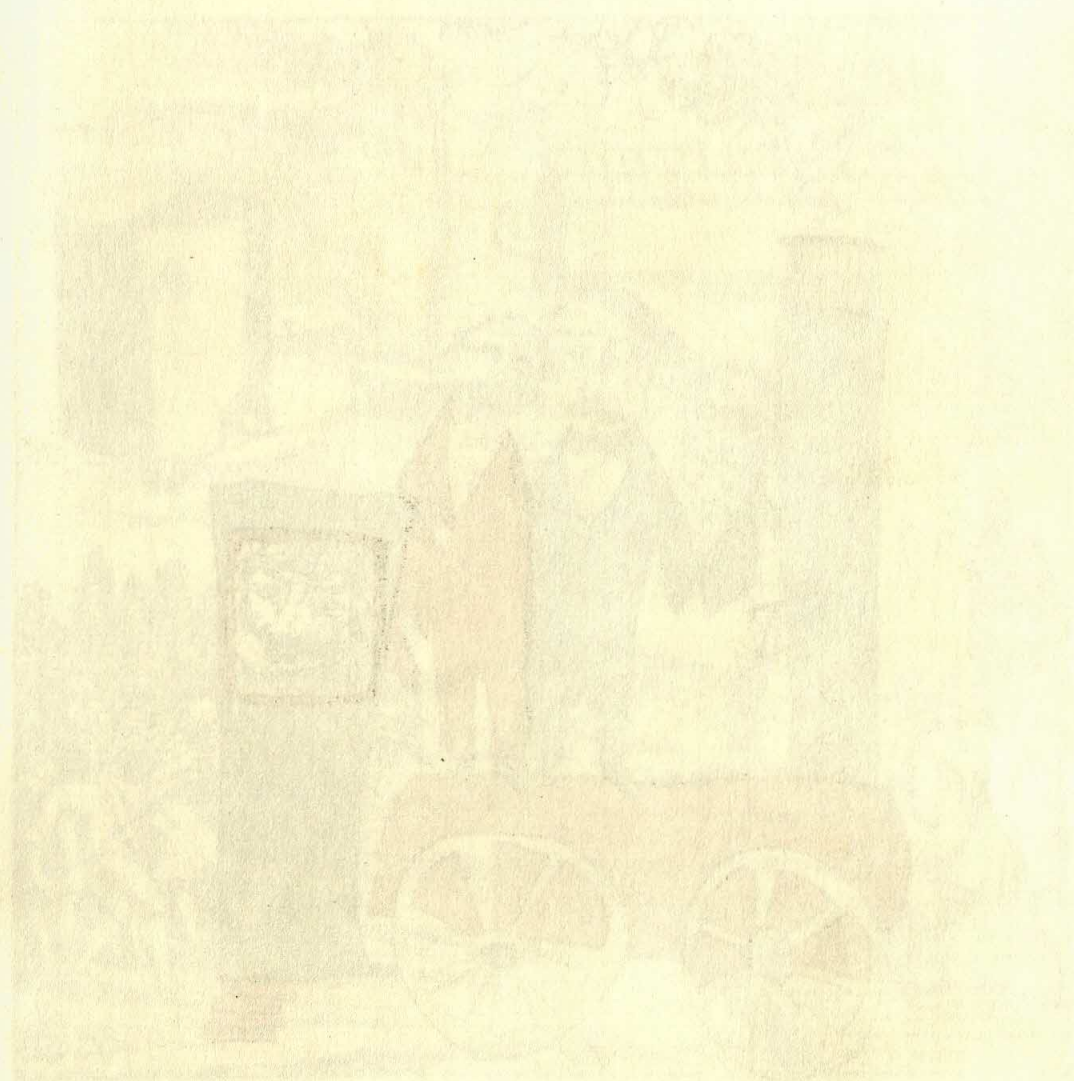
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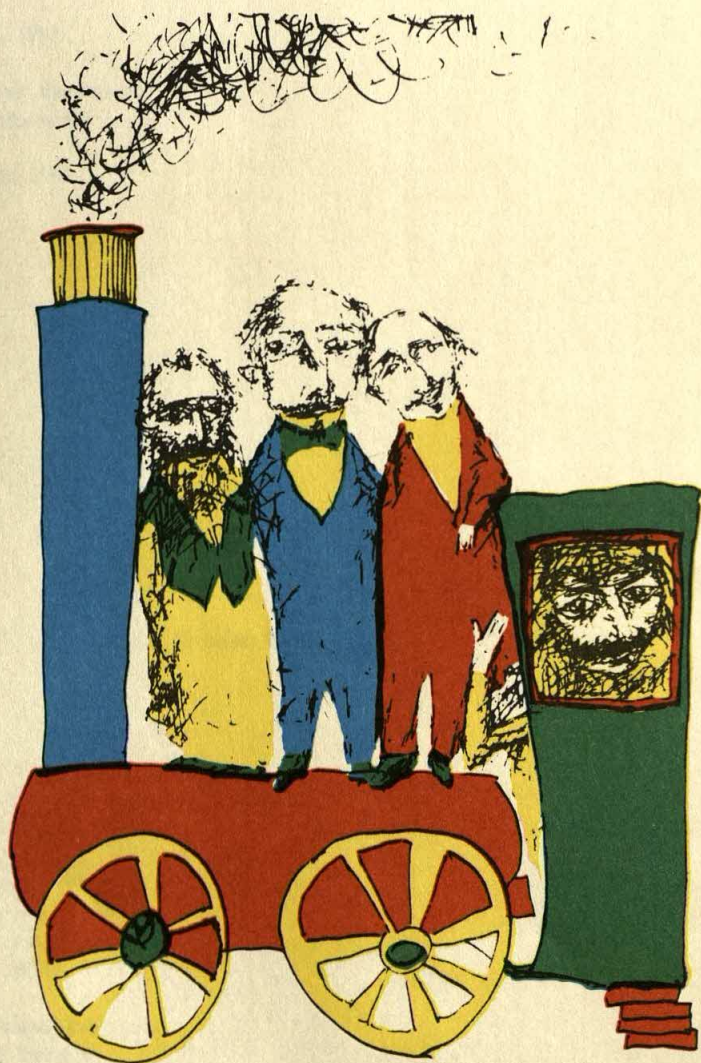
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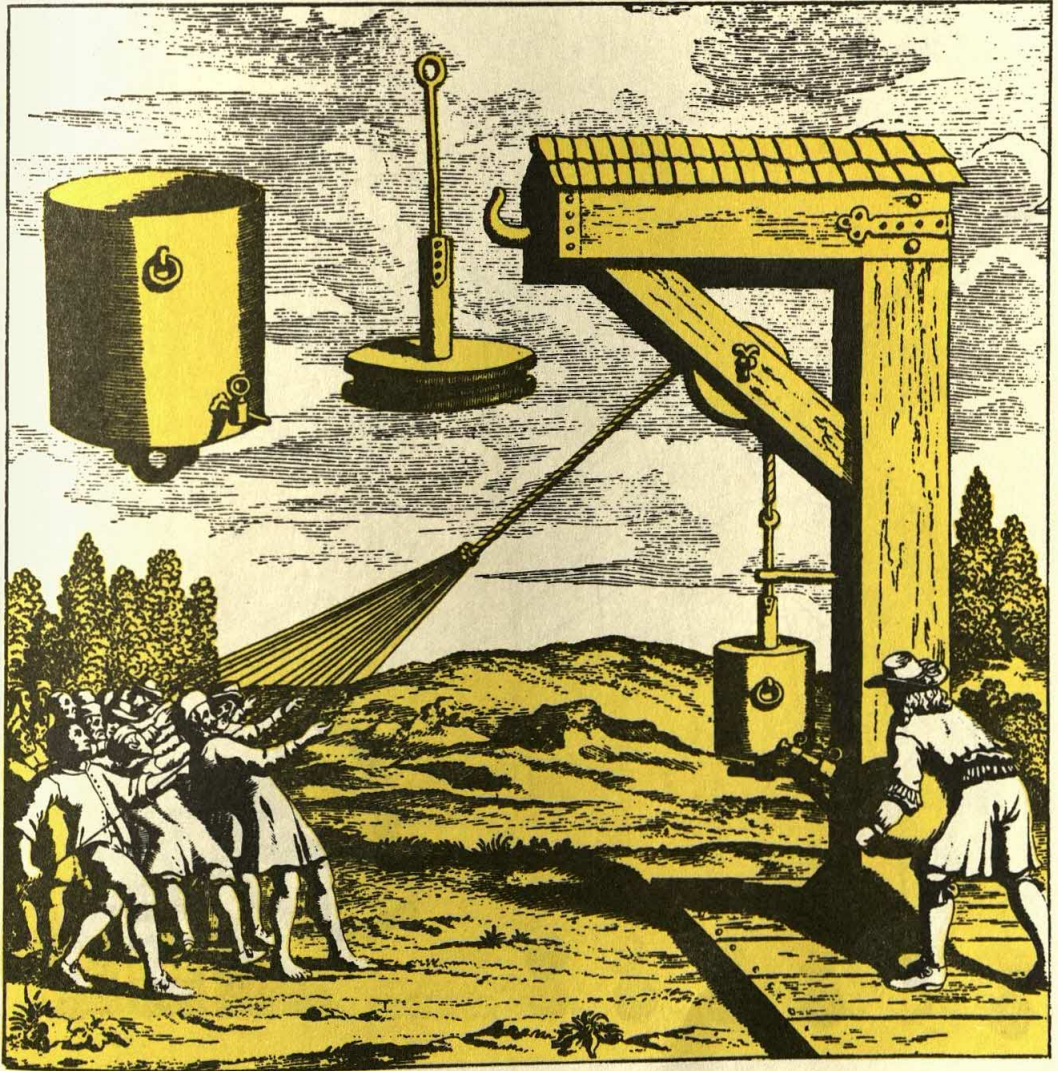
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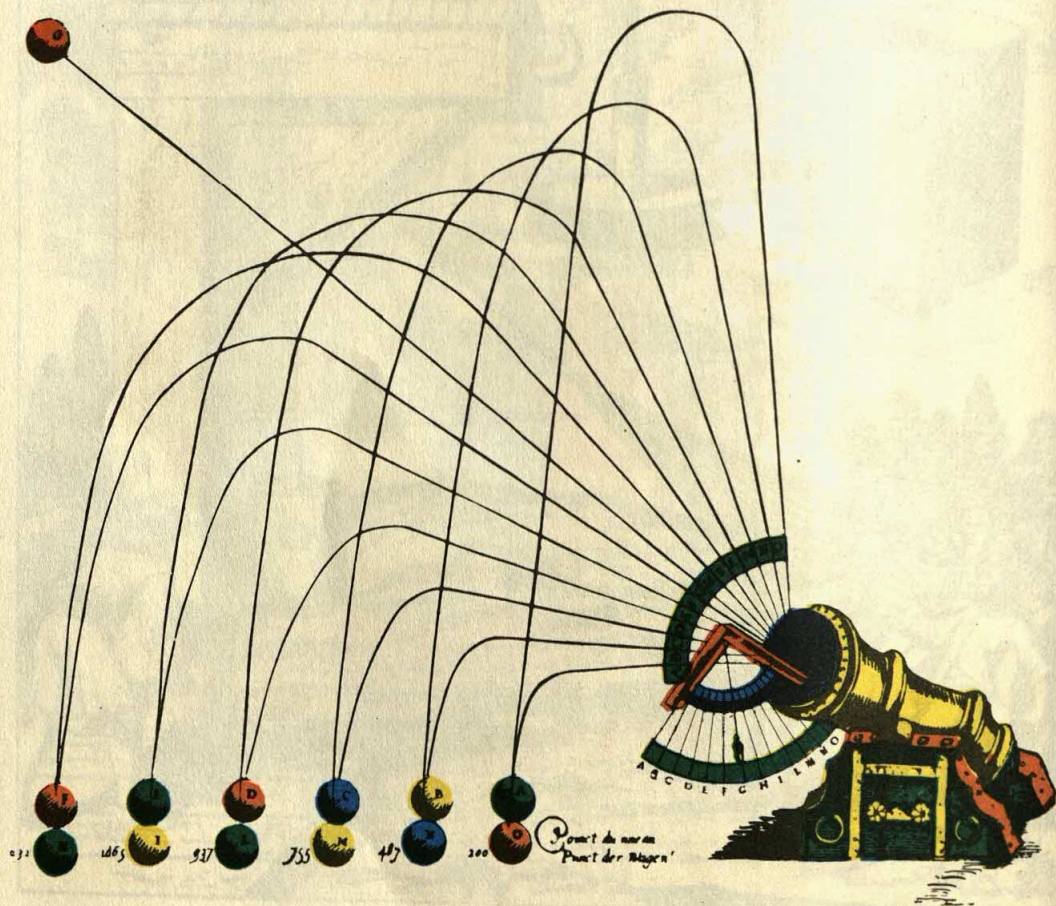
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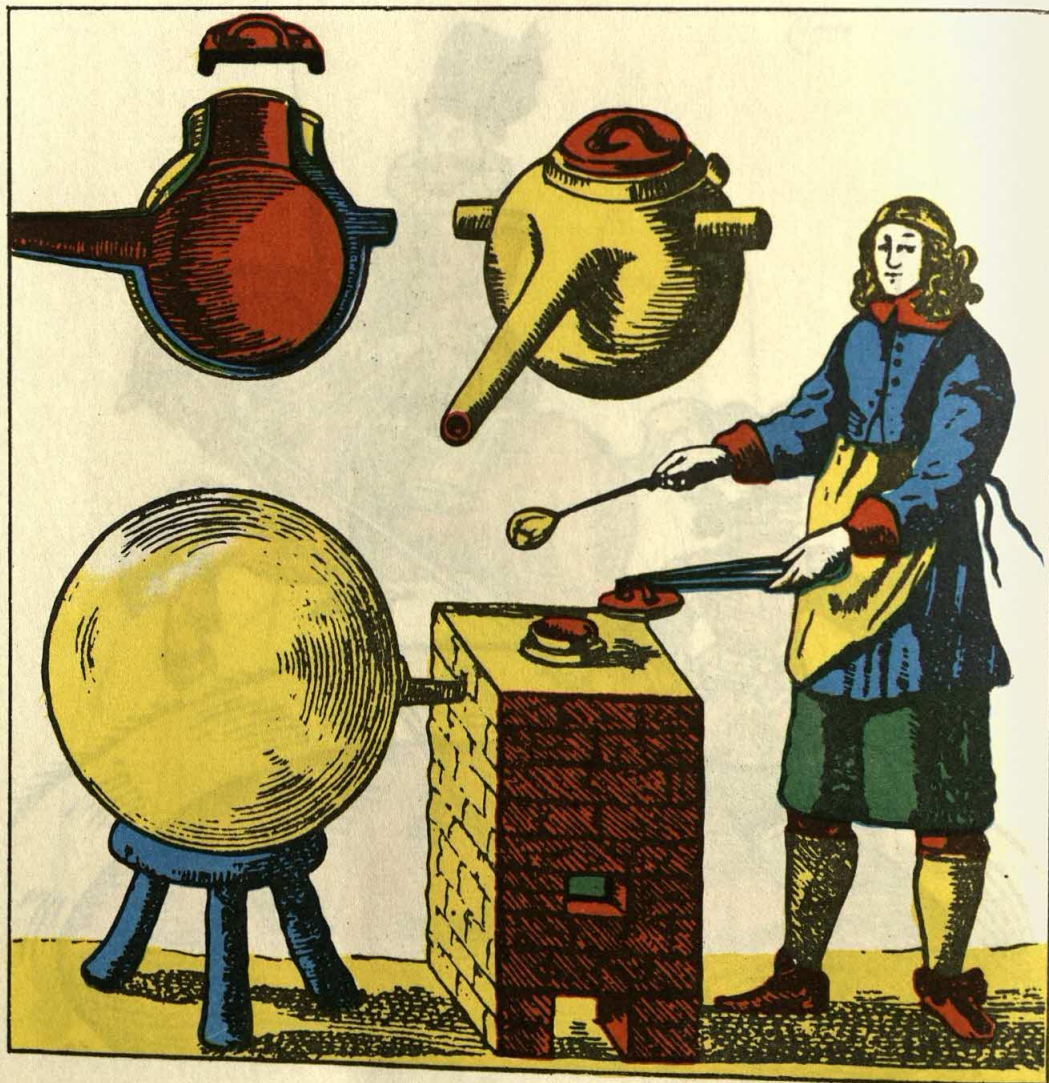
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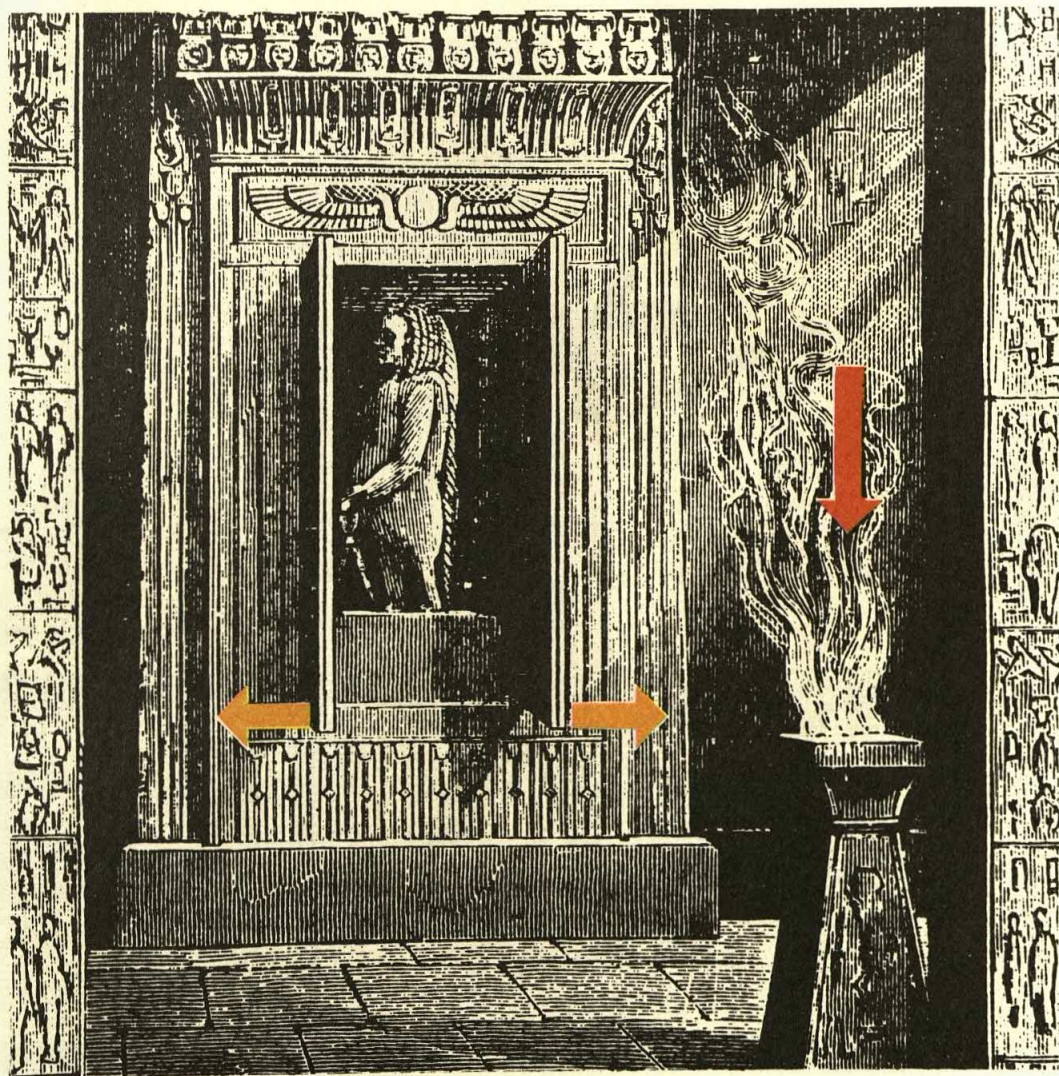


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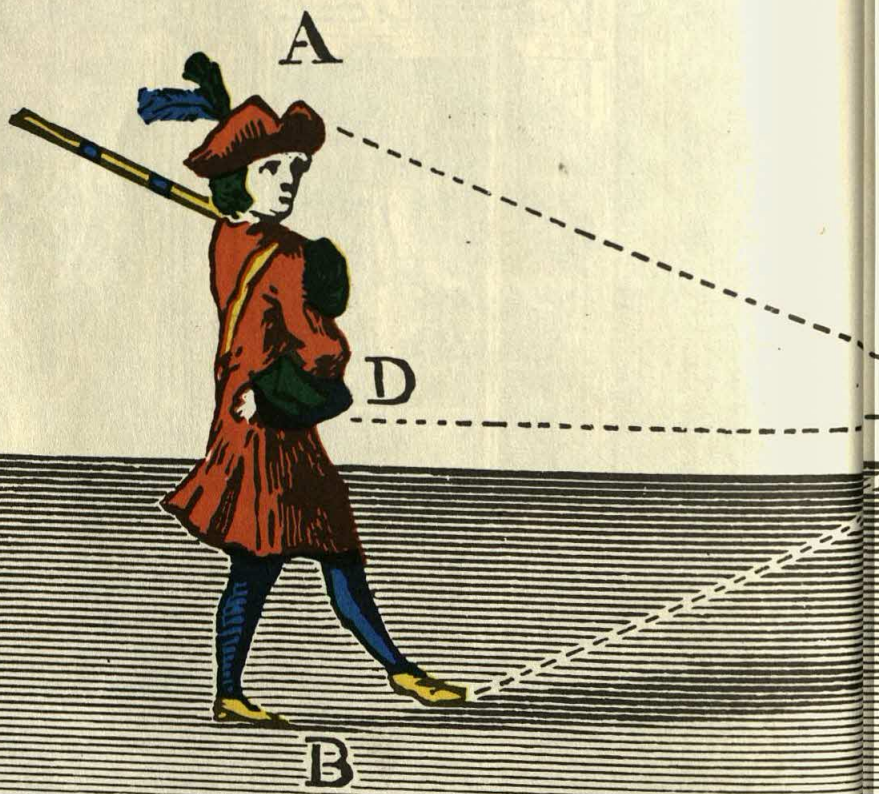
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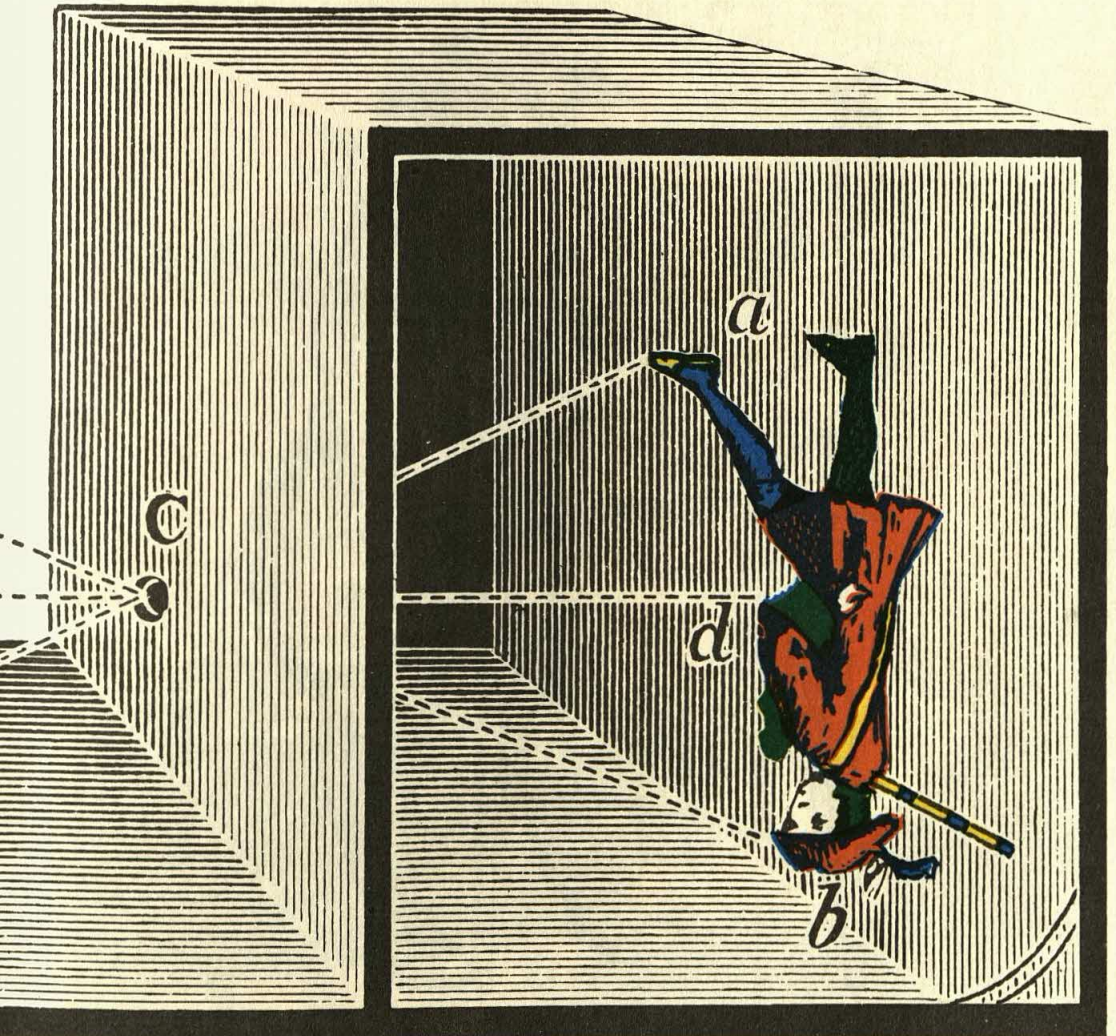
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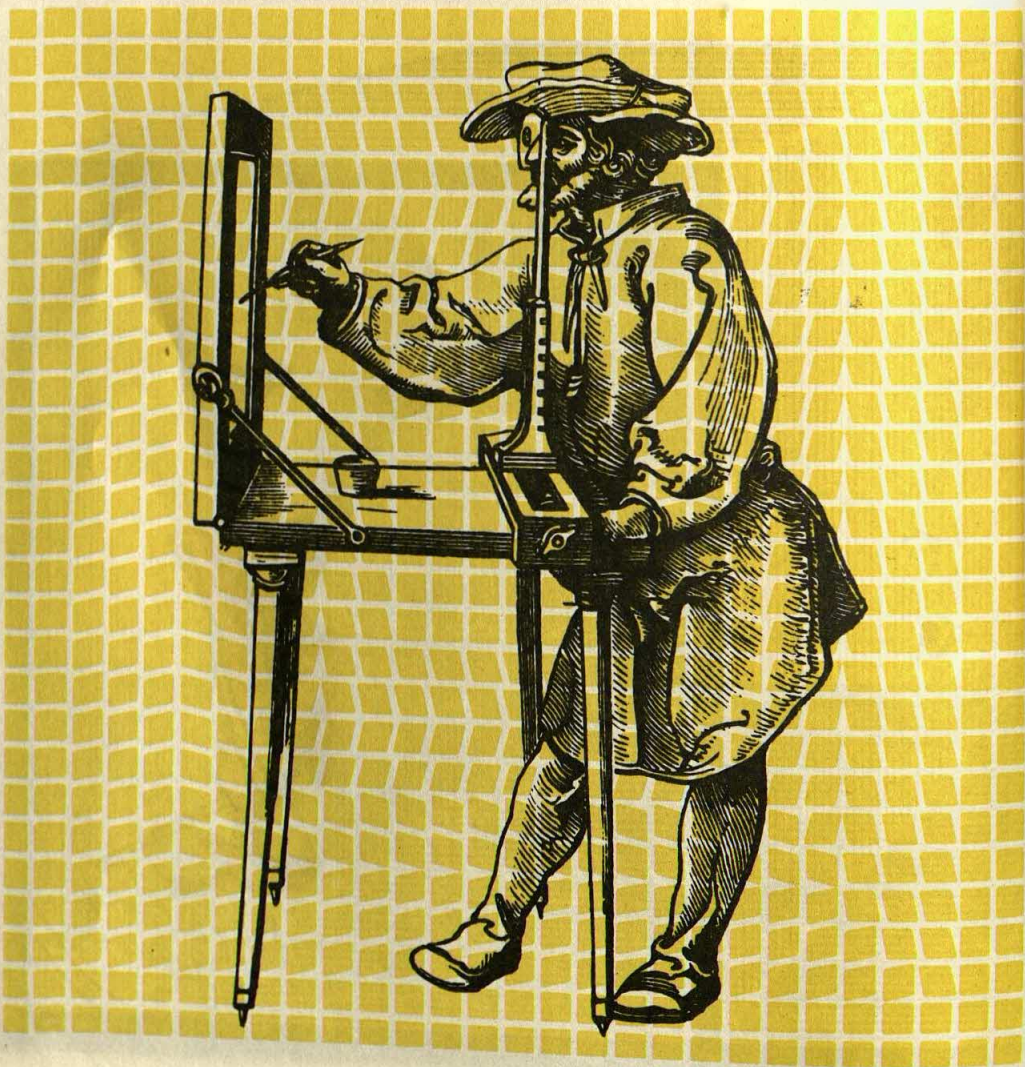




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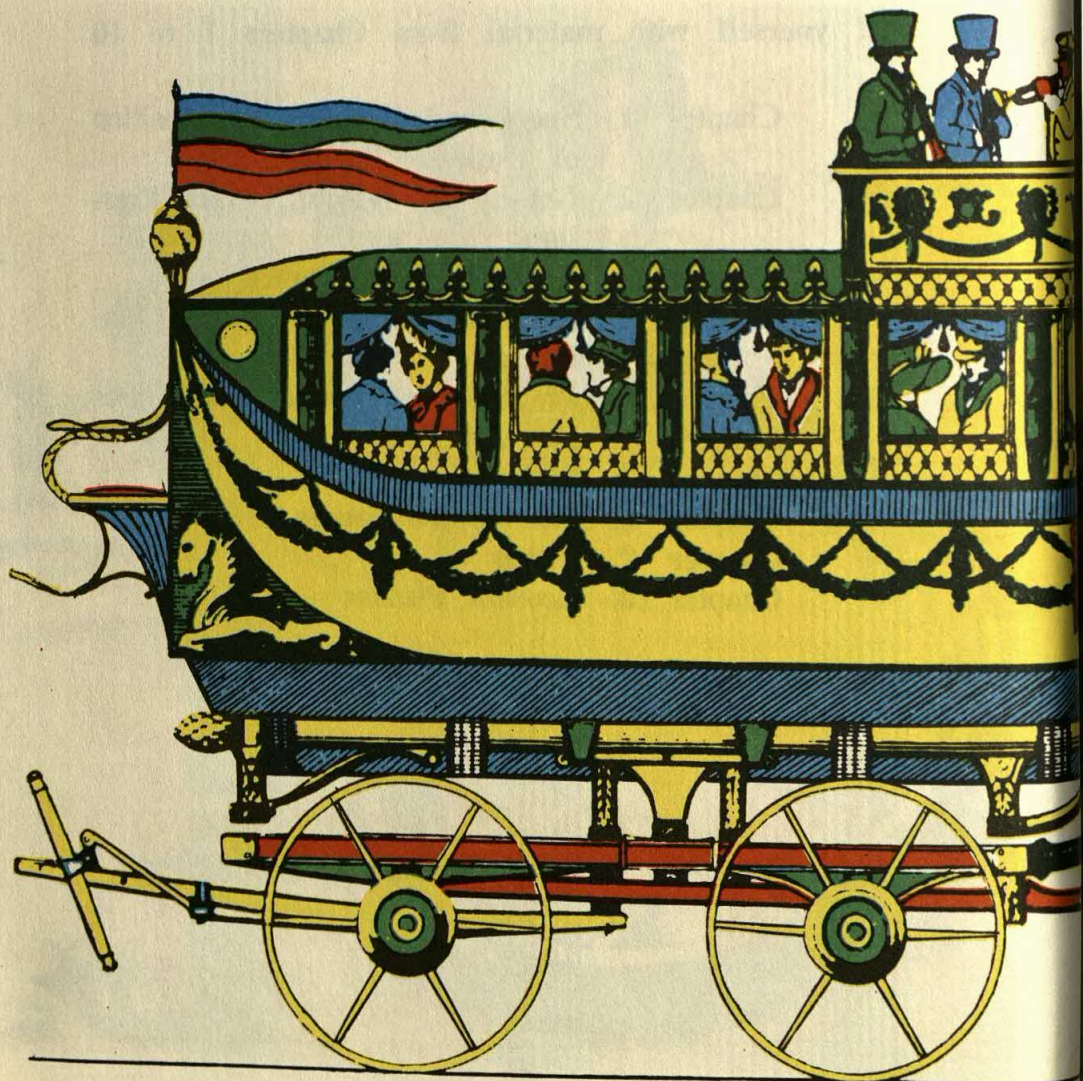
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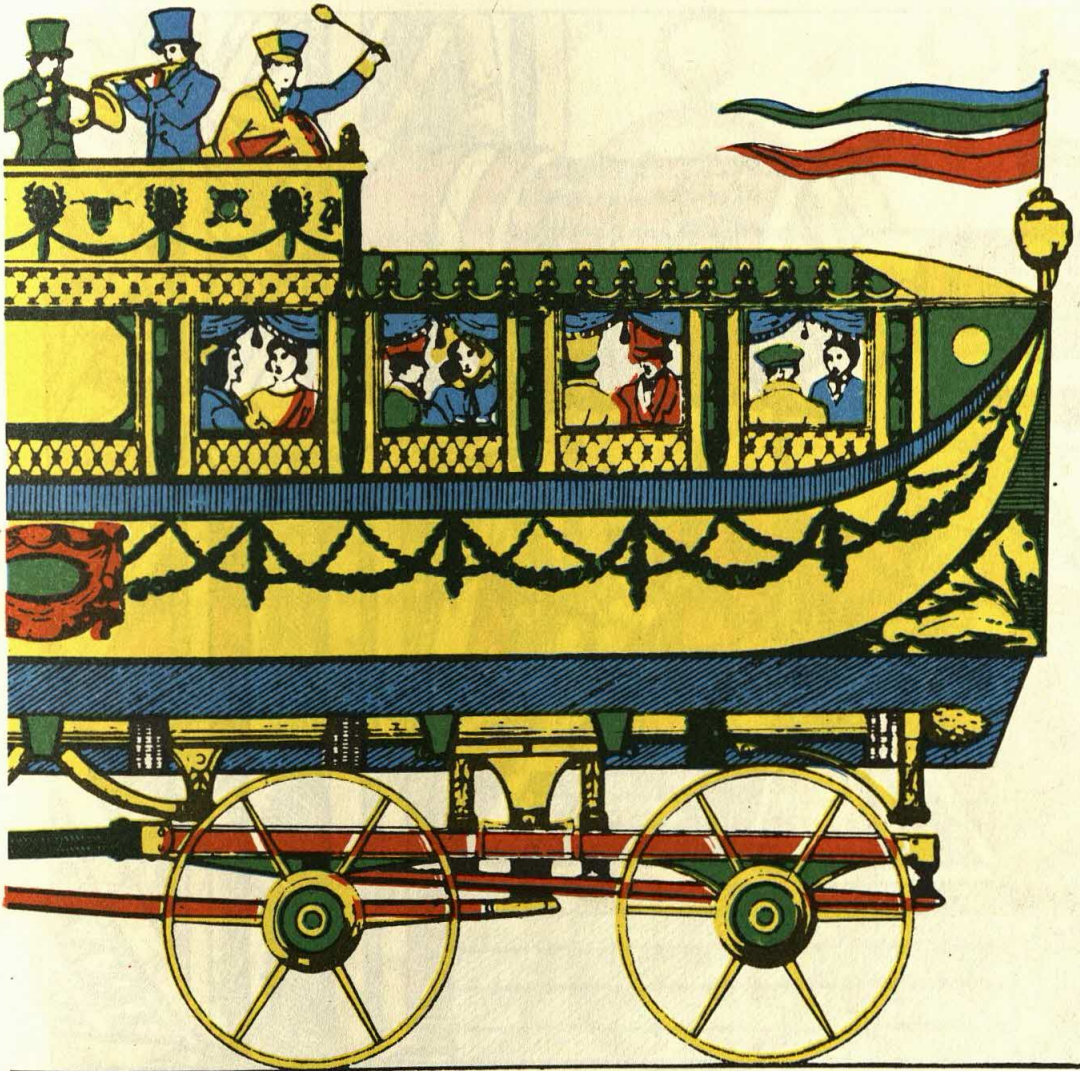
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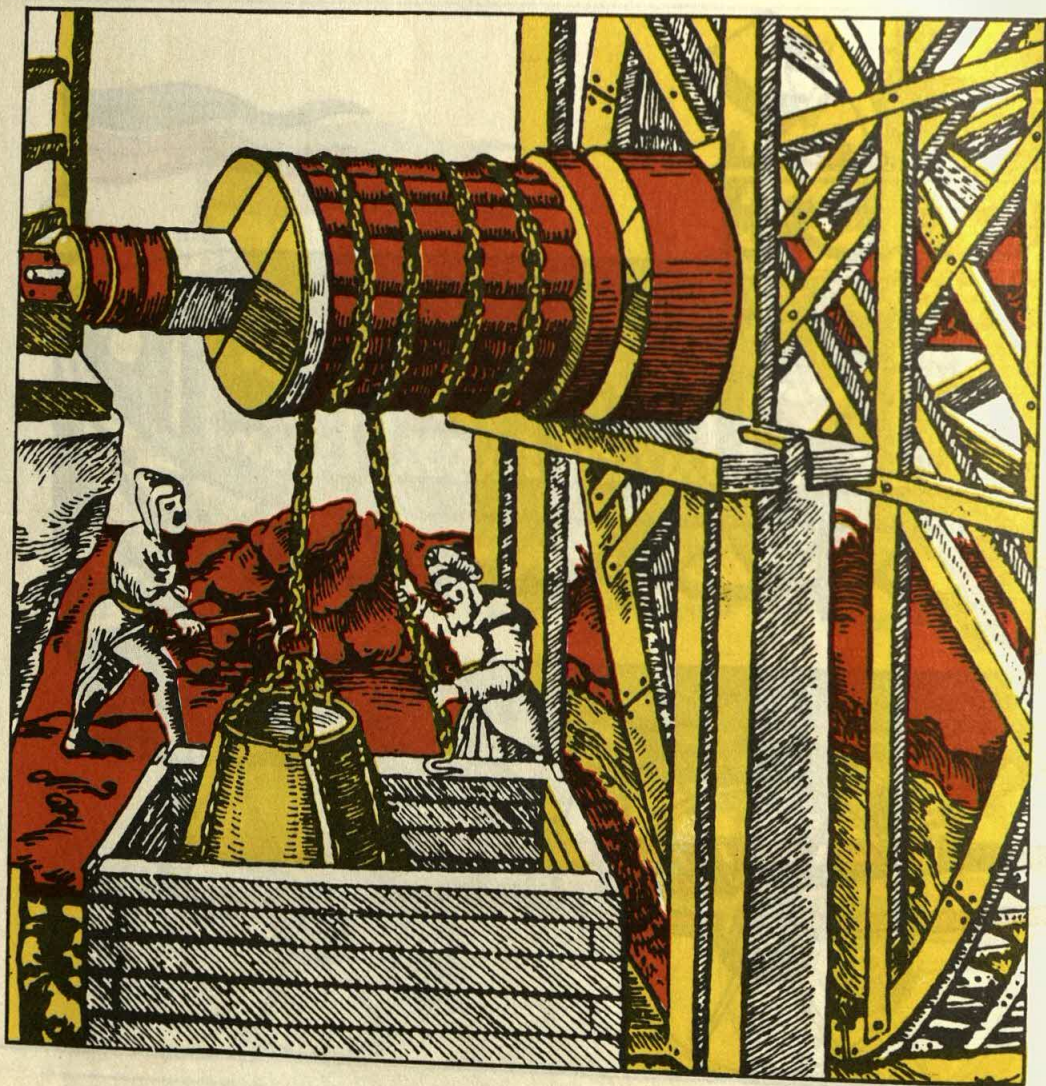
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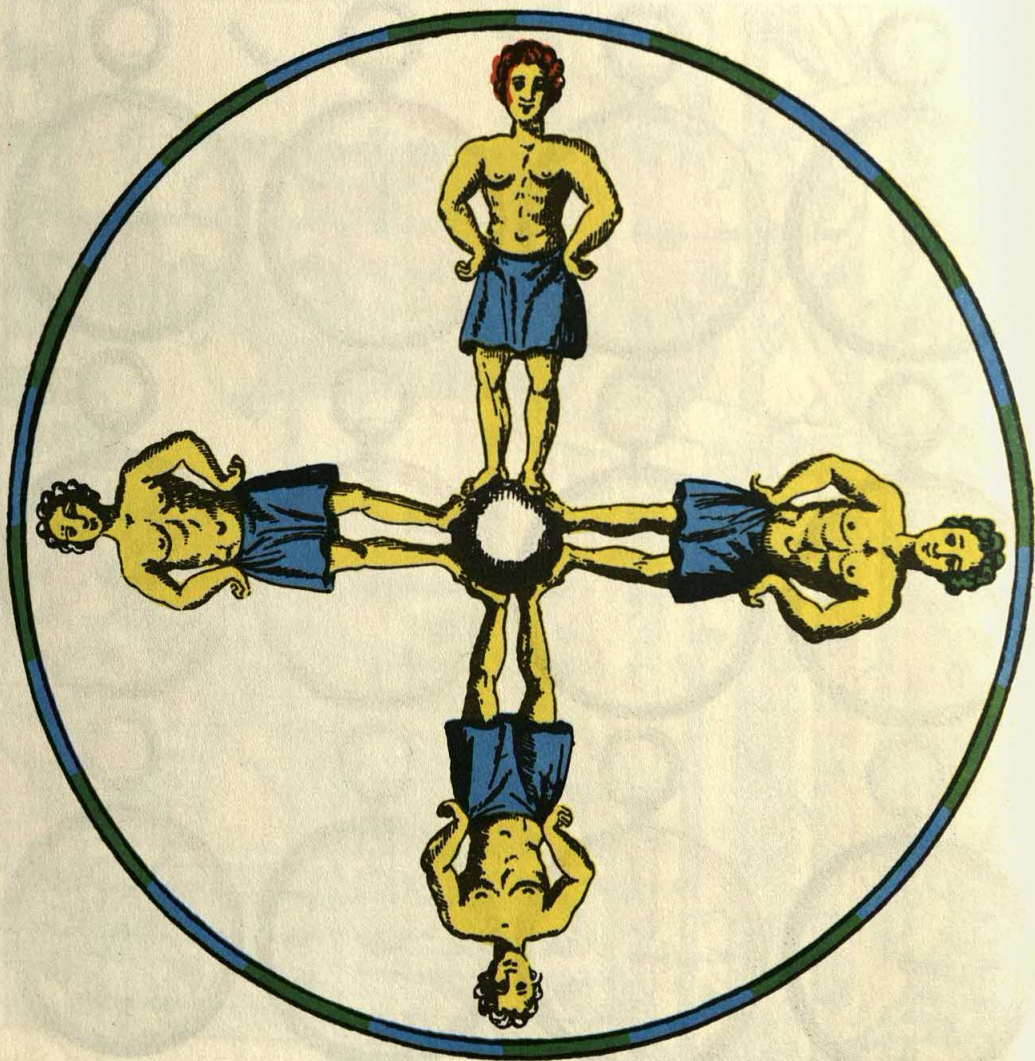


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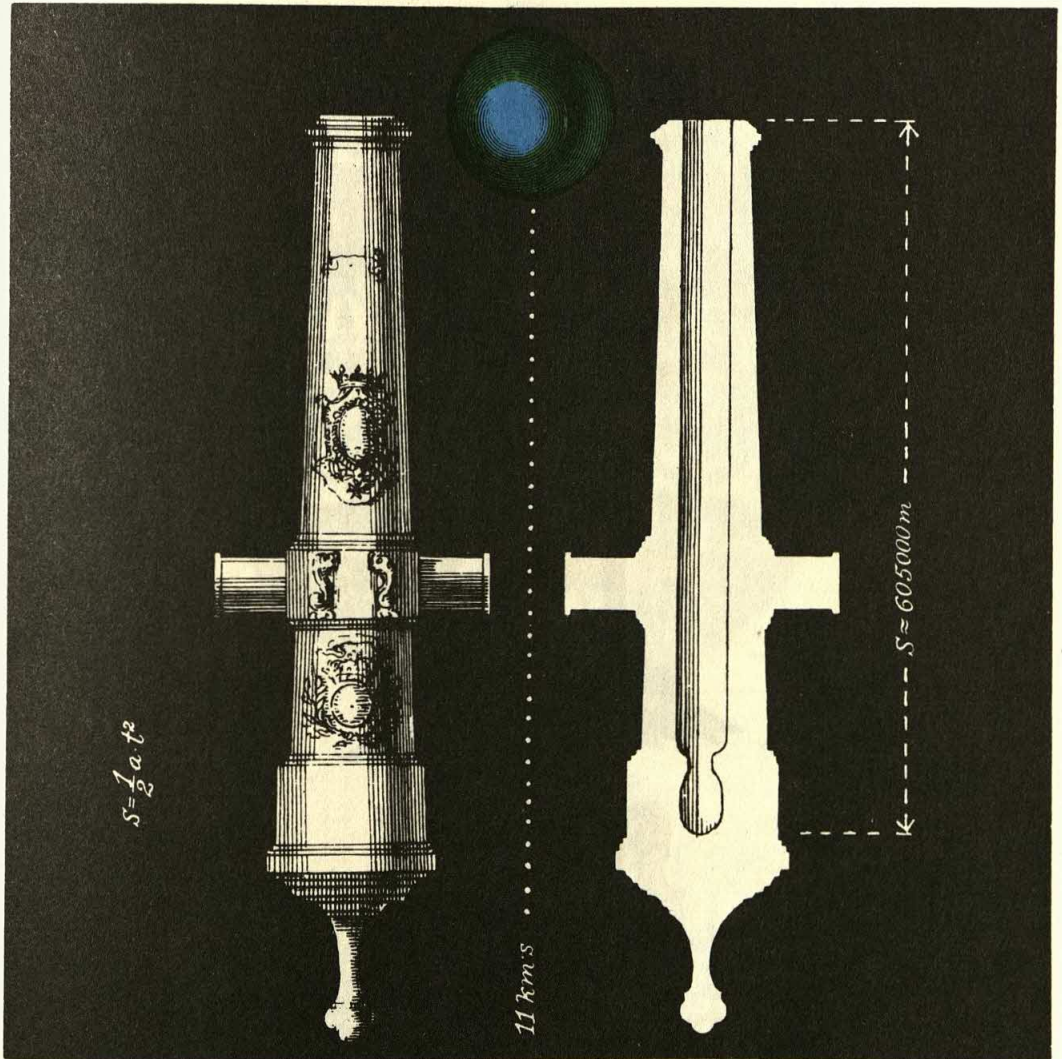


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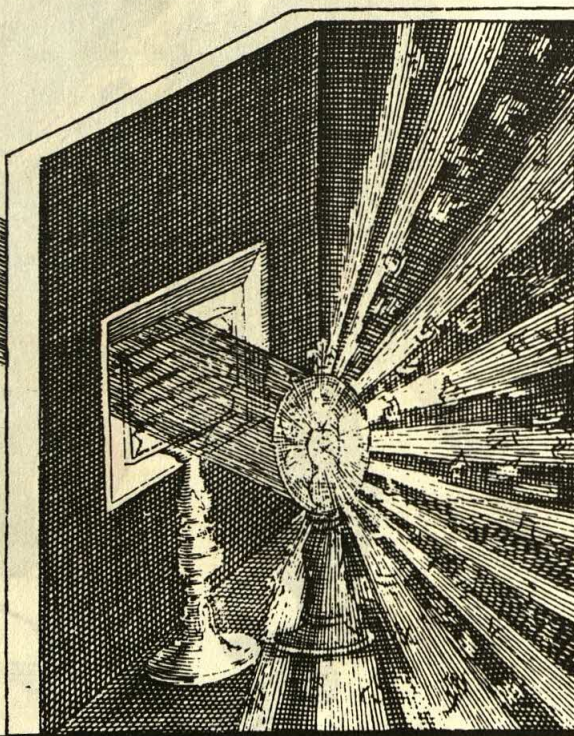
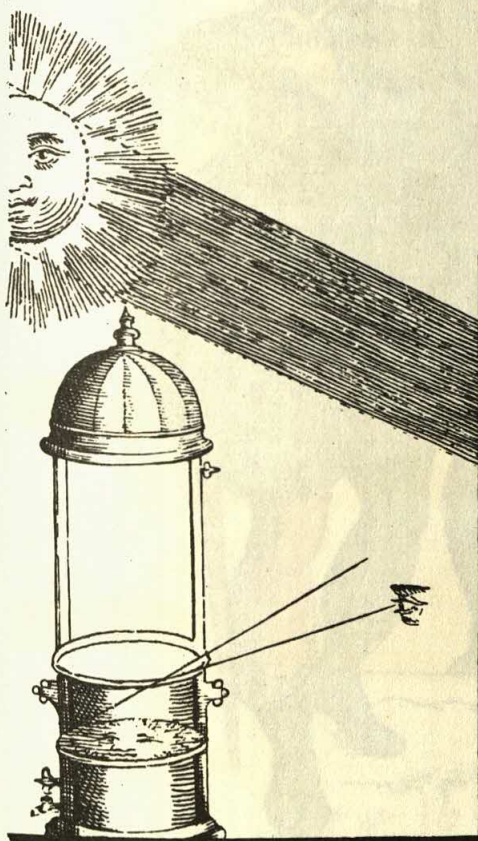
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Foreword

Perelman's *Physics for Entertainment* owes its wide popularity to the rare talent of its author who was able to single out and present in an entertaining form ordinary facts and phenomena that have a deep physical meaning.

The aim of the book is not so much to give you some fresh knowledge, as to help you "learn what you already know". In other words, the idea is to brush up and enliven your basic knowledge of physics, and to teach you how to apply it in various ways. To achieve this purpose, conundrums, brain-teasers, entertaining anecdotes and stories, amusing experiments, paradoxes and unexpected comparisons—all dealing with physics and based on everyday experience and science fiction—are included. The author quotes extensively from Jules Verne, H. G. Wells, Mark Twain and other writers, because besides providing entertainment, the fantastic experiments these writers describe may well serve as instructive illustrations at physics classes.

On the other hand, you will find very little in the way of parlour tricks or spectacular experiments. The book seeks to stimulate your thinking along scientific lines and to amass associations with a variety of things from everyday life. This English-language edition is a translation from the 21st Russian edition of *Physics for Entertainment*, Book 1 and Book 2. Chapters from 11th to 20th are Book 2. Although the two halves of the book are essentially independent and can be read in any sequence, the last ten chapters are, by and large, meant for the more advanced reader.

Perelman once noted that *Physics for Entertainment* has been written not to leave an inquisitive mind satisfied. On the contrary, its task is "to whet thirst for knowledge, to evoke desire for further reading".

Chapter **Speed and Velocity Composition of Motions** 1

HOW FAST DO WE MOVE?

When we travel on foot, we are rather modest movers: on average we cover only 1.5 m in a second. This is somewhat faster than the motion of water in most plain-land rivers, but slower than the motion of the air in a moderate wind (5 metres per second). True, as compared with a snail, which crawls at only 1.5 millimetres per second, a man is a speedster: he is 1000 times swifter than it! But if he were to race other animals, he would lose. Even a fly is three times faster than a pedestrian.

But even relatively simple devices, such as skates, give man the upper hand over many of his "competitors". A skilled skater can go faster than 10 metres per second, and so only few animals can pass him. A man on horseback can gallop at 15-20 metres per second and can literally "outrun" the wind, because a strong wind rarely blows at more than 20 metres per second. Thus the metaphor "to go like the wind" is not very much of exaggeration when applied to fast horses. A good bloodhound races even faster (25 metres per second). Birds are generally swift fliers.

The machines man has invented make him the fastest living thing on earth. As far back as 1896 the record achieved at the Paris-Brest car rally was 20 kilometres per hour, that is, about 6 metres per second. At the time this was considered to be a triumph of technology. But a year later cars were moving twice as fast, and at the 1909 Paris-Madrid race cars were moving five times faster – 108 kilometres per hour, or 30 metres per second. Travelling in a car, an express train or an airplane, we can easily outdistance a horse, a dog, or a swallow, and even a hurricane, which travels at more than 30 metres per second. To have some appreciation of the air speed in a hurricane, note that if you throw a stone with all your might during the first second it will travel at about half the speed of the hurricane, that is at about 15 metres per second.

A THOUSANDTH OF A SECOND

For us humans, a thousandth of a second is nothing from the angle of time. Time intervals of this order have only started to crop up in some of our practical work. When people used to reckon the time according to the sun's position in the sky, or to the length of a shadow, they paid no heed to minutes, considering

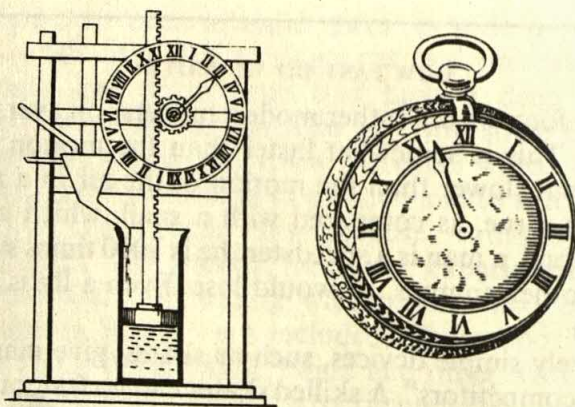


Fig. 1

An ancient water clock (left) and an old pocket-watch (right).
Note that neither has the minute hand

them even unworthy of measurement. The tenor of life in ancient times was so unhurried that the timepieces of the day, i. e. the sun-dials, water clock, sand-glasses and the like, had no special divisions for minutes (Fig. 1). The minute hand first appeared only in the early 18th century, while the second sweep came into use a mere 150 years ago.

But back to our thousandth of a second. What do you think could happen in this space of time? Very much, indeed! True, an ordinary train would cover only some 3 cm. But sound would already fly 33 cm and a plane half a metre. In its orbital movement around the sun, the earth would travel 30 metres. Light would cover the great distance of 300 km.

The minute organisms around us wouldn't think the thousandth of a second so negligible an amount of time, if they could think of course. For insects, for example, it is quite a tangible interval. In the space of a second a mosquito flaps its wings 500 to 600 times. Consequently in the space of a thousandth of a second it would manage either to raise its wings or lower them.

We can't move our limbs as fast as insects. The fastest thing we can do is to

blink our eyelids. This takes place so quickly that we fail even to notice transient obscurity of our field of vision. Few know, though, that this movement, "in the twinkling of an eye", which has become synonymous for incredible rapidity, is quite slow if measured in thousandths of a second. A full "twinkling of an eye" averages, as exact measurement has disclosed, two-fifths of a second, which gives us 400 thousandths of a second. This process can be divided into the following stages: firstly, the dropping of the eyelid which takes 75-90 thousandths of a second; secondly, the closed eyelid in a state of rest, which takes up 130-170 thousandths; and, thirdly, the raising of the eyelid which takes about 170 thousandths.

As you see, this one "twinkling of an eye" is quite a considerable time interval, during which the eyelid even manages to take a rest. If we could photograph mentally impressions lasting the thousandths of a second, we would catch in the "twinkling of an eye" two smooth motions of the eyelid, separated by a period during which the eyelid would be at rest.

Generally speaking, the ability to do such a thing would completely transform the picture we get of the world around us and we would see the odd and curious things that H. G. Wells described in his *New Accelerator*. This story relates of a man who drank a queer mixture which caused him to see rapid motions as a series of separate static phenomena. Here are a few extracts.

"Have you ever seen a curtain before a window fixed in that way before?"

"I followed his eyes, and there was the end of the curtain, frozen, as it were, corner high, in the act of flapping briskly in the breeze.

"No," said I, "that's odd."

"And here," he said, and opened the hand that held the glass. Naturally I winced, expecting the glass to smash. But so far from smashing it did not even seem to stir; it hung in mid-air motionless. 'Roughly speaking,' said Gibberne, 'an object in these latitudes falls 16 feet in a second. This glass is falling 16 feet in a second now. Only you see, it hasn't been falling yet for the hundredth part of a second.* That gives you some idea of the pace of my Accelerator.' And he waved his hand round and round, over and under the slowly sinking glass.

"Finally he took it by the bottom, pulled it down and placed it very carefully on the table. 'Eh?' he said to me, and laughed....

* Note also that in the first hundredth of the first second of its downward flight a body, the glass in this case, covers not the hundredth part of the distance, but the 10,000th part (according to the formula $S = gt^2/2$). This is only 0.5 mm and in the first thousandth of a second it would be only 0.005 mm.

"I looked out of the window. An immovable cyclist, head down and with a frozen puff of dust behind his driving-wheel, scorched to overtake a galloping *char-à-banc* that did not stir....

"We went out by his gate into the road, and there we made a minute examination of the statuesque passing traffic. The top of the wheels and some of the legs of the horses of this *char-à-banc*, the end of the whip lash and the lower jaw of the conductor (who was just beginning to yawn) were perceptibly in motion, but all the rest of the lumbering conveyance seemed still. And quite noiseless except for a faint rattling that came from one man's throat! And as parts of this frozen edifice there were a driver, you know, and a conductor, and eleven people!...

"A purple-faced little gentleman was frozen in the midst of a violent struggle to refold his newspaper against the wind; there were many evidences that all these people in their sluggish way were exposed to a considerable breeze, a breeze that had no existence so far as our sensations went....

"All that I had said and thought, and done since the stuff had begun to work in my veins had happened, so far as those people, so far as the world in general went, in the twinkling of an eye...."

Would you like to know the shortest stretch of time that scientists can measure today? Whereas at the beginning of this century it was only the 10,000th of a second, today the physicist can measure the 10,000,000,000th of a second; this is about as many times less than a second as a second is less than 300 years!

THE SLOW-MOTION CAMERA

When H. G. Wells was writing his story, scarcely could he have ever thought he would see anything of the like. However he did live to see the pictures he had once imagined, thanks to what has been called the slow-motion camera. Instead of 24 shots a second, as ordinary motion-picture cameras do this camera makes many times more. When a film shot in this way is projected onto the screen with the usual speed of 24 frames a second, you see things taking place much more slowly than normally, for instance, high jumps seem unusually smooth. The more complex types of slow-motion cameras will almost simulate H. G. Wells' world of fantasy.

WHEN DO WE MOVE AROUND THE SUN FASTER?

Paris newspapers once carried an ad offering a cheap and pleasant way of travelling for the price of 25 centimes. Several simpletons mailed this sum. Each received a letter of the following content:

“Sir, rest at peace in bed and remember that the earth turns. At the 49th

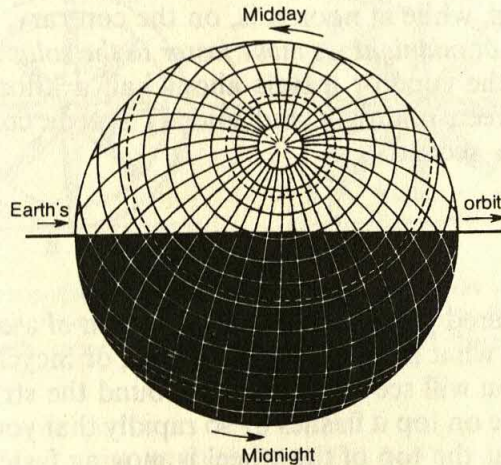


Fig. 2

On the dark side we move around the sun faster than on the sunlit side

parallel, that of Paris, you travel more than 25,000 km a day. Should you want a nice view, draw your curtain aside and admire the starry sky.”

The man who sent those letters was found and tried for fraud. The story goes that after quietly listening to the verdict and paying the fine demanded, the culprit struck a theatrical pose and solemnly declared, repeating Galileo’s famous words: “It turns.”

He was right, to some extent. After all, every inhabitant of the globe “travels” not only as the earth rotates, he is transported with still greater speed as the earth revolves around the sun. *Every second* this planet of ours, with us and everything else on it, moves 30 km in space, turning meanwhile on its axis. And thereby hangs a question not devoid of interest: When do we move around the sun faster? In the daytime or at night?

A bit of a puzzler, isn’t it? After all, it’s always day on one side of the earth and night on the other. But don’t dismiss my question as senseless. Note that I’m asking you not when the earth itself moves faster, but when we, who live

on the earth, move faster in the heavens. And that is another pair of shoes.

In the solar system we make two motions; we revolve around the sun and simultaneously turn on the earth's axis. The two motions add, but with different results, depending whether we are on the daylit side or on the nightbound one.

Figure 2 shows you that at midnight the speed of rotation is *added* to that of the earth's translation, while at noon it is, on the contrary, *subtracted* from the latter. Consequently, *at midnight we move faster in the solar system than at noon*. Since any point on the equator travels about half a kilometre a second, the difference there between midnight and midday speeds comes to as much as a whole kilometre a second.

THE CART-WHEEL RIDDLE

Attach a strip of coloured paper to the side of the rim of a cart-wheel or bicycle tire, and watch to see what happens when the cart, or bicycle, moves. If you are observant enough, you will see that near the ground the strip of paper appears rather distinctly, while on top it flashes by so rapidly that you can hardly spot it.

Doesn't it seem that the top of the wheel is moving faster than the bottom? And when you look at the upper and lower spokes of the moving wheel of a carriage, wouldn't you think the same? Indeed, the upper spokes seem to merge into one solid body, whereas the lower spokes can be made out quite distinctly.

Incredibly enough, *the top of the rolling wheel does really move faster than the bottom*. And, though seemingly unbelievable, the explanation is a pretty simple one. Every point on the rolling wheel makes *two* motions simultaneously—one about the axle and the other forward together with the axle. It's the same as with the earth itself. The two motions add, but with different results for the top and bottom of the wheel. At the top the wheel's motion of rotation is *added* to its motion of translation, since both are in the same direction. At the bottom rotation is made in the *reverse* direction and, consequently, must be *subtracted* from translation. That is why the stationary observer sees the top of the wheel moving faster than the bottom.

A simple experiment which can be done at convenience proves this point. Drive a stick into the ground next to the wheel of a stationary vehicle opposite the axle. Then take a piece of coal or chalk and make two marks on the rim of the wheel, at the very top and at the very bottom. Your marks should be right

opposite the stick. Now push the vehicle a bit to the right (Fig. 3), so that the axle moves some 20 to 30 cm away from the stick. Look to see how the marks have shifted. You will find that the upper mark *A* has shifted much further away than the lower one *B* which is almost where it was before.

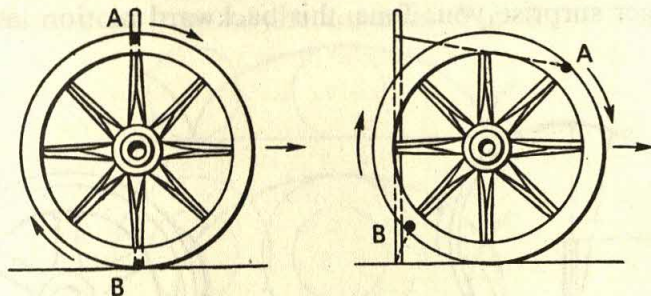


Fig. 3

A comparison between the distances away from the stick of points *A* and *B* on a rolling wheel (right) shows that the wheel's upper segment moves faster than its lower part

THE WHEEL'S SLOWEST PART

As we have seen, not all parts of a rolling cartwheel move with the same speed. Which part is slowest? That which touches the ground. Strictly speaking, at the moment of contact, this part is absolutely stationary. This refers only to a rolling wheel. For the one that spins around a fixed axle, this is not so. In the case of a flywheel, for instance, all its parts move with the same speed.

BRAIN-TEASER

Here is another, just as ticklish, problem. Could a train going from Leningrad to Moscow have any points which, in relation to the railroad track, would be moving in the opposite direction? It could, we find. All the train wheels have such points every moment. They are at the bottom of the protruding rim of the wheel (the bead). When the train goes forward, these points move backward. The following experiment, which you can easily do yourself, will show you how this happens. Attach a match to a coin with some plasticine so that the match protrudes in the plane of the radius, as shown in Fig. 4. Set the coin together with the match in a vertical position on the edge of a flat ruler and hold it with your thumb at its point of contact *C*. Then roll it to and fro. You will see that

points F , E and D of the jutting part of the match move not forward but backward. The further point D (the end of the match) is from the edge of the coin, the more noticeable the backward motion is (point D shifts to n').

The points on the bead of the train wheel move similarly. So when I tell you now that there are points in a train that move not *forward* but *backward*, this should no longer surprise you. True, this backward motion lasts only a neg-

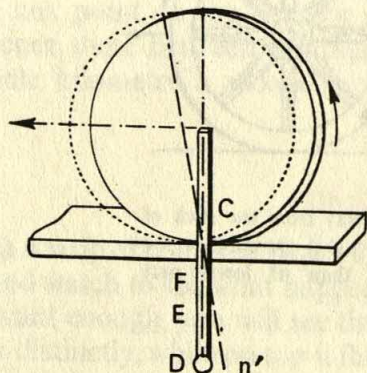


Fig. 4

When the coin is rolled leftward, points F , E and D of the jutting part of the match move backward

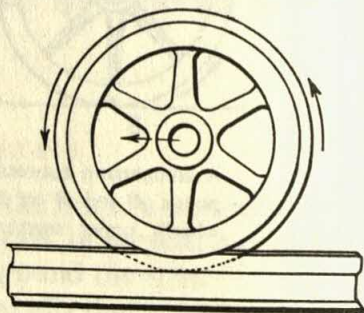


Fig. 5

When the train wheel rolls leftward the lower part of its rim rolls the other way

ligible fraction of a second. Still there is, despite all our habitual notions, a backward motion in a moving train. Figures 5 and 6 illustrate the explanation.

WHERE DID THE YACHT CAST OFF?

A rowboat is crossing a lake. Arrow a in Fig. 7 is its velocity vector. A yacht is cutting across its course; arrow b is its velocity vector. Where did the yacht cast off? You would naturally point at once to point M . But you would get a different reply from the people in the rowboat. Why?

They don't see the yacht moving at right angles to their own course, because they don't realize that they are moving themselves. They think they're stationary and everything else is moving with their own speed in the opposite direction. From their point of view the yacht is moving not only in the direction

of the arrow b but also in the direction of the dotted line a , opposite to their own direction (Fig. 8). The two motions of the yacht, the real one and the seeming one, are added according to the rule of the parallelogram. The result is that the people in the rowboat think the yacht to be moving along the diagonal of the parallelogram ab ; that is also why they think the yacht cast off not at point M , but at point N , way in front of the rowboat (Fig. 8).

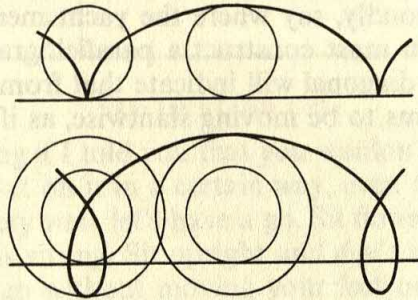


Fig. 6

Top: the curve (a cycloid) described by every point on the rim of a rolling cartwheel. Bottom: the curve described by every point on the rim of a train wheel

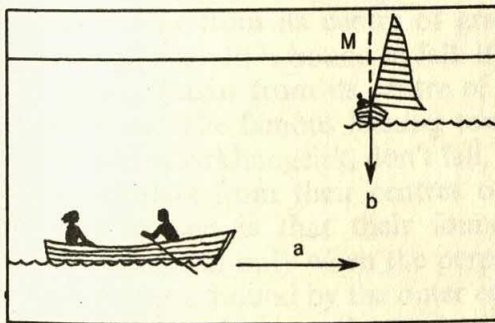


Fig. 7

The yacht is cutting across the rowboat's course. Arrows a and b designate the velocities. What will the people in the dinghy see?

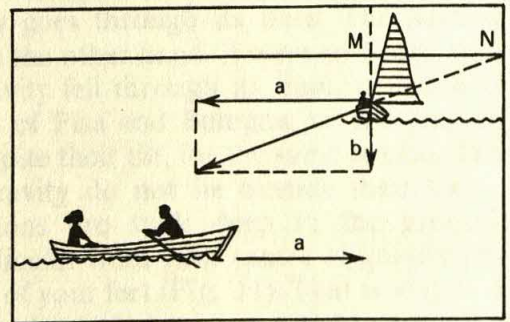


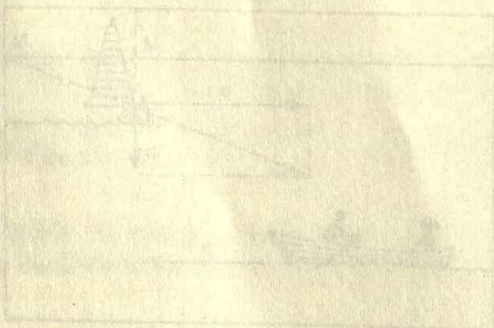
Fig. 8

The people in the dinghy think the yacht to be coming towards them slantwise—from point N

Travelling together with the earth in its orbital path, we also plot the position of the stars wrongly just as the people in the rowboat did when asked where the yacht cast off from. We see the stars displaced slightly forward in the direction

of the earth's orbital motion. Of course, the earth's speed is negligible compared with that of light (10,000 times less) and, consequently, this stellar displacement, known as aberration of light, is insignificant. However, we can detect it with the aid of astronomical instruments.

Did you like the yacht problem? Then answer two more questions related to the same problem. Firstly, give the direction in which the yachtsmen think the rowboat is moving. Secondly, say where the yachtsmen think the rowboat is heading. To answer, you must construct a parallelogram of velocities on the vector a (Fig. 8), whose diagonal will indicate that from the yachtsmen's point of view the rowboat seems to be moving slantwise, as if heading for the shore.



Chapter

Gravity and Weight. Levers Pressure

2

TRY TO STAND UP!

You'd think I was joking if I told you that you wouldn't be able to get up from a chair, provided you sat on it in a certain way, even though you wouldn't be strapped down to it. Very well, let's have a go. Sit down on a chair in the same way the boy in Fig. 9 is sitting. Sit upright and *don't shove your feet under the chair*. Now try to get up without moving your feet or bending forward. You can't, however hard you try. You'll never stand up until you push your feet under the chair or lean forward.

Before I explain, let me tell you about the equilibrium of bodies in general, and of the human body in particular. A thing will not topple only when the perpendicular from its centre of gravity goes through its base. The leaning cylinder in Fig. 10 is bound to fall. If, on the other hand, it were so broad that the perpendicular from its centre of gravity fell through its base, it wouldn't topple over. The famous leaning towers of Pisa and Bologna, or the leaning campanile in Arkhangelsk, don't fall, despite their tilt, for the same reason. The perpendiculars from their centres of gravity do not lie outside their bases. Another reason is that their foundations are sunk deep in the ground.

You won't fall only when the perpendicular from your centre of gravity lies within the area bound by the outer edge of your feet (Fig. 11). That is why it is so hard to stand on one leg and still harder to balance on a tight-rope. Our "base" is very small and the perpendicular from the centre of gravity may easily come to lie outside its limits. Have you noticed the odd gait of an "old sea dog"? He spends most of his life aboard a pitching ship where the perpendicular from the centre of gravity of his body may come to fall outside his "base" any moment. That accustoms him to walk on deck so that his feet are set wide apart and take in as large a space as possible, which saves him from falling. Naturally, he'll waddle in the same habitual fashion on hard ground as well.

Another instance is of an opposite nature this time. This is when the effort to keep one's balance results in a beautiful pose. Porters who carry loads on their

heads acquire a dignified posture, a point, I presume, you have noticed. You may have also seen exquisite statues of women holding jars on their heads. It is because they carry a load on their heads that these people have to hold their heads and bodies upright. If they were to lean in any direction, this would shift the perpendicular from the centre of gravity (which is higher than usual in this case because of the head-load) outside the base and unbalance them.



Fig. 9

It's impossible to get up

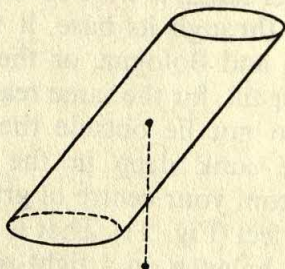


Fig. 10

The cylinder must topple as the perpendicular from its centre of gravity lies outside its base

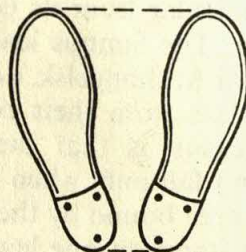


Fig. 11

When one stands, the perpendicular from the centre of gravity passes through the area bound by the soles of one's feet

Back now to the problem I set you at the beginning of the chapter. The sitting boy's centre of gravity is inside the body near the spine, about 20 centimetres above the level of his navel. Drop a perpendicular from this point. It will pass

through the chair behind the feet. You already know that for the man to stand up it should go through the area *taken up by the feet*. Consequently, when we get up we must either bend forward to shift the centre of gravity, or shove our feet beneath the chair to place our "base" below the centre of gravity. That is what we usually do when getting up from a chair. If we are not allowed to do this, we'll never be able to stand up; as you have already gathered from your own experience.

WALKING AND RUNNING

The things you do thousands of times a day, and day after day all your life, ought to be things you have a very good idea about, oughtn't they? Yes, you will say. But that is far from so. Take walking and running, for instance. Could anything be more familiar? But I wonder how many of you have a clear picture of what we really do when we walk and run, or of the difference between the two. Let's see what a physiologist has to say about walking and running. I'm sure most of you will find his description startlingly novel. (The passage is from Prof. Paul Bert, *Lectures on Zoology*. The illustrations are my own.)

"Suppose a person is standing on one leg, the right leg, for instance. Suppose further that he is lifting his heel, meanwhile bending forward. [When walking or running a person exerts on the ground, when pushing his foot away from it, a pressure of some 20 kg in addition to his weight. Hence a person exerts a greater pressure on the ground when he is moving than when standing.—Y. P.] In such a position the perpendicular from the centre of gravity will naturally be outside the base and the person is bound to fall forward. Scarcely has he started doing this than he quickly throws forward his left leg, which was suspended thus far, to put it down on the ground in front of the perpendicular from the centre of gravity. The perpendicular thus comes to drop through the area bound by the lines linking the points of support of both feet. Balance is thus restored; the person has taken a step forward.

"He may remain in this rather tiring position, but should he wish to continue forward, he will lean still further forward, shift the perpendicular from the centre of gravity outside the base, and again throw his leg, the right one this time, forward when about to fall. He thus takes another step forward. And so on and so forth. Consequently, walking is just *a series of forward fallings*, punctually forestalled by throwing the leg left behind into a supporting position.

"Let's try to get to the root of the matter. Suppose the first step has already been made. At this particular moment the right foot is still on the ground and

the left foot is already touching it. If the step is not very short the right heel should be lifted, because it is this rising heel that enables one to bend forward and upset one's balance. It is the heel of the left foot that touches the ground first. Next, when the entire sole stands on the ground, the right foot is lifted completely and no longer touches the ground. Meanwhile the left leg, which is slightly bent at the knee, is straightened by a contraction of the femoral

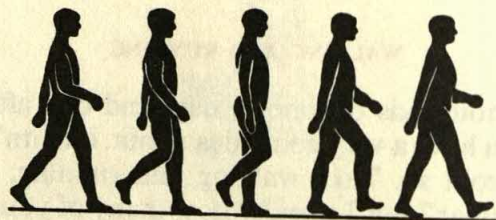


Fig. 12

How one walks. The series of positions in walking

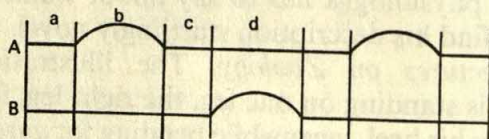


Fig. 13

A graph showing how one's feet move when walking. Line A is the left foot and line B is the right foot. The straight sections show when the foot is on the ground, and the curves—when the foot is in the air. In the time-interval a both feet are on the ground; in the time-interval b, foot A is in the air and foot B still on the ground; in the time interval c both feet are again on the ground. The faster one walks, the shorter the time-intervals a and c get (compare with the "running" graph in Fig. 15)

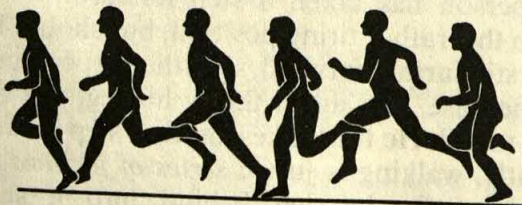


Fig. 14

How one runs. The series of positions in running, showing moments when both feet are in the air

quadriceps to become for an instant vertical. This enables the half-bent right leg to move forward without touching the ground. Following the body's movement the heel of the right foot comes to touch the ground in time for the next step forward. The left leg, which at this moment has only the toes of the foot touching the ground and which is about to rise, goes through a similar series of motions.

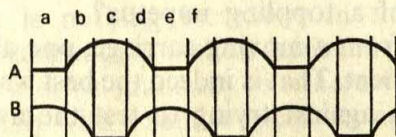


Fig. 15

A graph showing how one's feet move when running (compare with Fig. 13). There are time-intervals (*b*, *d* and *f*) when both feet are in the air. This is the difference between running and walking

“Running differs from walking in that the foot on the ground is energetically straightened by a sudden contraction of its muscles to throw the body forward so that the latter is *completely off the ground for a very short interval of time*. Then the body again falls to come to rest on the other leg, which quickly moves forward while the body is still in the air. Thus, running consists of a series of *hops* from one foot to the other.”

As for the energy a person expends in walking along a horizontal pavement it is not at all nil as some might think. With every step made, the centre of gravity of a walker's body is lifted by a few centimetres. A reckoning shows that the work spent in walking along a horizontal path is about a fifteenth of that required to raise the walker's body to a height equivalent to the distance covered.

HOW TO JUMP FROM A MOVING CAR

Most will surely say that one must jump forward, in the direction in which the car is going, in conformity with the law of inertia. But what does inertia have to do with it all? I'll wager that anyone you ask this question will soon find himself in a quandary, because according to inertia one should jump backward, contrary to the direction of motion. Actually inertia is of secondary importance. If we lose sight of the main reason (that has nothing to do with inertia) why we should jump forward, we will indeed come to think that we must jump backward and not forward.

Suppose you have to jump off a moving car. What happens? When you jump, your body has, at the moment you let go, the same velocity as the car itself (by inertia) and tends to move forward. By jumping forward, far from diminishing this velocity, we on the contrary, increase it. Then shouldn't we jump *backward* since in that case the velocity thus imparted would be *subtracted* from the velocity our body possesses by inertia, and hence, on touching the ground, our body would have less of a toppling impetus?

But, when one jumps from a moving carriage, one always jumps forward in the direction of its movement. That is indeed the best way, a time-honoured one, and I strongly warn you against trying to test the awkwardness of jumping backward.

We seem to have a contradiction, don't we? Now whether we jump forward or backward we risk falling, since our bodies are still moving when our feet touch the ground and come to a halt. When jumping forward, the speed with which our bodies move is even greater than when jumping backward, as I have already noted. But it is much *safer* to jump forward than backward, because then we mechanically throw a leg forward or even run a few steps, to steady ourselves. We do this *without thinking*; it's just like walking. After all, according to mechanics, walking, as was noted before, is nothing but *a series of forward fallings of our body, guarded against by the throwing out of a leg*. Since we don't have this guarding movement of the leg when falling *backward* the danger is much greater. Then even if we do fall forward we can soften the impact with our hands, which we can't do if we fall on our backs.

As you see, it is safer to jump forward, not so much because of inertia, but because of ourselves. This rule is plainly inapplicable to *one's belongings*, for instance. A bottle thrown from a moving car forward stands more chances of crashing when it hits the ground than if thrown backward. So if you have to jump from a moving car and have some luggage with you, first chuck out the luggage *backward* and then jump *forward* yourself. Old hands like tramcar conductors and ticket inspectors often jump off stepping *backward but facing the direction of the movement of the tram*. This gives them a double advantage: firstly they reduce the velocity that the body acquires by inertia, and, secondly, guard themselves against falling on their backs, as they jump with their faces forward, in the direction where they are most likely to fall.

CATCHING A BULLET

The following curious incident was reported during the First World War. One French pilot, while flying at an altitude of two kilometres, saw what he took to be a fly near his face. Trapping it with his hands, he was flabbergasted to find that he had caught a German bullet! How like the tall stories told by Baron Munchausen of legendary fame, who claimed he had caught cannon balls with bare hands! But there is nothing incredible in the bullet-catching story.

A bullet does not fly everlastingly with its initial velocity of 800-900 m/s. Air resistance causes it to slow down gradually to a mere 40 m/s towards the end of its journey. Since aircraft fly with a similar speed, we can easily have a situation when bullet and plane will be flying with the same speed, in which case the bullet, in its relation to the plane and its pilot, will be stationary or barely moving. The pilot can easily catch it with his hand, especially if gloved, because a bullet heats up considerably while whizzing through the air.

A MELON AS A BOMB

We have seen that in certain circumstances a bullet can lose its "sting". But there are instances when a gently thrown "peaceful" object has a destructive impact. During the Leningrad-Tiflis motor run in 1924, Caucasian peasants tossed melons, apples, and the like at the racing cars to express their admiration. However, these innocuous gifts made terrible dents in the cars and seriously injured the motorists. This happened because the car's velocity added to that of the tossed melons or apples, transforming them into dangerous projectiles. A 10-gram bullet possesses the same energy of motion as a 4-kilogram melon thrown at a car doing 120 km per hour. Of course, the impact of a melon is not the same as the bullet's since melons, after all, are squashy.

When we have hypervelocity planes doing about 3,000 km per hour, a bullet's approximate velocity, their pilots may chance to encounter what we have just described. Everything in the way of a hypervelocity aircraft will ram into it. Machine-gun fire or just a chance handful of bullets dropped from another plane will have the same effect; these bullets will strike the aircraft with the same impact as if fired from a machine gun. Since the relative velocities in both cases are the same—the plane and bullet meet with a speed of about 800 m/s, the destruction done when they collide is the same as well. On the contrary, bullets fired from behind at a plane moving with the same speed are harmless, as we have already seen.

In 1935 engine driver Borshchov prevented a train collision by cleverly taking

advantage of the fact that objects moving in the same direction at practically the same speed come into contact without knocking each other to pieces. He was driving a train between Yelnikov and Olshanka, in Southern Russia. Another train was puffing along in front. The driver of this train couldn't work up enough steam to make the grade. He uncoupled his engine and several waggons and set off for the nearest station, leaving a string of 36 waggons behind. But as

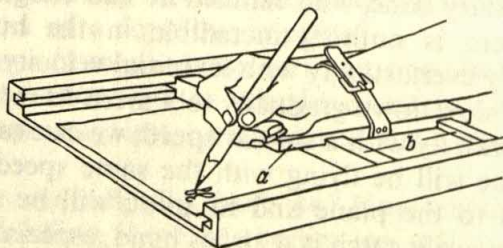


Fig. 16

Contraption for writing in a moving train

he did not place brake-shoes to block their wheels, these waggons started to roll back down the grade. They gathered up a speed of some 15 km/h and a collision seemed imminent. Luckily enough, Borshchov had his wits about him and was able to figure out at once what to do. He braked his own train and also started a backward manoeuvre, gradually working up the same speed of 15 km/h. This enabled him to bring the 36 waggons to rest against his own engine, without causing any damage.

Finally, this same principle is applied in a device making it easier for us to write in a moving train. You all know that this is hard to do because of the jolts when the train passes over the rail joints. They do not act simultaneously on both paper and pen. So our task is to contrive something that would make the jolts act simultaneously on both. In this case they would be in a state of rest with respect to each other.

Figure 16 shows one such device. The right wrist is strapped to the smaller board *a* which slides up and down in the slots in board *b*, in turn, slides to and fro along the grooves of the writing board placed on the train compartment table. This arrangement provides plenty of "elbow-room" for writing and at the same time causes each jolt to act simultaneously on both paper and pen, or rather the hand holding the pen. This makes the process as simple as writing on an ordinary table at home. The only unpleasant thing about it is that since the jolts again do not act simultaneously on both wrist and head, you get a jerky picture of what you're writing.

HOW TO WEIGH YOURSELF

You will get your correct weight only if you stand on the scales without moving. As soon as you bend down, the scales show less. Why? When you bend, the muscles that do this also pull up the lower half of your body and thus diminish the pressure it exerts on the scales. On the contrary, when you stop bending, your muscles push the upper and lower halves of the body away from each other; in this case the scales will register a greater weight since the lower half of your body exerts a greater pressure on the scales.

You will change your weight-readings, provided the scales are sensitive enough, even by lifting an arm. This motion already slightly increases your body's seeming weight. The muscles you use to lift your arm up have the shoulder as their fulcrum and, consequently, push it together with the body down, increasing the pressure exerted on the scales. When you stop lifting your arm you start using another, opposite set of muscles; they pull the shoulder up, trying to bring it closer to the end of the arm; this reduces the weight of your body, or rather its pressure on the scales. On the contrary, when you lower your arm you reduce the weight of your body, to increase it when you stop lowering it. In brief, by using your muscles you can increase or reduce your weight, meaning of course the pressure your body exerts on the scales.

WHERE ARE THINGS HEAVIER?

The earth's pull diminishes the higher up we go. If we could lift a kilogram weight 6,400 km up, to twice the earth's radius away from its centre, the force of gravity would grow $2^2 = 4$ times weaker, in which case a spring balance would register only 250 grams instead of 1,000. According to the law of gravity the earth attracts bodies as if its entire mass were concentrated in the centre; the force of this attraction diminishes inversely to the square of the distance. In our particular instance, we lifted the kilogram weight twice as far from the centre of the earth; hence attraction became $2^2 = 4$ times weaker. If we set the weight at a distance of 12,800 km away from the surface of the earth, i.e. three times the earth's radius, the force of attraction would become $3^2 = 9$ times weaker, in which case our kilogram weight would register only 111 grams on a spring balance.

You might conclude that the deeper down in the earth we were to put our one-kilogram weight, the greater the force of attraction would grow and the more it should weigh. However, you would be mistaken. The weight of a body

does not increase; on the contrary, it diminishes. This is because now the earth's attracting forces no longer act just on one side of the body but all around it. Figure 17 shows you the weight in a well; it is pulled down by the forces below it and simultaneously up by the forces above it. It is really only the pull of that spherical part of the earth, the radius of which is equal to the distance from the centre of the earth to the body, what is of importance. Consequently, the deeper

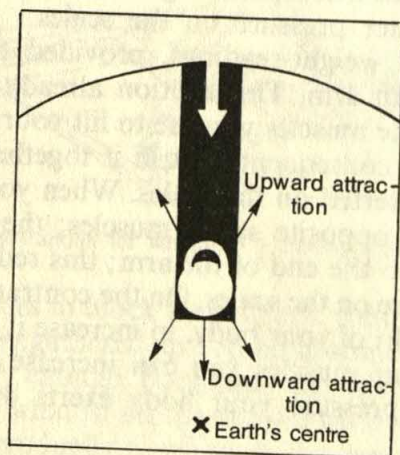


Fig. 17

Gravitational pull lessens the closer we get to the middle of the earth

down we go, the less a body should weigh. At the centre of the earth it should weigh nothing, as here it is attracted by equal forces on all sides.

To sum up: a body weighs most at the earth's surface; its weight diminishes whether it is lifted up from the earth's surface or let down (this would be true, naturally, only if the earth were homogeneous in density throughout). Actually, the closer to its centre, the greater the earth's density; at first the force of gravity grows to some distance down; only then does it start to diminish.

HOW MUCH DOES A FALLING BODY WEIGH?

Have you noticed that odd sensation you experience when you *start* to go down in a lift? You feel abnormally light; if you were falling into a bottomless abyss you would feel the same. This sensation is caused by *weightlessness*. At the very first moment when the lift-cabin floor has already started to go down but you yourself have still not acquired its velocity, your body exerts scarcely any

pressure at all on the floor, and, consequently, *weighs* very little. An instant later this queer sensation is gone. Now your body seeks to fall faster than the smoothly running lift; it exerts a pressure on the cabin floor, reacquiring its full weight.

Tie a weight to the hook of a spring balance and observe the pointer as you quickly lower the balance together with the weight. For convenience's sake

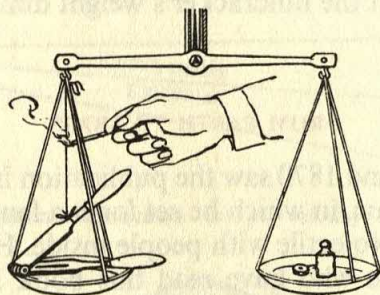


Fig. 18

Falling bodies are weightless

insert a small piece of cork in the slot and observe how it moves. The pointer will fail to register the full weight; it will be much less! If the balance were falling freely and you were able to watch its pointer meanwhile, you would see it register a zero weight.

The heaviest object will lose all its weight when falling. The reason is simple. "Weight" is the force with which a body pulls at something holding it up or presses down on something supporting it. A *falling* body cannot pull the balance spring as it is falling together with it. A falling body does not pull at anything or press down on anything. Hence, to ask how much something weighs when falling is the same as to ask how much it weighs when it does not weigh.

Galileo, the father of mechanics, wrote way back in the 17th century in his *Dialogue on Two New Sciences*: "We feel a load on our back when we try to prevent it from dropping. But if we were to drop as fast as the load does, how could it press upon and burden us? This would be the same as to try to transfix with a spear [without letting go of it—Y. P.] somebody running ahead of us as fast as we are running ourselves."

The following simple experiment illustrates this point. Place a nutcracker on one of the scale pans, with one arm on the pan and the other tied by a piece of thread to the hook of the scale arm (Fig. 18). Add weights to the other pan to balance the nutcracker. Apply a lighted match to the thread. The thread will

burn through and the suspended nutcracker arm will fall onto the pan. Will the pan holding the nutcracker dip? Will it rise? Or will it remain in equilibrium? Since you know by now that a falling body weighs nothing, you should be able to give the correct answer. The pan will rise for a moment.

Indeed, though joined to the lower arm the nutcracker's upper arm nevertheless exerts less of a pressure on the pan when falling than when stationary. For a moment the nutcracker's weight diminishes, and thus the pan holding it rises.

FROM EARTH TO MOON

The years between 1865 and 1870 saw the publication in France of Jules Verne's *From the Earth to the Moon*, in which he set forth a fantastic scheme to shoot at the moon an enormous projectile with people inside. His description seemed so credible that most of you who have read this book have probably hazarded whether this really could be done. Well, let's discuss it.*

Let's see at first whether we can fire a shell from a gun—at least theoretically—so that it never falls back to earth again. Theory tells us that it's possible. Indeed, why does a shell fired horizontally eventually fall back on earth again? Because the earth attracts it, curving its trajectory. Instead of keeping up a straight course, it curves towards the ground and is, therefore, bound to hit it sooner or later. The earth's surface is also curved, but the shell's trajectory is bent still more. However, if we made the shell follow a trajectory curved in exactly the same way as the earth's surface it would never fall back on earth again. Instead, it would trace an orbit concentric with the earth's circumference, becoming its satellite, a baby moon.

But how are we to make the shell follow such a trajectory? All we must do is to impart a sufficient initial velocity. Look at Fig. 19 which depicts a cross-section of part of the earth. A cannon is mounted on the hilltop at point *A* (we shall discount the actual altitude). A shell fired horizontally from it would reach point *B* a second later, if not for the earth's gravitational pull. Instead, it reaches point *C* five metres lower than *B*. Five metres is the distance any freely falling body travels (in a void) in the first second—due to earth's surface gravitational pull. If, after it drops these five metres, our shell is at exactly the

* Today, after Sputnik and Lunic, we know that it is rockets, not cannon projectiles, that will be used for space travel. However, since a rocket flies after its last engine burns out, in accord with the same laws of ballistics, don't think Perelman is behind the times.—Ed.

same distance from the ground as it was when fired at point A, it means that the shell is following a trajectory curved concentrically to the earth's circumference.

All that remains is to reckon the distance AB (Fig. 19), or, in other words, the distance the shell travels horizontally in the space of a second, which will tell us the speed we need. In the triangle AOB , the side OA is the earth's radius (roughly 6,370,000 m); $OC = OA$ and $BC = 5$ m; hence OB is 6,370,005 m.

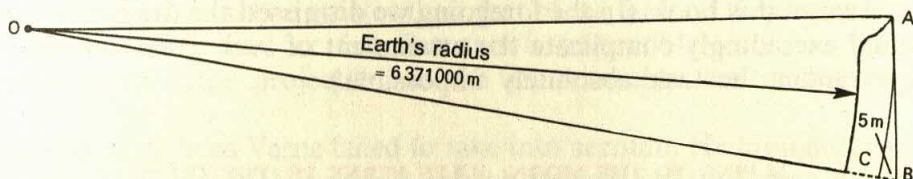


Fig. 19

How to reckon a projectile's "escape" velocity

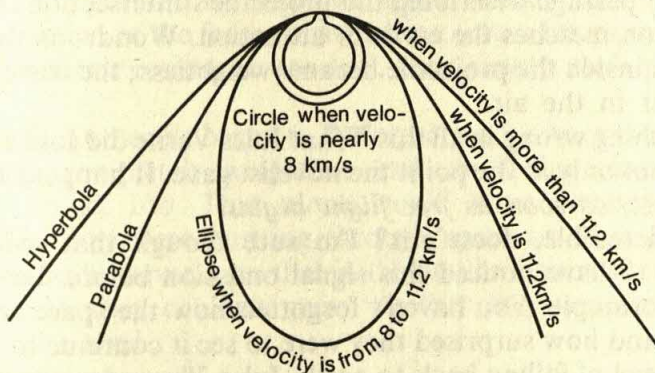


Fig. 20

When a projectile is fired with a starting velocity of 8 km/sec and more

Applying Pythagoras' theorem we get:

$$(AB)^2 = (6,370,005)^2 - (6,370,000)^2$$

We resolve this equation to find AB equal to roughly 8 km.

So, if there were no drag, a shell shot horizontally with a muzzle velocity of 8 km/sec *would never fall back to earth again*; it would be an everlasting baby moon.

Now suppose we imparted to our shell a still greater initial velocity. Where would it fly then? Scientists dealing with celestial mechanics have proved that

velocities of 8, 9 and even 10 km/sec give a trajectory shaped like an ellipse which would be the more elongated the greater the initial speed is. When the velocity reaches 11.2 km/sec, the shell will describe not an ellipse but a nonlocked curve, a parabola, and fly away from the earth never to return (Fig. 20). So, *theoretically* it is quite possible to fly to the moon inside a cannon ball, provided its muzzle speed is big enough. This, however, is a problem that may present some quite specific difficulties. Let me refer you, for greater detail, to Part Two of this book. (In the foregoing we dismissed the drag which in real life would exceedingly complicate the attainment of such great velocities and perhaps render the task absolutely impossible.)

FLYING TO THE MOON: JULES VERNE VS. THE TRUTH

Any of you who have read *From the Earth to the Moon* most likely remember the interesting passage describing the projectile's intersection of the boundary where the moon matches the earth in attraction. Wondrous things happened. All the objects inside the projectile became weightless; the travellers themselves began to float in the air.

There is nothing wrong in all this. What Jules Verne did lose sight of was that this happens not only at the point the novelist gave. It happens before and after as well, in fact, *as soon as free flight begins*.

It seems incredible, doesn't it? I'm sure though that soon you will be surprised not to have noticed this signal omission before. Let's turn to Jules Verne for an example. You haven't forgotten how the space travellers ejected the dead dog and how surprised they were to see it continue to trail behind the projectile instead of falling back to earth. Jules Verne described and explained this correctly. In a vacuum all bodies fall with the same speed, with gravity imparting an identical acceleration to each. So, owing to gravity, both the projectile and the dead dog should have acquired the same falling velocity (an identical acceleration). Rather should we say that due to gravity their starting velocities diminished in the same measure. Consequently, both should whizz along with the same velocity; that is why after its ejection the dead dog kept on trailing along in the projectile's wake.

Jules Verne's omission was: if the dead dog did not fall back to earth again *after the ejection*, why should it fall when *inside* the projectile? The same forces act in both cases! The dead dog suspended in mid-air inside the projectile should remain in that state as its speed is absolutely the same as the projectile's; hence it is in a state of rest *in respect to the projectile*.

What goes for the dead dog also goes for the travellers and all objects, in general, inside the projectile, as they all fly along the trajectory with the same speed as the projectile and should not fall, even though having nothing to stand, sit, or lie on. One could take a chair, turn it upside down and lift it to the ceiling; it won't fall "down", because it will go on travelling together with the ceiling. One could sit on this chair also upside down and not fall either. What, after all, could make him fall? If he did fall or float down, this would mean that the projectile's speed would be greater than that of the man on the chair; otherwise the chair wouldn't float or fall. But this is impossible since we know that everything inside the projectile has the same acceleration as the projectile itself.

This was what Jules Verne failed to take into account. He thought everything inside the projectile which is subject only to the action of the forces of attraction would continue to press down on its floor when it was in space. He forgot that if both object and support hurtle with the same velocity in space, a velocity imparted by the action of the forces of attraction (other forces, such as those of thrust and atmospheric resistance are out), they simply can't press down on each other.

So, as soon as the projectile began to fly further on by its own momentum, its travellers became completely weightless and could float inside it, just as everything else could, too. That alone would have immediately told the travellers whether they were hurtling through space or were still inside the cannon. Jules Verne, however, says that in the first half hour after the projectile was shot into space they couldn't guess whether they were moving or not, however hard they tried.

"Nicholl, are we moving?"

"Nicholl and Barbicane looked at each other; they had not yet troubled themselves about the projectile.

"Well, are we really moving?" repeated Michel Ardan.

"Or quietly resting on the soil of Florida?" asked Nicholl.

"Or at the bottom of the Gulf of Mexico?" added Michel Ardan."

These are doubts a steamboat passenger may entertain; they are absolutely out of the question for a space traveller, because he can't help noticing his complete loss of weight, which the steamboat passenger naturally retains.

Jules Verne's projectile must certainly be a very queer place, a tiny world of its own, where things are weightless and float and stay where they are, where objects retain their equilibrium wherever they are placed, where even water

won't pour out of an inclined bottle. A pity Jules Verne slipped up, when this offers such a delightful opportunity for fantasy to run riot!*

FAULTY SCALES CAN GIVE RIGHT WEIGHT

What is more important to get the right weight, scales or weights? Don't think both identically important. You can get the right weight even on faulty scales as long as you have the right weights. Of the several methods used, we shall deal with two.

One was suggested by the great Russian chemist Dmitry Mendeleev. You begin by placing anything handy on one of the pans. Make sure that it is heavier than the object you want to weigh. Balance it with weights on the other pan. Then place what you want to weigh on the pan holding the weights and remove the necessary number of weights to bring to balance again. Sum up the weights removed to get the weight of what you wanted to weigh. This is called "the constant load method" and is particularly convenient when several objects need to be weighed in succession. The initial load is used to weigh everything you have to weigh.

Another method, called the "Borda method" after the scientist who proposed it, is as follows. Place the object you want to weigh on one of the pans. Then pour sand or shot into the other pan till the scales balance. Remove your object from the pan (but don't touch the sand or shot in the other pan!) and place weights in the emptied pan till the scales balance again. Sum up these weights to find how much your object weighs. This is also called "replacement weighing".

This simple method can also be used for a one-pan spring balance, provided of course you have correct weights. In this case you don't need either sand or shot. Just put your object on the pan and note the reading. Then remove the object and place in the pan as many weights as needed to get the same reading. Their combined weight will give the weight of the object they replace.

STRONGER THAN YOU THINK

How much can you lift with one arm? Let's say it's ten kilograms. Does this amount qualify your arm's muscle-power? Oh, no. Your biceps is much stronger. Figure 21 shows how this muscle works. It is attached close to the fulc-

* We know very well what it is like to live and work in conditions of weightlessness from what Soviet and American spacemen have told us and from films taken in outer space. Then no doubt many of you will yourselves have seen the telecasts from outer space.—Ed.

rum of the lever that the bone of your forearm represents. The load you are lifting acts on the other end of this live lever. The distance between the load and the fulcrum, that is, the joint, is almost eight times more than that between the end of the biceps and the fulcrum. This means that if you are lifting a load of 10 kg your biceps is exerting eight times as much power, and, consequently, could lift 80 kg.

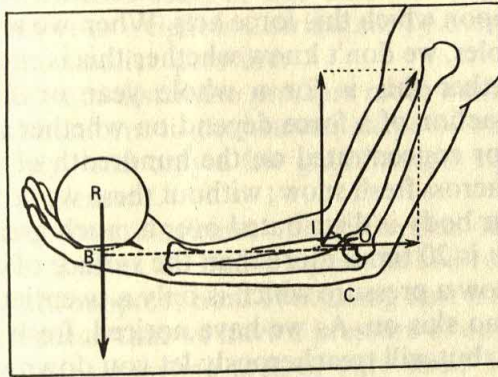


Fig. 21

Forearm *C* acts as a lever. The force acts on point *I*; the fulcrum is at point *O* and load *R* is being lifted from point *B*. *BO* is roughly eight times longer than *IO*

It would be no exaggeration to say that everybody is much stronger than he is, or rather that one's muscles are much more powerful than what we can really do with them. Is this an expedient arrangement? Not at all, you might think at first glance. We seem to have totally unrewarded loss. Recall, however, an old "golden rule" of mechanics: whatever you lose in power you gain in displacement. Here you gain in speed; your arm moves eight times faster than its muscles do. The arrangement of muscles in animals enables them to move extremities with greater agility, which is more important than strength in the struggle to survive. Otherwise, we would move around at literally a snail's pace.

WHY DO SHARP THINGS PRICK?

Have you ever wondered why a needle so easily pierces things? Why is it so easy to drive a needle through a piece of cloth or cardboard and so hard to do the same thing with a blunt nail? After all, doesn't the same force act in both cases? The force is the same, but the *pressure* isn't. In the case of the needle the entire force is concentrated on its point; in the case of the nail the same amount of

force is distributed over the larger area of the blunt end. So, though we exert the same force, the needle gives a much greater pressure than the blunt nail.

You all know that a twenty-tooth harrow loosens the soil more deeply than a sixty-tooth one of the same weight. Why? Because the *load on each tooth* of the first harrow is more than on each tooth of the second.

When we speak of pressure, we must always take into consideration, besides forces, also the area upon which this force acts. When we are told that a worker is paid a hundred rubles, we don't know whether this is much or little, because we don't know whether this is for a whole year or for just one month.

Similarly does the action of a force depend on whether it is distributed over a square centimetre or concentrated on the hundredth of a square millimetre.

Skis easily take us across fresh snow; without them we fall through. Why? On skis the weight of your body is distributed over a much greater area. Supposing the surface of our skis is 20 times more than the surface of our soles, on skis we would exert on the snow a pressure which is only a twentieth of the pressure we exert when we have no skis on. As we have noticed, fresh snow will bear you when you are on skis, but will treacherously let you down when you're without them.

For the same reason horses used in marshlands are shod in a special fashion giving them a wider supporting area and lessening the pressure exerted per square centimetre. For the same reason people take similar precautions when they want to cross a bog or thin ice, often crawling to distribute their weight over a greater area.

Finally, tanks and caterpillar tractors don't get stuck in loose ground, though they are very heavy, again because their weight is distributed over a rather great supporting area. An eight-ton tractor exerts a pressure of only 600 grams per square centimetre. There are caterpillars which exert a pressure of only 160 g/cm² despite a two-ton load, which makes for the easy crossing of peatbogs and sand-beaches. Here it is a large supporting area which gives the advantage, whereas in the case of the needle it is the other way round.

This all shows that a sharpened edge pierces things only because it has a very minute area for the force to act upon. That is why a sharp knife cuts better than a blunt one: the force is concentrated on a smaller area of the knife edge.

To sum up: sharp objects prick and cut well, because much pressure is concentrated on their points and edges.

COMFORTABLE BED ... OF ROCK

Why is it pleasanter to sit on a chair than on a flat-topped stool though both are of wood? Why is it pleasant to lie in a hammock though the pieces of rope that go to make it are by no means soft?

I suppose you've already guessed why. The stool-top is flat; when you sit on it, you press down with your entire weight on a small area. Chairs, on the other hand, usually have a concave seat; in this case you press down on a much greater area, over which your weight is distributed. To every unit of surface you have a smaller weight, smaller pressure.

The trick, as you see, is to distribute pressure more evenly. On a soft bed we make depressions that conform to the uneven shape of our bodies. Pressure is distributed rather evenly, with only a few grammes per square centimetre. No wonder we find it so pleasant.

The following calculation illustrates the difference. An adult person has a body surface of about 2 sq m, or 20,000 sq cm. In bed roughly a quarter of it, 0.5 sq m, or 5,000 sq cm, supports him. Presuming that he weighs about 60 kg, or 60,000 g, this would mean that we have a pressure of only 12 g/cm^2 . On bare boards he would have a supporting area of only some 100 sq cm. There are fewer points of contact. This means a pressure per sq cm of half a kilogram instead of a dozen grams. Quite a noticeable difference, isn't it? And one feels it at once.

But even the hardest of beds would be as soft as eiderdown, provided the weight of your body were distributed all over it. Suppose you left the imprint of your body in wet clay. When it hardens—drying clay shrinks by some five to ten per cent, but we shall discount this—you could lie in it again and think yourself in a featherbed. Though you would be lying on what is practically rock, it would feel soft, because your weight would be distributed over a much greater area of support.

Chapter Atmospheric Resistance

3

BULLET AND AIR

Every schoolboy knows that the air impedes a bullet in its flight. Few, however, know what a great impediment it is. Most think such a “caressing” environment as the air, which is something we usually never feel, could not really get in the way of a fast-flying rifle bullet.

However, one good glance at Fig. 22 will already make you realize that the air is quite a serious obstacle in the bullet's way. The large curve on the diagram designates the trajectory the bullet would describe were there no air. In this case, after flying out of a rifle tilted at 45° , and with an initial velocity of 620 m/s, the bullet would describe a vast arc ten kilometres high and fly almost 40 km. But actually our bullet flies only 4 km, describing the tiny arc which is scarcely noticeable side by side with the first one. That is what the resistance of the air, the air drag, does!

BIG BERTHA

The Germans were the first to practise long-range artillery bombardment from a distance of 100 kilometres and more in 1918, towards the close of the First World War, when French and British aircraft had put a stop to German air raids.

It was by chance that German gunners hit upon their absolutely novel method for shelling the French capital, which was then at least 110 km away from the front lines. Firing shells from a big cannon tilted up at a wide angle, they unexpectedly discovered that they could make them fly 40 km instead of 20. When a shell is fired steeply upwards with a great initial velocity, it reaches a high-altitude, rarefied atmospheric strata, where the air drag is rather weak. Here it flies for quite a distance, before falling to earth again. Fig. 23 illustrates the great difference in trajectory at different angles of the gun barrel. This became the basic principle of the long-range gun that the Germans designed to bombard Paris from 115 km away. Such a gun was made, Big Bertha, and it fired more than 300 shells at Paris throughout the summer of 1918.

It was learned later that Big Bertha consisted of a tremendous steel tube 34 metres long and one metre thick. The breech walls were 40 cm thick. The gun itself weighed 750 tons. Its 120-kg shells were one metre long and 21 cm thick. Each charge took 150 kg of gunpowder which developed a pressure of 5,000 atmospheres, ejecting the shell with an initial velocity of 2,000 m/s. Since the angle of elevation was 52° , the shell described a tremendous arc, reaching its

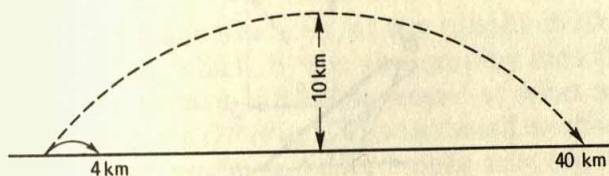


Fig. 22

Flight of a bullet in the air and in a vacuum. The big arc is the trajectory described when there is no atmosphere. The tiny left-hand arc is the real trajectory

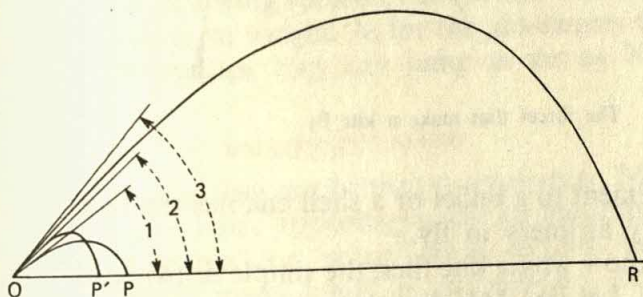


Fig. 23

The range changes when the mouth of a long-distance gun is tilted at different angles. In the case of angle 1, the projectile strikes P, and in the case of angle 2, P', but in the case of angle 3, it flies much farther as it goes through the rarefied stratosphere

highest point way up in the stratosphere 40 km above the ground. It took the shell only 3.5 minutes to reach Paris, 115 km away; two minutes were spent in the stratosphere.

Big Bertha was the first long-range gun in history, the progenitor of modern long-range artillery.

Let me note that the greater the initial velocity of a bullet or shell, the more resistance the air puts up, increasing, moreover, in proportion to the square, cube, etc., of the velocity, depending on its amount.

As a matter of fact these plant "gliders" beat man-made ones on many points. They can lift a load which may be much greater than their own weight and automatically stabilize it. Thus if the seed of the Indian jasmine should chance to turn over, it will automatically regain its initial position with its convex side downwards, but when it meets an obstacle it doesn't capsize and drop like a plummet, but coasts down instead.

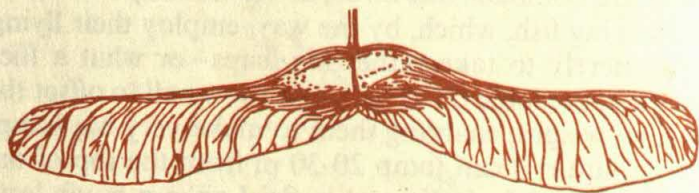


Fig. 25

Winged seeds of maple

DELAYED PARACHUTE JUMPING

This, naturally, brings to mind the brave jumps parachutists sometimes make. They bail out at altitudes of some ten kilometres and pull the ripcord only after plummeting like a stone without opening their parachutes for quite a distance. Many think that in this delayed jump the parachutist falls as if in empty space. If this were really so, the delayed jump would be a much shorter affair, while the near-ground velocity would be tremendous.

However, atmospheric resistance prevents acceleration. The velocity of the falling parachutist during a delayed jump increases only in the first ten seconds, only for the first few hundred metres. Meanwhile atmospheric resistance increases, to finally reach a point where all further acceleration stops and the falling becomes even.

Here is a crude idea of a delayed jump from the angle of mechanics. *Acceleration* continues for only the first 12 seconds or even less, depending on the parachutist's weight. In this period he drops some 400-450 m and works up a velocity of about 50 m/s. After that he falls uniformly, with the same speed, until he pulls the ripcord. Raindrops fall similarly. The only difference is that the initial period of acceleration for the raindrop is no more than a second. Consequently its near-ground velocity is not so great as in a delayed parachute jump, being between 2 and 7 metres a second, depending on its size.

THE BOOMERANG

For long this ingenious weapon, the most perfect technical device primitive man ever invented, intrigued scientists. Indeed, the queer tangled trajectory the boomerang traces (Fig. 26) can tease any mind. Nowadays we have an elaborate theory to explain the boomerang; it is no longer a wonder. This

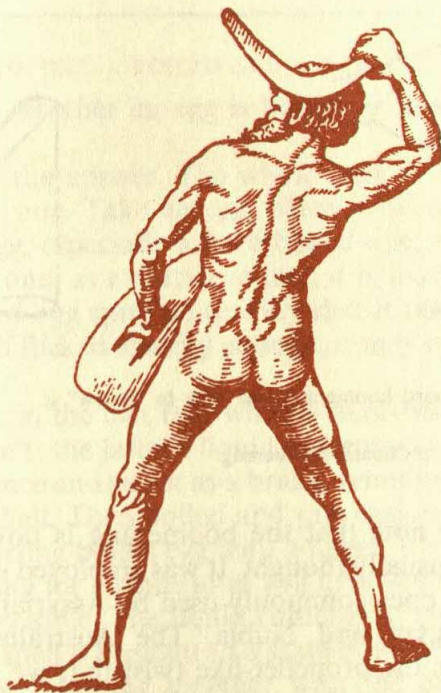


Fig. 26

Australian aborigine throwing a boomerang

theory is too intricate to explain at length. Let me merely note that boomeranging is the combined result of three factors: the initial throw, the boomerang's own rotation, and atmospheric resistance. The Australian aborigine instinctively knows how to combine all three, deftly changing the boomerang's tilt and direction, and he throws it with a greater or smaller force to obtain the desired result.

You, too, can acquire some knack in boomerang-throwing. To make one for indoors, cut it out of cardboard, in the form shown in Fig. 27. Each arm is about 5 cm long and a little less than a centimetre wide. Press it under the nail

of your thumb and flick it forward and a bit upward. It will fly some five metres, loop, and return to your feet, provided it doesn't hit anything on the way. You can make a still better boomerang by copying the one given in Fig. 28, and also by twisting it to look somewhat like a propeller (as shown at the bottom of Fig. 28). After some experience you should be able to make it describe intricate curves and loops before it returns to your feet.

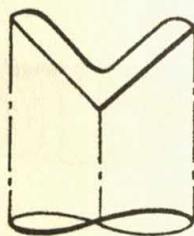
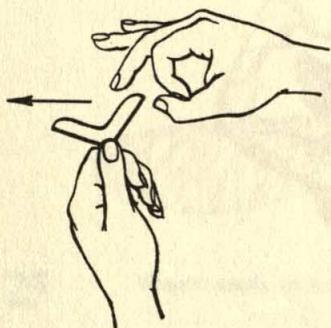


Fig. 27

A cardboard boomerang and how to "throw" it

Fig. 28

Another cardboard boomerang

In conclusion let me note that the boomerang is not at all exclusively an Australian missile as is usually thought. It was employed in India and according to extant murals it was once commonly used by Assyrian warriors. It was also familiar in ancient Egypt and Nubia. The Australian boomerang's only distinguishing feature is the propeller-like twist that we mentioned, sending it into such a maze of whirls and loops, returning it to the thrower, *should he miss*.

Chapter **Rotation Perpetual Motion Machines** 4

HOW TO TELL A BOILED AND A RAW EGG APART?

How can we find out whether an egg is boiled or not, without breaking the shell?

Mechanics gives us the answer. The whole trick is that a boiled egg spins differently than a raw one. Take an egg, place it on a flat plate and twirl it (Fig. 29). A cooked egg, especially a hard-boiled one, will revolve *much faster and longer* than a raw one; as a matter of fact, it is hard even to make the raw egg turn. A hard-boiled egg spins so quickly that it takes on the hazy form of a flat white ellipsoid. If flicked sharply enough, it may even rise up to stand on its narrow end.

The explanation lies in the fact that while a hard-boiled egg revolves as one whole, a raw egg doesn't; the latter's liquid contents do not have the motion of rotation imparted at once and so act as a brake, retarding by force of inertia the spinning of the solid shell. Then boiled and raw eggs stop spinning differently. When you touch a twirling boiled egg with a finger, it stops *at once*. But a raw egg will resume spinning for a while after you take your finger away. Again the force of inertia is responsible. The liquid contents of the raw egg still continue moving after the solid shell is brought to a state of rest. Meanwhile the contents of the boiled egg stop spinning together with the outer shell.

Here is another test, similar in character. Snap rubber bands around a raw egg and a boiled one, along their "meridian", as it were, and hang them up by two identical pieces of string (Fig. 30). Twist the strings, giving the same number of turns, and then let them go. You will spot the difference between the two eggs at once. Inertia causes the boiled egg to overshoot its starting position and give the string some more twists in the opposite direction; then the string unwinds again with the egg again giving several turns; this continues for some time, the number of twists gradually diminishing until the egg comes to rest. The raw egg, on the other hand, scarcely overshoots its initial position at all; it will give but one or two turns and stop long before the boiled egg does. As we already know, this is due to its liquid contents which impede its movement.

WHIRLIGIG

Open an umbrella, stand it up with its top on the floor and twist the handle. You can easily make it revolve rather quickly. Now throw a little ball or a crumpled piece of paper into the umbrella. It won't stay there; it will be shot out by what has wrongly come to be called the "centrifugal force" but which is

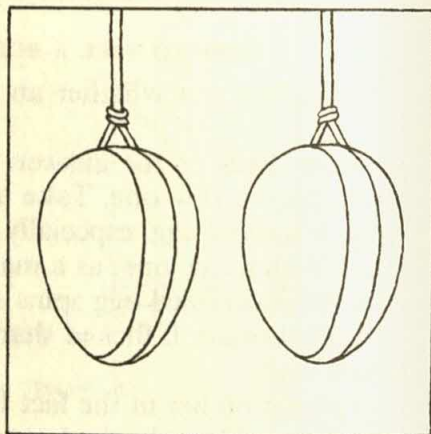
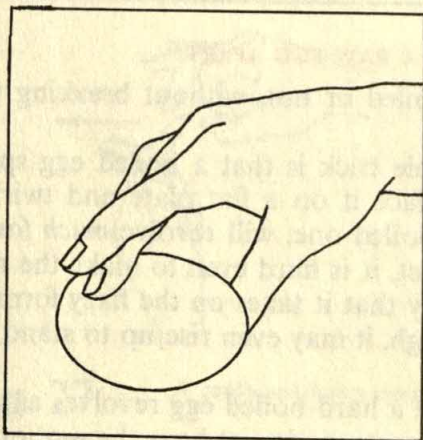


Fig. 29

Spinning an egg

Fig. 30

Telling a boiled egg from a raw one

actually nothing but a manifestation of the force of inertia. The ball or piece of paper will be thrown off, not along the continuation of the radius but at a tangent to the circular motion.

At some public parks one may find an amusement based on this principle of rotation, where you may try out the law of inertia on yourself. This is a sort of whirligig with a round floor on which people either stand, sit, or lie. A concealed motor starts the floor revolving, increasing its speed till inertia makes everybody on it slither or slide towards its edge. At first this is hardly noticeable, but the further away one gets from the centre, the more noticeable do both speed and, consequently, inertia grow. You try hard to hold on, but it is to no avail and finally you are hurled off.

The earth itself is, in fact, a huge whirligig. Though it doesn't hurl us off, it does reduce our weight. At the equator, where rotation is fastest, one can "shed" a 300th of one's weight in this manner. This, plus another factor, the earth's

compression, reduces weight at the equator by about 0.5 per cent or 1/200th. An adult person will consequently weigh 300 grams less at the equator than at any of the poles.

INKY WHIRLS

Make a teetotum, 42 mm in diameter, out of white cardboard and a match sharpened at one end (Fig. 31). No particular knack is needed to twirl it—it's

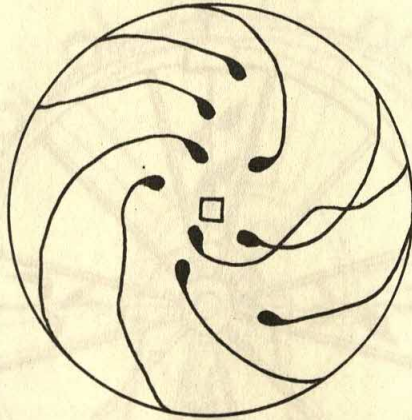


Fig. 31

Ink drop traces on a twirling teetotum

something any child can do. But though a child's toy, it can be very instructive. Do the following. Spill a few drops of ink on it and set it spinning before the ink dries. When it stops, look to see what has happened to the ink drops. They will have drawn whorls—a miniature whirlwind.

Incidentally, this resemblance is not accidental. The whorls on the teetotum trace the movement of the ink drops, which undergo exactly what you experienced on the revolving floor. As the drop shoots away from the centre due to centrifugal forces, it reaches a place on the teetotum having a greater speed of rotation than the speed of the drop itself. Here the disc spins faster than the drop which seems to glide away, lagging behind the radial "spokes", as it were. That is why the drops curve, and we see the trace of curvilinear motion.

The same is true for air currents diverging from a centre of high atmospheric pressure (in "anticyclones"), or converging in a centre of low atmospheric pressure (in "cyclones"). The ink whorls depict these stupendous whirlwinds in miniature.

THE DELUDED PLANT

The centrifugal force produced by fast rotation may even outvie gravity, a point that was demonstrated by the British botanist Knight more than a hundred years ago. It is common knowledge that a young plant always directs its stem contrary to gravity, or, in plain language, grows upwards. Knight, however,

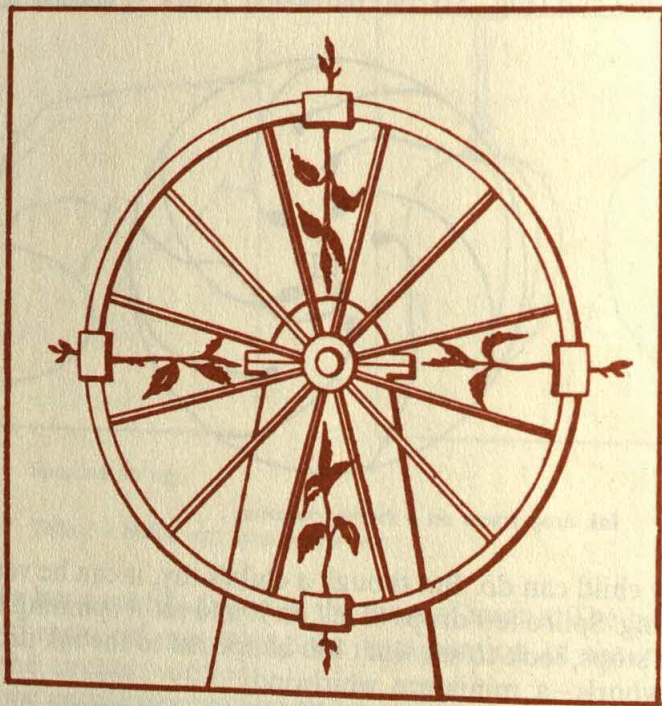


Fig. 32

Seeds germinating on the rim of a spinning wheel stem towards the axle and send their roots outwards

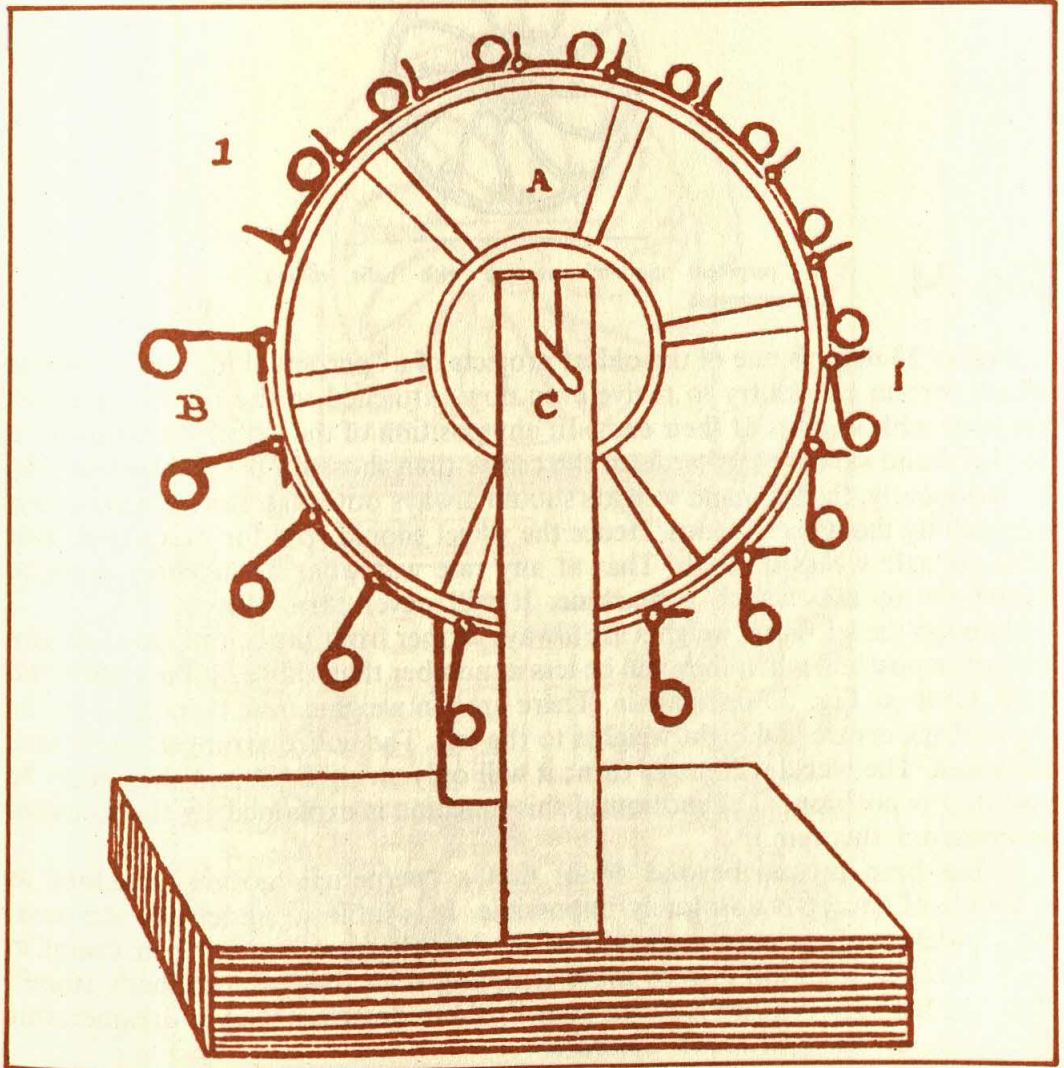
caused seeds to sprout inwards, from the outer rim of a quickly-spun wheel. The roots, on the other hand, were directed outwards (Fig. 32). He was able to fool the plant, as it were, substituting centrifugal force for gravity. The artificial gravity proved to be more powerful than the earth's natural pull – by the by, the modern theory of gravity does not present any objections, in principle, to this explanation.

PERPETUAL MOTION MACHINES

“Perpetual motion” is a topic that comes in for frequent mention, but I don’t think all realize what it actually means. The perpetual motion machine is an imagined mechanism which continues its motion without end and meanwhile

Fig. 33

An “everlastingly” moving wheel of the Middle Ages



can also do some useful work, as lifting a load, for instance. It has never been constructed, though attempts have been made since ancient times. The futility of this task gave rise to the firm conviction that a “perpetual motion” machine is impossible, and to the law of the conservation of energy which is fundamental for modern science. “Perpetual motion” as such is endless motion without any work done.

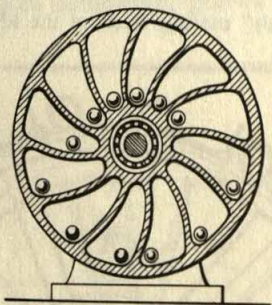


Fig. 34

A “perpetual motion” machine with balls rolling in compartments

Figure 33 depicts one of the oldest projects of a “perpetual motion” machine which certain cranks try to revive even now. Attached to the rim of the wheel are rods with weights at their ends. In any position of the wheel the weights on the left-hand side are farther from the centre than those on the right-hand side. Consequently, the left-hand weights should always outweigh the right side, thus compelling the wheel to turn. Hence the wheel should spin for ever, or at least until its axle wears through. That at any rate was what its inventor thought. Don’t try to make such a machine. It will never turn. Why?

Though the left-hand weights are always farther from the centre, you are sure to have a position when they will be less in number than those on the right-hand side. Look at Fig. 33 once again. There are ten weights (one is hidden) to the right of the centre and eight weights to the left. The entire arrangement is thus balanced. The wheel will never turn; it will only swing a bit and then come to rest in this position. (The motion of this machine is explained by the so-called momentum theorem.)

It has been proved beyond doubt that a “perpetual motion” machine as a source of energy is absolutely impossible. It is futile to undertake this task, which alchemists of yore, especially of the Middle Ages, racked their brains in vain to solve, thinking it even more tempting than the “philosopher’s stone”. The famous 19th-century Russian poet Pushkin describes such a dreamer, one Berthold, in his *Chivalrous Episodes*.

“What is *perpetuum mobile*?” Martin inquired.

“*Perpetuum mobile*,” Berthold returned, “is perpetual motion. If I find perpetual motion I see no bounds to man’s creative endeavour. For, my good Martin, while the making of gold is entrancing, a discovery perhaps both

Fig. 35

Fake *perpetuum mobile* as an advertisement for a Los Angeles café



curious and profitable, the finding of *perpetuum mobile*.... Ah, how grand that would be!”’

Hundreds of perpetual motion machines were invented, but none ever moved. Every inventor invariably omitted something that “upset the apple-cart”.

Figure 34 depicts another supposed perpetual motion machine—a wheel with heavy balls rolling in compartments between the outer rim and hub. The idea was that the balls closer to the outer rim on one side of the wheel would compel the wheel to turn by their weight.

But this will never happen, for the same reason as the wheel in Fig. 33 doesn’t turn. Still, in Los Angeles a tremendous wheel of this nature (Fig. 35) was built to advertise a café. Actually it was a fake, being turned by an artfully concealed mechanism; though people thought it was spun by the heavy balls rolling in the compartments. Other such fake perpetual motion machines, all set in motion by electricity, were placed in the windows of watchmaker’s shops to attract the eye of the public.

Incidentally, one ad of this nature impressed my students so greatly that they wouldn’t believe me when I told them that perpetual motion was impossible. Seeing is believing, they say, and when my students saw the balls rolling and turning the wheel, it seemed far more convincing than anything I could say. I told them that the fake “wonder” machine was driven by electricity from the city mains but that didn’t help either. Then I recalled that on Sundays the electricity was cut off. So I advised my pupils to call on the shop on a Sunday.

“Did you see the perpetual motion machine in action?” I asked afterwards.

“No,” they replied, their heads aching, “it was covered up with a newspaper.”

The law of the conservation of energy regained their confidence and they never lost faith in it again.

“THE SNAG”

Many ingenious home-taught Russian inventors tackled the fascinating problem of a perpetual motion machine. One, the Siberian peasant Alexander Shcheglov, is described under the name of Prezentov by the well-known 19th-century Russian satirist Saltykov-Shchedrin in his *Modern Idyll*. Below the writer describes a visit to the inventor’s workshop:

“Prezentov was a man of some 35 summers, gaunt and pale of face. He had

large pensive eyes and long hair which fell in strands onto his neck. Half of his rather roomy cottage was taken up by a big flywheel and we barely managed to squeeze in. It was a spoked wheel and had a rather large outer rim of boards nailed together like a box. Inside it was empty, and held the mechanism, the inventor's secret. There was nothing particularly cunning about it, merely bags of sand which were to balance one another. A stick in the spokes kept the wheel stationary.

"We've heard that you've applied the law of perpetual motion in practice. Is that true?" I began.

"I really don't know how to put it," he returned in confusion. "I think I've done it."

"Can we take a look?"

"Pray, do! I'll be delighted."

"He led us up to the wheel and then took us around to the other side. It was a wheel all right, from either side.

"Does it turn?"

"Well, it should. But it's a bit capricious."

"Can you take the stick out?"

"Prezentov removed it, but the wheel stood still.

"It's up to its tricks again!" he repeated. "It needs an impetus."

"He gripped the rim with both hands, swung it back and forth several times, then pushed it with all his might. The wheel began to turn. It made several turns rather quickly and smoothly. One could hear the bags of sand inside the rim banging against the boards and sliding away. Then the wheel began to turn more and more slowly. We heard a rasping and a creaking and, finally, the wheel stopped altogether.

"Must be a snag somewhere," the inventor explained in confusion as he strained and swung the wheel again. But the result was the same.

"Perhaps you forgot friction?"

"I didn't... Friction you say? It's not because of that. Friction's nothing. Sometimes it makes you happy and then, bang, it's up to its tricks, gets ornery, and that's that. If the wheel were made of real stuff, not scraps!"

It was of course not the "snag" or the "real stuff" that was a fault, but the wrong principle at the root. The wheel turned for a time owing to the impetus that the inventor gave it, but was bound to stop when friction exhausted the imparted outside energy.

"IT'S THEM BALLS THAT DO IT"

The writer Karonin (the pen-name of N. Ye. Petropavlovsky) describes another Russian "perpetual motion" machine inventor in his story "Perpetuum Mobile". This was Lavrenty Goldyrev, a peasant from Perm Gubernia who died in 1884. Karonin, who changed the name in the story to Pykhtin, describes the machine in great detail.

"Before us was a large queer machine resembling at first glance the sort of thing a blacksmith uses to shoe horses on. We could see some badly planed wooden pillars and beams and a whole system of flywheels and gear wheels. It was all a very clumsy-looking affair, rough and ugly. Several iron balls lay on the floor underneath the machine and there was a whole pile of them a bit to the side.

"Is that it?" the major-domo asked.

"That's it."

"Well, does it turn?"

"How else?"

"Have you got a horse to turn it?"

"A horse? What for? It turns by itself," Pykhtin returned and began to demonstrate the monster's workings.

"The main role was played by iron balls heaped up near by.

"It's them balls that do it. Look. First it goes whack into this scoop. Then it flies like lightning along that groove, is scooped up by that scoop, flies like mad back to that there wheel and again gives it a good push so hard that it even begins to whine. Meanwhile another ball is on its way. Again it flies along and goes whack here. From there it dashes along the groove and strikes that scoop, skips to the wheel, and again whack! That's how it goes. Wait, I'll start it off."

"Pykhtin darted to and fro, hastily collecting the scattered balls. Finally, after heaping them up into a pile by his feet, he picked one up and threw it with all his might at the nearest scoop on the wheel. Then he quickly picked up a second, then a third. The noise was something unimaginable. The balls clanked against the iron scoops, the wheel creaked, the pillars groaned. An infernal whine and racket filled this gloomy place."

Karonin claims that Goldyrev's machine moved. But this was patently a misunderstanding. The wheel could have turned only while the balls were dropping down, i. e. at the expense of the potential energy accumulated when lifted, in the manner of the weights of a pendulum clock. However, it couldn't have turned long because when all the lifted balls had "whacked" against the

scoops and had slipped down, it would stop, provided it hadn't stopped before by the countereffect of all the balls it was supposed to lift.

Later on, Goldyrev became disappointed in his invention when at an exhibition in Yekaterinburg, where he showed it, he saw real industrial machines. When asked about his "perpetual motion" contraption, he dejectedly replied: "The devil take it! Tell'em to chop it up for firewood."

UFIMTSEV'S ACCUMULATOR

Ufimtsev's so-called accumulator of kinetic energy well illustrated the pitfalls that may trap a cursory observer of a "perpetual motion" machine. Ufimtsev, an inventor from Kursk, devised a new kind of windmill power station with a cheap flywheel type of "inertia accumulator". In 1920 he built a model of it, shaped as a disc that spun round a vertical axle set on ball bearings inside an air-free jacket. When revved to 20,000 rpm, the disc could turn for 15 days on end. The unthinking observer could well believe that he had before him a real "perpetual motion" machine.

"A MIRACLE, YET NOT A MIRACLE"

The futile search for a "perpetual motion" machine clouded many lives. I once knew a factory worker who sank into absolute destitution, spending all his earnings and savings in the delusion that he could make a "perpetual motion" machine. Poorly clad and always hungry, he would beg everyone he met to give him some money to make the "finished model", which would "certainly move". It was a great pity to see this man suffering so much only because of his ignorance of the rudiments of physics.

It is curious to note that whereas the search for a "perpetual motion" machine was always abortive, the profound realization of its impossibility, on the contrary, often led to discoveries of great value.

A wonderful illustration in point is the method which the remarkable Dutch scientist Stevin, who lived at the turn of the 16th century, evolved to establish the law of the equilibrium of forces on an inclined plane. He deserves far greater fame than befell him for his many major discoveries that we now constantly address ourselves to. These are decimal fractions, the introduction of denominators in algebra, and the establishment of the hydrostatic law that Pascal rediscovered later.

Stevin evolved the law of the equilibrium of forces on an inclined plane

without invoking the rule of the parallelogram of forces. He proved it with the aid of a drawing, which is reproduced in Fig. 36. A chain of fourteen identical spheroids is slipped round a three-sided prism. What happens to it? The bottom, which droops garland-like, is in a state of balance, as you see. But do the other two parts balance each other? In other words, do the two spheroids on the right offset the four on the left? The answer is yes. Otherwise the chain

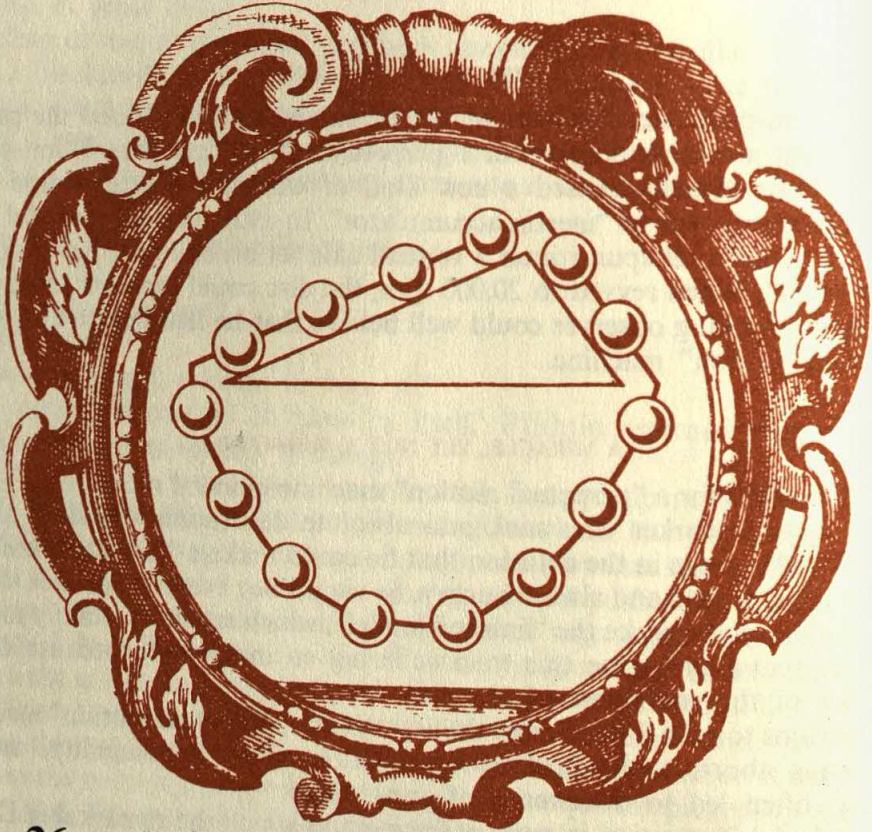


Fig. 36

"A miracle, yet not a miracle"

would keep on rolling of its own accord from right to left for ever while other spheroids would take the place of those that slide off and equilibrium would never be restored. But we know that a chain disposed in this fashion does not move of its own accord at all. It is quite obvious that the two spheroids on the right really offset the four on the left.

It seems a minor miracle, doesn't it? Two spheroids pull with the same force as four! This enabled Stevin to deduce an important law of mechanics. This is how he reasoned. The two parts, the long one and the short one, possess a different weight, one being as many times heavier than the other as the longer side of the prism is longer than the short side. Consequently, any two linked loads in general balance on tilted planes, provided each of the weights is directly proportional to the respective lengths of these planes.

When the short plane is vertical we get a well-known law of mechanics, which is: to hold a body in place on a tilted plane we must act in the direction of this plane with a force as many times less than the weight of the body as the length of the plane is greater than its height. So the idea that a "perpetual motion" machine is impossible led to an important discovery in the realm of mechanics.

MORE "PERPETUAL MOTION" MACHINES

Figure 37 shows a heavy chain fitted around wheels in such a way that the right-hand part is always longer than the left-hand part, whatever its position. The inventor thought that since the right-hand part would always outweigh the left-hand part, it would cause the entire arrangement to keep going. But does this really happen? Of course not. You already know that the heavier part of a chain may be offset by the lighter part, provided they are pulled by forces acting at different angles. In this particular system, the left-hand part of the chain droops vertically down, while the right-hand part is inclined. So, though it is heavier, still it cannot pull over the left-hand part and we do not achieve the "perpetual motion" expected.

I think the cleverest "perpetual motion" machine ever invented was one displayed at the Paris Exposition in the 1860's. It consisted of a large wheel with balls rolling about in its compartments. The inventor claimed that nobody would ever be able to stop the wheel. Many visitors tried to stop it but it went on turning as soon as they took their hands off it. Not a single person realized that the wheel turned precisely because of the effort made to stop it. The backward push he gave to stop it wound up the spring of an artfully concealed mechanism.

THE PERPETUAL MOTION MACHINE PETER THE GREAT WANTED TO BUY

Preserved in archives is a bulky correspondence which Peter the Great of Russia carried on between 1715 and 1722, when he wanted to buy a "perpetual motion" machine that had been devised in Germany by one Councillor Orffyr-

eus. This man whose “self-moving wheel” won him nation-wide fame consented to sell it to the tsar only for a princely sum. Peter the Great’s librarian Schumacher, whom the tsar had sent to Western Europe to collect rare oddities, reported the following, when asked to negotiate the purchase:

“The inventor’s last words were: One hundred thousand thalers and you get the machine.”

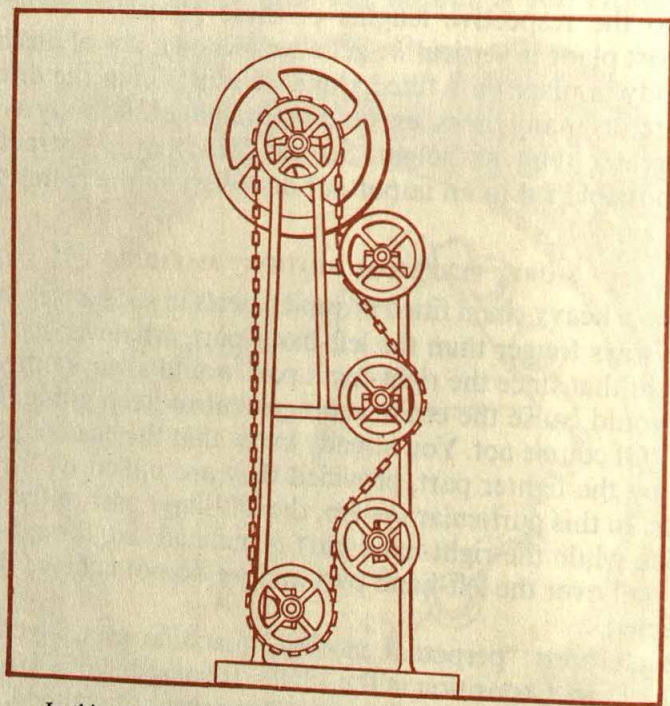


Fig. 37

Is this a “perpetual motion” machine?

As for the machine itself, according to Schumacher, the inventor claimed that it was no fake and that it could not be defamed “except out of malice, and the whole world is full of spiteful people whom one cannot believe”.

In January 1725 Peter the Great decided to go to Germany to see this notorious perpetual motion machine himself, but he died before he could accomplish his purpose.

Who was this mysterious Councillor Orffyreus and what was his “famous machine” really like? I was able to learn something both about the councillor himself and his machine.

Orffyreus' real name was Bessler. He was born in Germany in 1680. He studied theology, medicine and painting before he essayed the perpetual motion machine. Among the many thousands who tried to invent such a machine he is probably the most famous and, at any rate, the luckiest. Till the end of his days (he died in 1745) he lived in comfort on the income he netted by demonstrating his contraption.

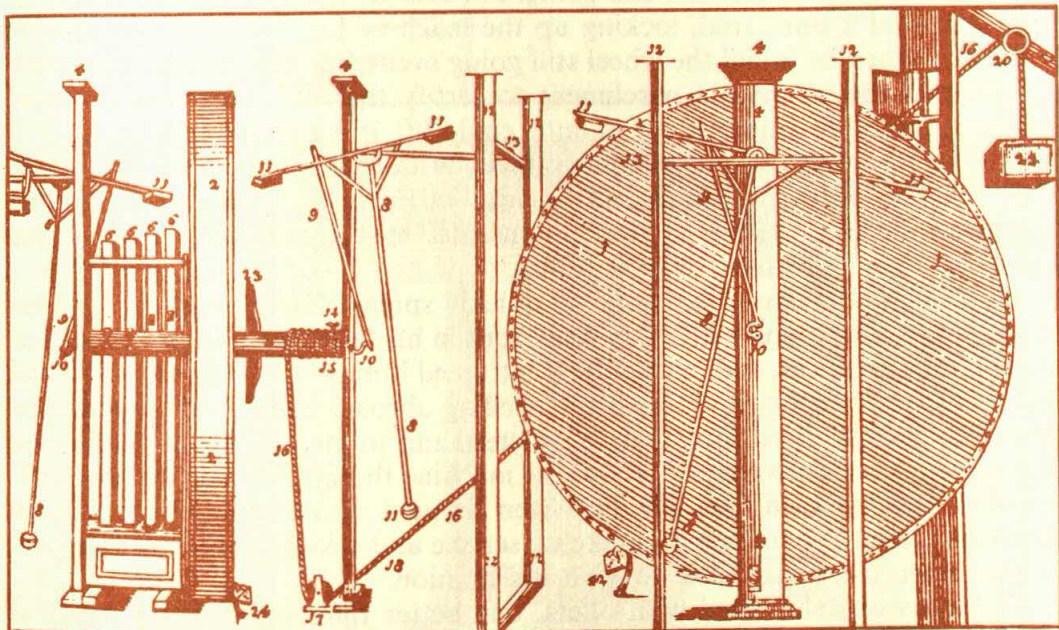


Fig. 38

Orffyreus' self-moving wheel which Peter the Great wanted to buy (from an old drawing)

Figure 38 is a reproduction of a drawing from an old book depicting Orffyreus' machine as seen in 1714. It shows a large wheel which apparently not only turned by itself, but even lifted a heavy load to quite a height.

The fame of this "miracle" machine, which the learned councillor first exhibited at various market fairs, quickly spread throughout Germany. Soon Orffyreus acquired powerful patrons. The Polish king displayed interest and then the Landgrave of Hesse-Cassel patronized the inventor, placing his castle at the latter's disposal and subjecting the machine to every kind of trial.

On November 12, 1717, the machine was placed in a room all apart and set into motion. The room was then locked and sealed, and two grenadiers were

posted outside. For a whole fortnight, until the seal was broken on November 26, no one dared to come near. Then the room was unlocked and the Landgrave and his retinue entered. The wheel was still spinning "with undiminishing speed". It was stopped, inspected carefully, and again set going. Now the room was locked and sealed for 40 days on end with grenadiers again stationed at the door. The seal was broken on January 4, 1718. A commission of experts entered and found that the wheel was still going. But this did not satisfy the Landgrave and he staged a third trial, locking up the machine for two whole months at a stretch. When he found the wheel still going even after that, he was delighted. He granted the inventor a parchment to certify that his "perpetual motion" machine did 50 revolutions per minute, could lift 16 kg to the height of 1.5 m and could also work, a grinder and bellows. With this document in his pouch, Orffyreus travelled the length and breadth of Europe. He apparently netted a princely income, considering that he consented to sell his machine to Peter the Great for not less than 100,000 rubles.

The fame of the councillor's marvel quickly spread, finally reaching the ears of Peter the Great, who had a very weak spot in his heart for all sorts of curious and cunning artifices, and, naturally, it intrigued him greatly. His attention had been called to it back in 1715 when travelling abroad, and it was then that he charged the celebrated diplomat A. I. Ostermann to inspect it. The latter soon forwarded an extensive report about the machine though he had not been able to see it with his own eyes. The tsar even thought of inviting Orffyreus as an eminent inventor to his court to take up service and asked the then well-known philosopher Christian Wolf to give his opinion.

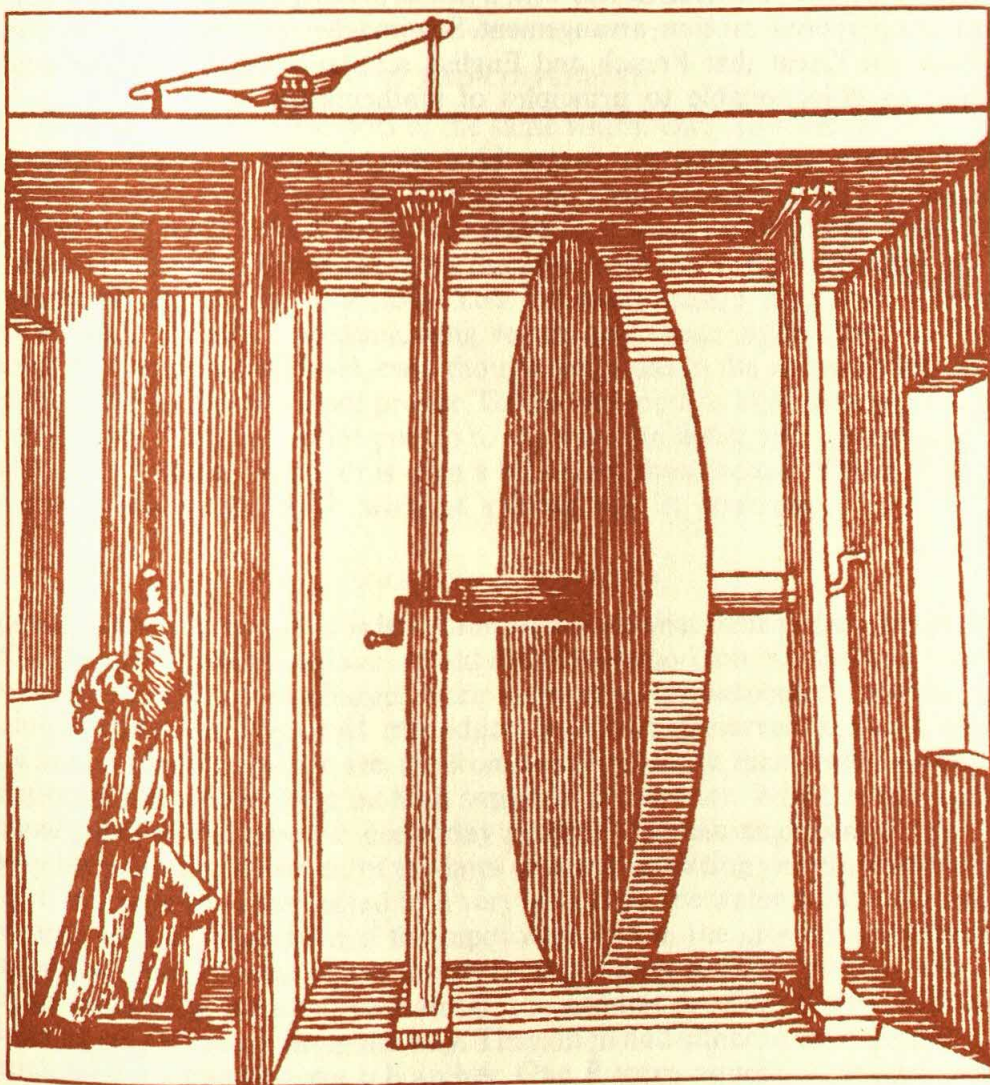
Orffyreus was showered with offers, one better than the other. Kings and princes bestowed munificent awards. Poets composed odes in honour of his wonder-wheel. But there were some who thought him a charlatan. The more daring openly accused him, even offering 1,000 marks to anyone who would come forth and expose the councillor. One lampoon against him gave a drawing which is reproduced in Fig. 39 and which provides a rather simple explanation for the mystery, namely, a cunningly hidden person who pulled at a rope wound round that part of the axle which was concealed in the pillars supporting the wheel.

The trick was bared by chance only because the councillor had had a tiff with his wife and maid who had both been initiated into the secret. Otherwise we would probably still be guessing. It appeared that the notorious machine was indeed turned by a hidden person, Orffyreus' brother, or maid, pulling at a slender cord. But the councillor did not lose face, persistently assuring all and

sundry even on his deathbed that his wife and maid had maligned him out of spite. However, trust in him was shattered. No wonder he tried to drum into the head of the tsar's envoy, Schumacher, the point that human beings were full of malice.

Fig. 39

The secret of Orffyreus' machine (from an old drawing)



Around the same time there also lived in Germany another renowned perpetual motion machine inventor, one Hertner. Schumacher wrote of his contraption the following: "Herr Hertner's *perpetuum mobile*, which I saw in Dresden, consists of tarpaulin filled with sand and a grinder-like machine which turns forward and backward by itself. However the inventor says it cannot be made larger." Undoubtedly this machine, too, gave no perpetual motion, being at best an artfully contrived device with a just as artfully concealed living, but by no means perpetual motion, arrangement. Schumacher was right when he wrote to Peter the Great that French and English scholars "mock these *perpetuum mobiles* as objectionable to principles of mathematics".

Chapter

Properties of Liquids and Gases

5

THE TWO COFFEE-POTS

Figure 40 shows two coffee-pots of the same width. One, however, is taller than the other. Which of the two will hold more? An unthinking person would probably point to the taller one. However, we would be able to fill it up only to the level of its spout, and if we poured more in, it would all spill out. Now since the spouts of both coffee-pots are on the same level, the lower one takes just as much liquid as the taller one does. You will easily realize why. The coffee-pot and its spout are two communicating vessels and hence inside both the liquid should be at an identical level, even though the liquid in the spout weighs much less than that in the coffee-pot proper. Unless the spout is high enough, you will never be able to fill the coffee-pot up to the top; the water will simply keep on spilling out. Usually the spout is even a bit higher than the top of the coffee-pot to enable one to incline it without spilling out its contents.

IGNORANCE OF ANCIENTS

Romans today still use what is left of the aqueducts that their remote forefathers built. Though the Roman slaves of old did a very good job, we can't say that of the Roman engineers in charge. Their knowledge of elementary physics was plainly inadequate. Figure 41 reproduces a picture preserved at the German Museum in Munich. As you see, the Romans did not sink their water systems in the ground but placed them on high supports of masonry. Why? Aren't underground pipes of the type we use today simpler? Roman engineers of old had a very hazy notion, however, of the laws of communicating vessels. They feared that in two reservoirs connected by a very long pipe, the water would not rise to the same level. Furthermore, if the pipes were laid in the ground and followed the natural relief, in some places the water would have to flow upwards, and this was something the Romans were afraid it would not do. That is why their aqueducts usually slope all along the way. They often had either to take the pipes on a roundabout route or erect tall arches. One Roman aqueduct, known as the

Aqua Marcia, is 100 km long, though it is half the distance between its two points as the crow flies. As you see, the ancient Romans' ignorance of an elementary law of physics caused 50 km of extra masonry to be built.

LIQUIDS PRESS ... UPWARDS

Even people who have never studied physics know that liquids press down on the bottom of the vessels holding them and sideways at the walls. Many,

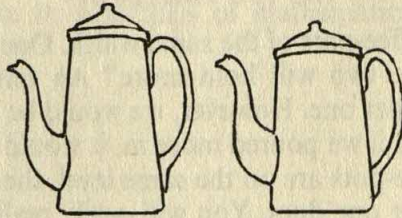


Fig. 40

Which coffee-pot takes more?

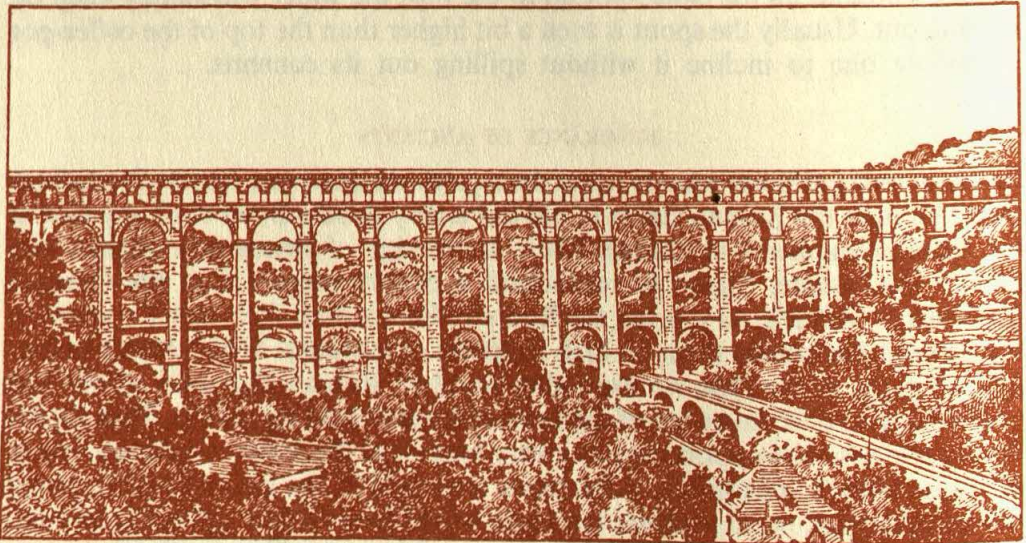


Fig. 41

The aqueducts of ancient Rome

however, have never suspected that liquids also press upwards. An ordinary lamp-glass will easily reveal this. Cut out of a piece of thick cardboard a disc large enough to cover the top of the lamp-glass. Cover the top of the glass with it and then dip the glass into a jar of water as shown in Fig. 42. To prevent the disc from slipping off when the lamp is immersed, tie a piece of thread to it and hold it as shown, or simply press it down with your finger. After you have dipped the glass far enough, you can let the thread, or your finger, go. The disc will remain where it is, being kept in place by the water pressing up on it.

If you want to, you can even gauge the value of this upward pressure. Carefully pour some water into the glass. As soon as the level of the water in the glass reaches that of the water in the jar, the disc slips off, because the pressure exerted by the water on the disc from below is offset by the pressure exerted on it from above by the column of water in the glass, the height of which is equal to the depth to which the glass has been dipped. Such is the law concerning the pressure that a liquid exerts on any immersed body. This incidentally results in that "loss" of weight in liquids of which Archimedes' famous principle speaks.

With the help of several lamp-glasses of different shapes but with tops of one and the same size you may test another law dealing with liquids: that the pressure a liquid exerts on the bottom of the containing vessel depends only on the size of the bottom and the height of the "column" of liquid; it does not depend at all on the vessel's shape. This is how you test this law. Take different glasses and dip them to one and the same depth. To see that no mistakes occur, first glue strips of paper to the glasses at equal heights from the bottom. The cardboard disc you used in the first experiment will slip off every time you pour in water to the same level (Fig. 43). Consequently the pressure exerted by columns of water of different shapes is the same as long as the bottom and height are the same. Note that it is the *height*, and not the *length*, that is important, because a long but *inclined* column exerts exactly the same pressure on the bottom as is exerted by a shorter but perpendicular column as *high* as the inclined one—provided, of course, the bottom of each is the same.

WHICH IS HEAVIER?

Place a pail of water, full up to the rim, on one pan of equal-arm beam scales. Then put on the other pan another pail of water, *also full up to the rim*, but with a piece of wood floating in it (Fig. 44). Which of the two is heavier? I asked this of different people and got contradictory answers. Some said the pail with the piece of wood in it would be heavier because it held a piece of wood in addition

to the water. Others said the pail of water without the piece of wood would be heavier, since water generally weighs more than wood. Neither were right. Both pails *weigh the same*. The second pail, true, contains less water than the first one, because the wood displaces some of the water. But, according to the related law, every *floating* body displaces with its immersed part exactly as *much liquid* (in weight) as *the whole of this body weighs*. That is why the scales balance.

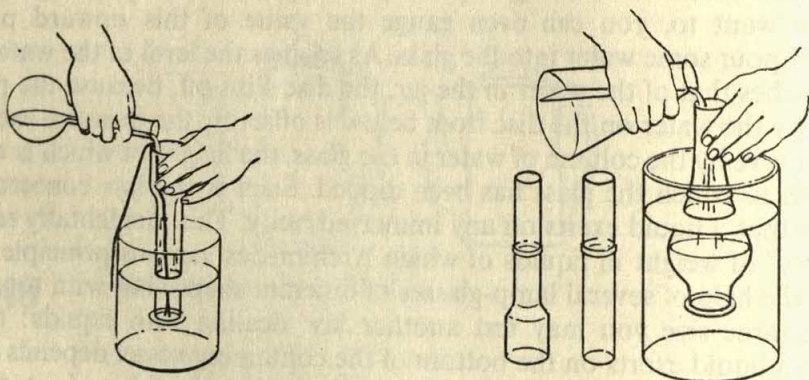


Fig. 42

Fig. 43

A simple way to demonstrate that liquids press upwards

The pressure liquid exerts on the bottom of the vessel depends only on the area of the base and the liquid's height. The drawing shows you how to check this

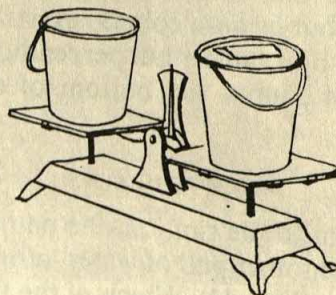


Fig. 44

Both pails are full to the rim. One has a piece of wood in it. Which is heavier?

Now try to solve another problem. Take a glass of water, put it on one of the pans, and put a weight next to it. Balance the scales. Then drop the weight next to the glass into it. What happens to the scales?

According to Archimedes' principle, in the water the weight should weigh less than when on the pan. Consequently, oughtn't this pan rise? However, the pans maintain their equilibrium. Why?

When dropped into the glass the weight displaced some of the water which then rose to a level higher than before. This added to the pressure exerted on the bottom of the vessel, which thus sustained an additional force equivalent to the weight lost by the weight.

A LIQUID'S NATURAL SHAPE

We are used to thinking that liquids have no shape of *their own*. That is not true.

The natural shape of any liquid is that of a sphere. As a rule, gravity prevents liquids from assuming this shape. A liquid either spreads in a thin layer if spilled out of a vessel, or takes the vessel's shape. But when inclosed in another liquid of the same specific gravity, it, according to Archimedes' principle, "loses" its weight, seeming to weigh nothing; now gravity has no effect on it and it assumes its natural spherical shape.

Since olive oil floats in water but sinks in alcohol we can mix the two in such proportions that the oil will neither sink nor float in this mixture. An odd thing happens when we drip in a little oil with the help of an eyedropper. The oil collects into a large round drop which neither floats nor sinks, but hangs suspended (Fig. 45). To get a true image of the sphere, you should do the experiment in a flat-walled vessel—or in one of any shape but placed inside a flat-walled vessel full of water.

You must do this experiment patiently and carefully, because otherwise you will get several smaller drops instead of a large one. Don't feel disheartened if it doesn't work out; even it's sufficiently illuminating.

Let's carry this experiment further. Take a long stick or a piece of wire and transfix the oil drop. Rotate it. The drop also participates in this revolution. You get still better results by attaching to the stick or wire a small cardboard disc soaked in oil and inserting it fully in the drop you are twirling. The spin compels the drop to compress and then give off a ring a few seconds later (Fig. 46). As it breaks up the ring creates new drops which continue to revolve round the central one.

The Belgian physicist Plateau was the first to conduct this instructive

experiment, of which I have given you the classical description. It would be much easier, and just as instructive, to do this experiment in another way. Take a small tumbler, rinse it with water, and fill it with olive oil. Place it on the bottom of a larger glass. Then carefully pour into the glass enough alcohol to cover the tumbler. Gradually add a little water with the help of a spoon. Do this very carefully, so that the water drips down the walls of the glass. The top of the

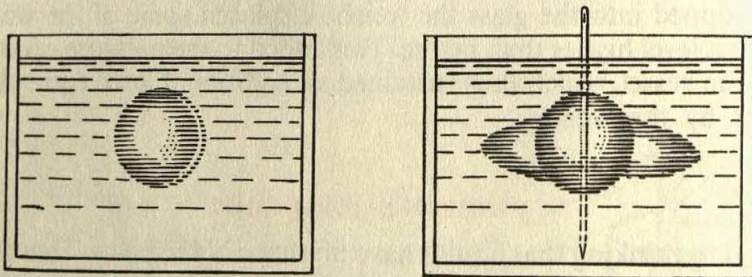


Fig. 45

Oil inside diluted alcohol collects into a drop which neither sinks nor floats. (Plateau's experiment)

Fig. 46

A ring is given off when the oil drop in the alcohol is spun by means of a rod

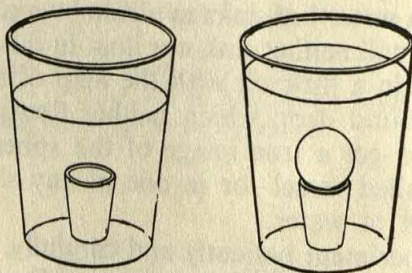


Fig. 47

Plateau's experiment simplified

oil in the tumbler starts to bulge, and when enough water has been poured in, the oil rises up from the tumbler in a rather large drop to hang suspended in this mixture of alcohol and water (Fig. 47).

For want of alcohol you can use aniline instead. Aniline is a liquid which is heavier than water at room temperature but lighter than water when heated to 75-85°C. By heating up the water, we can make the aniline swim inside it and assume the form of a large drop. At room temperature you can suspend an

aniline drop in a solution of table salt. Another convenient liquid is the dark-crimson orthotoluidine, which at 24°C has the same density as salt water, into which it is poured.

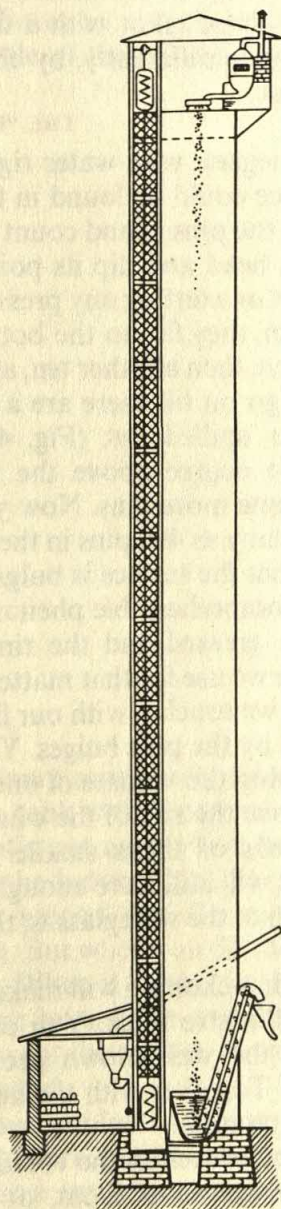
Fig. 48

A shot tower

WHY IS SHOT ROUND?

I noted earlier that any liquid will assume its natural spherical shape when gravity ceases to act on it. You need only remember what I said before about a falling body having no weight and discount the negligible atmospheric resistance when a body starts to fall (raindrops accelerate only when they start to fall; by the second half of the first second the fall already becomes *uniform* and the drop's weight is offset by atmospheric resistance which grows with the velocity of the falling drop) to realize that falling portions of liquid should also take on a spherical form.

That is really so. Falling raindrops are indeed round in shape. Shot is nothing but solidified drops of molten lead which in the process of making are dropped from a great height into cold water where they solidify in the shape of absolutely right spheres. Shot is also called "tower" shot because in its making it is dropped from the top of a tall "shot tower" (Fig. 48). Those towers are metal structures 45 m high. At the top they have a shot-pouring shop with boilers for melting the lead,



and at the bottom, a water bath. The ready shot is then graded and processed. The drop of molten lead solidifies into shot while falling. The water bath is needed merely to soften the impact and to prevent the shot from losing its spherical shape (shot with a diameter of more than 6 mm, so-called canister shot, is made differently, by chopping off pieces of wire, which are then rolled into balls).

THE "BOTTOMLESS" WINEGLASS

Fill a wineglass with water right up to the very rim. Take some pins. Do you think place could be found in the wineglass for a couple of them? Try and see.

Throw the pins in and count them as you do. But be careful about it. Take the pin by its head and dip its point into the water. Then carefully let go, without pushing it or exerting any pressure, so that water is not spilled out. As you drop the pins in, they fall to the bottom, but the level of the water is the same. You drop in ten, then another ten, and then another ten. The water does not spill out. You can go on till there are a hundred at the bottom of the glass. But still no water has spilled out (Fig. 49). Nor, for that matter, has it risen to any noticeable degree above the rim.

Add some more pins. Now you can even count them in hundreds. You may have as many as 400 pins in the glass, but still no water spills out. However, now you see that the surface is bulging above the rim. Therein lies the answer to this so far incomprehensible phenomenon. Water scarcely wettens glass as long as it is a little greased and the rim of the wineglass, like all the chinaware and glassware we use for that matter, is sure to have some traces of grease which are left when we touch it with our fingers. And as it doesn't wetten the rim the water displaced by the pins bulges. You can hardly see it, but if you went to the pains of reckoning the volume of one pin and of comparing it with the volume of the bulge above the rim of the wineglass you would realize that the former volume is hundreds of times smaller than the latter, which explains why a "full" wineglass will still have enough room for another few hundred pins. The wider the mouth of the wineglass is, the more pins it can take, because there is a larger bulge.

A rough reckoning will make the point clear. A pin is about 25 mm long and half a millimetre thick. You can easily reckon the volume of this cylinder by invoking the well-known geometrical formula ($\pi d^2 h/4$); it will be equal to 5 cu mm. Together with the head, the pin will have a total volume of not more than 5.5 cu mm.

Let us now reckon the volume of the water in the bulge. The diameter of the wineglass mouth is 9 cm, or 90 mm. The area of such a circle is about

6,400 sq mm. Assuming that the bulge is not more than 1 mm high, we thus get a volume of 6,400 cu mm, which is 1,200 times more than the volume of the pin. In other words, a "full" wineglass of water can take more than a thousand pins. And indeed we can get the wineglass to take a thousand pins if we are careful enough. To the eye they seem to occupy the whole of the wineglass and even stick out of it. But still no water spills out.



Fig. 49

The pins in the wineglass

UNPLEASANT PROPERTY

Anyone who has ever had to handle a kerosene lamp most likely knows what annoying surprises it can spring on one. You fill a tank with kerosene and then wipe the tank dry on the outside. An hour later it's wet again. You have only yourself to blame. You probably didn't screw on the burner tight enough, and the kerosene, trying to spread along the glass, seeped out. To avert such "surprises", screw the burner on as tight as you can. But when you do that, don't forget to see that the tank is not full up to the brim. When it warms up, kerosene expands rather considerably, increasing in volume by a tenth every time the temperature rises by another 100° . So if you don't want the tank to explode, you must leave some room for the kerosene to expand.

The property of kerosene to seep through causes unpleasant things aboard ships whose engines burn kerosene or oil. When due precautions are not taken, it is absolutely impossible to use such ships to carry any other cargoes except

kerosene or oil, because when they seep out through unnoticeable crevices in the tanks these liquids spread not only to the metal surfaces of the tanks but literally everywhere, even to the clothing of the passengers to which they impart a smell that nothing will kill.

Attempts to fight this evil are often to no avail. Jerome K. Jerome, the British humorist, wasn't guilty of much of an exaggeration when in his *Three Men in a Boat* he wrote of paraffin oil, which is remarkably alike kerosene.

"I never saw such a thing as paraffin oil is to ooze. We kept it in the nose of the boat, and, from there, it oozed down to the rudder, impregnating the whole boat and everything in it on its way, and it oozed over the river, and saturated the scenery and spoilt the atmosphere. Sometimes a westerly oily wind blew, and at other times an easterly oily wind, and sometimes it blew a northerly oily wind, and maybe a southerly oily wind; but whether it came from the Arctic snows, or was raised in the waste of the desert sands, it came alike to us laden with the fragrance of paraffin oil.

"And that oil oozed up and ruined the sunset: and as for the moonbeams, they positively reeked of paraffin....

"We tried to get away from it at Marlow. We left the boat by the bridge, and took a walk through the town to escape it, but it followed us. The whole town was full of oil." (Actually it was only the clothing of the travellers that reeked of paraffin oil.)

The property kerosene has of wettening the outer surface of tanks led people to wrongly think that kerosene could ooze through metal and glass.

THE UNSINKABLE COIN

It's to be found not only in fairy tales. A few easy experiments will show you that such things really exist. Start with a small object, a needle, for instance. It seems impossible to make a steel needle float, doesn't it? But it isn't really so hard to do. Place a strip of cigarette paper on top of the water in a glass and an absolutely dry needle on top of the paper. Carefully remove the cigarette paper in the following way. Take another needle or a pin and, gradually working to the middle, gently push the strip of paper into the water. When the strip is soaked through, it will sink, but the needle will continue to float (Fig. 50). By moving a magnet at water level from outside the glass you can even make the floating needle spin round.

With a little experience, you can dispense with the cigarette paper entirely. All you need do is to take the needle by the middle and, holding it parallel to the

water, drop it from a small height. You can make a pin, which like the needle must not be thicker than 2 mm, a light button, or some small metal object float in the same way. When you have got the knack of it, try a coin.

All these metal objects float because water hardly wettens metal covered with a very thin film of grease from our hands. You can even see the depression a floating needle makes on the surface of the water. Trying to regain its original

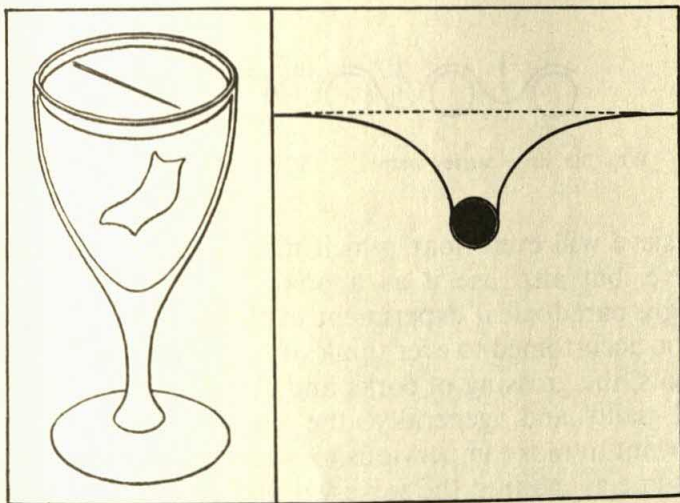


Fig. 50

A floating needle. Right: a cross-section of the needle (2 mm thick) and the depression it makes (a twofold magnification). Left: how to make the needle float by using a strip of paper

position, the surface film buoys up the needle which is also buoyed up by a force equal to the weight of the water displaced by the needle.

The easiest way of making a needle float is, of course, to cover it with grease. Then it will never sink.

CARRYING WATER IN A SIEVE

Neither is this something that can be done only in a fairy tale. Physics can help us to undertake this seemingly impossible task. Take a wire sieve of 15 cm across with holes not smaller than 1 mm in diameter and dip it into melted paraffin, to cover it with a thin, barely discernible film.

Your sieve remains a sieve; it still has holes in it through which a pin can go

quite freely, but now you can carry water in it, even quite a lot of it. Only be careful when pouring the water in and see to it that you don't jolt the sieve while doing that.

Why doesn't the water drip through? Failing to wetten the paraffin, the water forms a thin film which bulges through the holes of the sieve; it is this film that keeps the water from dripping through (Fig. 51).

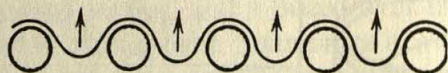


Fig. 51

Why the sieve carries water

This waxed sieve will even float, which means that you cannot only carry water in a sieve, but also use it as a boat.

This seemingly paradoxical experiment explains several ordinary things to which we are too accustomed to ever think of why they are done. The tarring of barrels and boats, the greasing of corks and stoppers with fat, the painting of roofs with oil paint and, generally, the coating with oily substances of everything we want to make impervious to water, as well as the rubberizing of cloth, are the same as making the sieve we just described, with the exception that the sieve, of course, seems exceedingly unusual.

FOAM HELPS ENGINEERS

The experiment of the floating steel needle or copper coin bears some resemblance to a process employed in mining to "enrich" ores, i.e. to increase the content of the minerals in them. Engineers know many methods for dressing ores, but the one we have in mind and which is called "flotation" is best; it is successful when all other methods fail.

Flotation consists in the following. Finely ground ore is loaded into a bath containing water and oily substances that enclose the mineral particles in a very thin film which water cannot wet. Air is then blown in to form foam composed of a multitude of tiny bubbles. The greased particles of the mineral attach themselves to the air bubbles and rise up with them much in the same way as an air balloon lifts a gondola (Fig. 52). The particles of ore gangue that have no

grease envelope cannot attach themselves to the air bubbles and so sink. Note that the air bubbles in the foam are much bigger than the particles they carry and are well able to lift the solid speck up. As a result, nearly all the particles of the mineral are floated on top in the foam which is skimmed off for further processing, during which the so-called concentrated ore, which is dozens of times richer in content than the original ore, is separated. Flotation techniques

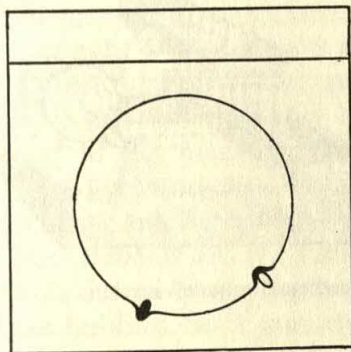


Fig. 52

The essence of flotation

are so well elaborated that a judicious choice of reagents will separate the mineral from the ore gangue in every particular case.

Incidentally, we have a chance accident, and no theory, to thank for the flotation method. One day, at the end of the past century, Carrie Everson, an American schoolmistress, was washing greasy sacks that had been used to stack copper pyrites. She happened to notice that the pyrite particles left in the sacks floated together with the lather. It was this that suggested the flotation method.

FAKE "PERPETUAL MOTION" MACHINE

You will sometimes find the following contraption (Fig. 53) described as a genuine perpetual motion machine. Oil (or water) poured into a vessel is soaked up by wicks at first into one vessel and then by more wicks into another vessel still higher up. The top vessel has a grooved outlet through which the oil pours onto a paddle wheel, causing it to turn. From the bottom tank the oil is again soaked up by wicks to the top. Thus, the oil supposedly never stops pouring onto the paddle wheel, making the wheel turn for ever and ever.

If the people who described this thing were to take the pains to make it, they

would realize that not a single drop of oil would ever reach the upper vessel, let alone make the wheel go.

Incidentally, we don't necessarily have to make this contraption to realize that this is so. Indeed, why should the inventor think the oil should necessarily flow off the upper bent portion of the wick? It is quite true that capillary attraction, having overcome gravity, lifts the oil up the wick. But it is the

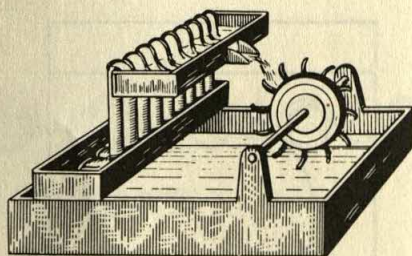


Fig. 53

Nonexistent "perpetual motion" machine

attraction that prevents the oil in the pores of the soaked wick from oozing off. Even supposing for a moment that the oil will reach the upper vessel of our fake "perpetual motion" machine due to capillary forces, we shall have to admit that the same wicks which supposedly lift the oil up would themselves lower it to the bottom tank.

The contraption we have just mentioned resembles another water-driven one, invented by the Italian mechanic Strada the Elder way back in 1575. As it turns, an Archimedes' screw lifts water to the upper tank, from which it pours out through a groove to strike at the paddles of the tank-filling wheel. This wheel turns a grinder and simultaneously operates by means of several gears the same Archimedes' screw which lifts the water to the upper tank. To make a long story short, the screw turns the wheel and the wheel turns the screw! If such contraptions were possible, the simplest thing would be to throw a rope over a pulley and tie identical weights to each end. As one weight fell it would lift the other one, which dropping in turn, would lift the first one. Wouldn't that be a fine "perpetual motion" machine?

BLOWING SOAP BUBBLES

Do you know how to blow soap bubbles? It is not so simple as it seems. I, too, thought there was nothing particular in it until I saw for myself that the ability

to blow big beautiful bubbles is in its way an art that needs some experience. But is it really worth while doing such a seemingly silly thing as blowing soap bubbles?

After all, they have won a rather bad reputation among the laymen. Physicists have other views, however. "Blow a soap bubble," said the great British physicist Kelvin, "and observe it. You may study it all your life, and draw one lesson after another in physics from it."

Indeed, that magic iridescence on the thinnest of soap films enables the physicist to gauge the length of light waves, while a study of the tension of these gossamer films helps him to formulate the laws governing the interaction of forces between particles – those self-same forces of cohesion without which the world would be but a cloud of the finest dust.

The few experiments described below do not have such serious aims; they are given simply to provide instructive entertainment and to teach you how to blow soap bubbles. In his book *Soap Bubbles and the Forces Which Mould Them*, the British physicist Charles Boys describes at length many different experiments that one can stage with these bubbles. So if you are interested in them, let me refer you to this wonderful book.

Below you will find only a few of the simplest experiments. Ordinary laundry soap will do, but you can also use pure olive-oil or almond-oil soap, which is best for obtaining large and beautiful bubbles. Carefully dissolve a cake of soap in pure cold water till you get a rather thick lather. Pure rain water or melted snow is best but you may use cooled boiled water instead. To prolong the life of the bubbles Plateau suggests adding glycerin to the lather in a mixture of one part to every three. Skim the froth and the small bubbles off with a spoon and then dip in the lather a slender clay pipe, with its end preliminarily soaped both on the inside and outside. Good results can be achieved also by using straws of about 10 cm long, that are split at the bottom in the form of a cross.

This is how you blow the bubble. Dip the pipe into the lather, holding it vertically so that it becomes covered with film. Then gently blow at the other end. As the bubble is filled with warm air from our lungs, which is lighter than the air in the room, it will float up at once as long as you can blow a bubble of some 10 cm across; otherwise you must add more soap until you can blow bubbles of this diameter. This alone is not enough; there is another test that you must make. After you blow the bubble, dip your finger in the lather and try to pierce the bubble with it. If it doesn't burst you can start experimenting. If it does, add a little more soap.

Do the experiments slowly, with care, and without undue haste. The room must be well lit; otherwise the proper iridescence will be lacking. Now for a few entertaining experiments.

(1) *A flower in a bubble*. Pour the lather three millimetres deep into a plate or tray. Then place a flower or a little vase in the middle and cover it with a glass funnel. Slowly lift the funnel, blowing meanwhile in its narrow end to get a soap bubble. When the bubble is large enough, tilt the funnel as shown in Fig. 54 and release the bubble. Your flower or vase will be under a transparent, semicircular, iridescent soap bubble.

You can take a *statuette* instead of a flower and crown it with a small soap bubble as shown in Fig. 54. To get the smaller bubble, you must spill a little lather on top of the statuette before you blow the big bubble. Then pierce the big bubble with a pipe and blow out the small bubble inside.

(2) *A nest of bubbles* (Fig. 54). Take the funnel you used for the previous experiment and blow a large bubble as you did before. Then take a straw and dip it into the lather, leaving only the very end which you blow through, dry. Gently pierce the wall of the first bubble till you get to the middle. Then slowly draw the straw back without bringing it out, and blow out a second bubble inside the first. Repeat to get a third bubble inside the second, a fourth inside the third, and so on.

(3) *A cylindrical bubble* (Fig. 55). For this purpose you must have two wire rings. Blow an ordinary round bubble onto one of them, the lower one. Then take the second ring, wet it and attach it to the top of the bubble. Lift it until the bubble assumes a cylindrical shape. Note that if you lift the upper ring to a height more than the ring's circumference, half of the cylinder will contract and the other half will bulge until the bubble divides into two.

The film of the soap bubble, which is continually in state of tension, presses on the enclosed air; by directing the narrow end of the funnel at the flame of a candle you will see that the strength of this very thin film is not so negligible as you might think, the flame wavers quite noticeably (Fig. 56).

It is interesting to observe a bubble floating out of a warm room into a cold one. It shrinks noticeably. Conversely, it expands when brought from a cold room into a warm one. This, naturally, depends on the contraction and expansion of the air inside. If you were to blow a bubble of 1,000 cu cm in a subzero frost of 15°C and then bring it into a room where the temperature is 15°C above zero, it would increase in volume by roughly 110 cu cm ($1,000 \times 30 \times 1/273$).

I must note that a soap bubble is not always as short-lived as is usually

thought. When handled with care it can be preserved for some ten days, if not more. The British physicist Dewar, who became famous for his studies of the liquefaction of air, preserved soap bubbles in special bottles, shielded from dust, dryness, and shock, and was able to keep some bubbles for a month and more. The American Lawrence kept soap bubbles under a bell-glass for years on end.

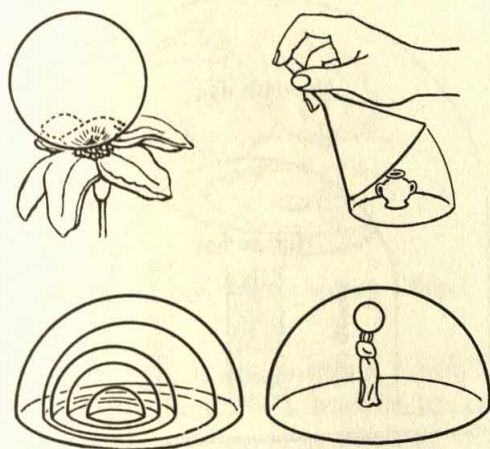


Fig. 54

Soap bubbles

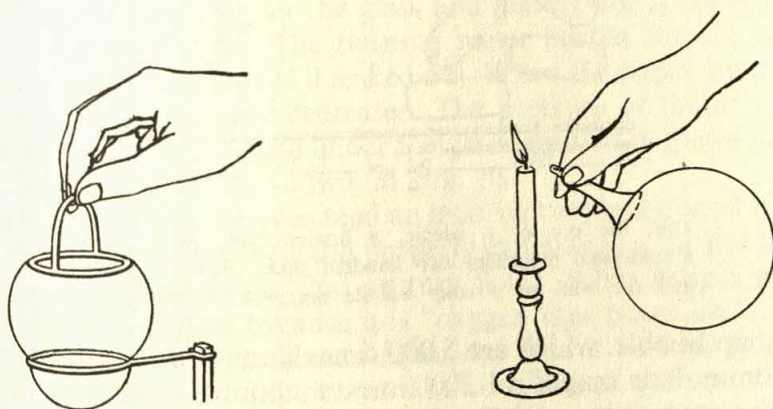


Fig. 55

How to make a cylindrical soap bubble

Fig. 56

The air forced out by the walls of the soap bubble causes the candle-flame to waver

THINNEST OF ALL

Few probably know that the film of a soap bubble is one of the thinnest things you can see with unaided eye. The customary comparisons we draw upon to express thinness are very thick compared with the film of a soap bubble. A thing "as thin as a hair" or "as thin as cigarette paper" is very thick compared with the

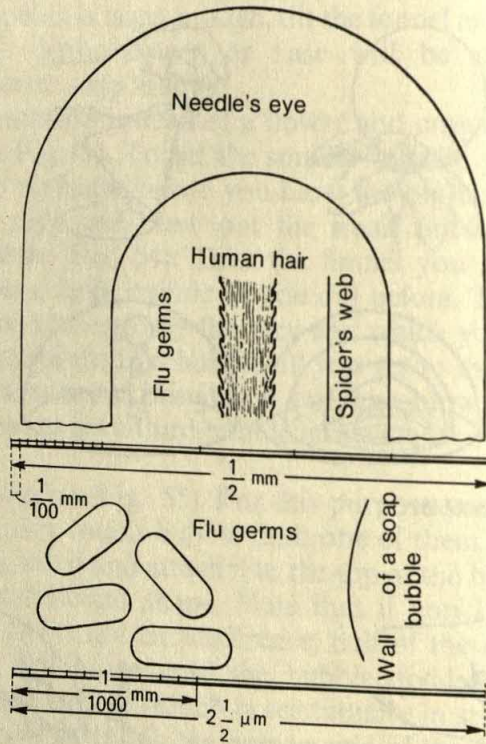


Fig. 57

Top: the eye of a needle, a human hair, germs, and a spiderweb magnified two hundred times. Bottom: germs and the wall of a soap bubble magnified 40,000 times

walls of a soap bubble, which are 5,000 times thinner than a hair or cigarette paper. A human hair magnified 200 times is about a centimetre thick. If we magnified the cross-section of the film of a soap bubble the same number of times, we still wouldn't see it. We would have to magnify it another 200 times to see it as a slender line. Then a hair, magnified 40,000 times, would be more than two metres thick. Figure 57 well illustrates this.

WITHOUT WETTING A FINGER

Take a large plate and put a coin on it. Then add enough water to cover the coin. Ask your guests to pick up the coin without wetting a finger. It seems impossible, doesn't it?

But it can be solved in a very simple way with the aid of a glass and some

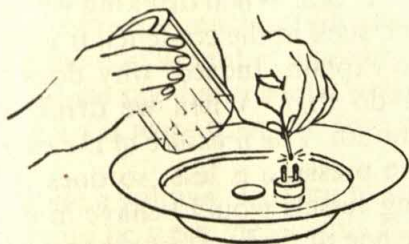


Fig. 58

How to pick up the coin without wetting a finger

paper. Take a piece of paper, light it and, while it is still burning, place it inside the glass. Then quickly put the glass down, bottom up, on the plate. The paper goes out, the glass fills with white wisps of smoke and all the water in the plate flows under it. The coin will naturally remain where it is. A minute or two later, as soon as the coin is dry, you can pick it up without wetting a finger.

What sucked the water under the glass and maintained it there at a certain level? Atmospheric pressure. The burning paper heated the air in the glass, increased its pressure and part of it leaked out. When the paper went out the air cooled again, and its pressure decreased. The pressure of the air outside the glass forced the water in the plate under the glass. Instead of paper you may use matches stuck in a cork as shown in Fig. 58.

It is not unusual to hear or even read an incorrect explanation of this very old experiment (it was first described and properly explained by the physicist Philon of Byzantium who lived in the 2nd century B.C.). Some people say that the water flows under the glass because it is "oxygen that burns out", and that is why the amount of gas in the glass diminishes. This is absolutely wrong. The water flows under the glass only because the air is *heated* and not at all because any oxygen is absorbed by the burning paper. You can check this statement in the following way. Heat up the glass by pouring boiling water into it, thus dispensing with the burning piece of paper. Then, if you take instead of paper a piece of cotton wool soaked in alcohol, which burns longer and heats up the

air better, the water will rise up to almost the middle of the glass; note that oxygen comprises only a fifth of the air in volume. Note, finally, that instead of the allegedly "consumed" oxygen, you have carbon dioxide and water vapour. While the first dissolves in water, vapour remains, replacing part of the oxygen.

HOW WE DRINK

Can this pose a problem? It can. When drinking we bring a glass or a spoonful of liquid up to our lips and suck in the contents. It is this simple thing we are so used to, that we have to explain. Indeed, why does the liquid rush into our mouth? What makes it do that? When we drink, our chest expands, thus rarefying the air in our mouth. *The pressure of the outer air* forces the liquid to rush into the place where pressure is less; so does it find itself in the mouth. Liquids in communicating vessels would behave in exactly the same way were we to rarefy the air above one of them. Atmospheric pressure would compel the liquid in this particular vessel to rise. If you enclose the mouth of a bottle with your lips you will fail to suck in the water as the pressure of the air in your mouth and above the water will be the same. So, strictly speaking, we drink not only with our mouths, but also with our *lungs*, since it is chest expansion that makes the liquid rush into our mouths.

A BETTER FUNNEL

Those who have ever poured liquids into a bottle through a funnel know that from time to time you have to lift the funnel a little because otherwise the liquid will stay in it. This is because the air in the bottle fails to find an outlet and so blocks up the liquid in the funnel. A little of the liquid drips in and as a result the air in the bottle is slightly compressed by the liquid's pressure. However, the cramped air will become resilient enough to offset the weight of the liquid in the funnel by its own pressure. By lifting the funnel, we give the compressed air a chance to escape. Then the liquid begins to flow in again. So, to make a better funnel, the narrower part should have ridges outside to prevent the funnel from fitting tightly in the mouth of the bottle.

A TON OF WOOD AND A TON OF IRON

What is heavier—a ton of wood or a ton of iron? Some heedlessly answer that the ton of iron is heavier, thus raising a laugh at their expense. The questioner would probably laugh still louder were he told that the ton of wood is heavier.

This seems absolutely incredible, but it is true, strictly speaking.

The point is that Archimedes' principle can be applied not only to liquids but also to gases. In the air, every object "loses" in weight as much as the volume of displaced air weighs. Wood and iron also lose a part of their weight, and to get their true weight, you must add the loss. Consequently, true weight of the wood in our case is one ton plus the weight of the air it displaces. The true weight of the iron is also one ton plus the weight of the air that the iron displaces. However, a ton of wood occupies a much larger space (about 15 times more) than a ton of iron. Hence, the true weight of a ton of wood is more than that of a ton of iron. Rather should we say that the true weight of the amount of wood which weighs a ton in the air is *more* than the true weight of iron which also weighs a ton in the air.

Since a ton of iron occupies a volume of $1/8$ cu m and a ton of wood a volume of about 2 cu m, the difference between the weights of the two different volumes of displaced air should be about 2.5 kg. It is by this amount that a ton of wood is really heavier than a ton of iron.

THE MAN WHO WEIGHED NOTHING

To be as light as a feather (incidentally, in spite of the popular notion, a feather is really hundreds of times heavier than air, and only hovers because due to its rather great "wing-spread" the atmospheric resistance it encounters is much greater than its weight) and even lighter than air, to rid oneself of the fetters of gravity and freely soar into the skies, has been the dream of many a child and even grown-up. But they forget that they can walk around with ease only because they are *heavier than air*.

"We live at the bottom of an ocean of air," Torricelli once said. If we were suddenly to grow a thousand times lighter, lighter than air, we would inevitably float up to the top of this ocean of air. We would rise miles up until we reached regions where the density of the rarefied air would be the same as that of our body. Our dream of hovering in free flight above the hills and vales would be shattered; we would have freed ourselves of gravity but would have been captured by other forces—those of the air currents.

H. G. Wells tells a story in which a very fat man wanted to rid himself of his fatness. The person who tells the story was the possessor of the recipe of a miraculous brew which could rid people of excessive weight. The fat man made the brew according to the recipe and drank it. And this is what happened.

"For a long time the door didn't open.

"I heard the key turn. Then Pyecraft's voice said, 'Come in.'

"I turned the handle and opened the door. Naturally I expected to see Pyecraft.

"Well, you know, he wasn't there!

"I never had such a shock in my life. There was his sitting-room in a state of untidy disorder, plates and dishes among the books and writing things, and several chairs overturned, but Pyecraft—

"It's all right, o'man; shut the door,' he said, and then I discovered him.

"There he was right up close to the cornice in the corner by the door, as though someone had glued him to the ceiling. His face was anxious and angry. He panted and gesticulated. 'Shut the door,' he said. 'If that woman gets hold of it—'

"I shut the door, and went and stood away from him and stared.

"If anything gives way and you tumble down,' I said 'you'll break your neck, Pyecraft.'

"I wish I could,' he wheezed.

"A man of your age and weight getting up to kiddish gymnastics—'

"Don't,' he said, and looked agonized.

"I'll tell you,' he said, and gesticulated.

"How the deuce,' said I, 'are you holding on up there?'

"And then abruptly I realized that he was not holding on at all, that he was floating up there just as a gas-filled bladder might have floated in the same position. He began a struggle to thrust himself away from the ceiling and to clamber down the wall to me.

"It's that prescription,' he panted, as he did so.

"Your great-gran—'

"He took hold of a framed engraving rather carelessly as he spoke and it gave way, and he flew back to the ceiling again, while the picture smashed on the sofa. Bump he went against the ceiling, and I knew then why he was all over white on the more salient curves and angles of his person. He tried again more carefully, coming down by way of the mantel.

"It was really a most extraordinary spectacle, that great, fat, apoplectic-looking man upside down and trying to get from the ceiling to the floor. 'That prescription,' he said. 'Too successful.'

"How?'

"Loss of weight—almost complete'.

"And then, of course, I understood.

"By Jove, Pyecraft,' said I, 'what you wanted was a cure for *fatness*! But you always called it *weight*. You would call it *weight*.'

"Somehow I was extremely delighted. I quite liked Pyecraft for the time. 'Let me help you!' I said, and took his hand and pulled him down. He kicked about, trying to get foothold somewhere. It was very like holding a flag on a windy day.

"That table,' he said pointing, 'is solid mahogany and very heavy. If you can put me under that—'

"I did, and there he wallowed about like a captive balloon, while I stood on his hearthrug and talked to him.

"...There's one thing pretty evident,' I said, 'that you mustn't do. If you go out of doors you'll go up and up....'

"...I suggested he should adapt himself to his new conditions. So we came to the really sensible part of the business. I suggested that it would not be difficult for him to learn to walk about on the ceiling with his hands—

"I can't sleep,' he said.

"But that was no great difficulty. It was quite possible, I pointed out, to make a shake-up under a wire mattress, fasten the underthings on with tapes, and have a blanket, sheet, and coverlet to button at the side. He would have to confide in his housekeeper, I said; and after some squabbling he agreed to that. (Afterwards it was quite delightful to see the beautifully matter-of-fact way with which the good lady took all these amazing inversions.) He could have a library ladder in his room, and all his meals could be laid on the top of his bookcase. We also hit on an ingenious device by which he could get to the floor whenever he wanted, which he could get to the floor whenever he wanted, which was simply to put the *British Encyclopaedia* (tenth edition) on the top of his open shelves. He just pulled out a couple of volumes and held on, and down he came. And we agreed there must be iron staples along the skirting, so that he could cling to those whenever he wanted to get about the room on the lower level.... (Then, you know, my fatal ingenuity got the better of me.) I was sitting by his fire drinking his whisky, and he was up in his favourite corner by the cornice, tacking a Turkey carpet to the ceiling, when the idea struck me. 'By Jove, Pyecraft!' I said, 'all this is totally unnecessary.'

"And before I could calculate the complete consequences of my notion I blurted it out. 'Lead underclothing,' said I, and the mischief was done.

"Pyecraft received the thing almost in tears. 'To be right ways up again—' he said.

"I gave him the whole secret before I saw where it would take me. 'Buy sheet lead,' I said, 'stamp it into discs. Sew 'em all over your underclothes until you have enough. Have lead-soled boots, carry a bag of solid lead, and the thing is

done! Instead of being a prisoner here you may go abroad again, Pyecraft; you may travel—'

"A still happier idea came to me. 'You need never fear a shipwreck. All you need do is just slip off some or all of your clothes, take the necessary amount of luggage in your hand, and float up in the air—'."

At first glance this all seems quite in conformity with the laws of physics. But objections can be made.

Firstly, even if Pyecraft had lost his weight, he wouldn't have risen up at all. Recall Archimedes' principle. Pyecraft should have "floated" up to the ceiling only if his clothes and everything in his pockets would have weighed less than the air displaced by his fat body.

We can easily reckon the weight of this volume of the air. We weigh almost the same as a similar volume of water, some 60 kg. Air of the usual density is 770 times lighter than water, so the amount we would displace would weigh only 80 grammes. However fat Mr. Pyecraft was, he could have scarcely weighed much more than 100 kg; consequently, he must have displaced not more than 130 grammes of air. There is no question that Pyecraft's suit, shoes, watch, wallet and all his other belongings weighed more. In that case the fat man should have remained on the floor. He would have felt rather shaky, true, but he certainly would not have "ballooned" up to the ceiling. That would have happened only if he had been stark naked. Dressed, he must have been like a man tied to a bouncing balloon. A small effort, a little jump and he would be up in the air, to smoothly descend again, provided, of course, there was no wind.

"PERPETUAL" CLOCK

You already know a few things about perpetual motion machines and of the futility of trying to invent them. Let me now tell you about what I shall call a "gift-power" machine, as it can work indefinitely without human interference, drawing its motive power from the inexhaustible sources of energy in nature.

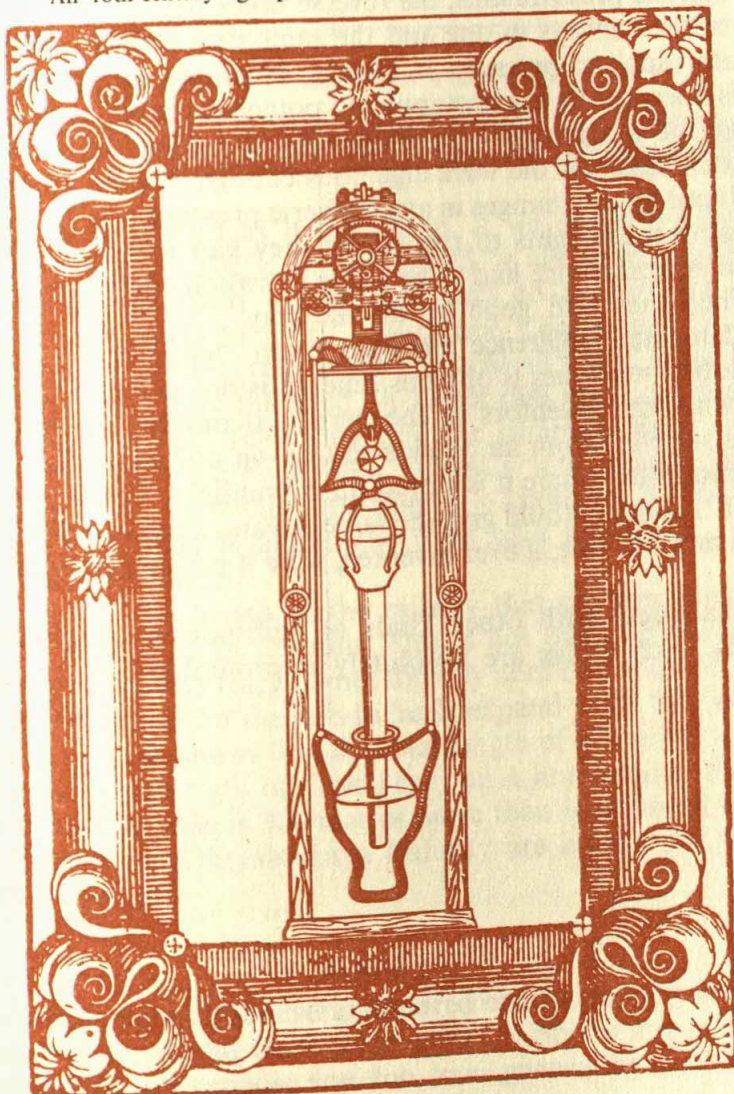
Everybody has most likely seen a barometer, a mercury or aneroid one. In the first one the mercury rises or falls depending on the changes in atmospheric pressure. And it is atmospheric pressure again that causes the arrow to swing in the aneroid barometer.

One 18th-century inventor availed himself of this arrangement to produce a self-winding clock that would never stop. The well-known British mechanic and astronomer James Ferguson saw it in 1774 and this is how he describes it. "I saw this clock," he says, "which is made to go without stopping by the endless

rising and falling of the mercury in a curiously arranged barometer. We have no reason to think that the clock would ever stop as the accumulated motive power is enough to make it go for a whole year, even if the barometer were removed. To be frank, I must say that this clock which I examined in detail is the cleverest mechanism I have ever seen, both in design and execution."

Fig. 59

An 18th-century "gift-power" machine



Unfortunately the clock was stolen and nobody knows what has become of it. Luckily enough, Ferguson made some drawings of it, so it can be reproduced.

Its mechanism consists of a large mercurial barometer, which has about 150 kg of mercury in two glass vessels, one with its mouth in the other, and both suspended in a frame. Both vessels move separately; when atmospheric pressure rises an ingenious system of levers lowers the top vessel and lifts the bottom one. When atmospheric pressure falls, the reverse takes place. This compels a small gear-wheel to turn always in one and the same direction. It doesn't turn only when the atmospheric pressure is steady. However, in these intervals the clockwork is operated by the accumulated potential energy. And though it isn't easy to make the weights rise simultaneously and wind the spring when they drop, the watchmakers of old were ingenious enough. It even happened that the energy produced by the changes in atmospheric pressure was far more than was needed, causing the weights to rise before they had managed to drop to the bottom. So a special device had to be made to switch off the weights at regular intervals, when they had gone up all the way.

The fundamental difference between such "gift-power" machines and perpetual motion machines is obvious. Energy is not produced out of nothing, which was what the inventors of the perpetual motion machines sought to achieve. It is supplied from an outside source—in our particular case, the surrounding atmosphere where it is stored up by sunlight. To all practical intents a "gift-power" machine would give the same advantage as could be derived from a "perpetual motion" one, if ever invented, were it not so costly, as it is in most cases.

Later I shall deal with other kinds of "gift-power" machines and shall illustrate why such things are absolutely unprofitable commercially.

Chapter

Hot and Cold

6

WHEN IS THE OKTYABRSKAYA RAILWAY LONGER?

When asked how long the Oktyabrskaya Railway is one person gave this answer: "It's 640 km on the average. But in summer it's about 300 m longer than in winter."

Now this is not so absurd as it may seem. If we meant by the length of a railway the length of its rails, it should indeed be longer in summer than in winter. Don't forget that heat causes steel rails to expand, by more than a 100,000th of their length to every one degree Centigrade. On a blazing summer day the temperature of rails might reach 30–40°C and more. Sometimes rails are so hot that they burn the hand. In winter rails may cool down to 25°C below zero and even lower. Supposing that the summer-winter difference in temperature is 55°; by multiplying the railway's total length (640 km) by 0.00001 and again by 55, we get about a third of a kilometre. So in summer the Moscow-Leningrad railway is indeed the third of a kilometre, i.e., roughly 300 m, longer than in winter.

It is, of course, not the length of the railway that changes but merely the sum-total of the lengths of all the rails. This is not one and the same thing, because the rails of a railway track do not directly abut one another. Small gaps are left between their joints for the rails to freely expand when they heat up. The calculation we have made shows that the total length of all the rails increases at the expense of the total length of these gaps; on a hot summer day the total length in our particular case is 300 metres more than in a winter frost. So, to sum up, the rails of the Oktyabrskaya Railway are indeed 300 m longer in summer than in winter.

UNPUNISHED THEFT

On the Moscow-Leningrad line several hundred metres of costly telephone and telegraph wire vanish without trace every winter. Nobody is ever worried; all know who the culprit is. I suppose you, too, have guessed by now. The thief, of

course, is the frost. What is true for rails is true for wire too. The only difference is that copper telephone wires expand 1.5 times more than steel, when heated. And since we have no gaps here we can really say, without any reservations whatsoever, that *in winter the Moscow-Leningrad telephone line is indeed 500 m shorter than in summer*. Every winter the frost steals nearly half a kilometre of wire and gets away with it! But it doesn't disrupt telephone or telegraph communications. All that is stolen is dutifully refunded when warmer days set in.

But when bridges, not wires, contract due to frosts the consequences are pretty bad. Newspapers had this to report in December 1927: "The unusual frosts France has been having lately have seriously damaged the bridge across the Seine in the heart of Paris. Due to frosts the bridge's steel framework contracted, causing the road blocks to fly out. The bridge has been temporarily closed to traffic."

HOW HIGH IS THE EIFFEL TOWER?

If I were to ask you now how high the Eiffel Tower is, before saying "3,000 metres" you would probably want to know in what weather, cold or warm? After all, the height of such an enormous steel structure could not be the same at all temperatures. We know that a steel rod 300 m long expands by 3 mm when heated by 1°C . The height of the Eiffel Tower should increase by roughly the same amount when the temperature rises by 1° . In warm sunny weather the steel framework of the tower might warm up in Paris to 40°C above zero, whereas on a cold rainy day its temperature might fall to 10°C and in winter down to zero and even to as much as 10° below (heavy frosts are rare in Paris). The temperature fluctuation is as much as 40° and more. This means that the height of the Eiffel Tower may be $3 \times 40 = 120 \text{ mm} = 12 \text{ cm}$ more or less.

Direct measurement has disclosed that the Eiffel Tower is still more sensitive to temperature fluctuations than the air itself. It warms up and cools quicker and reacts sooner to the sun's sudden appearance on a cloudy day. The changes in the height of the Eiffel Tower were detected by using a wire made of a special nickel steel on whose length temperature fluctuations have practically no effect. This wonderful alloy is called *invar* from the word *invariable*.

So, on a hot day the Eiffel Tower is taller than on a cold day by a bit equal to 12 cm and made of iron, which, incidentally, doesn't cost a sou.

FROM TEA GLASS TO WATER GAUGE

Before pouring tea into a glass, the experienced housewife puts in a tea spoon, especially a silver one, to prevent the glass from cracking. Practice has suggested the proper solution.

But what is its basic principle? Why does hot water crack a tea glass?

Because of the uneven expansion of the glass. When you pour hot water into a glass, its walls do not warm up at once. At first the inner layer warms up, the outer one remaining cold. The heated inner layer expands at once. Meanwhile, since the outer one does not expand, it feels a strong pressure from inside. It snaps and the glass breaks.

Don't think you can safeguard yourself against this by using thick-walled glasses. They, on the contrary, are liable to crack sooner than thin-walled ones. This is because a thin wall heats up faster and its temperature and expansion even out sooner. A thick-walled glass, on the other hand, warms up slowly.

One thing you mustn't forget when buying thin-walled glassware—make sure that the bottom of the glass is thin too, because it is the bottom that chiefly heats up. A thick-bottomed glass will crack, however thin its walls. So do glasses and china cups with thick-rimmed bottoms.

The thinner a glass vessel's walls are, the safer it is for heating. Chemists use very thin-walled vessels in which they boil water right over the burner.

The ideal vessel is one that wouldn't expand at all when heated. Quartz almost has this property: it expands 15-20 times less than glass. A thick-walled vessel of transparent quartz will never crack when heated, even if immersed red-hot in a bath of ice (vessels of quartz are good for laboratory work because quartz melts only at $1,700^{\circ}\text{C}$). This is also because of the fact that quartz conducts heat much better than glass does.

Tea glasses crack not only when warmed up quickly but also when cooled quickly. Now it is uneven contraction that is to blame. As it cools, the outer layer contracts and exerts a strong pressure on the inner layer, which has not cooled and contracted yet. A prudent housewife should not put a jar of hot jam out in the cold or into cold water.

But back to the tea spoon. How does it protect the glass from cracking? The difference in the expansion of the inner and outer layers is great only when very hot water is poured into the glass at once. Warm water, however, doesn't make glasses crack. What happens when you put a tea spoon in? As it pours in, the hot water loses part of its heat to the metal spoon, which is, contrary to glass, a good conductor of heat. Its temperature drops and it becomes almost

harmless, because now it is only warm. Meanwhile the glass has warmed up and more hot water won't crack it.

In a nutshell, a metal tea spoon, especially a heavy one, offsets the uneven heating of the glass and prevents it from cracking.

But why is a silver spoon still better? Because silver is a very good conductor of heat. It can take away the heat from the water sooner than a copper spoon. A silver spoon in a glass of hot tea burns the fingers. Since a copper spoon doesn't do that, you can easily tell the material the spoon is made of.

The uneven expansion of glass walls is a menace not only to tea glasses but also to very important elements of boilers, that is, the water gauges, which give the height of the water in the boiler. As the hot steam and water heat them up, the inner layers of these tubes of glass expand more than their outer layers. Add to this the great pressure exerted in the tubes by the steam and water, and you will realize why they may so easily burst. To prevent this, they are sometimes made of two layers of different kinds of glass, the inner one having a smaller expansion factor than the outer one.

THE BOOT IN THE BATH-HOUSE

"Why in winter is the day short and the night long, and in summer the other way round? The winter day is short because like all other visible and invisible things it contracts due to cold; meanwhile the night expands because it is warmed up when lights and lamps are lit." How comically silly this "explanation", afforded by Chekhov's retired Don Cossack sergeant, is. However, people who ridicule such "learned" reasoning sometimes father theories which are just as stupid. Have you ever heard the story of the boot which won't go on in the bath-house because "the heated foot has grown larger"? A classical instance, but with a totally wrong explanation.

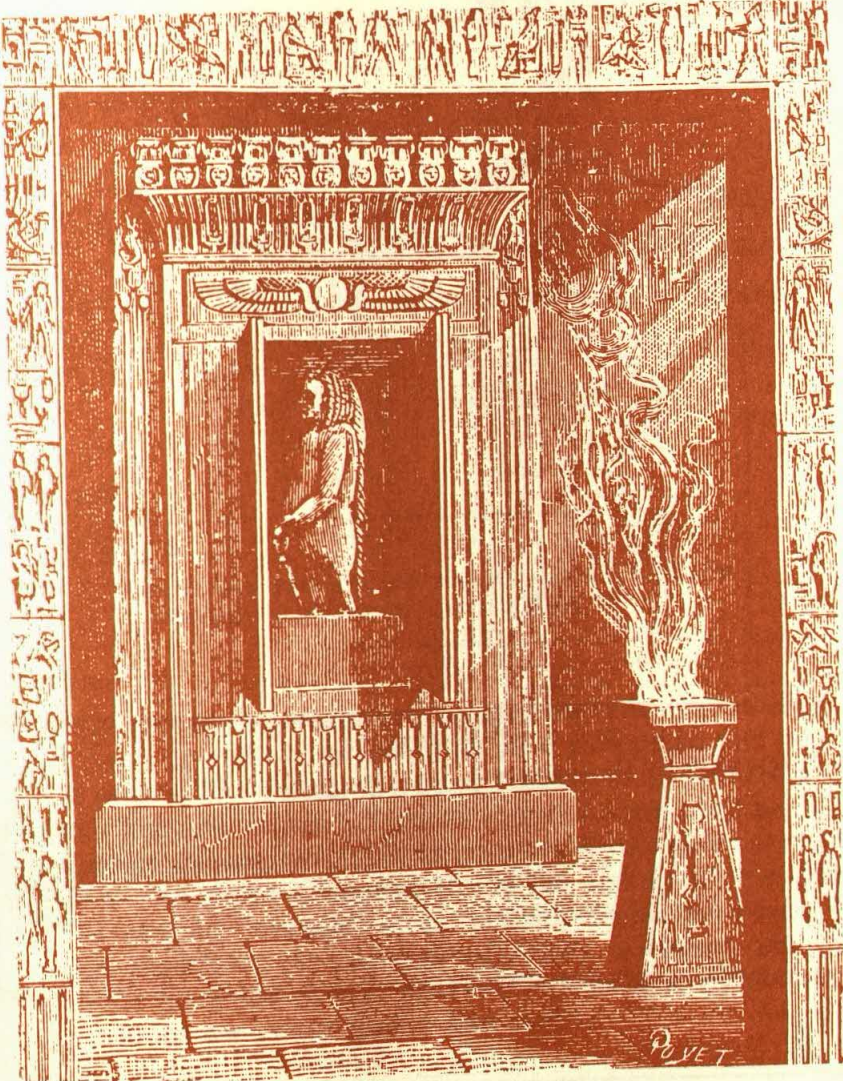
In the first place one's temperature hardly rises at all when one is in a bath-house, never by more than one degree Centigrade. Only a Turkish bath will make it go up two degrees. Our body successfully resists the surrounding heat, maintaining its temperature at a definite level. Furthermore, this "rise" in our body temperature increases the volume of our body by such a negligible fraction that one doesn't notice it when drawing on a boot. The expansion factor of our bones and flesh is never more than a few ten-thousandths.

Consequently, the sole and the instep could bulge only by a hundredth of a centimetre, no more. Boots and shoes are never sewn with such accuracy. After all, a hundredth of a centimetre is but the thickness of a hair!

Still it remains a fact that it is hard to draw a boot on after a hot bath. However, this is not because our foot expands due to heat but because the blood rushes to the foot, the skin swells, is damp, and grows tender, in a word, because of things that have nothing at all in common with expansion due to heat.

Fig. 60

Egyptian temple "miracle" explained. The doors open when incense is burned on the altar



HOW TO WORK MIRACLES

Heron of Alexandria, the ancient Greek mathematician and mechanic who invented the fountain that bears his name, has left the description of two artful methods which enabled Egyptian priests to take in worshippers by their "miracles".

Fig. 61

Diagram showing how the temple doors swing open.
(Compare with Fig. 60)

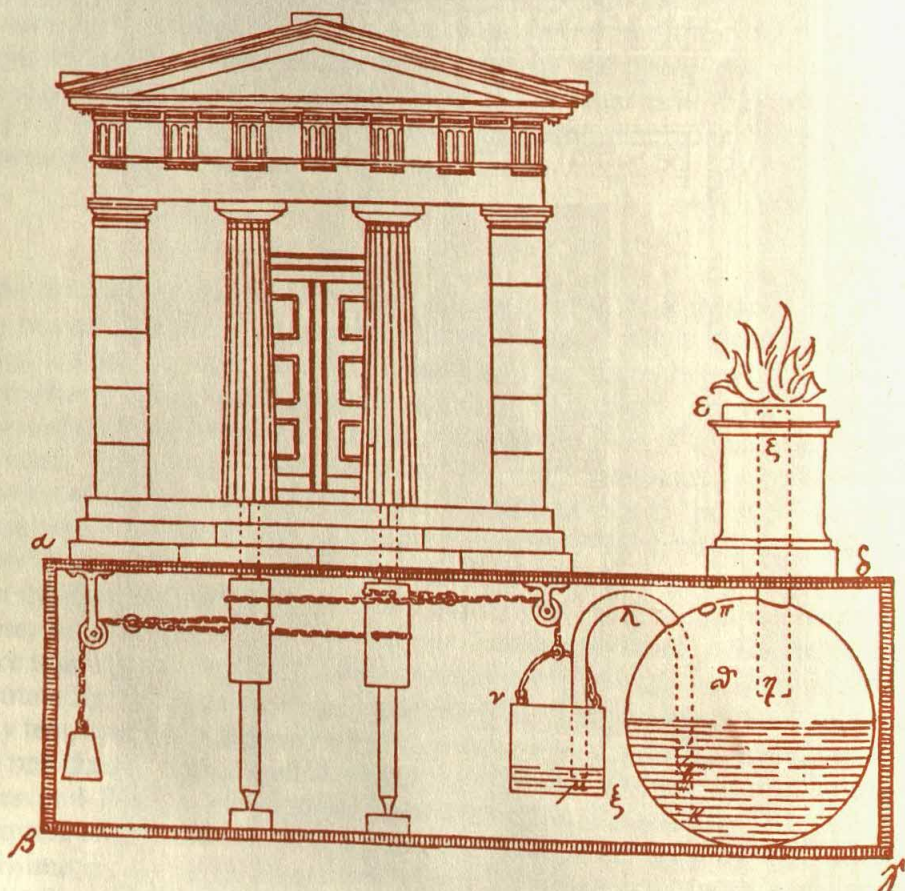


Figure 60 shows one such device consisting of a hollow metal altar which stood in front of the temple doors, and of the mechanism, hidden beneath the flagstones, that caused the temple doors to open. When incense was burned, the heated air inside the hollow altar exerted a greater pressure on the water in the vessel hidden below the floor, thus causing it to flow through a pipe into a pail which lowered and set in motion the door-opening mechanism (Fig. 61). The

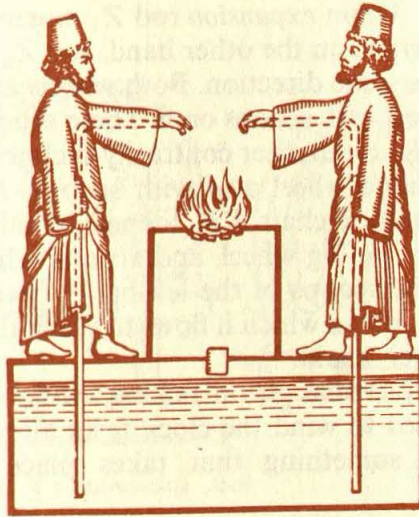


Fig. 62

Another fake miracle of the ancient priests. How incense "everlastingly" drips into the sacrificial flame

worshippers saw, of course, what they thought to be a "miracle": the temple doors swung open on their own accord as soon as incense and prayers were offered by the priests. They, naturally, knew nothing of the hidden mechanism.

Another fake "miracle" which the priests staged is shown in Fig. 62. As soon as incense is burned, the expanding air forces more of it to flow out of the cistern below the floor into pipes concealed inside the figures of the priests. The worshippers beheld the "miracle" of an undying flame. However, when the priest in charge considered the offerings too scanty, he unnoticeably removed the stopper in the lid of the cistern. This stopped the flow of incense, because now the superfluous air could find a free outlet.

SELF-WINDING CLOCK

At the close of the previous chapter I described a self-winding clock; its working principle was based on the changes in atmospheric pressure. Now I shall tell you about similar self-winding clocks, the principle of which is based on heat expansion. Figure 63 depicts the mechanism of one of them. The central element consists of rods Z_1 and Z_2 which are made of a special alloy with a considerable coefficient of expansion. Upon *expansion* rod Z_1 engages the teeth of wheel X , turning it. Upon *contraction*, on the other hand, rod Z_2 engages the teeth of the wheel Y , turning it in the same direction. Both wheels are set on shaft W_1 which also revolves a large wheel with scoops on it. These scoops lift the mercury from the lower inclined tray R_1 to another contrarily-inclined tray R_2 down which it flows towards the left-hand wheel also with scoops. As these scoops fill, the wheel turns, setting in motion chain KK , looped around wheel K_1 , which is set on the same shaft W_2 as the big wheel, and around wheel K_2 , which winds up the clock. Meanwhile the scoops of the left-hand wheel spill out the mercury into the inclined tray R_1 , down which it flows to reach the right-hand wheel, and the cycle begins all over again.

This clock, apparently, would go on ticking, while rods Z_1 and Z_2 expand and contract. All we need to wind the clock is an alternate rise and fall in air temperature, which is something that takes place without our interference.

Could we call this clock a "perpetual motion" machine then? Of course not. The clock will tick indefinitely until its mechanism wears out, but what makes it go is the heat of the surrounding air. The clock stores up the work of heat expansion and expends it portion after portion to turn its hands. This is really a "gift-power" machine since it does not require care or outlay. But it doesn't create energy out of nothing; its primary source is the heat of the sun, which warms up the earth.

Another specimen of a self-winding clock with a similar arrangement is given in Fig. 64. Its basic element is glycerin, which expands when the temperature of the air rises and causes a small weight to rise. The lowering of this weight makes the clock go. Since glycerin solidifies only at 30°C below zero and boils at 290°C above, this mechanism is quite suitable for town clocks. A two-degree temperature fluctuation is enough to keep it going. One such clock was tested for a whole year, and proved to be quite satisfactory.

Can any advantage be derived by designing other bigger machines of this kind? At first glance, such a "gift-power" machine might seem very economical.

Let us see, though, whether this is really so. To wind up an ordinary clock to run for 24 hours one requires only $1/7$ kgm of energy. This is merely $1/600,000$ of a kilogram-metre per second. Considering that one horsepower is equivalent to 75 kgm/s, the power of one clock mechanism is equivalent to only $1/45,000,000$ of a horsepower. Consequently, if the rods in the first clock mentioned or the contraption of the second were to cost one kopek, the investment made to

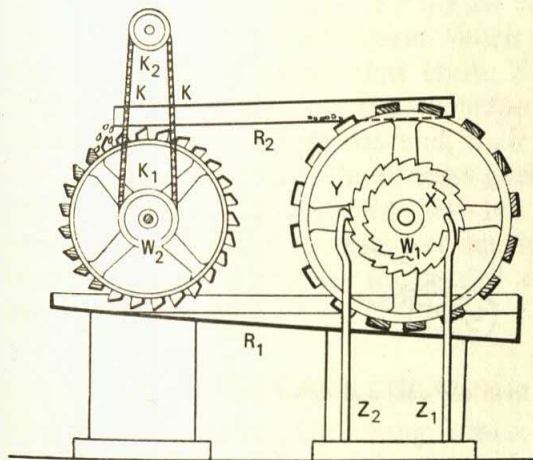


Diagram of a self-winding clock

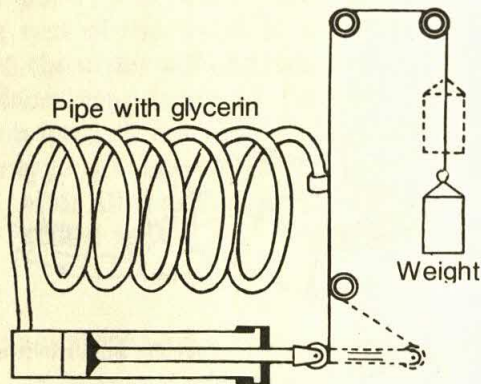


Diagram of another self-winding clock

Fig. 63

Fig. 64

produce one horsepower would be 45,000,000 kopeks, or 450,000 rubles. I think half a million rubles for one horsepower is a bit too much for a "gift-power" machine.

INSTRUCTIVE CIGARETTE

Figure 65 shows a straw-tipped cigarette on top of a match box. Smoke is curling out of both ends. However, at one end it *curls up*, and at the other *down*. Why? After all, isn't the smoke coming out of the two ends the same? It is, of course, but above the smouldering end there is an ascending current of warm air which carries the particles of smoke up. Meanwhile the air carrying the smoke through the straw tip cools off and no longer rises upward; since the particles of smoke are heavier than air, they float down.

ICE THAT DOESN'T MELT IN BOILING WATER

Take a test tube, fill it with water, and put a lump of ice in. To keep the ice down at the bottom (since it is lighter than water, it floats) press it down by some small weight, seeing to it that the water can get at the lump of ice. Now heat the test tube on a spirit lamp so that the flame licks only at the tube's upper part as

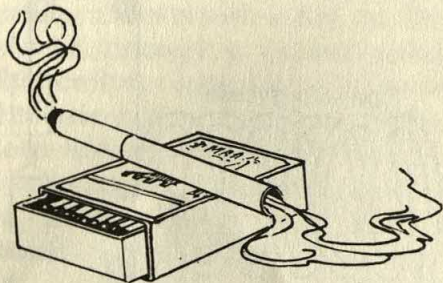


Fig. 65

Why does the smoke curl up from one end, and down from the other?

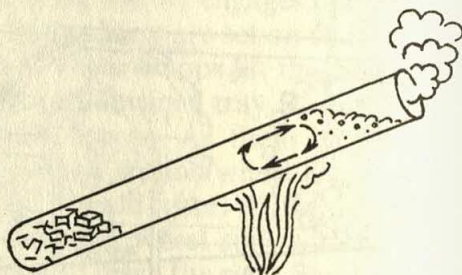


Fig. 66

The water at the top boils, but the ice at the bottom doesn't melt

shown in Fig. 66. The water will soon boil and send out steam. Oddly enough, the ice at the bottom of the tube doesn't melt. A minor miracle, one would think, ice that doesn't melt in boiling water!

The trick is that at the bottom of the tube the water doesn't boil at all; it remains *cold*. Actually we have not "ice in boiling water" but "ice beneath boiling water". As it expands due to heat, the water becomes lighter; it does not descend to the bottom and stays in the upper part of the tube. There is warm water and a mixture of warm and cold layers of water only in the tube's upper part. Heat can be transferred down only by a conductor, but water is a very poor conductor of heat.

ON TOP OR BENEATH?

When we want to heat water, we put the vessel that contains it right above the flame and not to the side of it. This is the right thing to do since the heated air which grows lighter is forced out from beneath the vessel upwards and thus envelops the vessel.

So by placing the object we want to heat up right above the flame we use the source of heat in the most advantageous way.

But what should we do to *cool* something with ice? Many put the thing they want to cool, a jug of milk, for example, on top of the ice. This is the wrong thing to do; as the air above the ice cools it *descends*, its place being taken by the warmer surrounding air. So if you want to cool a drink or a dish, don't put it *on top of the ice* but rather *the ice on top of it*.

Let me make the point clearer. When we put a jar of water on top of the ice, it is only the bottom layer that cools. The rest of the water is surrounded by uncooled air. But if we put the ice *on* the lid, the water will cool much faster. The cooled upper layers will descend, their place being taken by the warm layers rising from the bottom; the process goes on until all the water has cooled (note that pure water will cool not to zero but only to 4°C above, i. e. the temperature at which it possesses the greatest density. After all we never really cool drinks down to zero). Meanwhile the cooled air around the ice will also descend and envelop the vessel.

DRAUGHT FROM A CLOSED WINDOW

We often feel a draught coming from a window that is closed tight and hasn't a single crack in it. Though it seems odd there is nothing at all surprising in it.

The air inside a room is practically never in a state of rest. An invisible current circulates as the air warms or cools. As the air warms it rarefies and grows lighter. As it cools it becomes denser and heavier.

The cold heavy air near the windows and outer wall descends to the floor, forcing the warm light air to rise to the ceiling. A toy balloon reveals this circulation at once. Tie a small weight to it, light enough to keep it suspended in mid-air. Release the balloon near the stove or radiator. You will see it travel around the room, being carried by the invisible current from the fireplace or radiator up to the ceiling and towards the window, and from there down to the floor and back to the fireplace. Here it again sets out on the same journey. That is why we feel the draught, especially around the feet, coming from the window though it is closed tight in winter.

MYSTERIOUS TWIRL

Take some thin cigarette paper and cut out a piece in the form of a rectangle. Fold it down the middle and then straighten it again. The fold will tell you where the centre of gravity is. Now stick a needle upright into the table and

place the piece on the other end so that it is set on its centre of gravity and, hence, balanced. So far there is nothing mysterious about it. Bring up your hand as is shown in Fig. 67. Do this gently though, otherwise the piece of paper will be blown off by the rush of air. The paper will start to spin. At first it gyrates slowly but then it picks up speed. Take your hand away and gyration stops. Bring your hand up again and gyration resumes.

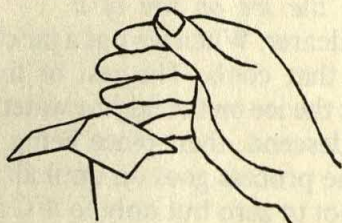


Fig. 67

Why does this piece of paper spin?

This mysterious gyration once, in the 1870's, caused many to believe that we, or rather our bodies, were endowed with some supernatural properties. Mystics thought this confirmed their wild theories about the strange fluids the human body was supposed to possess. Actually, there is nothing unnatural in it; as a matter of fact, everything is as simple as pie. When you bring your hand up, the air near it, which is warmed by its proximity, rises and, pressing against the piece of paper, causes it to spin. It revolves because it is slightly folded, thus acting the same role as a curled piece of paper suspended above a lamp.

A closer look will show you that the piece of paper always gyrates in one and the same direction, namely, from the wrist towards the finger-tips. This is because the finger-tips are always colder than the palm of the hand; consequently, the palm gives rise to a stronger ascending air current than the finger-tips. Incidentally, when one is feverish, or happens to be running a high temperature, the paper gyrates much faster. You might be interested to learn that this twirling, which once mystified so many, was the subject of a communication made to the Moscow Medical Society in 1876 (*The Gyration of Light Bodies Caused by the Heat of the Hand*, by N. P. Nechayev).

DOES A WINTER COAT WARM YOU?

If I told you that your fur coat *does not warm* you at all, you would probably think I was pulling your leg. But suppose I prove it? Stage the following experiment.

Take the reading of an ordinary thermometer. Then wrap it in your coat and let it be for some hours. Then read the thermometer again. It will be exactly the same as before. Has that convinced you that your fur coat doesn't warm you? Perhaps, it *cools* you then? Take two bags of ice and wrap one in your fur coat, leaving the other in a dish. When this second bag of ice melts, unwrap the coat. The ice in the first bag has hardly melted at all. As you see, the coat has not warmed it in the least; on the contrary, it seems even to have cooled it, since the ice took longer to melt!

So, does a winter coat warm you? No, if by warming we mean the *communication of heat*. A lamp does. So does a stove. And so does our body. They are all sources of heat. Your fur coat is not a source of heat; *it doesn't have any warmth of its own to give. It merely prevents our body from shedding its own warmth*. That is why a warm-blooded animal, whose body is actually a source of heat, feels much warmer in a coat of fur than without one. However, since the thermometer we took for our experiment is not a source of heat its reading naturally could not change simply because we wrapped it in the fur coat. The ice in the coat also took longer to melt because the coat is a rather poor conductor of heat and blocks any intake of surrounding warmth.

The snow on the ground is also like a fur coat; it is a poor conductor of heat like all powdery bodies and thus prevents the ground beneath from shedding its heat. The temperature of the ground beneath a protective layer of snow is often some 10°C higher than at a bare spot.

So the answer to the question "Does a winter coat warm you?" is: it merely helps us to warm ourselves; rather we ourselves warm the coat instead.

THE SEASON UNDERFOOT

It is summer on the ground and above it. What season of the year is it three metres down? You think it's summer? You're wrong! It's not at all the same season as one might think. The point is that the ground is a very poor conductor of heat. In Leningrad water mains don't burst even in the sharpest of frosts, because they are two metres deep. Above-surface temperature fluctuations reach the different subsoil strata with great delay. Direct measurements conducted in the town of Slutsk, Leningrad Region, showed that at three metres down the warmest time of the year comes 76 days late, while the coldest period is 108 days late. If the hottest day above the ground is July 25th, at three metres down the hottest day will come only on October 9th. On the other hand, if the

coldest day is January 15th, at the given depth the coldest day will come only in May. At greater depths the delay is still greater.

The further down we go, the weaker the temperature fluctuations become, to fade to an everlasting constant at a certain depth; here you have one and the same temperature round the year for centuries on end. This temperature is the mean annual temperature of the place in question. In the cellars of the Paris observatory, 28 metres below the ground, there is a thermometer which Lavoisier stored away there more than 150 years ago. The mercury has not budged a hair since, giving all the time one and the same temperature of 11.7°C above zero.

To sum up: underfoot we never have the season of the year we have above the ground. When it is winter for us it is still autumn three metres down, of course not the autumn we had, as the fall in temperature is not so pronounced. On the other hand, when it is summer for us, deep down we still have faint repercussions of winter frosts. One must always bear this important point in mind whenever one is dealing with the conditions of life underground, for instance for plant tubers and roots, and for cockchafer grub. It should not be surprising, for instance, that in tree roots the cells multiply in winter and that the tissue called the cambium ceases to function for practically the whole of summer, in contrast to the tissue of the above-ground tree-trunk.

PAPER POT

Look at Figure 68. An egg is boiling in water in a paper pot. Won't the paper burn through and the water spill out and extinguish the flame? Try to do it yourself, boiling the egg in some stiff parchment paper attached fast to a piece of wire (or better make the paper box shown in Fig. 69). Nothing happens to the paper! The reason is that in an uncovered pot one can warm water only up to boiling point, i. e. 100°C . The water, having a great heat capacity, absorbs the paper's extra heat and prevents it from warming to much more than 100°C , that is, to a point where it could burst into flame. The paper won't burn even if licked by the flame.

It is the same property of water that prevents a kettle from going to pieces, which is what would happen were we absent-minded enough to put the kettle on to boil without any water in it. For the same reason you must not put soldered pots on the fire unless they have water in them. The water used to cool the old Maxim machine guns saved the barrel from melting.

By using a little box made from a playing card, you can melt a lead pellet. To

do this, put the lead in the box right above the flame. Since lead is a good conductor of heat, it rapidly absorbs the heat of the box, preventing the box from heating up to way above its melting point, 335°C , which is too little yet for the box to break into flame.

Figure 70 gives another simple experiment. Take a thick nail or an iron (or better copper) rod and *tightly* curl screw-wise a narrow strip of paper around it.

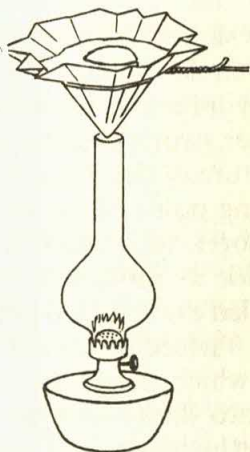


Fig. 68

An egg boiling in a paper pot

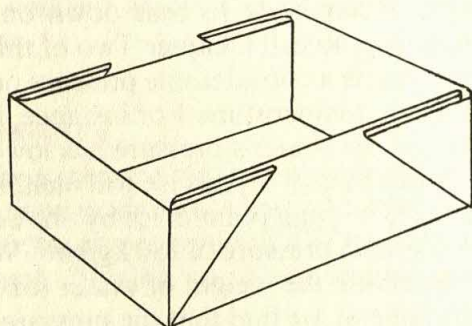


Fig. 69

A paper box for boiling water

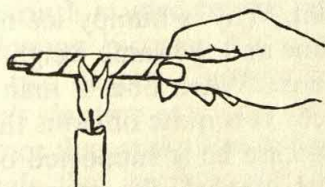


Fig. 70

Paper that doesn't burn

Then apply a flame. The flame will lick at the paper and even smoke it; but it'll start burning only when the rod grows red-hot. Again the metal's good heat conductivity is the reason. A glass stick, for instance, wouldn't do at all for this experiment.

WHY IS ICE SLIPPERY?

One slips on a smoothly polished floor much more easily than on one that isn't polished. Now, shouldn't *smooth* ice be much more slippery than bumpy ice? However, contrary to expectation, a sled goes much more easily over bumpy ice than over smooth ice, which you may have noticed yourself if you have ever happened to pull a sled. How come that bumpy ice is more slippery than glossy ice? Ice is slippery not because it's smooth but because its melting point drops when pressure is increased.

Let's see what happens when we sled or skate. On skates, we bring the whole weight of our body to bear down on a very small area, of but a few square millimetres. Recall Chapter Two of this book. You will realize that a person on skates exerts a considerable pressure on the ice. Under strong pressure ice melts at a lower temperature. For instance, if the temperature of the ice is 5°C below zero and the skater's pressure has lowered the melting point of the ice beneath his skates by 6 or 7° , this ice will melt. It has been theoretically calculated that to lower the melting point of ice by one degree Centigrade we must exert the rather considerable pressure of 130 kg/cm^2 . Will skater or sled exert such a pressure? If we distribute the weight of skater (or sled) over the surface of skate blades (or sled runners), we find that the pressure is much less, which shows that only part of the full surface of the blades or runners comes into direct contact with the ice*. This gives rise to a thin layer of water between the blades and the ice. No wonder the skater slides, or rather slips, along. And as soon as he moves further, the same thing repeats itself. The skater continually slides over a thin layer of water. It is only ice that has this property. One Soviet physicist even called it "nature's sole slippery body". All other bodies are smooth but not slippery.

Back now to our first point. Why is bumpy ice more slippery than smooth ice? We already know that one and the same weight exerts a stronger pressure when it rests on a smaller area. When does a man exert more pressure? On smooth ice? Or on bumpy ice? It is quite obvious that he exerts more pressure on bumpy ice because in this case he is supported only by a few bumps in the ice. The greater the pressure exerted, the more readily does ice melt and, consequently, the more slippery does ice become, provided the sled runners are

* In our theoretical calculations we must bear in mind that in the process of melting both ice and water are subjected to the same pressure. In the instances described, though, the water which the ice melted into, is subjected to atmospheric pressure, in which case less pressure is required to lower the melting point of ice.—Ed.

wide enough (this will not apply to the thin skate blades as the energy of motion is expended to slice off the bumps).

This pressure-induced lowering of the melting point of ice explains many other things that we see around us. This is why separate lumps of ice freeze into one when strongly pressed together. Boys throwing snowballs unconsciously avail themselves of this property; the separate snowflakes stick together because the pressure exerted to form the snowball lowers their melting point. To make a snowman we again apply this principle. (I suppose I needn't explain, though, why in strong frosts we are unable to mould good snowballs and snowmen.) Under the pressure of the many feet walking along the pavement snow gradually turns into one solid icy mass.

THE ICICLES PROBLEM

Have you ever stopped to wonder how the icicles we see drooping from eaves form? And when do they form? During a thaw or during a frost? And if during a thaw, then how does water freeze at an above-zero temperature? On the other hand, if during a frost, then where, in general, does the water that freezes come from?

As you see, the problem is not so simple as you may have thought. To produce icicles you need *two temperatures* simultaneously: one above zero for melting and the other below zero for freezing. That is really what happens. The snow on slanting rooftops melts because it is warmed by the sun to an *above-zero* temperature. Meanwhile the drops of water dripping off the eaves freeze, because here we have a *sub-zero* temperature. (We don't mean the icicles that form because of the warmth exuded by the heated room under the roof.)

Try to imagine the following picture. It's a clear and sunny day. The temperature is just one or two degrees Centigrade below zero. Everything is bathed in sunlight. The sun's slanting rays are not strong enough to melt the snow on the ground. But since they strike the *inclined* rooftop facing the sun *at an angle closer to a right angle*, they warm up the roof and melt the snow on it. Sunshine gives more light and warmth the wider the angle between the line of the rays and the plane on which they are incident. It acts in direct ratio to the *sine* of this angle. As for the case in Fig. 71, the snow on the rooftop gets 2.5 times more warmth than the snow on the ground, because the sine of 60° is 2.5 times more than the sine of 20° . The melting snow drips off the eaves. But since the temperature beneath the eaves is a *sub-zero* one, the drops of water, cooled furthermore by evaporation, freeze. Another drop drips onto the frozen one and

also freezes. Then comes a third, a fourth and so on, gradually producing a tiny pendant of ice. A couple of days later, or maybe a week later, we have the same kind of weather again. The pendant grows, producing a larger and larger icicle, in much the same way as lime stalactites form in underground caverns. That is how icicles form on the eaves of sheds and other unheated premises.

The changing angle of incidence of the sun's rays produces far grander



Fig. 71

The sun heats the slanted roof more than the ground

phenomena. The different climatic zones and seasons are largely due to that, but not wholly; another major factor is the varying daylength, or the time during which the sun warms the earth. Responsible for both is one and the same astronomical cause, the inclination of the earth's axis of rotation to the plane of the ecliptic. In winter the sun is practically as far away from us as in summer; it is just as far away from the poles as it is from the equator (the difference is so insignificant that it can be totally ignored). However, at the equator the angle of incidence of the sun's rays is wider than at the poles; in summer again, the angle of incidence is wider than in winter. This phenomenon gives rise to a pronounced variation in temperatures, and consequently to changes in nature in general.

Chapter

Light

7

TRAPPED SHADOWS

Our forefathers did find some use for their shadows even though they weren't able to catch them. This was the making of silhouettes, or shadow images. Today we go to the photographer's if we want our pictures or the pictures of friends and relatives taken. But in the 18th century there were no photographers. Portrait-painters asked a stiff price for their work and only the rich could afford it. That is why *silhouettes* were so widespread; in some measure they did for our present snapshots.

Silhouettes are actually trapped shadows. They were obtained mechanically and in this we can draw a certain parallel between them and their opposites, photographs; while photographers draw on *light* (*photos* is Greek for light) to make pictures, our ancestors used *shadows* for the same purpose.

Figure 72 shows you how silhouettes were made. The sitter turned his head to cast a characteristic profile and this profile was traced with a pencil. Then the inside of the outline was blacked, cut out, and glued onto a white ground. This was the silhouette. Whenever necessary, the silhouette was reduced by means of a special device called the pantograph (Fig. 73).

Don't think that this simple black outline could not give a notion of the characteristic features and profile of its prototype. A good silhouette is sometimes amazingly like the original.

This property intrigued some artists, who began to paint in this manner, thus starting a whole school. The very origin of the word is of interest. It derives from Etienne de Silhouette, an 18th-century French Minister of Finance, who urged his extravagant compatriots to show thrift and reproached the French aristocracy for wasting money on pictures and portraits. The cheapness of shadow likeness thus suggested the name—portraits “à la Silhouette”.

THE CHICK IN THE EGG

The properties shadows possess will enable you to stage an amusing parlour trick. Take a piece of greased paper and make a screen by sticking it on top of a square hole cut in a piece of cardboard. Put two unshaded table lamps behind this screen and seat your friends in front of it. Switch on the left lamp. Place an



Fig. 72

An old way of making shadow portraits

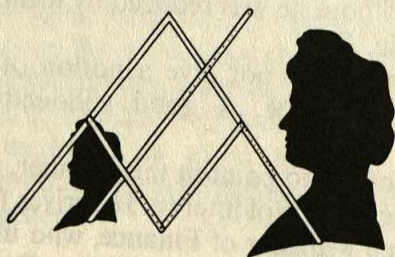


Fig. 73

How to reduce a silhouette

Fig. 74

A silhouette of Schiller (1790)



oval piece of cardboard mounted on a piece of wire between the lit lamp and the screen. Your friends will naturally see the outline of an egg. The right lamp is still not on. Now tell your friends that you have an X-ray machine that will detect the chick inside the egg. Hey, presto! and your friends see the egg's shadow pale and the rather distinct outline of a chick appear in the middle (Fig. 75).

It is really all very simple. Just switch on the right lamp which has a cardboard chick between it and the screen. Part of the oval shadow upon

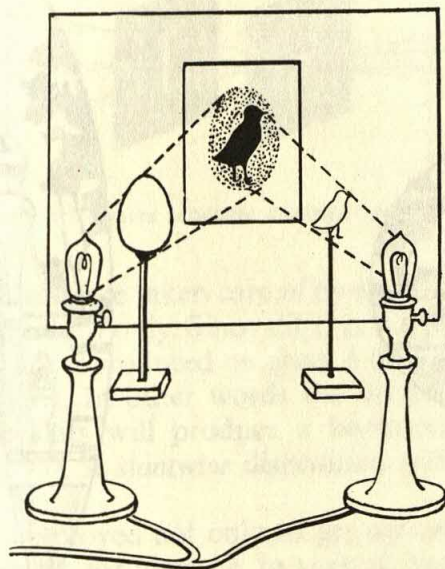


Fig. 75

A fake X-ray

which the chick's shadow is superimposed is illuminated by the right lamp. That is why its fringes are lighter. Since your friends don't see your manipulations, those ignorant of physics and anatomy may really think that you have X-rayed the egg.

PHOTOGRAPHIC CARICATURES

Many of you might not know that you can make a camera in which an ordinary small round hole will take the place of the lens. True, you get a fainter image in this case. An interesting modification of this lensless camera is the "slit" camera which has two criss-crossing slits instead of the round aperture. This camera has

in its front part two small slats, one having a vertical slit and the other a horizontal slit. When the two slats are superimposed, the image obtained is the same as produced by the aperture camera. In other words, the likeness is not distorted. But when the slats are moved apart (they are specially arranged so that this can be done) the image produced becomes distorted (Figs. 76 and 77), resembling a caricature rather than a photograph.



Fig. 76

A caricature obtained by means of a "slit" camera. The image is distended horizontally



Fig. 77

A similar caricature distended vertically

Why does this happen? Let us take the case when the slat with the horizontal slit is placed in front of that with the vertical slit (Fig. 78). The rays coming from the vertical line of figure *D* (a cross) pass through the first slit *C* as through any ordinary aperture; meanwhile slit *B* does not alter their course at all. Consequently, on the ground-glass screen *A* you get an image of the vertical line

on a scale corresponding to the distance between *A* and *C*. However, this disposition of the slats produces an entirely different image of *D*'s horizontal line. The rays pass through the horizontal slit without hindrance and don't cross until they reach the vertical slit *B*, which they pass as any round aperture to produce on screen *A* an image on a scale corresponding to the distance between *A* and *B*.

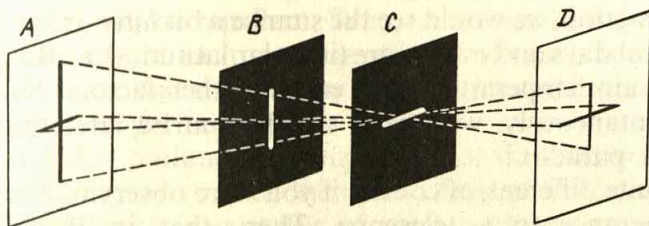


Fig. 78

Why the "slit" camera produces distorted images

In short, the vertical lines are taken care of by slit *C* only, and the horizontal lines, on the contrary, by slit *B* only. Since slit *C* is further away from the screen all vertical dimensions are reproduced on glass *A* on a scale larger than that of the horizontal dimensions. In other words the image is distended vertically. A redistribution of the slats will produce a horizontally distended likeness (compare Figs. 76 and 77). A *slantwise* disposition will distort the likeness in still another way.

This camera can be employed not only to get caricatures. It can also serve a more serious purpose, as, for instance, to vary architectural embellishments, carpet and wallpaper patterns, and in general any ornamental motif that may be distended or condensed at will in a definite direction.

THE SUNRISE PROBLEM

Suppose you get up exactly at five o'clock early in the morning to watch the sunrise. Since light does not propagate instantaneously some time must pass before the light reaches your eye from its source. So my question is: At what time would you see the sunrise were light able to propagate instantaneously?

Since it takes eight minutes for the light to travel from the sun to us here on earth, one might think that if light propagated *instantaneously* one would see the sunrise eight minutes earlier, i.e. at 4:52 a.m. You're in for a surprise if you think so; that answer is absolutely wrong. The sun "rises" when the earth turns

to face the *space that is already lit*. Therefore even if light propagated instantaneously we would still see the sunrise only at 5 a.m.

If we take what is called "atmospheric refraction" into consideration we get a still more startling result. Refraction curves the path of light, thus enabling us to see the sun "rise" *before* it really rises above the horizon. But if light propagated instantaneously, there would be no refraction as this is due to the different velocities with which light travels in different media. And as there would be no refraction, we would see the sunrise a bit *later*, from two minutes to as much as several days and even more (in polar latitudes), as this would depend on the latitude, air temperature, and certain other factors. So, were light to propagate instantaneously, we would see the sunrise later than we do now. A most curious paradox!

It would be quite different, of course, if you were observing the appearance of a solar protuberance in a telescope. Then, that is, if light propagated instantaneously, you would see it eight minutes earlier.

OVER THE OCEAN OF THE UNIVERSE

Speaking of the propagation of solar rays through space, it would be of interest to highlight one feature of light that is less known but one that prompted some fervid minds to come up with an idea of travelling over the ocean of the Universe. I mean the pressure of light.

It is to be stressed at this point that the pressure is extremely small; the sunlight incident on the Earth only acts on the ground with a force of 0.5 milligrams per square metre, or 0.5 kilograms per square kilometre. And so the total force acting on the Earth's surface exposed to the Sun is 60,000,000 kilograms. The figure, to be sure, seems to be astronomical, but it pales into insignificance when you learn that it is smaller than the force with which the Earth is attracted to the Sun by 60,000,000,000,000 times! As a matter of fact, the force due to the pressure of sunlight only amounts to the weight of a thousand locomotives.

For smaller bodies the ratio of the solar pressure force to the attraction force is larger than for the Earth. This is quite understandable because the light pressure force varies with a body's surface area, and the attraction force varies with mass. If the Earth were half smaller across, then its volume, and hence its mass, would be one eighth and its surface a quarter of what they are in reality, and so the pull would be eight times and the light pressure only four times smaller.

One curious consequence suggests itself. Since the pressure force falls off with

decreasing diameter of an exposed body slower than the pull, at a certain small diameter both forces must balance off each other. It has been found that a tiny drop of water (or any other microparticle), less than 0.001 millimetre across and situated as far from the Sun as the Earth, is pulled in by the Sun as strongly as the pressure of sunlight pushes it away. In other words, the droplet or particle will behave as if it were not attracted by the Sun. For yet smaller droplets the light pressure force will be even larger than the solar attraction, that is, the net force on the droplet will be repellant. True, the excess of the pressure over the pull is negligible, but then the mass of the droplet is tiny as well.

It is no wonder then that the velocity acquired by the droplet can be as high as tens of kilometres per second.

This makes not that outlandish to suppose that tiny bacteria, and especially their spores, could, having reached the upper atmosphere, leave our planet and travel through the limitless expanses of space with enormous, ever growing speeds. The Swedish scientist Svante Arrhenius went so far as to suppose that the germs of life may be carried over from one planet onto another this way. If you are endowed with an imaginative mind, you may have thought, upon reading these lines, that man could use this phenomenon for interplanetary travel. Alas, no. This would require a spacecraft with a surface-to-mass ratio as low as with the tiniest specks of dust and bacteria.

Chapter

Mirrors and Lenses

8

SEEING THROUGH WALLS

In the 1890's one could buy a curious contraption pompously called an "X-ray apparatus". I remember how puzzled I was when I, a schoolboy at the time, saw this ingenious device for the first time. It enabled me to see light through opaque objects, not only thick paper but even a knife blade, which is impenetrable to real X-rays. Figure 79, which shows the prototype of the contraption I just mentioned, "lets the cat out of the bag". It has four small mirrors, each slanted at the angle of 45° , to reflect and rereflect the rays coming from the object and thus lead them around the opaque obstacle.

The military extensively employ a similar device, the periscope, enabling them to follow the enemy's movements without exposing themselves to the hazard of enemy fire. The further away the exit of the periscope is from the eye of the observer the smaller the observer's field of vision. A special arrangement of optical lenses is used to enlarge the field of vision. But since the lenses absorb part of the light that enters the periscope, the image obtained is blurred. This limits the height of a periscope, with some twenty metres being already close to the "ceiling". Taller periscopes give a very small field of vision and a blurred image, especially in cloudy weather.

Submarine commanders also use periscopes to watch the ships they attack. Though a far more complicated affair than the army periscope, this periscope, which juts out of the water when the submarine submerges, is the same in principle, having a similar arrangement of mirrors (or prisms) (Fig. 80).

THE SPEAKING HEAD

This frequent side-show "marvel" dumbfounds the uninitiated. It does, indeed, astound one to see on a plate a live, seemingly severed human head, which rolls its eyes, speaks, and eats. And though you can't walk right up to the table on which it lies, you "quite perfectly" see that there is nothing underneath. If you ever see this side show, make a paper ball and throw it under the table.

Strangely enough, it bounces back. The mystery is no longer a mystery, it has bounced off a mirror. Even if it doesn't reach the table it will show you that there is a mirror there because you will see its reflection.

It is quite enough to have a mirror stretching from one table-leg to the other to give one the illusion that there is nothing beneath the table, provided, of course, that the mirror doesn't reflect the furnishings of the room or the

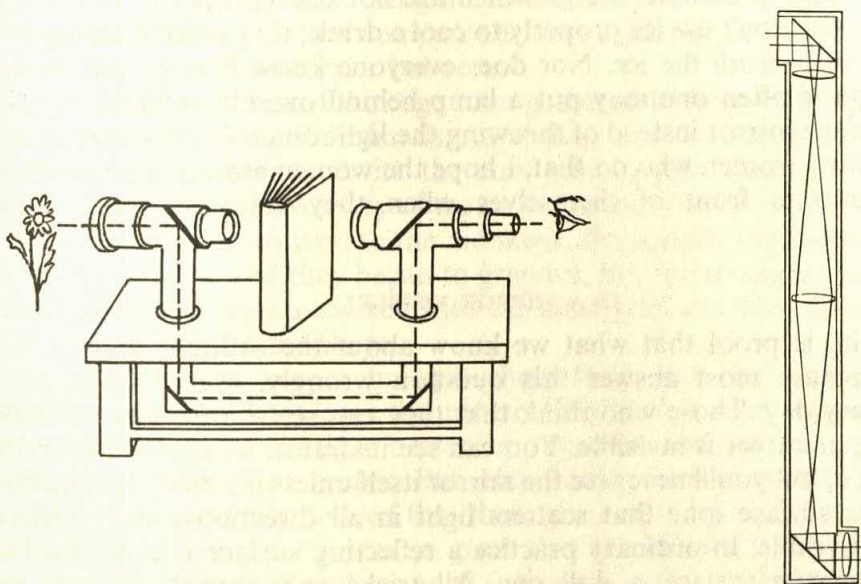


Fig. 79

A sham X-ray apparatus

Fig. 80

Diagram of a submarine periscope

audience. That is why it is absolutely necessary for the room to be bare and its walls all alike. The floor too should be in one tone, devoid of all ornamental design, and the audience must be kept at a respectful distance. As you see, the "secret" is as simple as pie, but until you're in the know, you just gape.

Sometimes the trick is still fancier. First the conjuror shows you a bare table, with nothing on top or beneath it. Then a closed box that is supposed to have the "live head" inside, but which is really empty, is brought onto the stage. The conjuror puts the box on the table and opens up the front flap. And lo! a speaking head appears. You've most likely guessed that the upper board of the table has sort of a trap-door in it through which the man squatting under the

table behind the mirror pokes his head when the bottomless empty box is placed on the table. There are other ways of doing this trick. You'll probably be able to work it out for yourself.

IN FRONT OR BEHIND

There are many household things which are not used properly. You already know that some don't use ice properly to cool a drink; they place it on top of the ice instead of *beneath* the ice. Nor does everyone know how to use a mirror properly. Quite often one may put a lamp behind oneself to "light up" one's reflection in the mirror instead of throwing the light on one's own person. Since there are many women who do that, I hope the women among my readers will put the lamp in front of themselves when they want to use a mirror.

IS A MIRROR VISIBLE?

There, again, is proof that what we know about the ordinary mirror is not enough, because most answer this question wrongly, even though all use mirrors every day. Those who think that they can see a mirror are mistaken. A good, clean mirror is invisible. You can see its frame, its rim and everything reflected in it, but you'll never see the mirror itself unless it's dirty. In contrast to a *dispersing* surface (one that scatters light in all directions) every *reflecting* surface is invisible. In ordinary practice a reflecting surface is a polished one, and a dispersing surface, a dull one. All tricks and optical illusions using mirrors, the "speaking head", for instance, are based precisely on their invisibility. All that you do see is the reflection in the mirror of different objects.

ANIMALS AT A MIRROR

It is curious (if not from the viewpoint of physics) to see how animals respond to their mirror images. Many animals just ignore them. I have never succeeded in making my cat notice its reflection. It is quite probable that for it the illusion is destroyed by the absence of those smells that in its brain accompany the visual perception of a live cat. Perhaps that is why animals at a water hole are scared by their reflections in the water. I conducted no experiments on horses or dogs, but it is beyond doubt that apes and monkeys are quite responsive to the illusion of the mirror. Here is an account of an observer at Leningrad Zoo:

A mirror was nailed up in an outdoor cage at ground level. In the morning two hamadryas baboons wanted to enter the cage, but having seen a new object in it they took fright and fled. They kept peeping out at it for a while afraid of walking out. Attracted by the gleam of the new object and encouraged by its immobility, they eventually dared slowly to enter the cage, turning away from the mirror and keeping a respectful distance. When they turned around to take another look at the enigmatic thing they were stunned to see their images but, having mistaken them for new companions, they cried out gaily and ran away to bring in the other hamadryas baboons.

"The entire population of the cage soon gathered in front of the mirror. The monkeys were stretching their hands out to their new comrades, were babbling something and seemed to invite the strangers to join them.

"In the long run the obstinacy of the new-comers, who did not want to enter the open cage started to irritate the monkeys, the sounds they uttered lost all trace of friendliness, and they began to grimace. But the strangers in the mirror were still silent and only answered with the same grimaces and capers, much to the annoyance of the monkeys.

"Several times the keeper brought them food, but the monkeys totally ignored her and would not leave the mirror. Finally, they were offered their favourite dish, raw egg and sugar beaten up together, and the hungry monkeys finally responded to their keeper. But, after having moved several paces from the mirror, they suddenly noticed that their new comrades were leaving as well. Their dismay at losing them was so great that the monkeys preferred to turn down their favourite food and resumed their exploration of the mirror. Having found that it was not an open door through which they could enter, the hamadryas baboons tried to peep behind it, tried to tear it from the wall, but all their efforts were to no avail, and so the mystery of the arrival of their new companions remained unsolved.

"By nightfall the monkeys who were now utterly exhausted by hunger and their fruitless efforts left to sleep, but at the crack of the dawn they were back again, around the mirror. The stubbornness and persistence the monkeys displayed returning to the mirror each morning to solve the mystery of the appearance of their new companions were amazing. The monkeys ceased eating regularly, and for days on end would sit in front of the mirror. In a week the mirror had to be removed, and life returned to normal."

IN THE LOOKING-GLASS

When we look in the looking-glass we see ourselves, many will say, adding that what we see is the exact copy of our own person down to the minutest detail.

Let's test that statement. Suppose you have a mole on your *right* cheek. The person you see in the mirror has a mole on his *left* cheek. You may be brushing

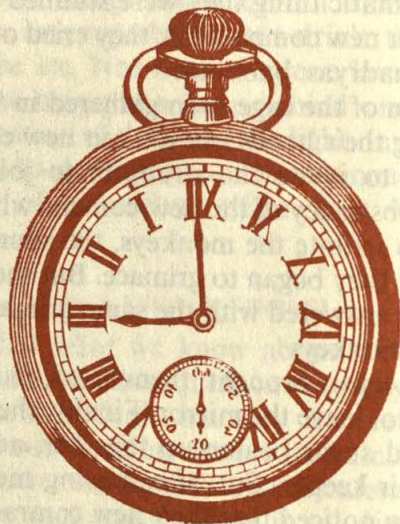


Fig. 81

Use a mirror

your hair to the *right*; your double in the mirror will be doing it to the *left*. Your right brow may be a bit higher and thicker than your left one; with your copy in the mirror it's the other way round. You keep your watch in your right-hand pocket and your wallet in the left; your double has quite opposite habits. Note the dial of his watch. Your watch isn't at all like that. The figures and their arrangement are most unusual. You see an eight marked before, as IIX, and standing where the twelve ought to be. Meanwhile there is no twelve at all. After a six comes a five, a four and so on. The hands of the watch's double in the mirror move the other way.

To cap it all, your looking-glass double has a physical handicap which you most likely don't have. He's left-handed. He writes, sews and eats with his left hand. And he'll stretch out his left hand to shake your right one. Then, does he know his letters? At any rate his knowledge is of a most peculiar brand. I greatly

doubt whether you will ever be able to read a single line in the book he holds or make out a single word in his left-handed scribble.

Such is the person who claims to be your exact copy, the person you claim is exactly like you!

But joking apart, if you really think that by looking in the mirror you are observing yourself, you are mistaken. The face, body and clothing of most

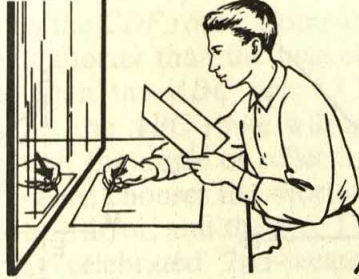


Fig. 82

Drawing in front of a looking-glass

people are not strictly symmetrical, but usually we don't notice that. The right side is not quite the same as the left side. In the looking-glass your left side assumes all the peculiar features of your right side and vice versa, so that you actually have a reflection that often produces quite a different impression than you do yourself.

MIRROR DRAWING

The fact that you and your reflection are not totally alike stands out still more when you do the following. Sit down at a table facing an upright mirror. Then take a piece of paper and try to draw, say, a rectangle with intersecting diagonals by looking at the reflection of your hand. This seemingly simple task becomes incredibly difficult.

As we grow up our visual impressions and motive sensations reach a definite degree of accord. The mirror violates this harmony as it gives us a distorted visual image of our hands in motion. Force of habit cries out against every move you make: you want to draw a line towards the right, but your hand pulls the pencil towards the left. You get still stranger results when you try in this manner to draw still more intricate figures or write something. You are bound to make a most comical mess of things.

The inky imprints on blotting paper are also a mirror-like symmetrical

reflection of your handwriting. But try to read them. You won't be able to make out a single word, even when the letters seem quite distinct. The writing will be slanted leftwise and all the strokes are topsy-turvy. However, as soon as you try to read this muddle in a mirror, you recognize your own customary handwriting. Actually, the mirror gives you a symmetrical reflection of what in itself is a symmetrical reflection of your own handwriting.

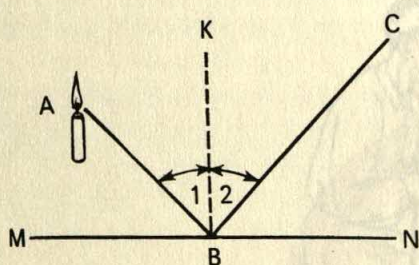
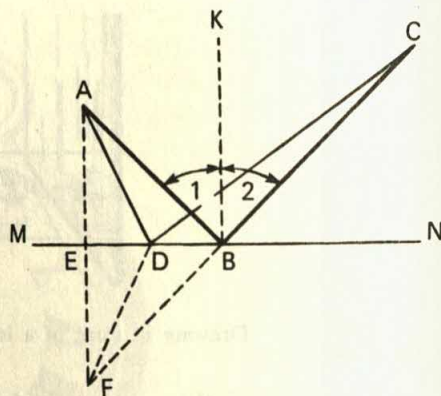


Fig. 83

The angle of reflection 2 is equal to the angle of incidence 1

Fig. 84

Reflecting light chooses the shortest path



SHORTEST AND FASTEST

In a homogeneous medium light propagates rectilinearly, that is in the fastest way possible. Light again picks the fastest route when reflecting from a mirror. Let us trace its passage. In Figure 83 A is the source of light, a candle, MN , a mirror, and ABC , the ray's passage from A to the eye C . The straight line KB is perpendicular to MN .

According to the laws of optics, the angle of reflection 2 is equal to the angle of incidence 1. Once we know this, we can easily prove that of all possible routes from A to C that a ray of light may take in the process of its reflection from the mirror MN , the route ABC is the shortest. To prove that this is so, let us compare ABC with some other route, for example, ADC (Fig. 84). Drop the perpendicular AE from point A onto MN and continue it further until it intersects with the continuation of the ray BC at point F . Then join points F and D by a straight line. Now let us see first whether the two triangles ABE and EBF

are equal. They are both right triangles and both have the side EB adjacent to the right angle. Besides that, the angles EFB and EAB are equal as they are respectively equal to the angles 2 and 1. Consequently, AE is equal to EF . Hence, the right triangles AED and EDF are equal because their respective sides adjacent to the right angles are equal. Consequently, AD is equal to DF .

We can thus replace the route ABC by the equal CBF route (since AB is equal to FB) and the ADC route by the CDF route. Comparing CBF and CDF , we see that the straight line CBF is shorter than the broken line CDF . Consequently, the ABC route is shorter than the ADC one. Q. E. D.!

Wherever point D may be, the ABC route will always be shorter than the ADC one, provided, of course, the angle of reflection is equal to the angle of incidence. As we see, light indeed chooses the shortest and fastest of all possible routes between its source, the mirror, and the eye. This was first pointed out by Heron of Alexandria, that celebrated 2nd-century Greek mathematician.

AS THE CROW FLIES

The ability to find the shortest way in cases like the one we discussed may come in handy when solving some brain-teasers. Take the following case.

A crow is perched on a branch, and there are some grains of millet scattered on the ground below. The crow swoops down, pecks at the millet and then flies up to perch on the fence. The question is: Where must the crow peck in order to take the shortest possible route? (Fig. 85.) This is an absolutely similar problem to the one just discussed. So we can easily supply the right answer: the crow should follow the path of the ray of light. In other words, it should fly so that angle 1 is equal to angle 2 (Fig. 86), which, as we already know, is the shortest way possible.

THE KALEIDOSCOPE

I suppose you all know what the kaleidoscope is. This amusing toy has a handful of various coloured bits of glass which are placed between two or three flat mirrors. They form extremely beautiful figures which change symmetrically with the slightest twist of the kaleidoscope. Though a very common toy, few suspect the tremendous assortment of different patterns one can get. Imagine that you have a kaleidoscope with 20 bits of glass inside and turn it to get ten new patterns every minute. How much time would you need to see all the

patterns these 20 bits of glass could form? Even the wildest of imaginations would never provide the right answer. The oceans would dry and the mountains crumble before you saw all; you would need at least 500,000 million years to see every figure produced!

The infinitely different and eternally changing patterns that this toy provides have long intrigued art designers, whose combined imaginations will never

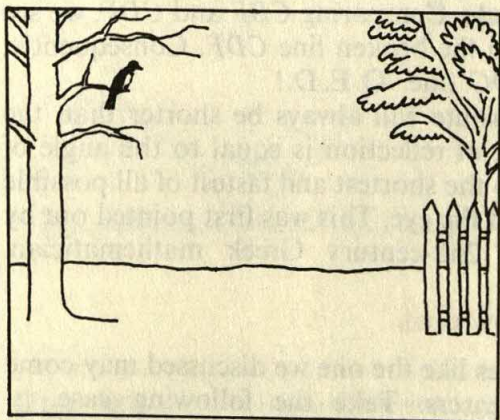


Fig. 85

The problem of the crow. Find the shortest line of flight to the ground and to the fence

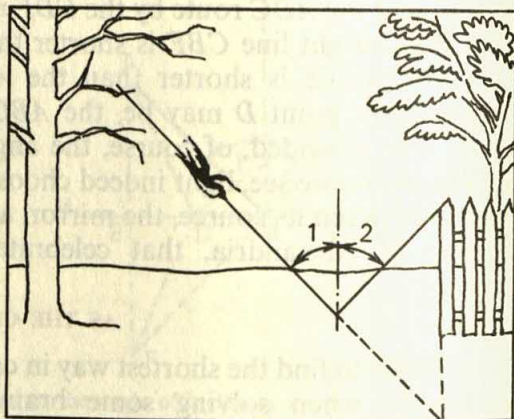


Fig. 86

The solution of the problem of the crow

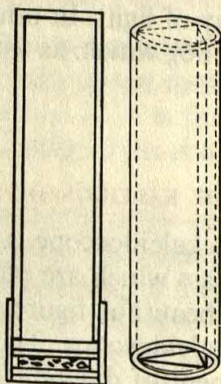


Fig. 87

A kaleidoscope

match the inexhaustible ingenuity with which it suggests lovely ornamental motifs for wallpaper, carpets and other fabrics. But among the general public it no longer excites the interest it did a hundred years ago when it was a fascinating novelty and when poets composed odes in its honour.

The kaleidoscope was invented in England in 1816. Some twelve to eighteen months later it was already arousing universal admiration. In the July 1818 issue of the Russian magazine *Blagonamerenny (Loyal)*, the fabulist A. Izmailov wrote about it: "Neither poetry nor prose can describe all that the kaleidoscope shows you. The figures change with every twist, with no new one alike. What beautiful patterns! How wonderful for embroidering! But where would one find such bright silks? Certainly a most pleasant relief from idle boredom, much better than to play patience at cards.

"They say that the kaleidoscope was known way back in the 17th century. At any rate, some time ago it was revived and perfected in England to cross the Channel a couple of months ago. One rich Frenchman ordered a kaleidoscope for 20,000 francs, with pearls and gems instead of coloured bits of glass and beads."

Izmailov then provides an amusing anecdote about the kaleidoscope and finally concludes on a melancholic note, extremely characteristic of that backward time of serfdom: "The imperial mechanic Rospini, who is famed for his excellent optical instruments, makes kaleidoscopes which he sells for 20 rubles a piece. Doubtlessly, far more people will want them than to attend the lectures on physics and chemistry from which, to our regret and surprise, that loyal gentleman, Mr. Rospini, has derived no profit."

For long the kaleidoscope was nothing more than an amusing toy. Today it is used in pattern designing. A device has been invented to photograph the kaleidoscope figures and thus mechanically provide sundry ornamental patterns.

PALACES OF ILLUSIONS AND MIRAGES

I wonder what sort of a sensation we would experience if we became midgets the size of the bits of glass and slipped into the kaleidoscope? Those who visited the Paris World Fair in 1900 had this wonderful opportunity. The so-called "Palace of Illusions" was a major attraction there, a place very much like the insides of a huge rigid kaleidoscope. Imagine a hexagonal hall, in which each of the six walls was a large, beautifully polished mirror. In each corner it had architectural embellishments, columns and cornices, which merged with the sculptural

adornments of the ceiling. The visitor thought he was one of a teeming crowd of people, looking all alike, and filling an endless enfilade of columned halls that stretched on every side as far as the eye could see. The halls shaded vertically in Fig. 88 are the result of a single reflection, the next twelve, shaded perpendicularly, the result of a double reflection, and the next eighteen, shaded slantwise, the result of a triple reflection. The halls multiply in number with each

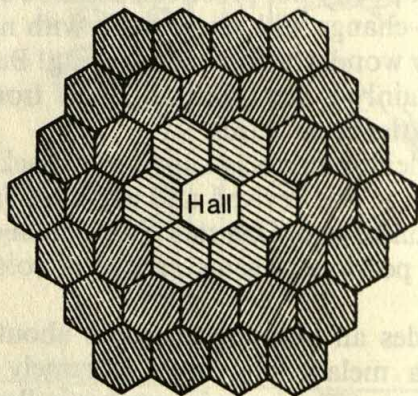


Fig. 88

A three-fold reflection from the walls of the central hall produces 36 halls

new multiple reflection, depending, naturally, on how perfect the mirrors are and whether they are disposed at exact parallels. Actually, one could see 468 halls as the result of the 12th reflection.

Everybody familiar with the laws that govern the reflection of light will realize how the illusion is produced. Since we have here three pairs of parallel mirrors and ten pairs of mirrors set at angles to each other, no wonder they give so many reflections.

The optical illusions produced by the so-called Palace of Mirages at the same Paris Exposition were still more curious. Here the endless reflections were coupled with a quick change in decorations. In other words, it was a huge but seemingly *movable* kaleidoscope, with the spectators inside. This was achieved by introducing in the hall of mirrors hinged revolving corners—much in the manner of a revolving stage. Figure 89 shows that three changes, corresponding to the corners 1, 2, and 3, can be effected. Supposing that the first six corners are decorated as a tropical forest, the next six corners as the interior of a sheikh's palace, and the last six as an Indian temple. One turn of the concealed

mechanism would be enough to change a tropical forest into a temple or palace. The entire trick is based on such a simple physical phenomenon as light reflection.

WHY LIGHT REFRACTS AND HOW

Many think that the fact that light refracts when passing from medium to medium is one of Nature's whims. They simply can't understand why light does not keep on in the same direction as before but has to strike out obliquely. Do

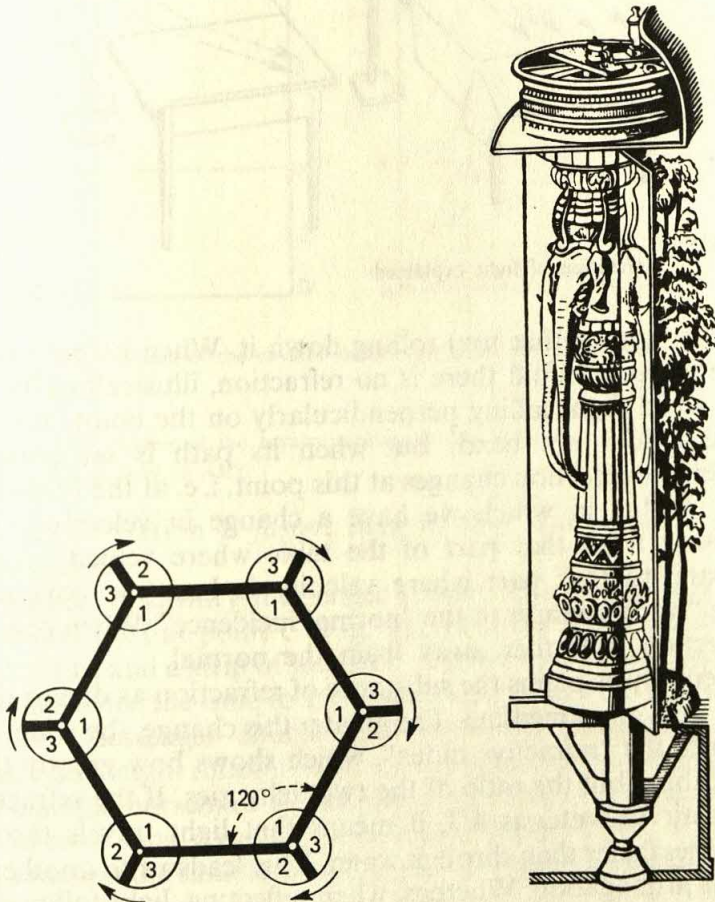


Fig. 89

The secret of the "Palace of Mirages"

you think so too? Then you'll probably be delighted to learn that light behaves just as a marching column of soldiers does when they step from a paved road to one full of ruts.

Here is a very simple and instructive illustration to show how light refracts. Fold your tablecloth and lay it on the table as shown in Fig. 90. Incline the table-top slightly. Then set a couple of wheels on one axle (from a broken toy

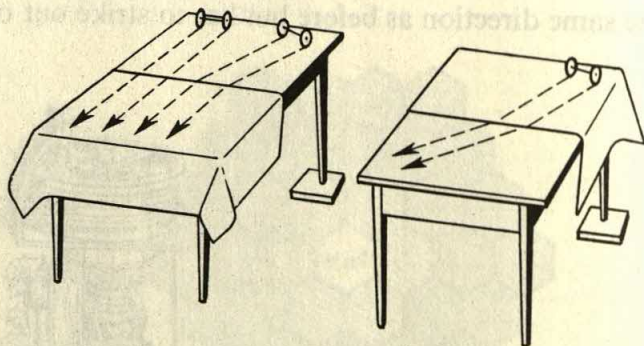


Fig. 90

Refraction of light explained

steam engine or some other toy) rolling down it. When its path is set at right angles to the tablecloth fold there is no refraction, illustrating the optical law, according to which light falling perpendicularly on the boundary between two different media does not bend. But when its path is set obliquely to the tablecloth fold, the direction changes at this point, i. e. at the boundary between two-different media, in which we have a change in velocity.

When passing from that part of the table where velocity is greater (the uncovered part) to that part where velocity is less (the covered part), the direction (the "ray") is nearer to the "normal incidence". When rolling the other way the direction is farther away from the normal.

This, incidentally, explains the substance of refraction as due to the change in light velocity in the new medium. The greater this change, the wider the angle of refraction, since the "refractive index", which shows how greatly the direction changes, is nothing but the ratio of the two velocities. If the refractive index in passing from air to water is $4/3$, it means that light travels through the air roughly 1.3 times faster than through water. This leads us to another instructive aspect of light propagation. Whereas, when reflecting, light follows the *shortest* route, when refracting, it chooses the *fastest* way; no other route will bring it to its "destination" sooner than this crooked road.

LONGER WAY FASTER

Can a crooked route really bring us sooner to our destination than the straight one? Yes, when we move with different speeds along different sections of our route. Villagers living between two railway stations A and B , but closer to A , prefer to walk or cycle to station A and board the train there for station B , if

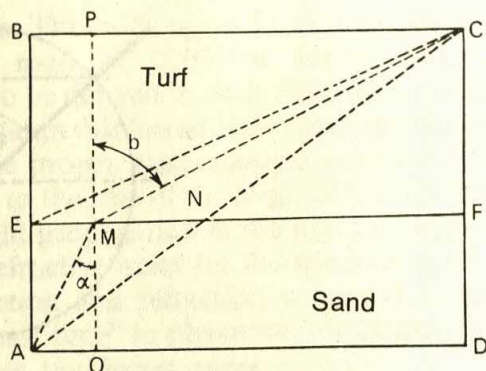
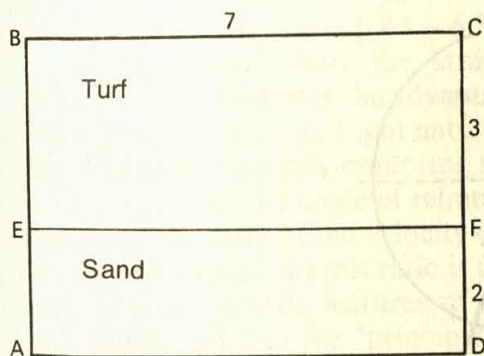


Fig. 91

The problem of the cavalry messenger. Find the fastest way from A to C

Fig. 92

The problem of the cavalry messenger and its solution. The fastest way is AMC

they want to get to station B *faster*, than to take the *shorter* way which is straight to station B .

Another instance. A cavalry messenger is sent with despatches from point A to the command post at point C (Fig. 91). Between him and the command post lie a strip of turf and a strip of soft sand, divided by the straight line EF . We know that it takes twice the time to cross sand than it does to cross turf. Which route would the messenger choose to deliver the despatches sooner?

At first glance one might think it to be the straight line between A and C . But I don't think a single horseman would pick that route. After all, since it takes a longer time to cross sand, a cavalryman would rightly think it better to cut the time spent by crossing the sand less obliquely. This would naturally lengthen his way across the turf. But since the horse would take him across it twice as fast, this longer distance would actually mean less time spent. In other words, the horseman should follow a road that would *refract* on the boundary between

sand and turf, moreover, with the path across the turf forming a wider angle with the perpendicular to this boundary than the path across the sand.

Anyone will realize that the straight path AC is actually not the quickest way and that considering the different width of the two strips and the distances as given in Fig. 91, the messenger will reach his destination sooner if he takes the crooked road ABC (Fig. 92). Figure 91 gives us a strip of sand two kilometres

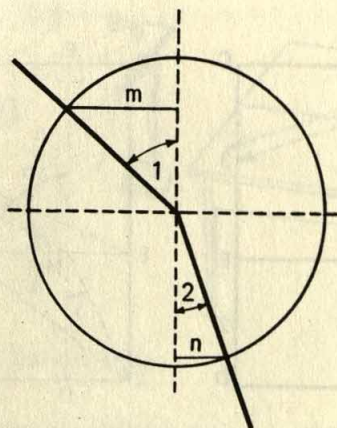


Fig. 93

What is the sine? The ratio of m to the radius is the sine of angle 1, while the ratio of n to the radius is the sine of angle 2

wide, and a strip of turf three kilometres wide. The distance BC is seven kilometres. According to Pythagoras, the entire route from A to C (Fig. 92) is equal to $\sqrt{5^2 + 7^2} = \sqrt{74} = 8.6$ km. Section AN , across the sand, is two-fifths of this, or 3.44 km. Since it takes twice as long to cross sand than it does to cross turf, the 3.44 km of sand mean from the time angle 6.88 km of turf. Hence the 8.6 km straight-line route AC is equivalent to 12.04 km across turf. Let us now reduce to "turf" the crooked AEC route. Section AE is two kilometres, which corresponds to four kilometres in time across turf. Section EC is equal to $\sqrt{3^2 + 7^2} = \sqrt{58} = 7.61$ km, which, added to four kilometres, results in a total of 11.61 km for the crooked AEC route.

As you see, the "short" straight road is 12.04 km across turf, while the "long" crooked road only 11.61 km across turf, which thus saves $12.04 - 11.61 = 0.43$ km, or nearly half a kilometre. But this is still not the quickest way. This, according to theory, is that (we shall have to invoke trigonometry) in which the ratio of the sine of angle b to the sine of angle a is the same as the ratio of the

velocity across turf to that across sand, i.e., a ratio of 2 : 1. In other words, we must pick a direction along which the sine of angle b would be twice the sine of angle a . Accordingly, we must cross the boundary between the sand and turf at point M , which is one kilometre away from point E . Then $\sin b = 6/\sqrt{3^2 + 6^2}$, while $\sin a = 1/\sqrt{1 + 2^2}$, and the ratio of $\sin b/\sin a = 6/\sqrt{45} : 1/\sqrt{5} = 6/3 \sqrt{5} : 1/\sqrt{5} = 2$, which is exactly the ratio of the two velocities. What would this route, reduced to "turf", be? $AM = \sqrt{2^2 + 1^2}$ which corresponds to 4.47 km across turf, $MC = \sqrt{45} = 6.71$ km. This adds up to 11.18 km, which is 860 metres *shorter* than the straight road of 12.04 km across turf.

This instance illustrates the advantage to be derived in such circumstances by choosing a crooked road. Light naturally takes this fastest route because the law of light refraction strictly conforms to the proper mathematical solution. The ratio of the sine of the angle of refraction to the sine of the angle of incidence is the same as the ratio of the velocity of light propagation in the new medium to that in the first medium; this ratio is the refractive index for the specified media. Combining the specific features of reflection and refraction we arrive at the "Fermat principle", or the "principle of least time" as physicists sometimes call it, according to which *light always takes the fastest route*.

When the medium is heterogeneous and its refractive properties change gradually, as in our atmosphere, for instance, again "the principle of least time" holds. This explains the slight curvature in light as it comes from the celestial objects through our atmosphere. Astronomers call this "atmospheric refraction". In our atmosphere, which becomes denser and denser the closer we get to the ground, light bends in such a way that the inside of the curve faces the earth. It spends more time in higher atmospheric layers, where there is less to retard its progress, and less time in the "slower" lower layers, thus reaching its destination more quickly than were it to keep to a strictly rectilinear course.

The Fermat principle applies not only to light. *Sound* and all *waves* in general, whatever their nature, travel in accord with this principle. Since you probably want to know why, let me quote from a paper which the eminent physicist Schrödinger read in 1933 in Stockholm when receiving the Nobel Prize. Speaking of how light travels through a medium with a gradually changing density, he said:

"Let the soldiers each firmly grasp one long stick to keep strict breastline formation. Then the command rings out: Double! Quick! If the ground gradually changes, first the right end, and then the left end will move faster, and the breastline will swing round. Note that the route covered is not straight but

crooked. That it strictly conforms to the shortest, as far as the time of arrival at the destination over this particular ground is concerned, is quite clear, as each soldier tried to run as fast as he could."

THE NEW CRUSOES

If you have read Jules Verne's *Mysterious Island*, you might remember how its heroes, when stranded on a desert isle, lit a fire though they had no matches and no flint, steel and tinder. It was lightning that helped Defoe's Robinson Crusoe; by pure accident it struck a tree and set fire to it. But in Jules Verne's novel it was the resourcefulness of an educated engineer and his knowledge of physics that stood the heroes in good stead. Do you remember how amazed that naïve sailor Pencroft was when, coming back from a hunting trip, he found the engineer and the reporter seated before a blazing bonfire?

"But who lighted it?" asked Pencroft.

"The sun!"

"Gideon Spilett was quite right in his reply. It was the sun that had furnished the heat which so astonished Pencroft. The sailor could scarcely believe his eyes, and he was so amazed that he did not think of questioning the engineer.

"Had you a burning-glass, sir?" asked Herbert of Harding.

"No, my boy," replied he, "but I made one."

"And he showed the apparatus which served for a burning-glass. It was simply two glasses which he had taken off his own and the reporter's watch. Having filled them with water and rendered their edges adhesive by means of a little clay, he thus fabricated a regular burning-glass, which, concentrating the solar rays on some very dry moss, soon caused it to blaze."

I dare say you would like to know why the space between the two watch glasses had to be filled with water. After all, wouldn't an air-filling focus the sun's rays well enough?

Not at all. A watch glass is bounded by two, outer and inner, parallel (concentric) surfaces. Physics tells us that when light passes through a medium bounded by such surfaces it hardly changes its direction at all. Nor does it bend when passing through the second watch glass. Consequently, the rays of light cannot be focussed on one point. To do this we must fill up the empty space between the glasses with a transparent substance that would refract rays better than air does. And that is what Jules Verne's engineer did.

Any ordinary ball-shaped water-filled carafe will act as a burning-glass. The ancients knew that and also noticed that the water didn't warm up in the

process. There have been cases when a carafe of water inadvertently left to stand in the sunlight on the sill of an open window set curtains and tablecloths on fire and charred tables. The big spheres of coloured water, which were traditionally used to adorn the show-windows of chemists' shops, now and again caused fires by igniting the inflammable substances stored near by.

A small round retort, 12 cm in diameter is quite enough, full of water will do to boil water in a watch glass. With a focal distance of 15 cm (the focus is very close to the retort), you can produce a temperature of 120°C . You can light a cigarette with it just as easily as with a glass. One must note, however, that a glass lens is much more effective than a waterfilled one, firstly, because the refractive index of water is much less, and, secondly, because water intensively absorbs the infrared rays which are so very essential for heating bodies.

It is curious to note that the ancient Greeks were aware of the ignition effect of glass lenses a thousand odd years before eyeglasses and spyglasses were invented. Aristophanes speaks of it in his famous comedy *The Cloud*. Socrates propounds the following problem to Streptiadis:

"Were one to write a promissory note on you for five talents, how would you destroy it?

"*Streptiadis*: I have found a way which you yourself will admit to be very artful. I suppose you have seen the wondrous, transparent stone that burns and is sold at the chemist's?

"*Socrates*: The burning-glass, you mean?

"*Streptiadis*: That is right.

"*Socrates*: Well, and what?

"*Streptiadis*: While the notary is writing I shall stand behind him and focus the sun on the promissory note and melt all he writes."

I might explain that in Aristophanes' days the Greeks used to write on waxed tablets which easily melted.

ICE HELPS TO LIGHT FIRE

Even ice, provided it is transparent enough, can serve as a convex lens and, consequently, as a burning-glass. Let me note, furthermore, that in this process the ice does not warm up and melt. Its refractive index is a wee bit less than that of water, and since a spherical water-filled vessel can be used as a burning-glass, so can a similarly shaped lump of ice. An ice "burning-glass" enabled Dr. Clawbonny in Jules Verne's *The Adventures of Captain Hatteras* to light a fire when the travellers found themselves stranded without a fire or anything

to light it in terribly cold weather, with the mercury at 48°C below zero.

“‘This is terrible ill-luck,’ the captain said.

“‘Yes,’ replied the doctor,

“‘We haven’t even a spyglass to make a fire with!’

“‘That’s a great pity,’ the doctor remarked, ‘because the sun is strong enough to light tinder.’

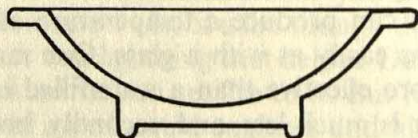


Fig. 94

A bowl for making an ice burning-glass

“‘We’ll have to eat the bear raw, then,’ said the captain.

“‘As a last resort, yes,’ the doctor pensively replied. ‘But why not....’

“‘What?’ Hatteras inquired.

“‘I’ve got an idea.’

“‘Then we’re saved,’ exclaimed the bosun.

“‘But...’ the doctor was hesitant.

“‘What is it?’ asked the captain.

“‘We haven’t got a burning-glass, but we can make one.’

“‘How?’ asked the bosun.

“‘From a piece of ice!’

“‘And you think....’

“‘Why not? We must focus the sun’s rays on the tinder and a piece of ice can do that. Fresh-water ice is better though since it’s more transparent and less liable to break.’

“‘The ice boulder over there,’ the bosun pointed to a boulder some hundred steps away, ‘seems to be what we need.’

“‘Yes. Take your axe and let’s go.’

“The three walked over to the boulder and found that it was indeed of fresh-water ice.

“The doctor told the bosun to chop off a chunk of about a foot in diameter, and then he ground it down with his axe, his knife, and finally polished it with his hand and produced a very good, transparent burning-glass. The doctor focussed the sun’s bright rays on the tinder which began to blaze a few seconds later.”

Jules Verne's story is not an impossibility. The first time this was ever done with success was in England in 1763. Since then ice has been used more than once for the purpose. It is, of course, hard to believe that one could make an ice burning-glass with such crude tools as an axe and knife and "one's hand" in a frost of 48°C below zero. There is, however, a much simpler way: pour some water into a bowl of the proper shape, freeze it, and then take out the ice by slightly heating the bottom of the bowl. Such a "burning-glass" will work only in the open air on a clear and frosty day. Inside a room behind closed windows it is out of the question, because the glass panes absorb much of the solar energy and what is left of it is not strong enough.

HELPING SUNLIGHT

Here is one more experiment which you can easily do in wintertime. Take two pieces of cloth of the same size, one black and the other white, and put them on the snow out in the sun. An hour or two later you will find the black piece half-sunk, while the white piece is still where it was. The snow melts sooner under the black piece because cloth of this colour absorbs most of the solar rays falling on it, while white cloth disperses most of the solar rays and consequently warms up much less.

This very instructive experiment was first performed by Benjamin Franklin, an American scientist who was famous at the time of the War of Independence, and who is also known for having invented the lightning conductor.

"I took a number of little square pieces of broad cloth from a tailor's pattern card, of various colours. There were black, deep blue, lighter blue, green, purple, red, yellow, white, and other colours, or shades of colours. I laid them all out upon the snow in a bright sunshiny morning. In a few hours (I cannot now be exact as to the time), the black, being warmed most by the sun, was sunk so low as to be below the stroke of the sun's rays; the dark blue almost as low, the lighter blue not quite so much as the dark, the other colours less as they were lighter; and the quite white remained on the surface of the snow, not having entered it at all.

"What signifies philosophy that does not apply to some use?—May we not learn from hence, that black clothes are not so fit to wear in a hot sunny climate or season, as white ones; because in such clothes the body is more heated by the sun when we walk abroad, and we are at the same time heated by the exercise, which double heat is apt to bring on putrid dangerous fevers? That summer

hats for men or women should be white, as repelling that heat which gives headaches to many, and to some the fatal stroke that the French call the *coup de soleil*?... That fruit walls being blacked may receive so much heat from the sun in the daytime, as to continue warm in some degree through the night, and thereby preserve the fruit from frosts, or forward its growth?—with sundry other particulars of less or greater importance, that will occur from time to time to attentive minds?”

The benefit that can be drawn from this knowledge was well illustrated during the expedition to the South Pole that the Germans made aboard the good ship *Hauss* in 1933.

The ship was jammed by icepacks and all methods usually applied in such circumstances, i.e. explosives and ice-saws, proved abortive. Solar rays were then invoked. A two-kilometre-long strip, a dozen metres in width, of dark ash and coal was strewn from the ship's bow to the nearest rift. Since this happened during the Antarctic summer, with its long and clear days, the sun was able to accomplish what dynamite and saws had failed to do. The ice melted and cracked all along the strip, releasing the ship from its clutches.

MIRAGES

I suppose you all know what causes a mirage. The blazing sun heats up the desert sands and lends to them the property of a mirror because the density of the hot surface layer of air is less than that of the strata higher up. Oblique rays of light from a remote object meet this layer of air and curve upwards from the ground as if reflected by a mirror after striking it at a very obtuse angle. The desert-traveller thus thinks he is seeing a sheet of water reflecting the objects standing on its banks (Fig. 95). Rather should we say that the hot surface layer of air reflects not like a mirror but like the surface of water when viewed from a submarine. This is not an ordinary reflection but what physicists call total reflection, which occurs when light enters the layer of air at an extremely obtuse angle, much broader than the one in the figure. Otherwise the “critical angle” of incidence will not be exceeded.

Please note, to avoid misunderstanding, that a denser strata must be above the rarer layers. However, we know that denser air is heavier and always seeks to descend to take the place of lighter lower layers and force them upwards. Why, in the case of a mirage, is the denser air above the rarer air? Because air is in constant motion. The heated surface air keeps on being forced up by a new replacing lot of heated air. This is not responsible for some rarefied air always

remaining just above the hot sand. It need not be the same rarefied air all the time—but that is something that makes no difference to the rays.

This phenomenon has been known from times immemorial. (A somewhat different type of mirage is caused by reflection in upper rarefied layers.) Most people think this classical type of mirage can be observed only in the blazing southern deserts and never in more northerly latitudes. They are wrong. This is

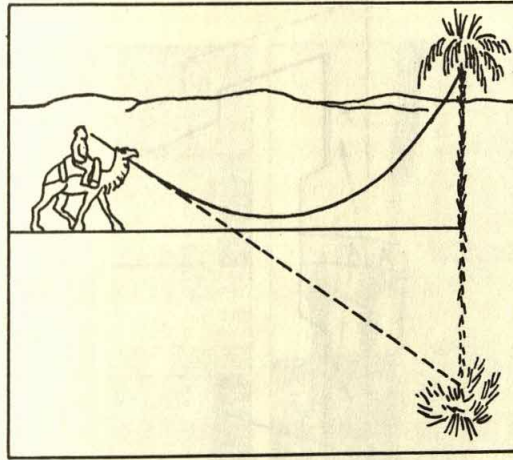


Fig. 95

Desert mirages explained. In the drawing, usually given in textbooks, the ray's course towards the ground is too steep

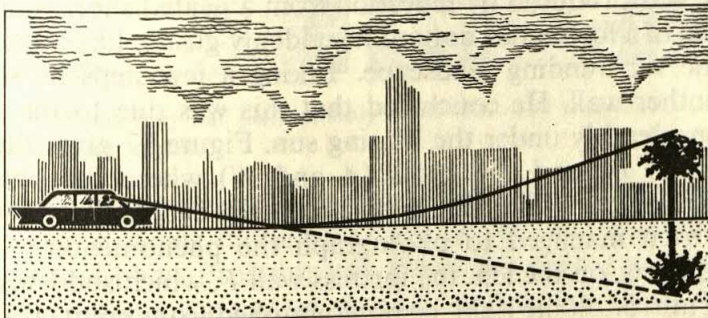


Fig. 96

Mirage on paved highway

frequently to be observed in summer on asphalted roads which, because they are dark, are greatly heated by the sun. The dull road's surface seems to look like a pool of water able to reflect distant objects. Figure 96 shows the path light takes in this case. A sufficiently observant person will see these mirages oftener than one might think.

There is one more type of mirage, a side one, which people usually do not have the faintest suspicion about. This mirage, which has been described by

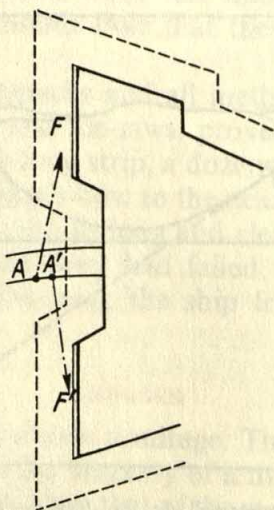


Fig. 97

Ground plan of the fortress where the mirage was seen. Wall F seemed polished from point K , and wall F' from point K'

a Frenchman, was produced by reflection from a heated sheer wall. As he drew near to the wall of a fortress he noticed it suddenly glisten like a polished mirror and reflect the surrounding landscape. Taking a few steps he saw a similar change in another wall. He concluded that this was due to the walls having heated up considerably under the blazing sun. Figure 97 gives the position of the walls (F and F') and the spots (A and A') where the observer stood.

The Frenchman found that the mirage recurred every time the wall was hot enough and even managed to photograph the phenomenon.

Figure 98 depicts, on the left, the fortress wall F , which suddenly turned into the glistening mirror on the right, as photographed from point A' . The ordinary grey concrete wall on the left naturally cannot reflect the two soldiers near it. But the same wall, miraculously transformed into a mirror on the right, does

symmetrically reflect the closer of the two soldiers. Of course it isn't the wall itself that reflects him, but its surface layer of hot air. If on a hot summer day you pay notice to walls of big buildings, you might spot a mirage of this kind.

"THE GREEN RAY"

"Have you ever seen the sun dip into the horizon at sea? No doubt, you have. Have you ever watched it until the upper rim touches the horizon and then

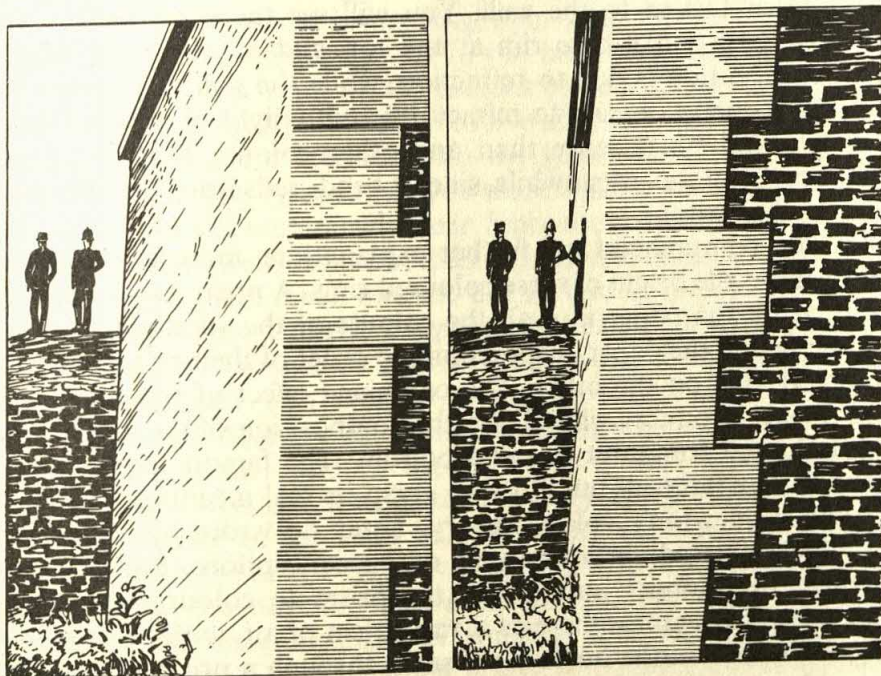


Fig. 98

Rough, grey wall (left) suddenly seems to act like a polished mirror (right)

'disappears? Probably you have. But have you ever noticed what happens on the instant when our brilliant luminary sheds its last ray, provided the sky is a cloudless, pellucid blue? Probably not. Don't miss this opportunity. You will see, instead of a red ray, one of an exquisite green that no artist could ever reproduce and that nature herself never displays either in the variously tinted plants or in the most transparent of seas."

This note published in an English newspaper sent the young heroine of Jules Verne's *The Green Ray* in raptures and made her roam the world solely to see this phenomenon with her own eyes. Though, according to Jules Verne, this Scottish girl failed to see the lovely work of nature, still it exists. It is no myth, though many legends are associated with it. Any lover of nature can admire it, provided he takes the pains to hunt for it.

Where does the green ray or flash come from? Recall what you saw when you looked at something through a prism. Try the following. Hold the prism at eye level with its broad horizontal plane turned downwards and look through it at a piece of paper tacked to the wall. You will see the sheet firstly loom and secondly display a violet-blue rim at the top and a yellow-red edge at the bottom. The elevation is due to refraction, while the coloured rims owe their origin to the property of glass to refract differently light of different colours. It bends violets and blues more than any other colour. That is why we see a violet-blue rim on top. Meanwhile, since it bends reds least, the bottom edge is precisely of this colour.

So that you comprehend my further explanations more easily, I must say something about the origin of these coloured rims. A prism breaks up the white light emitted by the paper into all the colours of the spectrum, giving many coloured images of the paper, disposed in the order of their refraction and often superimposed, one on the other. The combined effect of these superimposed coloured images produces white light (the composition of the spectral colours) but with coloured fringes at top and bottom. The famous poet Goethe who performed this experiment but failed to grasp its real meaning thought that he had debunked Newton's colour theory. Later he wrote his own *Theory of Colours* which is based almost entirely on misconceptions. But I suppose you won't repeat his blunder and expect the prism to colour everything anew.

We see the earth's atmosphere as a vast prism of air, with its base facing us. Looking at the sun on the horizon we see it through a prism of gas. The solar disc has a blue-green fringe on top and a yellow-red one at the bottom. While the sun is above the horizon, its disc's brilliant colour outshines all other less bright bands of colour and we don't see them at all. But during the sunrises and sunsets, when practically the entire disc of the sun is below the horizon, we may spot the blue double-tinted fringe on the upper rim, with an azure blue right on top and a paler blue, produced by the mixing of green and blue, below it. When the air near the horizon is clear and translucent, we see a blue fringe, or the "blue ray". But often the atmosphere disperses the blues and we see only the remaining green fringe, the "green ray". However, most often a turbid

atmosphere disperses both blues and greens and then we see no fringe at all, the setting sun becoming crimson.

The Soviet astronomer G. A. Tikhov, who devoted a special monograph to the "green ray", gives us some tokens by which we may see it.

"When the setting sun is crimson-hued and it doesn't hurt to look at it with the naked eye you may be sure that there will be no green flash." This is clear enough: the fact of a red sun means that the atmosphere intensively disperses blues and greens, or, in other words, the whole of the upper rim of the solar disc. "On the other hand," he continues, "when the setting sun scarcely changes its customary whitish yellow and is very bright [in other words, when atmospheric absorption of light is insignificant – Y. P.], you may quite likely expect the green flash. However, it is important for the horizon to be a distinct straight line with no uneven relief, forests or buildings. We have all these conditions at sea, which explains why seamen are familiar with the green flash."

To sum up: to see the "green ray", you must observe the sun when setting or rising and when the sky is extremely clear. Since the sky at the horizon in southern climes is much more translucent than in northern latitudes, one is liable to see the "green ray" there much oftener. But neither in middle latitudes is it so rare as many think, most likely, I suppose, because of Jules Verne. You will detect the "green ray" sooner or later as long as you look hard enough. This phenomenon has been seen even in a spyglass.

Here is how two Alsatian astronomers describe it:

"During the very last minute before the sun sets, when, consequently, a goodly part of its disc is still to be seen, a green fringe hems the waving but clearly etched outline of the sun's ball. But until the sun sets altogether, it cannot be seen with the naked eye. It will be seen only when the sun disappears completely below the horizon. However, should one use a spyglass with a powerful enough magnification, of roughly 100, one will see the entire phenomenon very well. The green fringe is seen some ten minutes before the sun sets at the latest. It incloses the disc's upper half, while a red fringe hems the lower half. At first the fringe is extremely narrow, encompassing at the outset but a few seconds of an arc. As the sun sets, it grows wider, sometimes reaching as much as half a minute of an arc. Above the green fringe one may often spot similarly green prominences, which, as the sun gradually sinks, seem to slide along its rim up to its apex and sometimes break away entirely to shine independently a few seconds before fading".

Usually this phenomenon lasts a couple of seconds. In extremely favourable conditions, however, it may last much longer. A case of more than 5 minutes has

been registered; this was when the sun was setting behind a distant mountain and the quickly walking observer saw the green fringe as seemingly sliding down the hill.

The instances recorded when the "green ray" has been observed during a sunrise, that is, when the upper rim of our celestial luminary peeps out above the horizon, are extremely instructive, as they debunk the frequent suggestion that the phenomenon is presumably nothing more than an optical illusion to which the eye succumbs owing to the fatigue caused by looking at the brilliant setting sun. Incidentally, the sun is not the only celestial object that sheds the "green ray". Venus has also produced it when setting.

Chapter

Vision

9

BEFORE PHOTOGRAPHY WAS INVENTED

Photography is so ordinary nowadays that we find it hard to imagine how our forefathers, even in the past century, got along without it. In his *Posthumous Papers of the Pickwick Club* Charles Dickens tells us the amusing story of how British prison officers took a person's likeness some hundred or so years ago. The action takes place in the debtors' prison where Pickwick has been brought. Pickwick is told that he'll have to sit for his portrait.

"'Sitting for my portrait!' said Mr. Pickwick.

"'Having your likeness taken, sir,' replied the stout turnkey.

"'We're capital hands at likenesses here. Take'em in no time, and always exact. Walk in, sir, and make yourself at home.'

"Mr. Pickwick complied with the invitation, and sat himself down, when Mr. Weller, who stationed himself at the back of the chair, whispered that the sitting was merely another term for undergoing an inspection by the different turnkeys, in order that they might know prisoners from visitors.

"'Well, Sam,' said Mr. Pickwick. 'Then I wish the artists would come. This is rather a public place.'

"'They won't be long, sir, I des-say,' replied Sam. 'There's a Dutch clock, sir.'

"'So I see,' observed Mr. Pickwick.

"'And a bird-cage, sir,' said Sam. 'Veels within veels, a prison in a prison. Ain't it, sir?'

"As Mr. Weller made this philosophical remark, Mr. Pickwick was aware that his sitting had commenced. The stout turnkey having been relieved from the lock, sat down, and looked at him carelessly, from time to time, while a long thin man who had relieved him thrust his hands beneath his coat-tails, and planting himself opposite, took a good long view of him. A third, rather surly-looking gentleman, who had apparently been disturbed at his tea, for he was disposing of the last remnant of a crust and butter when he came in, stationed himself close to Mr. Pickwick; and, resting his hands on his hips, inspected him narrowly, while two others mixed with the group, and studied his features with

most intent and thoughtful faces. Mr. Pickwick winced a good deal under the operation, and appeared to sit very uneasily in his chair; but he made no remark to anybody while it was being performed, not even to Sam, who reclined upon the back of the chair, reflecting, partly on the situation of his master, and partly on the great satisfaction it would have afforded him to make a fierce assault upon all the turnkeys there assembled, one after the other, if it were lawful and peaceable so to do.

"At length the likeness was completed, and Mr. Pickwick was informed that he might now proceed into the prison."

Still earlier it was a list of "features" that did for such memorized "portraits". In his *Boris Godunov*, Pushkin tells us how Grigory Otrepyev was described in the tsar's edict: "Of short stature, and broad chest; one arm shorter than the other; the eyes are blue and hair ginger; a wart on one cheek and another on the forehead." Today we needn't do that; we simply provide a photograph instead.

WHAT MANY DON'T KNOW HOW TO DO

Photography was introduced in Russia in the 1840's, first as daguerreotypes, that is, prints on metal plates that were called so after their inventor, Daguerre. It was a very inconvenient method; one had to pose for quite a long stretch, some twenty minutes or so.

"My grandfather," Prof. B. P. Weinberg, the Leningrad physicist, told me, "had to sit for 40 minutes before the camera to get just one daguerreotype, from which, moreover, no prints could be made."

Still the chance to have one's portrait made without the artist's intervention seemed such a wonderful novelty that it took the general public quite a time to get used to the idea. One old Russian magazine for 1845 contains quite an amusing anecdote on the score:

"Many still cannot believe that the daguerreotype acts by itself. One gentleman came to have his portrait done. The owner [the photographer - Y. P.] begged him to be seated, adjusted the lenses, inserted a plate, glanced at his watch, and retired. While the owner was present, the gentleman sat as if rooted to the spot. But he had barely gone out when the gentleman thought it no longer necessary to sit still; he rose, took a pinch of snuff, examined the camera from every side, put his eye to the lens, shook his head, mumbled, 'How ingenious,' and began to meander up and down the room.

"The owner returned, stopped short in surprise at the doorway, and exclaimed: 'What are you doing? I told you to sit still!'

“Well, I did. I got up only when you went out.”

“But that was exactly when you should have sat still.”

“Why should I sit still for nothing?” the gentleman retorted.”

We’re certainly not so naïve today.

Still, there are some things about photography that many do not know. Few, incidentally, know how one should *look* at a photograph. Indeed, it’s not so

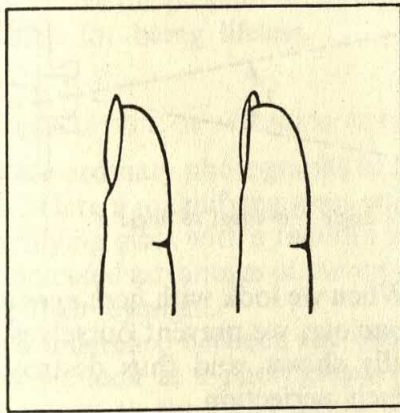


Fig. 99

A finger as seen separately by the left and right eye when held close to the face

simple as one might think, though photography has been in existence for more than a century now and is as common as could be. Nevertheless, even professionals don’t look at photographs *in quite the proper way*.

HOW TO LOOK AT PHOTOGRAPHS

The camera is based on the same optical principle as our eye. Everything projected onto its ground-glass screen depends on the distance between the lens and the object. The camera gives a perspective, which we would get with *one eye*—note that!—were our eye to replace the lens. So, if you want to obtain from a photograph the same visual impression that the photographed object produced, we must, firstly, look at the photograph with *one eye* only, and, secondly, hold it *at the proper distance away*.

After all, when you look at a photograph with *both eyes* the picture you get is flat and not three-dimensional. This is the fault of our own vision. When we look at something solid the image it causes on the retina of either eye is not the same (Fig. 99). This is mainly why we see objects in relief. Our brain blends the

two different images into one that springs into *relief* (this is the basic principle of the stereoscope). On the other hand, if we are looking at something that is flat, a wall, for instance, both eyes get an identical sensory picture telling our brain that the object we are looking at is really flat.

Now you should realize the mistake we make when we look at a photograph with both eyes. In this manner we compel ourselves to believe that the picture

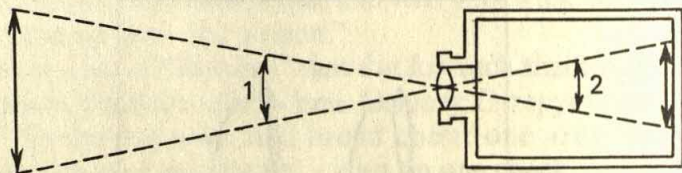


Fig. 100

In a camera angle 1 is equal to angle 2

we have before us is flat. When we look with *both eyes* at a photograph which is really intended only for *one eye*, we prevent ourselves from seeing the picture that the photograph really shows, and thus destroy the illusion which the camera produces with such perfection.

HOW FAR TO HOLD A PHOTOGRAPH

The second rule I mentioned, that of holding the photograph *at the proper distance* away from the eye, is just as important, for otherwise we get the wrong perspective. How far away should we hold a photograph? To recreate the proper picture we must look at the photograph from the same angle of vision from which the camera lens reproduced the image on the ground-glass screen, or in the same way as it "saw" the object being photographed (Fig. 100). Consequently, we must hold the photograph at a distance from the eye that would be as many times less than the distance between the object and the lens as the size of the image on the photograph is less than its actual size. In other words, we must hold the photograph at a distance which is roughly the same as the focal length of the camera lens.

Since most cameras have a focal length of 12-15 cm (the author has in mind the cameras that were in use when he wrote this book—*Ed.*), we shall never be able to get the proper distance for the photographs they give, as the focal length of a normal eye at best (25 cm) is nearly twice the indicated focal length of the camera lens. A photograph tacked on a wall also seems flat because it is looked

at from a still greater distance away. Only the short-sighted with their short focal length of vision, as well as children, who are able to accommodate their vision to see objects very close up, will be able to admire the effect that an ordinary photograph produces when we look at it properly with one eye, because when they hold a photograph 12-15 cm away, they get not a flat image but one in relief, the kind of image a stereoscope produces.

I suppose you will now agree with me in noting that it is only due to ignorance that we do not derive the pleasure a photograph can give, and that we often unjustly blame them for being lifeless.

QUEER EFFECT OF MAGNIFYING GLASS

The short-sighted easily see ordinary photographs in relief. What should people with normal eyesight do? Here a magnifying glass will help. By looking at photographs through a magnifying glass with a twofold power, people with normal eyesight will derive the indicated advantage of the short-sighted, and see them in relief without straining their eyesight.

There is a tremendous difference between the effect thus produced and the impression we get when we look at a photograph with both eyes from quite a distance. It almost amounts to the stereoscopic effect. Now we know why photographs often spring into relief when looked at with one eye through a magnifying glass, which, though a generally known fact, has seldom been properly explained. One reviewer of this book wrote to me in this connection:

"Please take up in a future edition the question of why photographs appear in relief when viewed through a magnifying glass. Because I contend that the involved explanation provided of the stereoscope holds no water at all. Try to look in the stereoscope with one eye. The picture appears in relief despite all that theory has to say."

I am sure you will agree that this does not pick any holes in the theory of stereoscopic vision.

The same principle lies at the root of the curious effect produced by the so-called panoramas. This is a small box, in which an ordinary photograph of a landscape or a group of people is placed and viewed through a magnifying glass with one eye, which in itself already gives a stereoscopic effect. The illusion is usually enhanced by some of the objects in the foreground being cut out and placed separately in front of the photograph proper. Our eye is very sensitive to the solidity of objects close by; as far as distant objects are concerned, the impression is much less perceptible.

ENLARGED PHOTOGRAPHS

Can we make photographs so that people with *normal* eyesight are able to see them properly, without using a magnifying glass? We can, merely by using cameras having lenses with a long focal length. You already know that a photograph obtained with the aid of a lens having a focal distance of 25-30 cm will appear in relief when viewed with one eye from the usual distance away.

One can obtain photographs that won't seem flat even when looked at with *both eyes* from quite a distance. You already know that our brain blends two identical retinal images into one flat picture. However, the greater the distance from the object, the less our brain is able to do that. Photographs taken with the aid of a lens having a focal distance of 70 cm can be looked at with both eyes without losing the sense of depth.

Since it is inconvenient to resort to such lenses, let me suggest another method, which is to *enlarge* the picture you take with any ordinary camera. This increases the distance at which you should look at photographs to get the proper effect. A four or fivefold enlargement of a photograph taken with a 15 cm lens is already quite enough to obtain the desired effect, you can look at it with both eyes from 60 to 75 centimetres away. True, the picture will be a bit blurred but this is barely discernible at such a distance. Meanwhile, as far as the stereoscopic effect and depth are concerned, you only stand to gain.

BEST SEAT IN MOVIE-HOUSE

Cinema-goers have most likely noticed that some films seem to spring into unusually clear relief; to such an extent at times that one seems to see real scenery and real actors. This depends not on the film, as is often thought, but on where you take your seat. Though motion pictures are taken with cameras having lenses with a very short focal length, their projection on the screen is a hundred times larger and you can see them with both eyes from quite a distance ($10\text{ cm} \times 100 = 10\text{ m}$). The effect of relief is best when you look at the picture from the same angle of vision as the movie camera "looked" when it was shooting the film.

How should one find the distance corresponding to such an optimal angle of vision? Firstly, one must choose a seat *right opposite the middle of the screen*. Secondly, one's seat must be away from the screen at a distance which is as many times the screen's width as the focal length of the movie-camera lens is greater than the width of the film itself. Movie-camera lenses usually have a focal

length of 35 mm, 50 mm, 75 mm, or 100 mm, depending on the subject being shot. The standard width of film is 24 mm. For a focal length of 75 mm, for instance, we get the proportion:

$$\frac{\text{the distance}}{\text{screen width}} = \frac{\text{focal length}}{\text{film width}} = \frac{75}{24} \approx 3$$

So, to find how far away you should seat yourself from the screen, you should multiply the width of the screen, or rather the projection onto the screen, by three. If the width is six of your steps, then the best seat would be 18 steps away from the screen. Keep this in mind when trying various devices offering a stereoscopic effect, because one may easily ascribe to the invention what is really due to the circumstances mentioned.

FOR READERS OF ILLUSTRATED MAGAZINES

Reproductions in books and magazines naturally have the same properties as the original photographs from which they were made; they also spring into relief when looked at with one eye from the proper distance. But since different photographs are taken by cameras having lenses with different focal lengths, one can find the proper distance only by trial and error. Cup one eye with your hand and hold the illustration at arm's length. Its plane must be perpendicular to the line of vision and your open eye must be right opposite the middle of the picture. Gradually bring the picture closer, steadily looking at it meanwhile; you easily catch the moment when it appears in clearest relief.

Many illustrations that seem blurred and flat when you look at them in your habitual way acquire depth and clearness when viewed as I suggest. One will even catch the sparkle of water and other such purely stereoscopic effects.

It's amazing that few people know these simple things though they were all explained in popular-science books more than half a century ago. In his *Principles of Mental Physiology, with Their Application to the Training and Discipline of the Mind, and the Study of Its Morbid Conditions*, William Carpenter has the following to say about how one should look at photographs.

"It is remarkable that the effect of this mode of viewing photographic pictures is not limited to bringing out the solid forms of objects; for other features are thus seen in a manner more true to the reality, and therefore more suggestive of it. This may be noticed especially with regard to the representation of *still water*, which is generally one of the most unsatisfactory parts of a photograph; for although, when looked at with *both eyes*, its surface appears opaque, like white

wax, a wonderful depth and transparence are often given to it by viewing it with only *one*. And the same holds good also in regard to the characters of *surfaces* from which light is reflected, as bronze or ivory; the material of the object from which the photograph was taken being recognized much more certainly when the picture is looked at with *one* eye, than when *both* are used (unless in stereoscopic combination)."

There is one more thing we must note. Photographic enlargements, as we have seen, are more lifelike; photographs of a reduced size are not. True, the smaller-size photograph gives a better contrast; but it is flat and fails to give the effect of depth and relief. You should now be able to say why: it also reduces the corresponding perspective, which is usually too little as it is.

HOW TO LOOK AT PAINTINGS

All I have said of photographs applies in some measure to paintings as well. They appear best also at the proper distance, for only then do they spring into relief. It is better, too, to view them with but one eye, especially if they are small.

"It has long been known," Carpenter wrote in the same book, "that if we gaze steadily at a picture, whose perspective projection, lights and shadows, and general arrangement of details, are such as accurately correspond with the reality which it represents, the impression it produces will be much more vivid when we look with *one* eye only, than when we use both; and that the effect will be further heightened, when we carefully shut out the surroundings of the picture, by looking through a tube of appropriate size and shape. This fact has been commonly accounted for in a very erroneous manner. 'We see more exquisitely,' says Lord Bacon, 'with one eye than with both, because the vital spirits thus unite themselves the more and become the stronger'; and other writers, though in different language, agree with Bacon in attributing the result to the *concentration* of the visual power, when only one eye is used. But the fact is, that when we look with *both* eyes at a picture within a moderate distance, we are *forced* to recognize it as a flat surface; whilst, when we look with only *one*, our minds are at liberty to be acted on by the suggestions furnished by the perspective, chiaroscuro, etc.; so that, after we have gazed for a little time, the picture may begin to start into relief, and may even come to possess the solidity of a model."

Reduced photographic reproductions of big paintings often give a greater illusion of relief than the original. This is because the reduced size lessens the ordinarily long distance from which the painting should be looked at, and so the photograph acquires relief, even close up.

STEREOSCOPE

Why is it that we see solid objects as things having three dimensions and not two? After all the retinal image is a flat one. So why do we get a sensory picture of geometrical solidity? For several reasons. Firstly, the different lighting of the different parts of objects enables us to perceive their shape. Secondly, the strain

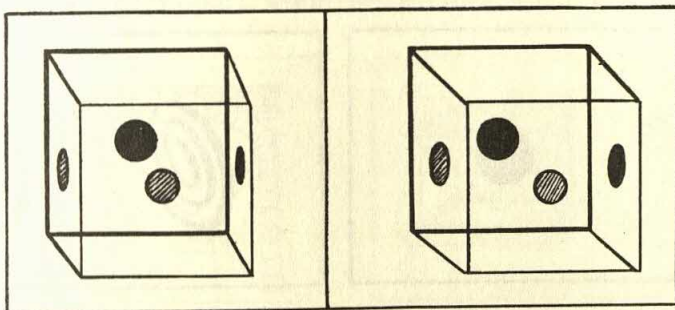


Fig. 101

A spotted glass cube as seen with the left and the right eye

we feel when accommodating our eye to get a clear perception of the object's different parts that are at different distances from the eye also plays a role; this is not a flat picture in which all the parts of the object depicted are set at the same distance away. And thirdly, the most important cause is that the two retinal images are different, which is easy enough to demonstrate by looking at some close object, shutting alternately the right and left eye (Figs. 99 and 101).

Imagine now two drawings of one and the same object, one as seen by the left eye, and the other, as seen by the right eye. If we look at them so that each eye sees only its "own" drawing, we get instead of two separate flat pictures one in relief. The impression of relief is greater even than the impression produced when we look at a solid object with one eye only.

There is a special device, called the stereoscope, to view these pairs. Older types of stereoscopes used mirrors and the later models convex glass prisms to superimpose the two images. In the prisms, which slightly enlarge the two images because they are convex, the light coming from the pair is refracted in such a way that its imagined continuation causes this superimposition. As you see, the stereoscope's basic principle is extremely simple; all the more amazing, therefore, is the effect produced. I suppose most of you have seen various stereoscopic pictures. Some may have used the stereoscope to learn stereometry more easily. However, I shall proceed to tell you about applications of the stereoscope which I presume many of you do not know.

BINOCULAR VISION

Actually we can, provided we accustom our eyes to it, dispense with the stereoscope to view such pairs, and achieve the same effect, with the sole difference that the image will not be magnified as it usually is in stereoscope. Wheatstone, the inventor of the stereoscope, made use of this arrangement of

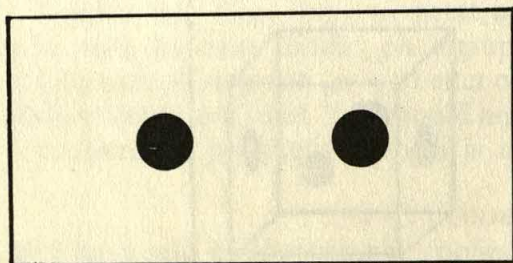


Fig. 102

Stare at the space between the two dots for several seconds.
The dots seem to merge

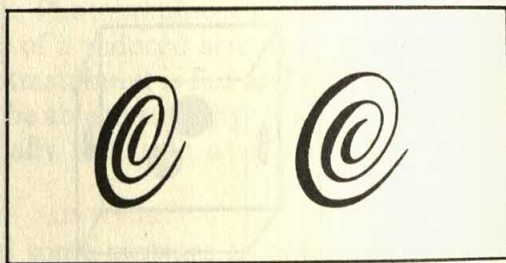


Fig. 103

Do the same, after which turn to the next exercise

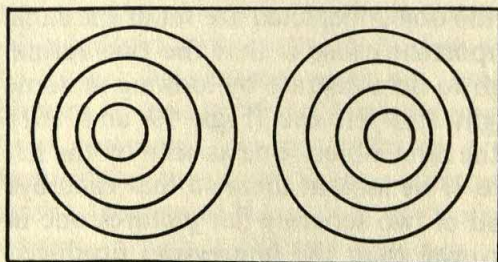


Fig. 104

When these images merge you will see something like the inside of a pipe receding into the distance

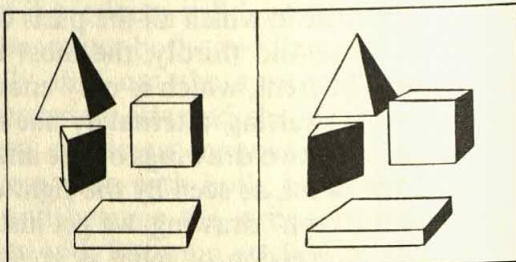


Fig. 105

When these four geometrical bodies merge, they seem to hover in mid-air

nature. Provided here are several stereoscopic drawings graded in difficulty, that I would advise you to try viewing without a stereoscope. Remember that you will achieve results only if you exercise. (Note that not all can see stereoscopically, even in a stereoscope: some, the squint-eyed or people used to working with one eye, are utterly incapable of adjustment to binocular vision;

others achieve results only after prolonged exercise. Young people, however, quickly adapt themselves, after a quarter of an hour.)

Start with Fig. 102 which depicts two black dots. Stare several seconds at the space between them, meanwhile trying to look at an imagined object behind. Soon you will be seeing double, seeing four dots instead of two. Then the two extreme dots will swing far apart, while the two innermost dots will close up and

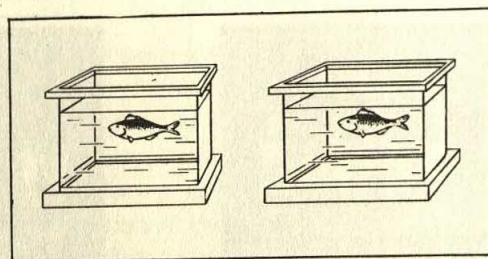
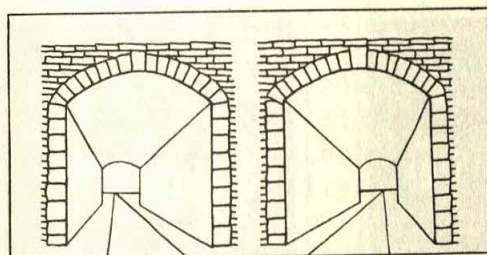


Fig. 106

This pair gives a long corridor receding into the distance

Fig. 107

A fish in an aquarium

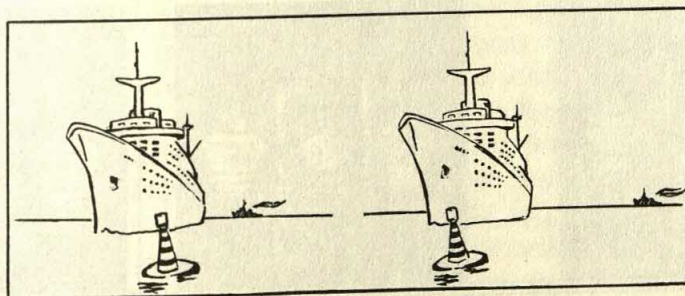


Fig. 108

A stereoscopic seascape

become one. Repeat with Figs. 103 and 104 to see something like the inside of a long pipe receding into the distance.

Then turn to Fig. 105 to see geometrical bodies seemingly suspended in mid-air. Figure 106 will appear as a long corridor or tunnel. Figure 107 will produce the illusion of transparent glass in an aquarium. Finally, Figure 108 gives you a complete picture, a seascape.

It is easy to achieve results. Most of my friends learned the trick very quickly, after a few tries. The short-sighted and far-sighted needn't take off their glasses;

they view the pairs just as they look at any picture. Catch the proper distance at which they should be held by trial and error. See that the lighting is good, this is important.

Now you can try to view stereoscopic pairs in general without a stereoscope. You might try the pairs in Figs. 109 and 112 first. Don't overdo this so as not to strain your eyesight. If you fail to acquire the knack, you may use lenses for the

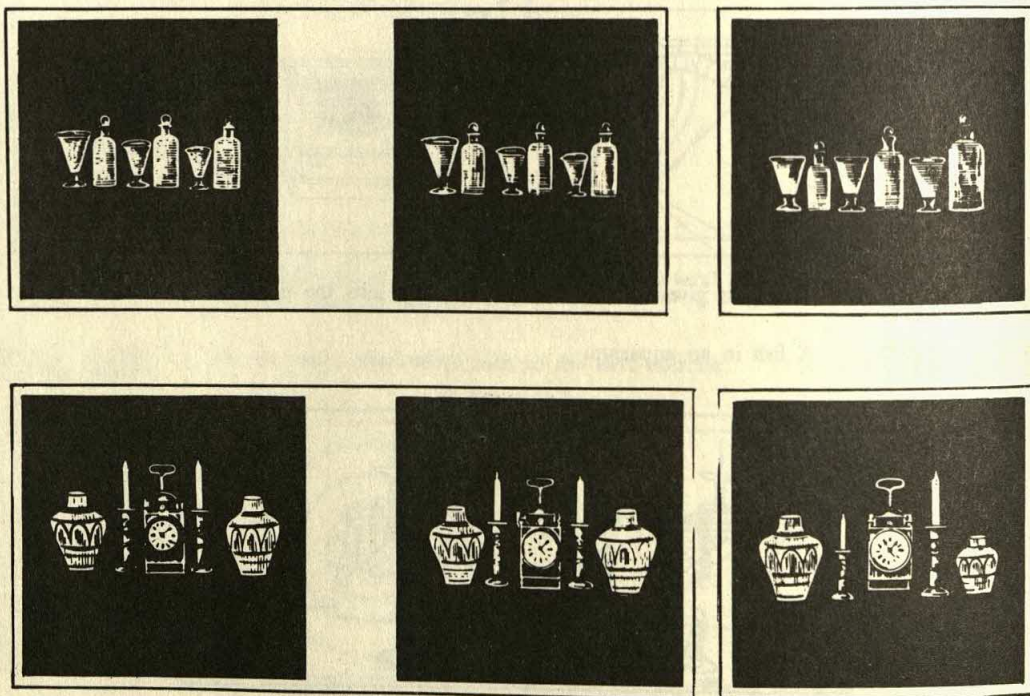


Fig. 109

far-sighted to make a simple but quite serviceable stereoscope. Mount them side by side in a piece of cardboard so that only their inner rims are available for viewing. Partition off the pairs with a diaphragm.

WITH ONE EYE AND TWO

Figure 109 (the upper left-hand corner) gives two photographs of three bottles of presumably one and the same size. However hard you look you cannot detect

any difference in size. But there is a difference, and, moreover, a significant one. They seem alike only because they are not set at the same distance from the eye or camera. The bigger bottle is further away than the smaller ones. But which of the three is the bigger bottle? Stare as much as you may, you will never get the answer. But the problem is easily solved by using a stereoscope or exercising binocular vision. Then you clearly see that the left-hand bottle is furthest away, and the right-hand bottle closest. The photo in the upper right-hand corner shows the real size of the bottles.

The stereoscopic pair at the bottom of Fig. 109 provides a still bigger teaser. Though the vases and candlesticks seem identical there is a great difference in size between them. The left-hand vase is nearly twice as tall as the right-hand one, while the left-hand candlestick, on the contrary, is much smaller than the clock and the right-hand candlestick. Binocular vision immediately reveals the cause. The objects are not in one row; they are placed at different distances, with the bigger objects being further away than the smaller articles. A fine illustration of the great advantage of binocular "two-eyed" vision over "one-eyed" vision!

DETECTING FORGERY

Suppose you have two absolutely identical drawings, of two equal black squares, for instance. In the stereoscope they appear as one square which is exactly like either of the twin squares. If there is a white dot in the middle of each square, it is bound to show up on the square in the stereoscope. But if you shift the dot on one of the squares slightly off centre, the stereoscope will show one dot, however, it will appear either *in front of*, or *beyond*, the square, not on it. The slightest of differences already produces the impression of depth in the stereoscope. This provides a simple method for revealing forgeries. You need only put the suspected bank-bill next to a genuine one in a stereoscope, to detect the forged one, however cunningly made. The slightest discrepancy, even in one teeny-weeny line, will strike the eye at once, appearing either in front of, or behind, the banknote. (The idea, which was first suggested by Dove in the mid-19th century, is not applicable, for reasons of printing technique, to all currency notes issued today. Still his method will do to distinguish between two proofs of a book-page, when one is printed from newly-composed type.)

AS GIANTS SEE IT

When an object is very far away, more than 450 metres distant, the stereoscopic impression is no longer perceptible. After all, the six centimetres at which our

eyes are set apart are nothing compared with such a distance as 450 metres. No wonder buildings, mountains, and landscapes that are far away seem flat. So do the celestial objects all appear to be at the same distance, though, actually, the moon is much closer than the planets, while the planets, in turn, are very much closer than the fixed stars. Naturally, a stereoscopic pair thus photographed will not produce the illusion of relief in the stereoscope.

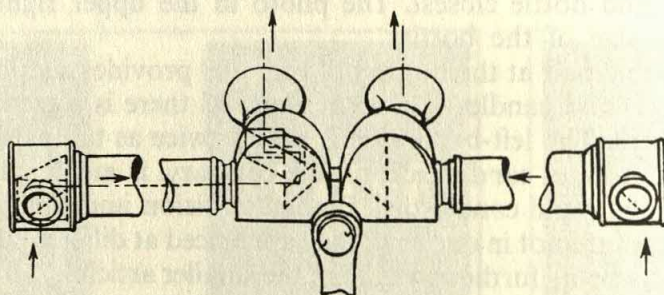


Fig. 110 Telestereoscope

There is an easy way out, however. Just photograph distant objects from two points, taking care that they be further apart than our two eyes. The stereoscopic illusion thus produced is one that we would get were our eyes set much further apart than they really are. This is actually how stereoscopic pictures of landscapes are made. They are usually viewed through magnifying (convex) prisms and the effect is most amazing.

You have probably guessed that we could arrange two spyglasses to present the surrounding scenery in its real relief. This instrument, called a telestereoscope, consists of two telescopes mounted further apart than eyes normally are. The two images are superimposed by means of reflecting prisms (Fig. 110).

Words fail to convey the sensation one experiences when looking through a telestereoscope, it is so unusual. Nature is transformed; distant mountains spring into relief; trees, rocks, buildings and ships at sea appear in all three dimensions. No longer is everything flat and fixed; the ship, that seems a stationary spot on the horizon in an ordinary spyglass, is moving. That is most likely how the legendary giants saw surrounding nature. When this device has a tenfold power and the distance between its lenses is six times the interocular distance ($6.5 \times 6 = 39$ cm), the impression of relief is enhanced 60-fold (6×10), compared with the impression obtained by the naked eye. Even objects 25

kilometres away still appear in discernible relief. For land surveyors, seamen, gunners and travellers this instrument is a godsend, especially if equipped with a range-finder. The Zeiss prism binoculars produces the same effect, as the distance between its lenses is greater than the normal interocular distance (Fig. 111). The opera glass, on the contrary, has its lenses set not so far apart, to reduce the illusion of relief, so that the décor and settings present the intended impression.

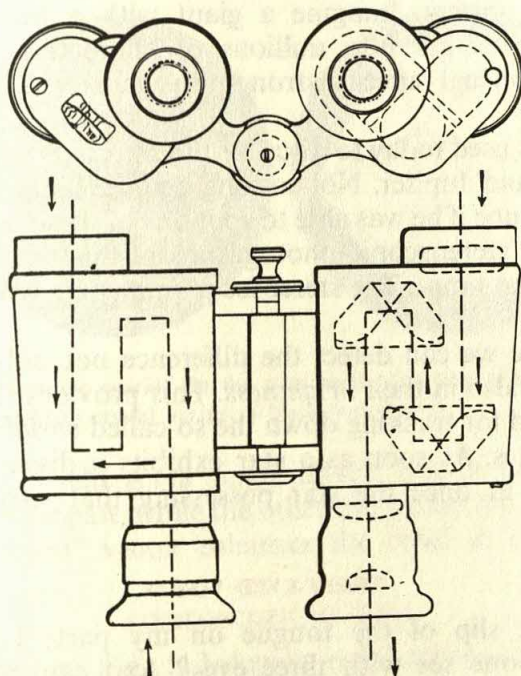


Fig. 111

Prism binoculars

UNIVERSE IN STEREOSCOPE

If we direct our telestereoscope at the moon or any other celestial object we shall fail to obtain any illusion of relief at all. This is only natural, as celestial distances are too big even for such instruments. After all, the 30-50 cm distance between the two lenses is nothing compared with the distance from the earth to the planets. Even if the two telescopes were mounted tens and hundreds of kilometres apart, we would get no results, as the planets are tens of millions of kilometres away.

This is where stereoscopic photography steps in. Suppose we photograph a planet today and take another photograph of it tomorrow. Both photographs will be taken from one and the same point on the globe, but from different points in the solar system, as in the space of 24 hours the earth will have travelled millions of kilometres in orbit. Hence the two photographs won't be identical. In the stereoscope, the pair will produce the illusion of relief. As you see, it is the earth's orbital motion that enables us to obtain stereoscopic photographs of celestial objects. Imagine a giant with a head so huge that its interocular distance ranges into millions of kilometres; this will give you a notion of the unusual effect astronomers achieve by such stereoscopic photography.

The stereoscope is used today to discover the asteroids which swarm between the orbits of Mars and Jupiter. Not so long ago the astronomer considered it a stroke of good fortune if he was able to spot one of these asteroids. Now it can be done by viewing stereoscopic photographs of this part of space that have been taken at different times. The stereoscope immediately reveals the asteroid; it "sticks" out.

In the stereoscope we can detect the difference not only in the *position* of celestial objects but also in their *brightness*. This provides the astronomer with a convenient method for tracking down the so-called *variable* stars whose light periodically fluctuates. As soon as a star exhibits a dissimilar brightness the stereoscope detects at once the star possessing that varying light.

THREE-EYED VISION

Don't think this a slip of the tongue on my part; I really mean three eyes. But how can one see with three eyes? And can one really acquire a third eye?

Science cannot give you or me a third eye, but it can give us the magic power to see an object as it would appear to a three-eyed creature.

Let me note first that a one-eyed man can get from stereoscopic photographs that impression of relief which he can't and doesn't get in ordinary life. For this purpose we must project onto a screen in rapid sequence the photographs intended for right and left eyes that a normal person sees with both eyes simultaneously. The net result is the same because a rapid sequence of visual images fuses into one image just as two images seen simultaneously do. (It is quite likely that the surprising "depth" of movie films at times, in addition to the causes mentioned, is due also to this. If the movie camera sways with an even

motion, as often happens because of the film-winder, the stills will not be identical and, as they rapidly flit onto the screen, they will appear to us as one three-dimensional image.)

In that case couldn't a two-eyed person simultaneously watch a rapid sequence of two photographs with one eye and a third photograph, taken from yet another angle, with the other eye? Or, in other words, a stereoscopic "trio"?

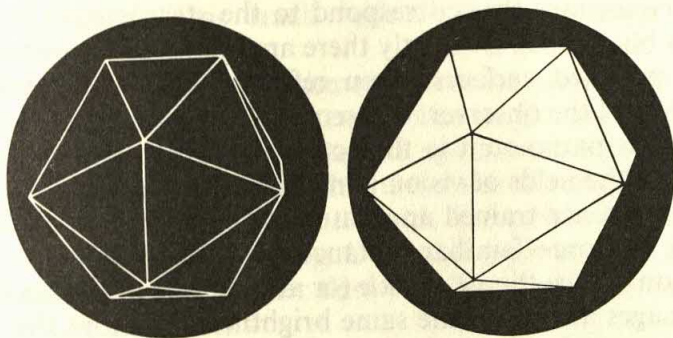


Fig. 112

Stereoscopic sparkle. In the stereoscope this pair produces a sparkling crystal against a black background

We could. One eye would get a single image, but in relief, from a rapidly alternating stereoscopic pair, while the other eye would look at the third photograph. This "three-eyed" vision enhances the relief to the extreme.

STEREOSCOPIC SPARKLE

The stereoscopic pair in Fig. 112 depicts polyhedrons, one in white against a black background and the other in black against a white background. How would they appear in a stereoscope? This is what Helmholtz says:

"When you have a certain plane in white on one of a stereoscopic pair and in black on the other, the combined image seems to sparkle, even though the paper used for the pictures is dull. Such stereoscopic drawings of models of crystals produce the impression of glittering graphite. The sparkle of water, the glisten of leaves and other such things are still more noticeable in stereoscopic photographs when this is done."

In an old but far from obsolete book, *The Physiology of the Senses. Vision*, which the Russian physiologist Sechenov published in 1967, we find a wonderful explanation of this phenomenon.

“Experiments artificially producing stereoscopic fusion of differently lighted or differently painted surfaces repeat the actual conditions in which we see sparkling objects. Indeed, how does a dull surface differ from a glittering polished one? The first one reflects and diffuses light and so seems identically lighted from every point of observation, while the polished surface reflects light in but one definite direction. Therefore you can have instances when with one eye you get many reflected rays, and with the other practically none (these are precisely the conditions that correspond to the stereoscopic fusion of a white surface with a black one). Evidently there are bound to be instances in looking at glistening polished surfaces when reflected light is unevenly distributed between the eyes of the observer. Consequently, the stereoscopic sparkle proves that experience is paramount in the act during which images fuse bodily. The conflict between the fields of vision immediately yields to a firm conception, as soon as the experience-trained apparatus of vision has the chance to attribute the difference to some familiar instance of actual vision.”

So the reason we see things *sparkle* (or at least one of the reasons) is that the two retinal images are not of the same brightness. Without the stereoscope we would have scarcely guessed it.

TRAIN WINDOW OBSERVATION

I noted a little earlier that different images of one and the same object produce the illusion of relief when in rapid alternation they perceptibly fuse. Does this happen only when we see moving images and stand still ourselves? Or will it also take place when the images are standing still but we are moving? Yes, we get the same illusion, as was only to be expected. Most likely many have noticed that movies shot from an express train spring into unusually clear relief, just as good as in the stereoscope. If we pay heed to our visual perceptions when riding in a fast train or car we shall see this ourselves. Landscapes thus observed spring into clear relief with the foreground distinctly separate from the background. The “stereoscopic radius” of our eyes increases appreciably to far beyond the 450-metre limit of binocular vision for stationary eyes.

Doesn't this explain the pleasant impression we derive from a landscape when observing it from the window of an express train? Remote objects recede and we distinctly see the vastness of the scenic panorama unfolding before us. When we ride through a forest we stereoscopically perceive every tree, branch, and leaf; they do not blend into one flat picture as they would to a stationary observer.

On a mountain road fast driving again produces the same effect. We seem to sense tangibly the dimensions of the hills and valleys.

One-eyed people will also see this—and I'm sure it will afford a startlingly novel sensation, as this is tantamount to the rapid sequence of pictures producing the illusion of relief, a point mentioned before. (This, incidentally, accounts for the noticeable stereoscopic effect produced by movie films shot from a train taking a bend, when the objects being photographed lie in the radius of this bend. This track "effect" is well-known to camera-men.)

It is as easy as pie to check my statements. Just be mindful of your visual perceptions when riding in a car or a train. You might also notice another amazing circumstance, which Dove remarked upon some hundred years ago (what is well forgotten is indeed novel!), that the closer objects flashing by seem smaller in size. The cause has little to do with binocular vision. It's simply because our estimate of distance is wrong. Our subconscious mind suggests that a closer object should really be smaller than usually, to seem as big as always. This is Helmholtz's explanation.

THROUGH TINTED EYEGLASSES

Looking through red-tinted eyeglasses at a *red* inscription on *white* paper you see nothing but a plain red background. The letters disappear entirely from view, merging with the red background. But look through the same red-tinted glasses at *blue* letters on *white* paper and the inscription distinctly appears in *black*, again on a red background. Why black? The explanation is simple. Red glass does not pass blue rays; it is red because it can pass red rays only. Consequently, instead of the blue letters you see the absence of light, or black letters.

The effect produced by what are called colour *anaglyphs*, the same as produced by stereoscopic photographs, is based precisely on this property of tinted glass. The anaglyph is a picture in which the two stereoscopic images for the right and left eye, respectively, are *superimposed*; the two images are coloured differently, one in blue and the other in red.

The anaglyphs appear as one black but three-dimensional image when viewed through differently-tinted glasses. Through the red glass the right eye sees only the *blue* image, the one intended for the right eye, and sees it, moreover, in black. Meanwhile the left eye sees through the blue glass only the *red* image which is intended for the left eye, again in black. Each eye sees only

one image, the one intended for it. This repeats the stereoscope and, consequently, the result is the same, the illusion of depth.

"SHADOW MARVELS"

The "shadow marvels" that were once shown at the cinemas are also based on the above-mentioned principle. Shadows cast by moving figures on the screen appear to the viewer, who is equipped with differently-tinted glasses, as objects

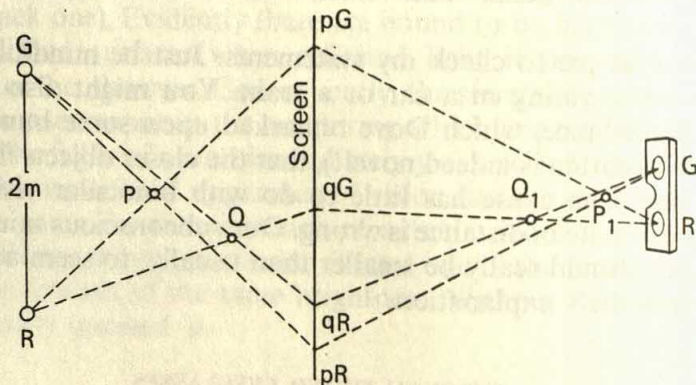


Fig. 113

The "shadow marvel" explained

in three dimensions. The illusion is achieved by bicoloured stereoscopy. The shadow-casting object is placed between the screen and two adjacent sources of light, red and green. This produces two partially superimposed coloured shadows which are viewed through viewers matching in colour.

The stereoscopic illusion thus produced is most amusing. Things seem to fly right your way; a giant spider creeps towards you; and you involuntarily shudder or cry out. The apparatus required is extremely simple. Figure 113 gives the idea. In this diagram G and R stand for the green and red lamps (left); P and Q represent the objects placed between the lamps and the screen; pG , qG , pR and qR are the tinted shadows that these objects cast on the screen; P_1 and Q_1 show where the viewer, looking through the differently-tinted glasses (G is the green glass, and R , the red one), sees these objects. When the "spider" behind the screen is shifted from Q to P the viewer thinks it to be creeping from Q_1 to P_1 .

Generally speaking, every time the object behind the screen is moved towards the source of light, thus causing the shadow cast on the screen to grow larger,

the viewer thinks the object to be moving from the screen towards him. Everything the viewer thinks is moving towards him from the screen is actually moving on the other side of the screen, in the opposite direction, from the screen to the source of light.

MAGIC METAMORPHOSES

I think it would be appropriate at this stage to describe a series of illuminating experiments conducted at the Science for Entertainment Pavilion of the Leningrad recreation park. A corner of the pavilion was furnished as a parlour. Its furniture was covered with dark-orange antimacassars, the table was laid with green baize, on which there stood a decanter full of cranberry juice and a vase with flowers in it, and there was a shelf full of books with coloured inscriptions on their bindings.

The visitors first saw the "parlour" lit by ordinary white electric light. When the ordinary light was turned off and a *red* light switched on instead, the orange covers turned pink and the green tablecloth a dark purple; meanwhile the cranberry juice lost its colour and looked like water; the flowers in the vase changed in hue and seemed different; and some inscriptions on the book-bindings vanished without trace. Another flick of the switch and *green* light went on. The "parlour" was again transformed beyond recognition.

These magic metamorphoses well illustrate Newton's theory of colour, the gist of which is that a surface always possesses the colour of the rays it diffuses, rather than of the rays it absorbs. This is how Newton's compatriot, the celebrated British physicist John Tyndall, formulates the point.

"Permitting a concentrated beam of white light to fall upon fresh leaves in a dark room, the sudden change from green to red, and from red back to green, when the violet glass is alternately introduced and withdrawn, is very surprising ... question of absorption."

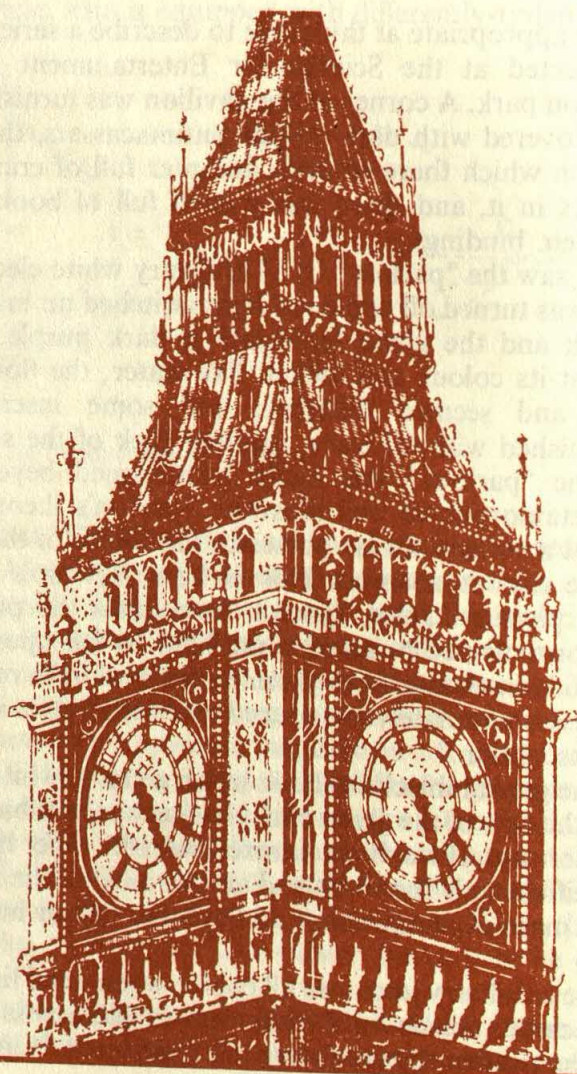
Consequently the green tablecloth shows up as green in white light because it diffuses primarily the rays of the green and adjacent spectral bands and absorbs most of all the other rays. If we direct a mixed red and violet light at this green tablecloth, it will diffuse only the violet and absorb most of the red, thus turning purple. This is the main explanation for all the other colour metamorphoses in the "parlour".

But why does the cranberry juice lose all colour when a red light is directed at it? Because the decanter stands on a white runner laid across the green baize. Once we remove the runner, the cranberry juice turns red. It loses its colour (in

red lighting) only against the background of the runner, which, though it turns red, we ourselves *continue to regard as white*, both by force of habit and due to the contrast it presents to the purple tablecloth. Since the juice has the same colour as the runner, which we imagine to be white, we involuntarily think the

Fig. 114

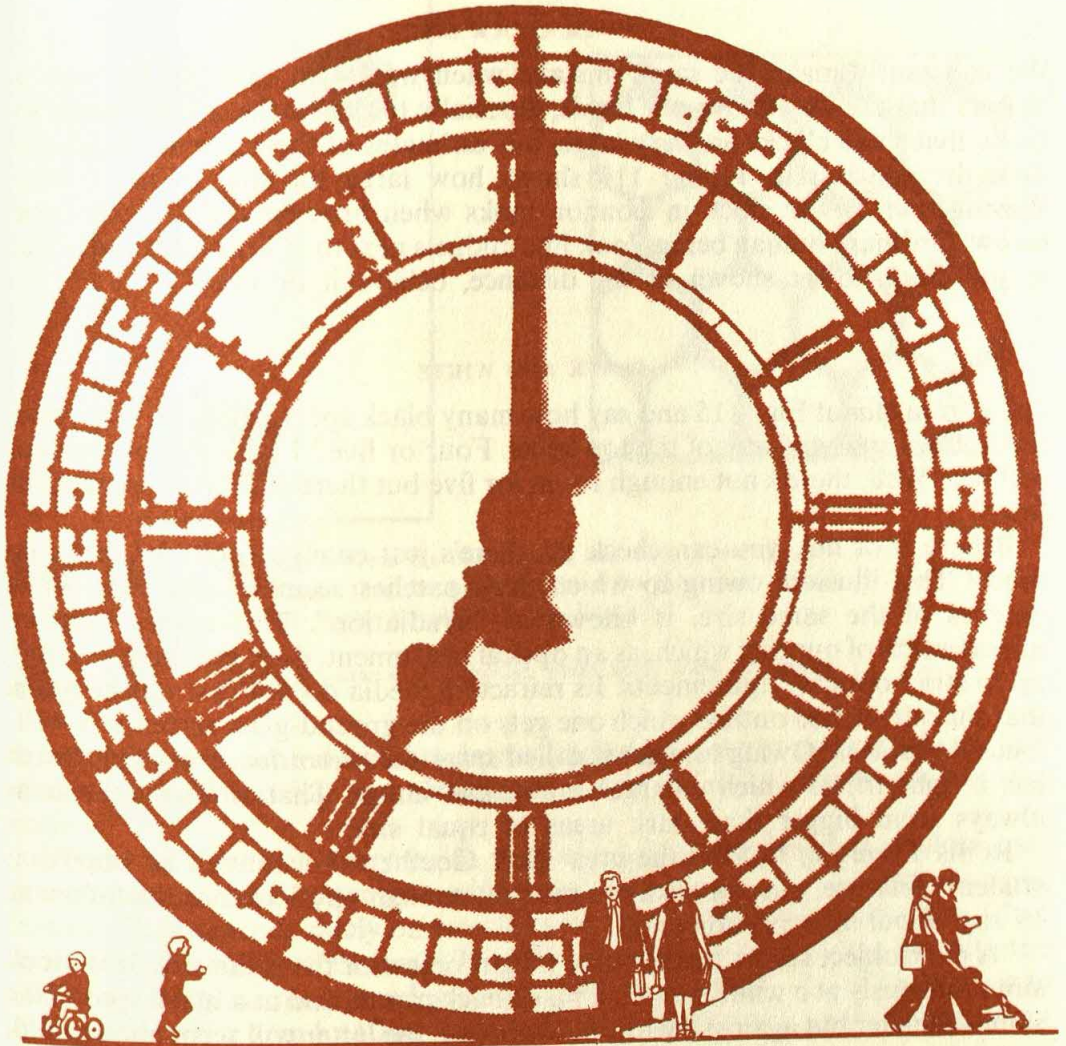
The size of the Westminster Tower clock



juice to be white too. That is why it appears no longer as red juice but as colourless water. You may derive the same impressions by viewing the surroundings through tinted glasses.

HOW TALL IS THIS BOOK?

Ask a friend to show you how high the book he is holding would be from the floor, if he stood it up on one edge. Then check his statement. He is sure to guess



wrongly: the book will actually be half as tall. Furthermore, better ask him not to bend down to show how high the book would come up to, but provide the answer in so many words, with you assisting. You can try this with any other familiar object—a table lamp, say, or a hat. However, it should be one you have grown accustomed to seeing at the level of your eyes. The reason why people err is because every object diminishes in size when looked at edgeways.

TOWER CLOCK DIAL

We constantly make the same mistake when we try to estimate the size of objects that are way above our heads, especially tower clocks. Even though we know that these clocks are very large, our estimates of their size are much less than the actual size. Figure 114 shows how large the dial of the famous Westminster Tower clock in London looks when brought down to the road below. Ordinary human beings look like midgets next to it. Still it fits the orifice in the clock tower shown in the distance, believe it or not!

BLACK AND WHITE

Look from *afar* at Fig. 115 and say how many black spots would fit in between the bottom spot and any of the top spots. Four or five? I daresay your answer will be: "Well, there's not enough room for five but there's certainly enough for four."

Believe it or not, you can check it!, there's just enough room for three, no more! This illusion, owing to which dark patches seem smaller than white patches of the same size, is known as "irradiation". This comes from an imperfection of our eye, which, as an optical instrument, does not quite measure up to strict optical requirements. Its refracting media do not cast on the retina that sharply-etched outline which one gets on the ground-glass screen of a well-focussed camera. Owing to what is called *spherical aberration*, every light patch has a light fringe which enlarges the retinal image. That is why light areas always seem bigger than dark areas of equal size.

In his *Theory of Colours* the great poet Goethe, who, though an observant student of nature, was not always a prudent enough physicist, has the following to say about this phenomenon:

"A dark object seems smaller than a light object of the same size. If we look simultaneously at a white spot on a black background and at a black spot of the same diameter but against a white background, the latter will seem about a fifth

smaller than the former. If we render the black spot correspondingly larger, the two spots will seem identical. The crescent moon seems part of a circle the diameter of which would be larger than that of the moon's darker portion, which we sometimes see [the ashen light witnessed when the "old moon is in the new moon's arms"—Y. P.]. In dark dress we seem slimmer than in clothes of light tones. Light coming over the rim of something seems to make a depression

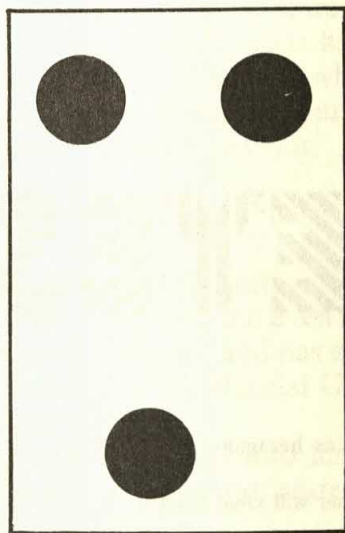


Fig. 115

The gap between the bottom spot and each of the top two seems more than the distance between the outer edges of the two top spots. Actually, they are identical

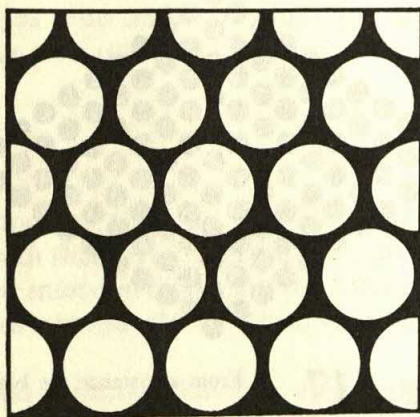


Fig. 116

From a distance the circular white spots seem hexagonal

in it. A ruler from behind which we see a candle flame seems to have a notch in it at this point. The rising and setting sun seems to make a depression in the horizon."

Goethe was right on every point, with the sole exception that a white spot does not always seem larger than a black spot of equal size by one and the same fraction. This depends solely on how far away you look at the spots. Why? Just move Fig. 115 still further away. The illusion is still more striking, because the additional fringe we mentioned is always of the same width. Close up, the fringe enlarges the white area by 10 per cent; further away, it takes up from 30 to even

50 per cent of the white area, because the actual image of the spot is already smaller itself. This also explains why we see the circular white spots in Fig. 116 as hexagons when viewed from two or three steps away. From six to eight steps away this figure will already seem a typical honeycomb.

To say that irradiation is responsible for this illusion is an explanation that has not quite satisfied me, ever since I noticed that *black* dots on a white back-

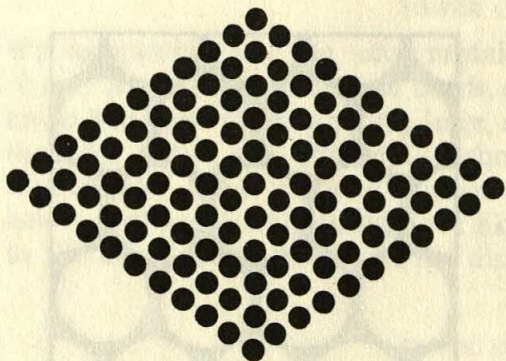


Fig. 117

From a distance the black dots appear as hexagons

Fig. 118

Look at this word with one eye. One letter will seem blacker than the rest



ground (Fig. 117) also seem hexagonal from far away, though irradiation does not enlarge, but, on the contrary, reduces the dots in size. One must note that the explanations afforded for optical illusions in general are not completely satisfactory. As a matter of fact, most illusions still have to be explained.

WHICH IS BLACKER?

Figure 118 introduces us to another imperfection of the eye, *astigmatism* this time. Look at it with one eye. Not all four letters will seem identical in blackness. Note which is the blackest and turn the drawing sideways. The letter you thought the blackest will suddenly go grey, and now another letter will seem the blackest. Actually, all four letters are identical in blackness; they are merely shaded in different directions. If our eyes were just as perfect and faultless as expensive glass lenses, the direction of shading would have no effect on the blackness of the letters; but since our eyes do not refract light identically in

different directions, we cannot see vertical, horizontal, and slanting lines just as distinctly.

Very seldom is the eye absolutely free of this shortcoming. With some people astigmatism is so great that it noticeably lessens the acuteness of vision and they have to wear special glasses to correct this. Our eyes also have other imperfections, which opticians know how to correct. This is what Helmholtz had to say about them:

"If an optician were to dare sell me an instrument with such imperfections, I would most roundly chide him and demonstratively return the instrument."

Besides these illusions which our eyes succumb to due to certain imperfections in them, there are many other illusions to which they fall victim for totally different reasons.

STARING PORTRAIT

You have most likely seen at one time or another portraits that not only look you square in the eye, but even follow you with their eyes wherever you go. This was noticed long ago and has always baffled many, giving some the jitters. The great Russian writer Nikolai Gogol provides a wonderful description of this in his "Portrait":

"The eyes dug right into him and seemed wanting to watch only him and nothing else. The portrait stared right past everything else, straight at him and into him."

Quite a number of superstitions and legends are associated with this mysterious stare. Actually it is nothing more than an optical illusion. The trick is that on these portraits the pupil is placed square in the middle of the eye, just as we would see it in the eye of anybody looking at us point-blank. When a person looks past us, the pupil and the entire iris are no longer in the centre of the eye; they shift sideways. On the portrait, however, the pupil stays right in the centre of the eye whichever way we step. And since we continue to see the face in the same position in relation to us, we, naturally, think that the man in the portrait has turned his head our way and is watching us. This explains the odd sensation we derive from other such pictures, the horse seems to be charging straight at us however hard we try to dodge it; the man's finger keeps pointing straight at us, and so on and so forth. Figure 119 is one such picture. They are often used to advertise or for propaganda purposes.

MORE OPTICAL ILLUSIONS

There doesn't seem to be anything out of the ordinary in the set of pins in Fig. 120, does there? However, lift the book to eye level and, cupping one eye, look at the pins so that your line of vision slides along them, as it were. Your eye must be at the point where the imagined continuations of these pins cross. Then

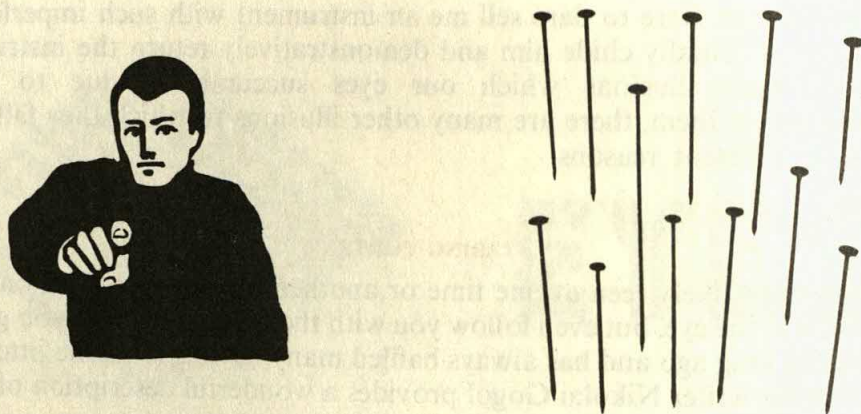


Fig. 119 The mysterious portrait

Fig. 120 Fix one eye (have the other shut) at the point where the imagined continuations of the pins would converge. The pins will seem to be stuck in the paper upright. By gently shifting the book from side to side, you get the impression that the pins are swaying

the pins will seem to be stuck in the paper upright. When you shift your head sideways, the pins seem to sway in the same direction.

This illusion is governed by laws of perspective. The drawing is of upright pins projected on paper as they appear to the observer when viewed from the given point.

Our ability to succumb to optical illusions should not at all be regarded as just an imperfection of our eyesight. This ability is a definite advantage (which is often overlooked), without it we would have no painting; nor, in general, would we derive any pleasure from the fine arts. Artists draw extensively on these imperfections of our vision.

"The whole art of painting is based on this illusion," the brilliant 18th-century scholar Euler wrote in his famous *Letters on Various Physical Subjects*. "If we

passed judgement on things by what they really were, this art (painting) could not exist and we would be blind. The painter would strive in vain to mix his colours, for we would say here is red and there is blue, here is black and there are dashes of white. Everything would be contained in one plane; no difference in distance would be observed and no object could be depicted. Whatever the painter would want to show would all seem to us as writing on paper. And given



Fig. 121

The letters are upright

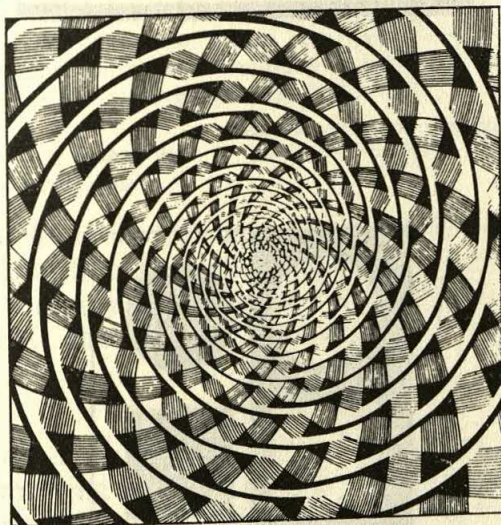


Fig. 122

This seems to be a spiral; actually the curves are circles, which you can see for yourself by following the lines with a pointed pencil

this perfection, would we not be deserving of pity on being robbed of the delight such pleasant and useful artistry affords us daily?"

There are very many optical illusions, enough to fill albums. Many are common, others are less known. I shall give you some of the more curious instances that are less known. The illusions provided by Figs. 121 and 122, with lines on a checkered background, are particularly effective. One simply can't

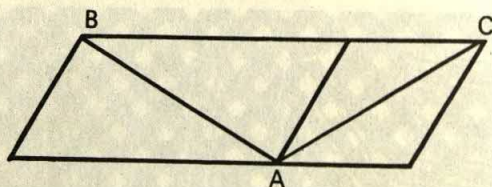


Fig. 123

AB is equal to AC, though AB seems longer

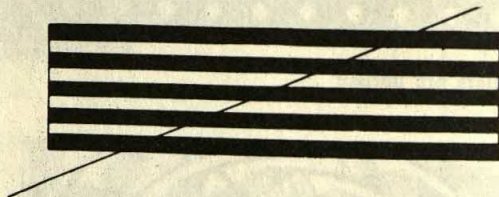


Fig. 124

The slanting line seems broken

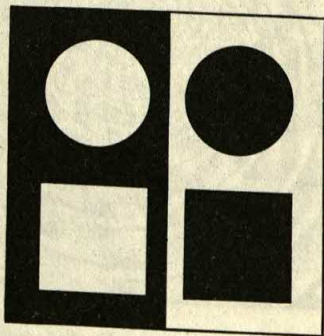


Fig. 125

The white and black squares are identical, as, too, are the round white and black spots

believe that the letters in Fig. 121 are straight and it is still harder to believe that the circles in Fig. 122 do not constitute one spiral. The only way to check it is to apply a pencil and trace the circles. Only a pair of compasses will tell us that the straight line AC in Fig. 123 is just as long as AB and not shorter, as it appears to be. The other illusions in Figs. 124, 125, 126, and 127 are explained in the captions. The following curious incident shows how effective the illusion

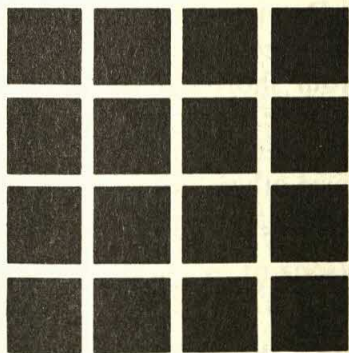


Fig. 126

Tiny faint grey squares seem to appear and disappear where the white strips cross, though the strips are really white throughout, as can be demonstrated by closing up the black squares with a piece of paper. The illusion is due to contrasts

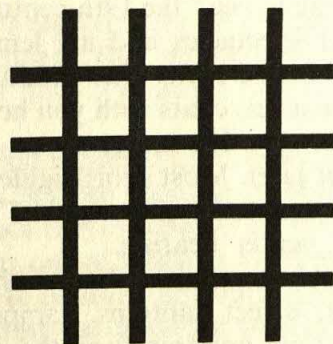


Fig. 127

Faint grey squares seem to appear and disappear where the black strips cross

Fig. 126 provides is. When the publisher of a previous edition of this book was examining the cliché, he thought it badly done and was about to return it to the printshop to have the grey splotches at the intersection of the white lines scraped off, when I chanced to intervene and explained the matter

SHORT-SIGHTED VISION

With his spectacles off, a short-sighted person sees badly. But what he sees and how he sees it is something of which people with normal eyesight have a very hazy notion. Since many are short-sighted, it would not be without interest to learn how they see.

Firstly, to the short-sighted person everything seems blurred. What to a person with normal eyesight are leaves and twigs, all clearly etched against the

sky, are to the short-sighted merely an amorphous mass of green. He misses the minor details. Human faces seem younger and more attractive; crow's feet and other minor blemishes are not seen; the coarse ruddiness that may be the product of nature or make-up appears as a delicate flush. He may miscalculate age, being as much as 20 years out. He has odd taste, to those with good eyesight, of the beautiful. He may be considered tactless when he looks a person straight in the eye but does not recognize him. He is not to blame. It is his near-sightedness that is the culprit.

"At the Lycée," the 19th-century Russian poet Delvig wrote, "I was forbidden to wear spectacles and my female acquaintances seemed exquisite creatures. How shocked I was after graduation!" When your short-sighted friend (minus his spectacles) chats with you he doesn't see your face, or, at any rate, what you think he sees. His image of you is blurred. No wonder he fails to recognize you an hour later. Most short-sighted people recognize others not so much by their appearance as by the sound of their voices. Inadequate vision is compensated for by acuter hearing.

Would you like to know what the near-sighted sees at night? All bright objects, street lanterns, lamps, lighted windows, etc., assume enormous proportions and transform the world around into a chaotic jumble of shapeless bright splotches and dark and misty silhouettes. Instead of a row of street lamps the short-sighted sees two or three huge bright patches, which blot out the rest of the street. He cannot make out an approaching motor car; instead he sees just the two bright halos of its front lights and a dark mass behind. Even the sky seems different. The short-sighted sees stars of only the first three or four stellar magnitudes and so instead of several thousand stars he sees only a few hundred, which seem to be as large as lamps. The moon seems tremendous and very close, while a crescent moon takes on a fantastic form.

The fault lies in the structure of the eye; the eyeball is too deep, so much so that its changed refractive power causes images from distant objects to be focussed before they reach the retina. The blurred retinal image is produced by diverging beams of light.

Chapter

Acoustic Puzzles

10

HUNTING THE ECHO

Mark Twain tells a very funny story of the misadventures of a man whose hobby was to collect... you'll never guess, echoes! This eccentric spared no effort to buy up every tract of land that would have a multiple echo or some other extraordinary natural echo.

"His first purchase was an echo in Georgia that repeated four times; his next was a six-repeater in Maryland; his next was a thirteen-repeater in Maine; his next was a nine-repeater in Kansas; his next was a twelve-repeater in Tennessee, which he got cheap, so to speak, because it was out of repair, a portion of the crag which reflected it having tumbled down. He believed he could repair it at a cost of a few thousand dollars, and, by increasing the elevation with masonry, treble the repeating capacity; but the architect who undertook the job had never built an echo before, and so he utterly spoiled this one. Before he meddled with it, it used to talk back like a mother-in-law, but now it was only fit for the deaf and dumb asylum."

Joking apart, there are some wonderful discrete multiple echoes in various, primarily mountainous, spots, some of which are of long-standing universal fame. The following are some of the better-known echoes. The Woodstock castle echo in England repeats seventeen syllables quite distinctly. The ruins of the Derenburg castle near Halberstadt echoed 27 syllables before one of its walls was blown up. There is one definite place in the rocky cirque near Adersbach in Czechoslovakia which echoes seven syllables thrice; however, a few steps aside even a gunshot will fail to produce any response. There was a castle near Milan that had a very fine repeater-echo before it was demolished. A shot fired from a window in one of its wings echoed back 40 to 50 times, and a word said in a loud voice, some 30 times.

It is not so easy to find even a discrete single echo. The USSR is a bit better off in this respect as it has many open plains ringed by woods and many forest clearings, where a shout will already produce a response in the form of a more or less distinct echo coming back from the wall of forest. In mountain land

echoes are more varied than in plains but occur much more seldom and are harder to catch. Why is this so? Because an echo is nothing but a train of sound waves reflected back by some obstacle. Sound abides by the same laws as light: its angle of incidence is equal to its angle of reflection.

Imagine yourself at the foot of a hill (Fig. 128), with the sound-reflecting barrier AB higher than you are. Naturally the sound waves propagating along

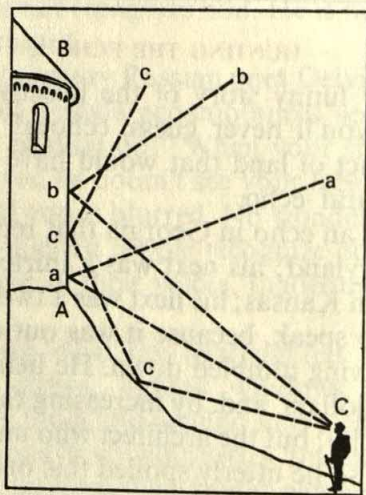


Fig. 128

There is no echo

the lines Ca , Cb and Cc will not reflect back to your ear but into the air along the directions aa' , bb' and cc' . On the other hand, when the sound-reflecting barrier is at the same level with you or even a bit lower, as in Fig. 129, you will hear an echo. The sound travels down along Ca and Cb and returns along the broken lines $CaaC$ or $CbbC$, bouncing off the ground once or twice. The pocket between the points acts like a concave mirror and makes the echo still more distinct. Were the ground between the two points C and B a bulge, the echo would be very faint and might not reach you at all, because it would diffuse sound just as a convex mirror diffuses light.

You must develop a certain knack to detect an echo on uneven terrain, and even then you must also know how to produce it. In the first place, don't stand too close to the obstacle. The sound waves must travel a long enough distance because otherwise the echo will occur too early and merge with the sound itself. Since sound propagates with the speed of 340 m/sec, at a distance of 85 metres

away the echo should be heard exactly half a second later. Though every sound has its echo, not every echo is as distinct, depending on whether it is a beast roaring in a forest, a bugle blowing, thunder reverberating, or a girl singing. The more abrupt and loud the sound, the more distinct is the echo. A hand-clap is best. The human voice is less suitable, especially a man's voice. The high-pitched voices of women and children furnish a more distinct echo.

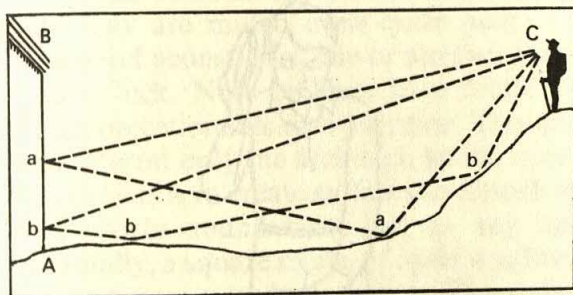


Fig. 129

There is a distinct echo

SOUND AS RULER

Sometimes one can use one's knowledge of the velocity with which sound travels in air to measure the distance to an inaccessible object. Jules Verne provides a case in point in his *Journey to the Centre of Earth*, where in the course of their subterranean exploration the two travellers, the professor and his nephew, lost each other. They hallooed, and when they finally heard each other the following conversation took place between them.

"Uncle?"

"My child!" he replied, after the lapse of several seconds.

"We must first ascertain what distance separates us."

"That is easy."

"You have your chronometer?"

"Yes."

"Well, take it! Call my name, and note the exact moment. I will repeat it the instant I hear it, and you will again note the precise moment."

"Yes! and half the interval between the question and the answer will be the time required for my voice to reach you."

"Just so, uncle!"

“Are you ready?”

“Yes!”

“Well, listen now; I am going to call out your name!”

“I put my ear to the wall, and as soon as the word ‘Axel’ reached me I instantly answered ‘Axel’, and then waited.

“‘Forty seconds,’ said my uncle. ‘Therefore the sound took twenty seconds to



Fig. 130

Concave sound mirrors

ascend. Now, at the rate of 1,020 feet per second, that makes 20,400 feet, or nearly four miles.’”

Now you should be able to answer this question: How far away is the train engine if I hear its toot one and a half seconds after I see the wisp of smoke rise from the whistle?

SOUND MIRRORS

A forest wall, high fence, building, mountain, or any echo-producing obstacle in general is nothing but a sound *mirror*, as it reflects sound in the same way as an ordinary flat mirror reflects light.

You can also have a concave sound mirror that would focus the wave-trains of sound. With two soup dishes and a watch you can stage the following illuminating experiment. Put one dish on the table and hold the watch a few centimetres above its bottom. Hold the other dish near your ear as shown in Fig. 130. If you gauge the position of all three objects right (do this by trial and error) the ticking of the watch will seem to come from the dish near your ear. By shutting your eyes you enhance the illusion and your ear alone will not tell you in which hand you are holding the watch.

Medieval castle-builders often played tricks with sound, by placing a bust either in the focus of a concave sound mirror or at the tail end of a speaking pipe cunningly concealed in the wall.

SOUND IN THEATRE

The theatre- and concert-goer knows very well that there are halls with good acoustics and bad acoustics. In some speech and music carry distinctly to quite a distance; in others they are muted even quite near.

Not so long ago the good acoustics of one or another theatre was considered simply a stroke of good luck. Now builders have found ways and means of successfully suppressing objectionable reverberation. Though I shall not expand on this point as it can interest only the architect, let me note that the main way of avoiding acoustical defects is to create surfaces to absorb superfluous sounds.

An open window absorbs sound best, just as any aperture is best for absorbing light. Incidentally, a square metre of open window has been accepted as the standard unit to estimate sound absorption. The audience itself is a good sound-absorber, with every person being equivalent to roughly half a square metre of open window. "The audience literally absorbs what the speaker says," one physicist said; it is just as true that the absence of an absorbing audience is literally a great annoyance for a speaker.

When too much sound is absorbed, this is also bad, as, firstly, it mutes speech and music, and, secondly, suppresses reverberation so much that the sounds seem ragged and brittle. As we see, some measure, neither too long, nor too short, of reverberation is desirable. This measure cannot be the same for all halls and must be quantitatively estimated by the designing architect.

There is another place in the theatre of interest from the angle of physics. This is the prompt box. It always has the same shape, have you ever noticed that? Physics is responsible. Its ceiling is a concave sound mirror which serves a dual purpose: firstly, to prevent what the prompter is saying from reaching the audience, and, secondly, to reflect his voice towards the actors on the stage.

SEA-BOTTOM ECHO

Echoes were useless until a method was devised to sound sea and ocean depths with their help. We stumbled upon this invention by accident. When in 1912 the huge ocean liner *Titanic* ran afoul of an iceberg and went down with nearly all its passengers, navigators thought of employing the echo during fogs or at night

to detect obstacles in a ship's way. Though this failed to achieve its original purpose, it suggested a fine method, whereby sea depths could be sounded by the echo from the sea-bottom.

Figure 131 shows you how this is done. By igniting a detonator against the ship's skin near the keel a sharp signal is sent. The sound pierces the water, reaches the sea-bottom and echoes back. This echo, the reflected signal, is

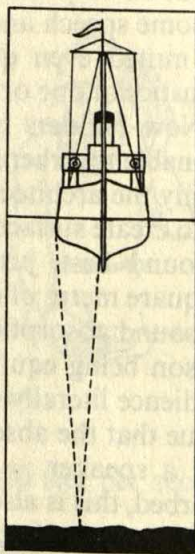


Fig. 131

Echo depth-sounding

recorded by a sensitive device placed against the ship's skin. An accurate timepiece gauges the time interval between the sending of the signal and the reception of the echo. Knowing how fast sound travels in water, we can easily reckon the distance to the reflecting barrier, or, in other words, ascertain the depth.

Echo sounder completely revolutionized sounding practices. To use the old methods one had to stop the ship; and, in general, they were a very tedious affair. The line was payed out very slowly at the rate of 150 metres a minute and it took the same amount of time to rewind it. For instance, it took about 45 minutes to sound a depth of three kilometres. Echo sounder produces the same result in but a few seconds. Furthermore, we don't have to stop the ship to do it and the result is incomparably more accurate, being never more than a quarter

of a metre out, provided the time is gauged with an accuracy down to the three-thousandths of a second.

Whereas the exact sounding of great depths is important for oceanography, the quick, reliable and accurate ascertainment of shallow depths is essential for safe steering, especially in offshore waters.

To take soundings today, people employ not ordinary sounds but extremely intensive "ultra-sounds", which we will never hear as their frequency ranges into several million vibrations a second. These sounds are produced by the vibrations of a quartz plate (a piezo-quartz) which is placed in a quickly alternating electric field.

WHY DO BEES BUZZ?

Indeed, why? After all most insects have no special organ for the purpose. The buzzing, which is heard only while the insect is flying, is produced by the flapping of the insect's wings, which vibrate with a rapidity of several hundred times a second. The wings act the role of a vibrating plate, and any plate vibrating with sufficiently great rapidity (more than 16 times a second) produces a tone of a definite pitch.

It is this that reveals to scientists how many times a second an insect moves its wings in flight. To determine the number of times, it is enough to ascertain the pitch of the insect's buzzing, because each tone has its own vibration frequency.

With the aid of the slow-motion camera (mentioned in Chapter One) scientists proved that each insect vibrates its wings with practically the same rapidity on every occasion; to regulate its flight it modifies only the "amplitude" of its wing movement and the angle at which the wing is inclined; it increases the number of wing movements per second only in cold weather. That is why the tone of the buzz remains on one level. The ordinary house fly, for instance (its buzz gives the tone *F*) vibrates its wings 352 times a second. The bumble-bee moves its wings 220 times. A honey-bee vibrates its wings 440 times a second (tone *A*) when not burdened with honey, and only 330 times (tone *B*) when carrying it. Beetles, whose buzzing is lower-pitched, move their wings much less nimbly. Mosquitoes, on the other hand, vibrate their wings between 500 and 600 times a second. Let me note for the sake of comparison that an airplane propeller averages only some 25 revolutions a second.

AUDITORY ILLUSIONS

Once we for some reason imagine the source of a slight noise to be far away, the noise will seem *much louder*. We frequently succumb to these illusions but rarely pay any heed to them. The following curious instance was described by the American scientist William James in his *Psychology*.

"Sitting reading, late one night, I suddenly heard a most formidable noise proceeding from the upper part of the house, which it seemed to fill. It ceased, and in a moment renewed itself. I went into the hall to listen, but it came no more. Resuming my seat in the room, however, there it was again, low, mighty, alarming, like a rising flood or the *avant-courier* of an awful gale. It came from all space. Quite startled, I again went into the hall, but it had already ceased once more. On returning a second time to the room, I discovered that it was nothing but the breathing of a little Scotch terrier which lay asleep on the floor. The noteworthy thing is that as soon as I recognized what it was, I was compelled to think it a different sound, and could not then hear it as I had heard it a moment before."

Has anything of the sort ever happened to you? Most likely it has; I, for one, have observed such things more than once.

WHERE'S THE GRASSHOPPER?

We very often err in determining not how far away the sound is, but the direction from which it comes. We can distinguish pretty well by ear whether the shot was fired to the right or left of us, but we are often unable to determine whether it was fired in front of us or behind us (Fig. 132). We often hear a shot fired in front of us as one coming from behind. All we can say in such cases is whether it is near or far—depending on how loud the shot is.

Here is a very instructive experiment. Blindfold your friend and seat him in the middle of a room. Ask him to sit still and not turn his head. Then take two coins and click them against each other, standing meanwhile in the imagined vertical plane that passes between your friend's eyes, and ask him to guess where the sound was made. Surprisingly enough, he will point anywhere except at you. But as soon as you leave that plane of symmetry which I mentioned, his guessing will be much better, because his ear closest to you will hear the sound a bit earlier and a bit louder.

This experiment, incidentally, explains why it is so difficult to spot a chirring grasshopper. You hear this shrill singing some two steps away on your right.

You turn your head but see nothing, and now hear the grasshopper on your left. Again you turn your head, only to hear the singing come from some other spot. The quicker you turn your head, the nimbler our invisible musician seems. Actually, the grasshopper hasn't moved; you've only imagined it to be hopping about. You have fallen victim to an auditory illusion.

Your mistake is that you turn your head so that the grasshopper occupies its

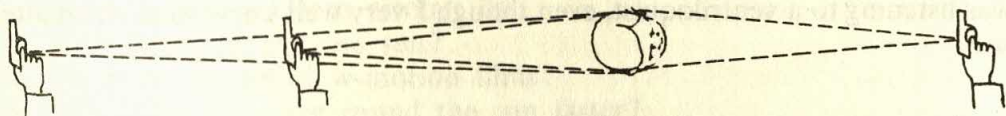


Fig. 132

Where was the shot fired? In front? Or behind?

symmetrical plane. As you already know, this readily causes you to blunder in determining the direction. So, if you want to find the grasshopper, the cuckoo, or any other similar distant source of sound, turn your head not in the direction from which it comes but away from it, which, incidentally, is exactly what one does when one "pricks up one's ears".

THE TRICKS OUR EARS PLAY

When we nibble at a rusk we hear a noise that is simply deafening. But for some reason our neighbour makes hardly any noise though he is doing the same. How come? The noise we make is one that only we ourselves can hear and it doesn't annoy our neighbours. The point is that like all solid elastic bodies, the bones of our head are very good conductors of sound. The denser the medium through which sound travels, the louder it is. The sound our neighbour makes when nibbling a rusk is a very light one as it travels through air, but this same sound turns into thunder when it reaches the auditory nerve via the solid bones of your head.

Do the following. Grip the strap-ring of your pocket watch between your teeth and stop up your ears. The bones of your head will amplify the ticking so greatly that you seem to hear the pounding of heavy hammers.

The deaf Beethoven, the story goes, could hear a piano being played by placing one end of his walking stick on it and gripping the other end between his teeth. In the same way deaf people can dance to music, provided there is nothing wrong with their internal ear. The music reaches the auditory nerve via the floor and the bones of the head.

Ventriloquism and the "marvels" it works are all based on the peculiar properties of hearing that have just been described.

The illusion that ventriloquism produces depends wholly on our inability to determine both where the voice is coming from and how far away it is. Ordinarily we can do this only approximately. As soon as we find ourselves in unusual circumstances we already make the crudest of blunders in trying to say where the sound comes from. I, too, couldn't rid myself of the illusion when I was listening to a ventriloquist, even though I very well knew what the matter was.

99 Review Questions

1. How much slower is a snail than you are?
2. How fast do modern aircraft fly?
3. Can you overtake the sun?
4. How do we get slow-motion films?
5. When do we move round the sun faster?
6. Why are the upper spokes of a rolling wheel blurred and the lower spokes seen distinctly?
7. Which points in a train going forward move backward?
8. What is aberration of light?
9. Why do we lean forward or shove our feet under a chair when we get up?
10. Why does a sailor waddle?
11. What is the difference between running and walking?
12. How should one jump off a moving car? Explain.
13. Baron Munchausen, that famous teller of "tall stories", claimed he had caught flying cannon balls with his hands. Could he have done that?
14. Would you like to have presents tossed at you when you're driving a car?
15. Does a body weigh more or less when falling than when at rest?
16. Must every thing thrown up fall back to earth?
17. Is Jules Verne's description of life inside the projectile, that set off for the moon, right?
18. Can you weigh things right on faulty scales with correct weights, or on a properly calibrated balance, but with wrong weights?
19. Are the bones of our arm advantageous levers?
20. Why doesn't a skier sink into soft snow?
21. Why is it pleasant to loaf in a hammock?
22. How was Paris shelled in the First World War?
23. Why does a kite fly?
24. Does a stone continue accelerating all the time it drops?
25. What is the greatest speed a parachutist making a delayed jump can achieve?
26. Why does a boomerang boomerang?
27. Can we find out whether an egg is boiled without cracking it open?

28. Where is a thing heavier? Closer to the equator or to the poles?
29. When a seed germinates on the rim of a spinning wheel, in which direction does it stem?
30. What is *perpetuum mobile*?
31. Has a perpetual motion machine ever been made?
32. Where does a body immersed in a liquid experience the greatest pressure? From the top, the sides or the bottom?
33. What happens when a small weight suspended on a piece of thread is dipped into a jar of water balanced on a pair of scales?
34. What shape does liquid take when it weighs nothing? Can you prove this experimentally?
35. Why are raindrops round?
36. Is it true that kerosene oozes through glass and metal? Why do people think it does?
37. Can you make a steel needle float?
38. What is flotation?
39. Why does soap wash dirt off?
40. Why does a soap bubble rise? And where does it rise faster, in a cold or warm room?
41. What is thinner, the human hair or the film of a soap bubble? How many times is one thinner than the other?
42. Water gathers under a glass when it is placed, with a burning piece of paper in it, bottom up on a tray of water. Why does this happen?
43. Why does a liquid rise when sipped through a straw?
44. A stick is balanced by weights on a pair of scales. Will the equilibrium be disturbed if the scales are placed under an evacuated bell?
45. What happens to these scales if placed in liquefied air?
46. If you lost your weight, but your clothes didn't, would you fly up into the air?
47. What difference is there between a perpetual motion machine and a gift-power machine? Have any gift-power machines been made?
48. What happens to tram rails on a very hot day or on a very cold one? And why is the weather not so dangerous for railway tracks?
49. When do telegraph and telephone wires sag most?
50. What sort of tumblers crack more often because of hot or cold water?
51. Why do lemonade glasses have a thick bottom and why are they no good as tea glasses?

52. What sort of transparent material that wouldn't crack because of heat or cold is best for tableware?
53. Why is it hard to draw a boot on after a hot bath?
54. Can we make a self-winding clock?
55. Can the self-winding principle be used for bigger machines?
56. Why does smoke curl up?
57. What would you do if you wanted to ice a bottle of lemonade?
58. Will ice melt sooner if wrapped in fur?
59. Is it true that the snow warms the earth?
60. Why doesn't water freeze in underground pipes in winter?
61. Where is it winter in the Northern Hemisphere in July?
62. Why can you boil water in a welded vessel, without fearing that it might come to pieces?
63. Why does a sled cross snow with difficulty in a heavy frost?
64. When can we roll good snowballs?
65. How do icicles form?
66. Why is it warmer at the equator than at the poles?
67. When would we see the sun rise if light propagated instantaneously?
68. What would happen to telescopes and microscopes if light propagated instantaneously in any medium?
69. Can we make light circumvent obstacles?
70. How is a periscope made?
71. Where should you place a lamp to see yourself better in a mirror?
72. Are you and your reflection in a mirror completely identical?
73. Is the kaleidoscope of any benefit?
74. How can we use ice to light a fire?
75. Can you see mirages in the temperate zones?
76. What is the "green ray"?
77. How should one look at photographs?
78. Why do photographs acquire relief and depth when looked at through a magnifying glass or in a concave mirror?
79. Why is it best to seat oneself in the middle of a movie-house?
80. Why is it better to look at a painting with one eye?
81. How does a stereoscope work?
82. How can we see things like the giants in fairy tales?
83. What is a telestereoscope?
84. Why do things sparkle?

85. Why does the landscape acquire deeper relief when viewed from a passing train?
86. How are stereoscopic photographs of celestial objects taken?
87. What is the effect of the so-called "shadow marvel" based on?
88. What colour does a red flag assume in blue light?
89. What is irradiation and astigmatism?
90. What kind of pictures follow you with their eyes? And why?
91. Is it a person with normal eyesight or a short-sighted person who thinks the bright stars bigger?
92. When you hear the echo 1.5 seconds after you clap your hands, how far away is the sound barrier?
93. Are there such things as sound mirrors?
94. Where does sound propagate faster, in air or in water?
95. To what technical uses can echoes be put?
96. Why does a bee buzz?
97. Why is it so hard to spot a chirring grasshopper?
98. What transmits sound better, air or some denser medium?
99. What is ventriloquism based upon?

Chapter Fundamentals of Mechanics 11

THE CHEAPEST WAY OF TRAVELLING

In his satirical *History of Lunar States and Empires* (1657) the witty 17th-century French writer Cyrano de Bergerac describes an amazing thing which had supposedly happened to him. Experimenting one day, he was lifted up into the air with all his retorts. On landing several hours later, he was astonished to find himself not in his own land of France nor even in Europe, but in Canada. Strangely enough Cyrano de Bergerac believed his transatlantic flight quite possible, claiming that while he was up in the air, the earth had continued to rotate eastwards which was why he had landed in North America and not France.

A very cheap and simple mode of travel, I must say! Just ascend and stay suspended a few minutes and you'll return to a totally different place much further westwards. Why tire yourself globe-trotting? Simply hover in mid air and wait till your destination reaches you.

Alas, this is nothing but a figment of the imagination. In the first place when we ascend in the air, we don't really separate ourselves from Mother Earth. We are still tied together, because we are hanging in that envelope of air which also participates in the earth's axial rotation (Fig. 133). The air (or rather its lower denser strata) spins together with the planet, carrying along everything in it: clouds, aircraft, birds and insects. After all if the air didn't spin together with our planet, we would always be buffeted by a wind of so terrible a force that in comparison with it the worst of hurricanes would seem a gentle zephyr (a hurricane, or tornado, moves with a speed of 40 m/s or 144 km/h; at Leningrad's latitude, for instance, the earth would carry us through the air with a speed of 230 m/s or 828 km/h). It would make no difference at all, whether we would be standing still with the air moving by, or whether the air would be still while we would be moving in it. In both cases we would feel the same strong wind. A motor cyclist dashing along with a speed of 100 km/h braves a formidable oncoming wind even in the calmest weather.

Then even if we were able to ascend to the top of the atmosphere or if the

earth had no envelope of air at all, we would not be able to benefit by the cheap method of travel which the French satirist imagined. Indeed, when we separate from the surface of the spinning earth, we *continue by force of inertia to move with the same speed*, that is, the speed with which the earth is moving beneath us. Back on earth again we would find ourselves where we were before we went up. This is the same as to make a hop inside the carriage of a moving train. We hop

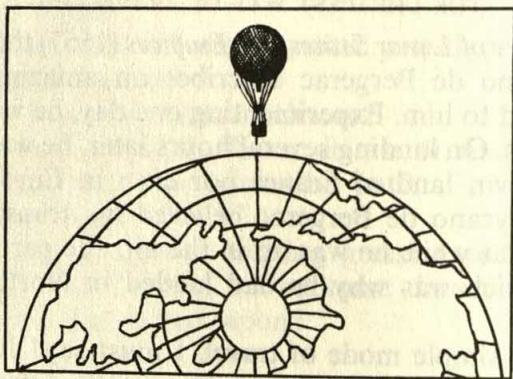


Fig. 133

Will one be able to see the earth turning from a balloon?
(Scale is not observed.)

up and land again in the same place. True, we would be moving by force of inertia rectilinearly (along a tangent), while the earth beneath us would be tracing an arc. For small intervals of time, however, this can be totally ignored.

STOP, EARTH!

The celebrated British science-fiction novelist H. G. Wells tells the story of an office clerk who was able to work miracles. Though a rather dull young man, fate had endowed him with the surprising gift of making any wish that he expressed come true at once. However, this fascinating ability, it turned out, brought only trouble. As far as we are concerned, it is the end of the story that is instructive.

After a carousal, the clerk, scared of what his family would say if he turned up home in the wee hours of the morning, thought he might as well take advantage of his talent to prolong the night. Wondering how to do it, he decided to order the stars to stop in their tracks. He couldn't bring himself to do it, and when his

friend suggested that he halt the moon, he took a long look at it and said musingly:

“That’s a bit tall.”

“Why not?” said Mr. Maydig. ‘Of course it doesn’t stop. You stop the rotation of the earth, you know.... It isn’t as if we were doing harm.’

“H’m!” said Mr. Fotheringay. ‘Well.’ He sighed. ‘I’ll try. Here—’

“He buttoned up his jacket and addressed himself to the habitable globe, with as good an assumption of confidence as lay in his power. ‘Just stop rotating, will you?’ said Mr. Fotheringay.

“Incontinently he was flying head over heels through the air at the rate of dozens of miles a minute. In spite of the innumerable circles he was describing per second, he thought and willed: ‘Let me come down safe and sound. Whatever else happens, let me down safe and sound.’

“He willed it only just in time.... He came down with a forcible but by no means injurious bump in what appeared to be a mound of fresh-turned earth. A large mass of metal and masonry... ricocheted over him, and flew into stonework, brick, and masonry, like a bursting bomb. A hurtling cow hit one of the larger blocks and smashed like an egg.... A vast wind roared throughout earth and heaven, so that he could scarcely lift his head to look....

“‘Lord!’ gasped Mr. Fotheringay, scarce able to speak for the gale, ‘I’ve had a squeak! What’s gone wrong? Storms and thunder.... It’s Maydig set me on to this sort of thing. ...’

“He looked about him so far as his flapping jacket would permit. ... ‘The sky’s all right anyhow,’ said Mr. Fotheringay. ... ‘There’s the moon overhead. But as for the rest—Where’s the village? Where’s—where’s anything? And what on earth set this wind a-blowing? I didn’t order no wind.’

“Mr. Fotheringay struggled to get to his feet in vain, and after one failure, remained on all fours, holding on. He surveyed the moonlit world to leeward, with the tail of his jacket streaming over his head. ‘There’s something seriously wrong,’ said Mr. Fotheringay. ‘And what it is—goodness knows....’

“Mr. Fotheringay... perceived that his miracle had miscarried, and with that a great disgust of miracles came upon him. He was in darkness now, for the clouds had swept together and blotted out his momentary glimpse of the moon, and the air was full of fitful struggling tortured wraiths of hail. A great roaring of wind and waters filled earth and sky, and, peering under his hand through the dust and sleet to windward, he saw by the play of the lightning a vast wall of water pouring towards him....

"Stop!" cried Mr. Fotheringay to the advancing water. 'Oh, for goodness' sake, stop!'

"Just a moment," said Mr. Fotheringay to the lightnings and thunder. 'Stop. ...'

"He remained on all fours ... very intent to have everything right.

"Ah!" he said. 'Let nothing what I'm going to order happen until I say Off. ...'

"Now then!—here goes! Mind about that what I said just now. In the first place, when all I've got to say is done, let me lose my miraculous power, let my will become just like anybody else's will, and all these dangerous miracles be stopped...'

"And the second is ... let everything be just as it was before the miracles began. ... No more miracles, everything as it was—me back in the *Long Dragon* just before I drank my half-pint....'

"AIR MAIL"

Imagine yourself in an airplane high up in the sky. You look down and see familiar places—you are approaching your friend's house. You think it wouldn't be a bad idea to send him a message. You quickly jot down a few words on your writing-pad, tear out the sheet of paper, wrap it around some heavy object, which for convenience's sake we shall henceforth call "weight", and drop it as soon as your friend's house is right underneath. If you think it will fall into your friend's front garden, you're making a terrific mistake. You'll miss it as sure as eggs is eggs even though your friend's house is right below.

If you watched the weight as it fell you would see a strange thing. While falling, the weight at the same time will continue to *travel along beneath the plane*, as if tied to it by an invisible piece of thread. And as it falls on the ground it will be off the target by a long shot.

This is again a manifestation of that selfsame law of inertia, which prevents us from travelling in Bergerac's way. While the weight was in the plane it was moving together with it. But when dropped and having separated from the plane, it does not lose its initial speed. As it falls it continues to move in the air in the same direction as the plane. Both movements, perpendicular and horizontal, are added and, as a result, the load traces a curved trajectory, which keeps it beneath the plane, provided, of course, that the aircraft does not veer away from the original course or fly faster. In point of fact, the weight follows the same trajectory as that of a horizontally thrown body: a bullet discharged

from a horizontally pointed rifle, for instance, would trace an arc-shaped trajectory that ends on the ground.

Note that all I have mentioned above would be valid if not for the air drag. Actually it impedes both the vertical and horizontal movements, the result being that the weight gradually lags behind the plane.

The deviation from a plumb-line trajectory may be pretty great when the

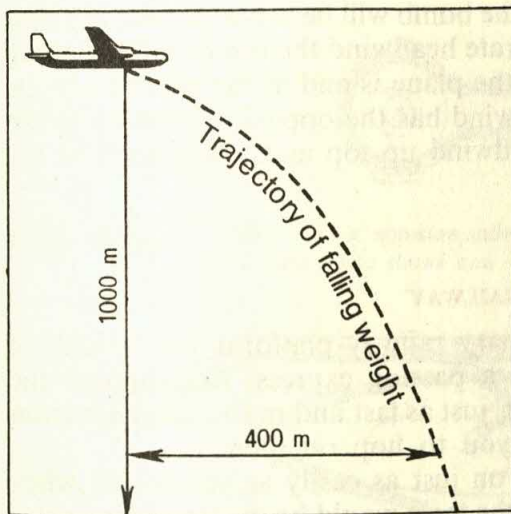


Fig. 134

A weight dropped from an airplane in motion will fall not vertically down, but along a curved trajectory

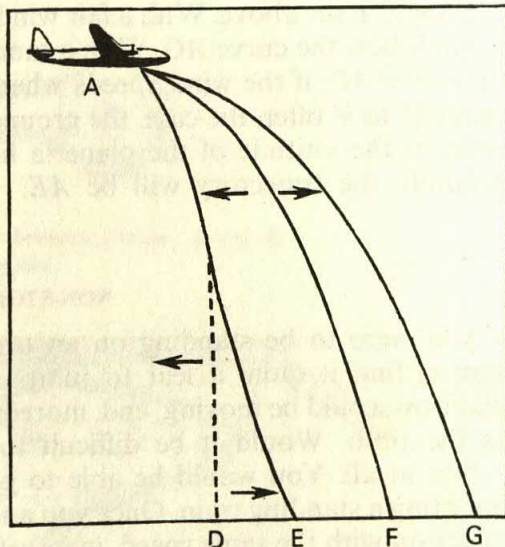


Fig. 135

plane is high up and is flying fast. On a windless day, a weight dropped from a plane flying with a speed of 100 km/h at an altitude of 1,000 metres would land some 400 metres in front of the spot that was directly beneath the plane when the weight was dropped (Fig. 134). We shall find the answer to the problem easily enough, providing, of course, that we ignore the air drag. The formula for computing the length of the path covered in the case of uniformly accelerated motion is $S = gt^2/2$, whence $t = \sqrt{2S/g}$. This means that from 1,000 metres up, it should take a stone $\sqrt{2 \times 1000/9.8}$ or 14 seconds to fall. In this period of time it will move horizontally forward by $100,000/3,600 \times 14 = 390$ metres.

BOMBING

Now you can imagine the difficulties experienced by a bomber pilot who has to drop a bomb so that it hits a target: he has to take into account the plane's velocity, the drag experienced by the bomb as it falls, and the wind. Figure 135 shows schematically the various paths a bomb may take under different conditions. If there is no wind, the bomb follows the curve AF —for an explanation see above. With a fair wind, the bomb will be driven forward so that it will follow the curve AG . With a moderate headwind the bomb will fall along the curve AD , if the wind speeds where the plane is and at the ground are the same. If, as is often the case, the ground wind has the opposite direction to the wind at the altitude of the plane (a headwind up top and a fair wind at the ground), the trajectory will be AE .

NON-STOP RAILWAY

If you were to be standing on an ordinary railway platform you would, of course, find it quite a feat to jump on a passing express. But suppose the platform would be moving, and, moreover, just as fast and in the same direction as the train. Would it be difficult for you to hop on then?

Not at all. You would be able to get on just as easily as you would when boarding a standing train. Once you and the train would be moving in the same direction with the same speed, *in its relation to you, the train would be in a state of rest*. Its wheels would be turning, true, but as far as you would be concerned, they would seem to be marking time.

Strictly speaking, all objects that we usually take to be standing still, as, for instance, a train that has come to a full halt at railway station, are really moving together with us around the earth's axis and around the sun as well. But since this motion doesn't bother us in the least, we can disregard it.

To all practical intents, we could easily get a train to take on and disgorge passengers without stopping. Exhibitions and fairs often provide such arrangements to enable visitors to see quickly and conveniently all there is to see. The entrance and exit of the fair ground are linked together by a non-stop railway: passengers may board, or alight from its moving cars at their convenience.

Figures 136 and 137 give some idea of this interesting arrangement. A and B in Fig. 136 designate the termini. Each terminus has a circular *stationary platform* in the middle of a large rotating disc. Looped around the spinning discs

of the two stations is a string of railway cars. Now see what happens when the disc revolves. The cars go round the discs with the same speed as that of the outer rim of the disc. Consequently, a passenger may safely hop on or off the train from the disc. After he alights, the passenger walks towards the centre of the rotating disc to the stationary platform in the middle. Here it is easy enough to cross from the inner rim of the moving disc to the stationary platform, since

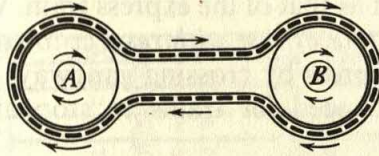


Fig. 136 Diagram of a non-stop railway between stations *A* and *B*.
The next figure shows how it works

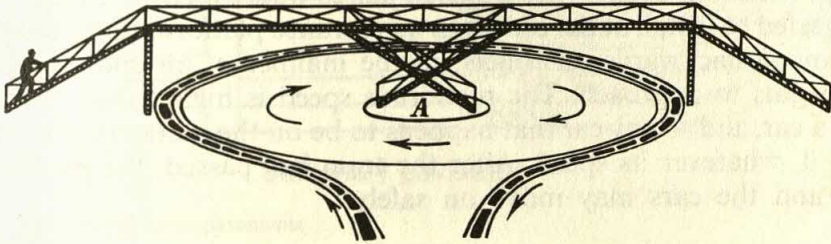


Fig. 137 A station of a non-stop railway

when the radius is small, circumferential velocity is also small (as is only natural, the points on the inner rim move much more slowly than the points on the outer rim, because in one and the same period of time they describe a far smaller circumference). Now the passenger has only to cross the overhead bridge to get to the ground outside the railway (Fig. 137).

Since there are no frequent stops much time and locomotive energy is saved. It is a fact that trams, for instance, spend most of the time and nearly two-thirds of the locomotive power to work up speed after stops and to slow down when coming to a stop.

Incidentally, the amount of energy lost when slowing down could be saved by causing the tram's electric motors to operate as dynamos and reverse current to

the network. In this way the electricity expenditure on tramcar traffic in the Berlin suburb of Scharlottenburg was reduced by 30 per cent*.

Railway stations could even dispense with a special moving platform, to have trains take and disgorge passengers on the go. Imagine an express train dashing by an ordinary stationary platform. We want it to take on some more passengers without stopping. To do that these passengers should enter another train standing on a parallel reserve track. This train would start moving till it worked up the same speed as that of the express train. When the two trains draw parallel *they will be in a state of rest with respect to each other*. The passengers could easily get on the express by crossing gangways from the auxiliary train. Then there would be no need for trains to stop at stations.

ACCIDENT PREVENTION

An interesting example of the uses of the principle of relative motion is a device to prevent collisions of cars with trains in places where highways cross railways. It is suggested to install at the crossings an entrance platform that automatically starts moving backwards on rollers, in the manner of an endless belt, when a train begins to approach. The platform's speed is higher than the maximal speed of a car, and so any car that happens to be on the platform will be carried back by it, whatever its speed. After the train has passed, the platform stops moving and the cars may move on safely.

MOVING PAVEMENTS

Another device, so far used only at exhibitions – the “moving pavement”, is also based on the principle of the relativity of motion. The first moving pavements appeared at the 1893 Chicago Fair. The 1900 Paris Fair also had moving pavements.

Figure 138 shows a nest of five pavement strips moving at different speeds. The outermost one is the slowest. Its speed is only 5 km/h, which being our ordinary walking speed makes it simple enough for us to get onto it. The second strip next to it already has a speed of 10 km/h. If we had to hop onto it from a stationary pavement, we would find it pretty dangerous, but to cross over to it from the first strip, is simple enough, because in relation to this first strip, with

* This method is now extensively employed on the electric Vladivostok-Moscow line. – Ed.

its speed of 5 km/h, the *second*, with its speed of 10 km/h, is moving with a speed of only 5 km/h. This means that it is just as easy to cross from the first strip to the second strip as it was to cross from the ground to the first strip. The *third* pavement strip has a speed of 15 km/h, but again it is easy enough to cross over onto it from the *second* strip. So will it be just as easy to cross from the third strip to the *fourth* one with its speed of 20 km/h, and finally from the fourth one

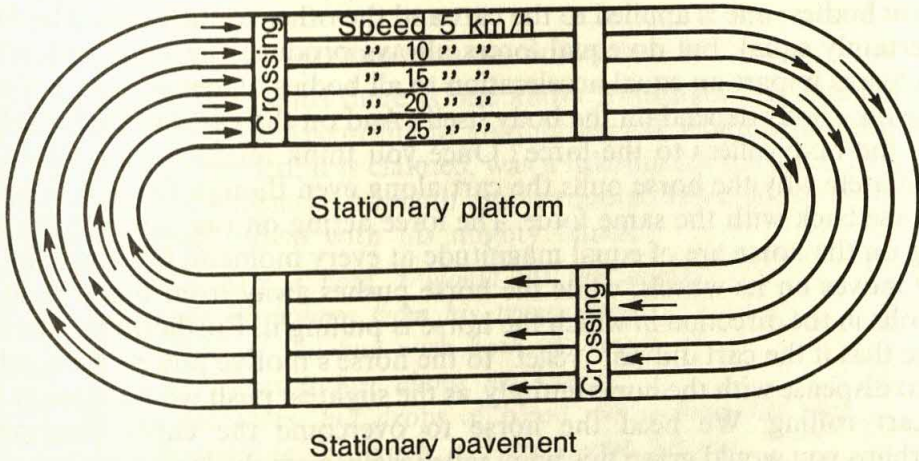


Fig. 138

Moving pavements

to the *fifth* one, which already does 25 km/h. Standing on this fifth strip the passenger reaches his destination where he skips from strip to strip to get back to firm ground again.

KNOTTY LAW

None of Newton's three fundamental laws of dynamics is so perplexing as the famous third one, the *law of action and reaction*. Everybody knows it and some even know how to apply it correctly in certain cases. However few understand it fully. You may have been lucky enough to grasp its meaning at once, but I confess, for one, that it took me ten years before I got to the heart of the matter.

Most people with whom I have discussed this law are prepared to admit that it is right, making however a few essential reservations. They willingly admit that it holds for stationary objects but cannot understand how it applies to the

interaction of moving bodies. According to the law for every action there is always an equal and opposite reaction: Consequently, when a horse pulls at a cart, it means that the cart is pulling at the horse with the same force. In that case the cart should stay where it is, shouldn't it? Nevertheless it moves. Why don't these forces offset each other, since they are equal?

That is the usual argument raised when this law comes up. Does this mean that the law is wrong? Of course not. It is just that we don't understand it correctly. The forces do not offset each other simply because they are applied to *different* bodies: one is applied to the cart and the other to the horse. The forces are certainly equal; but do equal forces always produce the same action? Do equal forces impart an equal acceleration to all bodies? Does not the action of a force on a body depend on the body itself? And on the value of the "reaction" which the body offers to the force? Once you think about it you will realize immediately why the horse pulls the cart along even though the cart is pulling the horse back with the same force. The force acting on the cart and the force acting on the horse are of equal magnitude at every moment, but since the cart freely moves on its wheels, while the horse pushes away from the ground, the cart rolls in the direction in which the horse is pulling it. Furthermore one must realize that if the cart did not "react" to the horse's motive power, we would be able to dispense with the horse entirely, as the slightest push would already start the cart rolling. We need the horse to overcome the cart's reaction.

Perhaps you would grasp this point more easily were the law expressed not so laconically as it usually is, "action is equal to reaction", but as: "The force of the reacting body is equal to the force of the acting body." After all it is only the *forces* that are of equal magnitude: the actions of the forces if understood, as they are usually understood, as the translation of a body, are, on the other hand, different as a rule, because the forces are applied to *different* bodies.

In February 1934 the Soviet ship *Chelyuskin* was crushed in the Arctic. Newton's third law easily explains why. When the ice pressed on the *Chelyuskin's* hull, the hull pressed back with an equal force. The disaster occurred precisely because while the thick ice was able to withstand this pressure without crumbling, the hollow hull succumbed to this force and was crushed even though it was made of steel (you will find more about the *Chelyuskin* disaster further on).

Even in falling, every body strictly obeys the law of reaction. An apple falls, because it is attracted by the earth's gravity. However, *the apple itself attracts the whole planet with exactly the same force*. Strictly speaking, the apple and the earth fall towards each other, but their speeds of falling are different. The equal

forces of mutual attraction impart to the apple an acceleration of 10 m/s^2 while to earth they impart an acceleration which is as many times less as many times the earth's mass is more than the mass of the apple. Naturally, the earth's mass is an incredible number of times greater than that of the apple. No wonder the earth's movement is so infinitesimally small that for all practical purposes it can be considered as nonexistent. Now you know why we say that the apple falls on the earth, instead of saying that the "apple and the earth fall on each other".

WHY DID SVYATOGOR PERISH?

Among Russian folk legends there is one about Svyatogor, an epic hero who tried to lift up the earth. According to another legend, Archimedes planned to do the same. All he needed, it is claimed, was a fulcrum for his lever. Svyatogor, however, possessed enormous strength and needed no lever. All he wanted was something he could grasp with his mighty hands.

"Could I gain a hold, I would lift the world."

Svyatogor dismounts from his trusty steed,

Takes hold of the bag with both his hands,

Then he raises it just above his knees,

While not tears, but drops of blood run a-down his face.

And he sank in the earth and could not get out,

And then it was that he met his end.

If Svyatogor had known the law of action and reaction he would have realized that his strength, when applied to the earth, would evoke an equal and, consequently, just as enormous opposite force which would draw him down into the ground. At any rate the legend shows us that the reaction the earth presents when pressed against had been observed long ago. People unconsciously, applied the law of reaction thousands of years before Newton first enunciated it in his immortal *Principia*.

CAN ONE WALK WITHOUT SUPPORT?

When we walk we push off with our feet from the ground or floor. We can hardly walk at all across a very smooth floor or ice, from which we can't push off our feet. A steam engine pushes away from the track with its driving wheels. But if we were to grease the rails, our locomotive would stay where it was. Sometimes, in icy weather, the rails are sanded in front of the locomotive's

driving wheels to get the train started. When wheels and track (at the time railways first appeared) were geared to each other, the idea was that the wheels should push themselves away from the rail. A ship pushes itself away from the water by means of its paddles or screw. A plane also pushes itself away from the air, with the aid of a propeller.

To make a long story short, in whatever medium an object moves, it uses it as a support when moving. But would a body be able to move, if it *didn't have any support*?

You would think this incredible, wouldn't you? It would be like lifting oneself up by one's hair and that was something which only that king of liars, Baron Munchausen, could do. Nevertheless we often see this seemingly impossible motion. It is true enough that a body cannot start moving all by itself, due to the effort of inner forces alone. But it can make part of itself move in one direction and the rest in the opposite direction. You have probably seen a rocket whizzing up into the air. But have you ever stopped to wonder why it shoots up? It provides a most graphic illustration of the kind of motion we are now discussing.

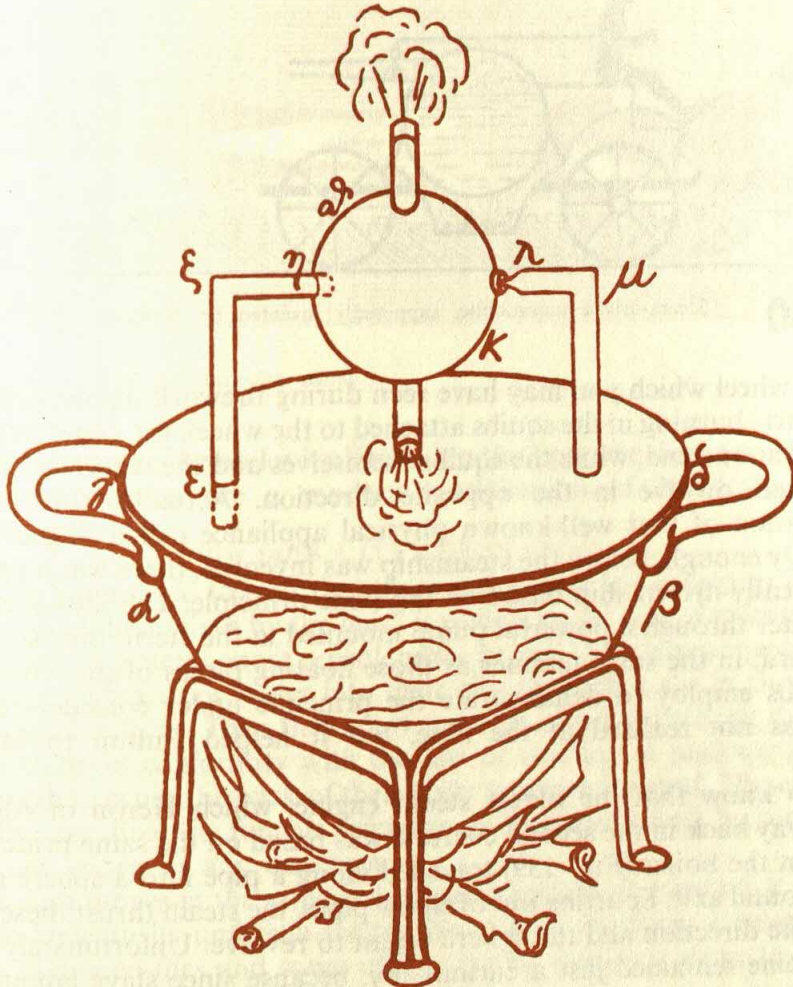
WHY DOES A ROCKET GO UP?

Even from students of physics one may often hear a totally wrong explanation of a rocket's flight. They claim that it goes up by *thrusting itself away from the air* with the help of the gases formed from gunpowder combustion. That incidentally is what ancients thought (rockets were invented long, long ago). But if we were to fire a rocket in an airless void it would fly, and even better than in the air. The real cause of a rocket's flight is absolutely different.

The Russian revolutionary Kibalchich, who was executed for attempting to assassinate Tsar Alexander II, furnished a very lucid and simple exposition of rocket motion in the notes he wrote in his death cell and in which he described the flying vehicle that he had invented. Explaining the design of a rocket which was to be used as a military weapon, he wrote: "In a tin cylinder, closed at one end and open at the other, we insert a cylinder of the same size consisting of closely packed gunpowder with a channel in the centre. Combustion begins at the surface of this channel and spreads within a definite period of time to the outer surface of the packed gunpowder. The combustion gases press on every side: but while the pressure the gases exert sideways is offset, the pressure they exert on the bottom of the tin cylinder is not offset by an opposite pressure (as here the gases have a free outlet). They are thus able to thrust the rocket forward in the direction in which it was mounted before ignition."

The same thing takes place when a projectile is fired from a gun, the projectile flies forward, while the gun rolls back. Take the “recoil” of a rifle, or of any firing weapon for that matter. If our gun were suspended in mid air and had nothing to rest upon, it would move back, after the projectile were fired, with a speed as

Fig. 139 World's oldest steam machine or turbine, which legend has ascribed to Heron of Alexandria (circa 200)



many times less than that of the projectile as the latter would be lighter than the gun itself. In Jules Verne's science-fiction novel *Upside Down*, its heroes even thought of using the recoil of a tremendous cannon to carry out the stupendous project of "straightening the earth's axis".

The rocket is also a gun, but instead of shooting out projectiles it gives a burst of combustion gases. It is this that explains the spinning of the so-called

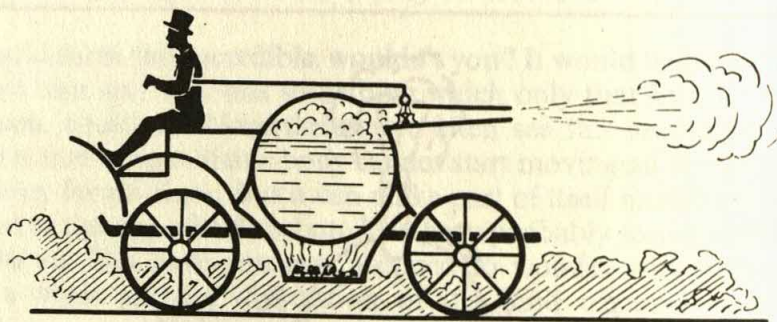


Fig. 140

Steam-driven automobile, supposedly invented by Newton

Catherine wheel which you may have seen during firework displays. When the powder starts burning in the squibs attached to the wheel, the combustion gases stream out at one end, while the squibs themselves and the wheel to which they are attached revolve in the opposite direction. Actually, this is merely a modification of that well-known physical appliance called Segner's wheel.

Curiously enough, before the steamship was invented, there was a project for a mechanically-driven ship based on the same principle. The idea was to eject a jet of water through a powerful pump mounted in the stern, thus sending the ship forward, in the same manner as those floating pieces of tin, which school physics labs employ to demonstrate the principle under consideration. This project was not realized at the time, but it helped Fulton to invent his steamship.

We also know that the oldest steam engine, which Heron of Alexandria invented way back in the second century, was based on the same principle. The steam from the boiler (Fig. 139) travelled along a pipe into a sphere mounted on a horizontal axle. Spurting out of elbow pipes, the steam thrust these pipes in the opposite direction and the sphere began to revolve. Unfortunately Heron's steam turbine remained just a curious toy, because since slave labour was so cheap in ancient times, nobody ever thought of deriving any practical benefit

from it. However its principle has not been forgotten; today it is applied in the making of jet turbines.

One of the earliest designs for a steam-driven automobile based on the same principle is ascribed to Newton, the author of the law of action and reaction. According to it the steam coming from a wheel-mounted boiler spurted out in

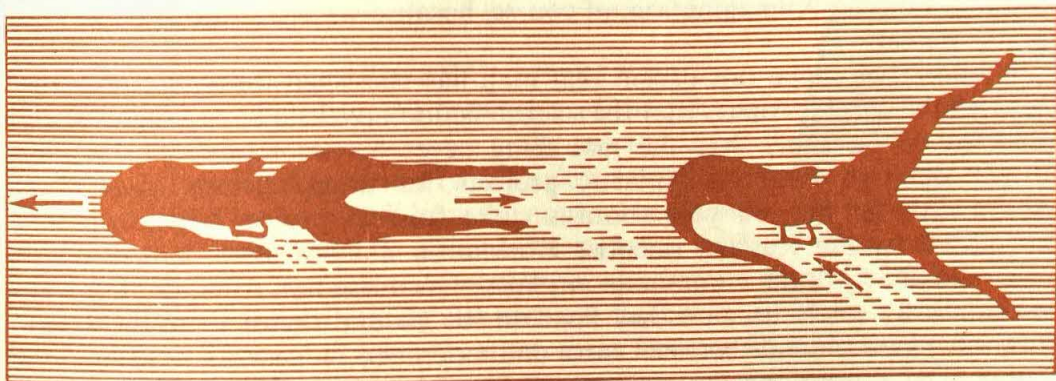


Fig. 141 How the cuttle-fish swims

one direction to make the boiler itself recoil in the opposite direction (Fig. 140).

Rocket automobiles are a modern modification of Newton's carriage.

HOW DOES A CUTTLE-FISH SWIM?

It may strike you as odd to hear that there are quite a few creatures for whom the "lifting up of themselves by the hair" is quite a usual way of swimming. The cuttle-fish and, in general, most *cephalopodae* propel themselves through water in this fashion. They draw water into their gills through a slit in the side and a special funnel in front. Then they spurt out a jet of water through this funnel. This gives them, in conformity with the law of reaction, a backward impetus strong enough to cause the back of their body to move forward. The cuttle-fish, incidentally, can direct its funnels sideways or backwards and, by sending out jets of water, move in any direction.

The jelly-fish moves in the same fashion: contracting its muscles, it ejects the water from beneath its umbrella-shaped body, thus receiving a recoil. *Salpas*, the larvae of *dragon-flies* and some other aquatic creatures swim in the same fashion. Yet we doubted it!

ROCKET TRAVELS TO THE STARS*

Could anything be more thrilling than to travel to the moon and from planet to planet? How many science-fiction novels have been written on that subject. Voltaire in *Micromégas*, Jules Verne in *A Journey to the Moon* and Hector Servadac and H. G. Wells in *The First Men in the Moon* have, together with their many less-talented colleagues, taken us on many an exciting journey to the celestial objects, in imagination, of course, because we are still captives of our home planet.

Couldn't we make this dream that man has cherished for ages come true? Will all the clever projects that the science-fiction novelists have suggested and that are all so much like the real thing never be accomplished?

We shall go back to fantastic projects for interplanetary travel later. Meanwhile let me tell you about a quite feasible project which was first suggested by the Russian scientist Konstantin Tsiolkovsky.

Could one fly to the moon in an airplane? Of course not. After all planes and dirigibles fly solely because they float on the air and thrust themselves away from it. There is no air between earth and moon and, in general, nothing dense enough to support an "interplanetary dirigible". Consequently, one has to invent a vehicle that would be able to fly without any support. We have already discussed a vehicle of this kind—the toy rocket. Couldn't we construct a huge rocket with special compartments for people, provisions, air tanks and all the other necessary things? Imagine the crew of such a rocket would carry with them a big enough store of fuel and be able to send out bursts of gas in any direction. This would be a real guided spaceship, one that would be able to take us to the moon and the planets. By firing these bursts of gas its crew would be able gradually to accelerate motion in such a way that would cause no harm. If they thought of landing on some planet they could, on the contrary, decelerate to make a soft landing. And they could employ the same method to return to earth.

* Today, when artificial earth satellites go up with astonishing regularity and space probes reach neighbouring planets, when man has set foot on the moon and samples of lunar rock have been brought back to earth, our younger reader—who will no doubt take all this more or less for granted as he or she will have been conscious from early childhood, if not the cradle, of the age of space exploration, which began in 1957—may think the author's glowing enthusiasm for space travel somewhat naïve. Still we have decided to reproduce the related passages as written, as they are of definite historical interest.—Ed.

Chapter

Force Work Friction

12

THE KRYLOV FABLE PROBLEM

The story of how the swan, the crawfish and the pike attempted to get a cart going is the subject of a well-known fable, one variant of which was written by the 19th-century Russian writer Ivan Krylov. I hardly suppose any one of you has ever stopped to examine it from the angle of mechanics. The result we would obtain in that case would be quite different from Krylov's denouement. The fable actually poses a problem in mechanics with several forces acting at angles to each other – the swan pulling the cart up, the crawfish, back, and the pike, into the river. Figure 142 gives us these three forces – the swan's upward pull (OA), the pike's sideways pull (OB) and the crawfish's backward pull (OC). Don't forget that we have yet a fourth force, the cart's weight, which is directed downwards. Krylov claims in the fable that the cart remained where it was, or, in other words, that the resultant of all the forces applied to the cart is nil.

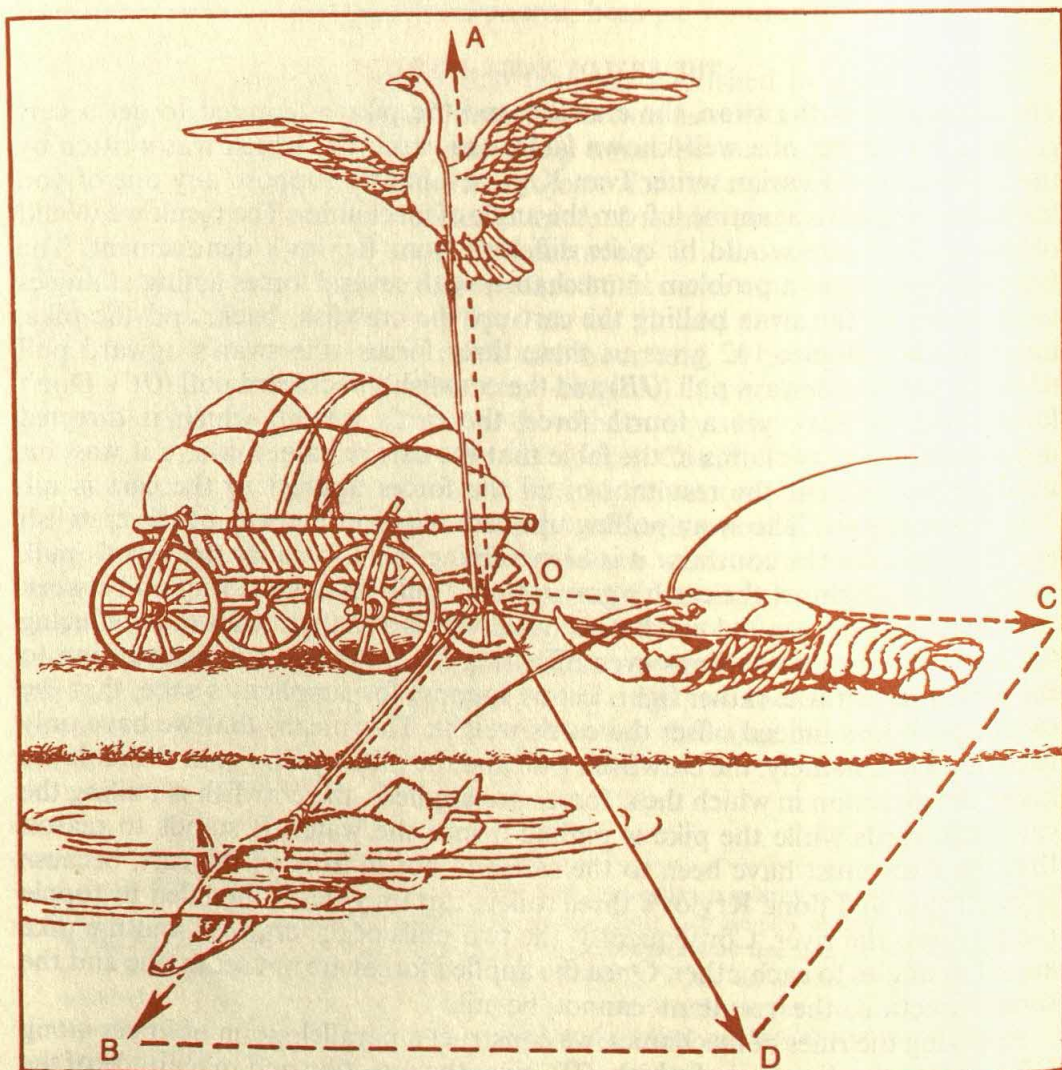
Is this really so? The swan pulling upwards is not in the way of the crawfish and the pike. On the contrary, it is even helping them, because the swan's pull, being directed against the earth's gravitational pull, lessens the friction between the wheels and the ground and between the wheels and their axles thus reducing the cart's weight and perhaps even offsetting it completely, since according to the fable the cart was rather light. Let us suppose for simplicity's sake, that the swan's pull does indeed offset the cart's weight. This means that we have only two forces left, namely, the crawfish's pull and the pike's pull. From the fable we know the direction in which these forces are applied – the crawfish is pulling the cart backwards while the pike is pulling it into the water. It stands to reason that the river must have been to the side and not in front of the cart, because after all said and done Krylov's three toilers certainly never intended to topple the cart into the river. Consequently, the two pulls of the crawfish and the pike are set at angles to each other. Once the applied forces are not set in one and the same direction, the resultant cannot be nil.

Applying the rules of mechanics, we construct a parallelogram of forces along OB and OC , the diagonal of which, OD , gives the direction and magnitude of the

resultant force. It is quite plain that this resultant force must cause the cart to move, all the more since its weight has been fully or partially offset by the swan's pull. The next question is: In which direction will the cart move, forward,

Fig. 142

Problem of Krylov's swan, pike and crawfish, solved in conformity with the rules of mechanics. The resultant force (OD) should pull the cart into the river



backward, or sideways? This naturally depends on the ratio of the two forces and the value of the angle between them.

Those of you who have added and resolved forces before, will realize that even when the swan's pull does not offset the weight of the cart it cannot stay put. It won't move only if the friction between the wheels and the axles and between the wheels and the ground is greater than the applied forces. In that case the cart wouldn't have seemed so light—as Krylov claims. At any rate the poet had no ground to say that the cart would have stayed put, which of course does not change the moral of the fable.

IN DEFIANCE OF KRYLOV

We have just seen that Krylov's moral, that "when friends fall out, nothing goes right" does not always dovetail with mechanics. Forces may not be applied in one direction, but notwithstanding, will give some result. Few know that those assiduous toilers, the ants, whom the same Krylov praised as exemplary workmen, do their job by using the very method that he ridiculed, and do get things going. Again it is thanks to the composition of forces. If you take the trouble to watch ants at work, you will see that their supposedly intelligent cooperation is a fiction because actually it is a case of each ant for itself, without caring for what the others do.

This is how Elachich, the zoologist, described ants at work in his book *Instinct*:

"When you have some dozen ants dragging a large object across even ground, all act in the same fashion, and you have, on the face of it, what seems to be cooperation. Suppose, however, that the trophy, a caterpillar, for instance, is obstructed by a blade of grass or a pebble. The obstacle has to be circumvented: it is no longer possible to go on dragging the caterpillar forward. It is then that you clearly see how each ant tries to cope with the obstacle separately, by itself, without any thought of cooperating with its mates (Figs. 143 and 144). One pulls to the right, another to the left, a third forward and a fourth backward. They change places, grasp the caterpillar in another place, each one pushing or pulling by itself. When, finally, it so happens that the forces of the ants are applied in such a way that you have four ants moving the caterpillar in one direction and six in another, eventually it moves in the direction that the six are pulling, despite the resistance offered by the other four."

Let me give you another instructive instance to graphically illustrate this sham cooperation between ants. Figure 145 shows a rectangular piece of cheese

with 25 ants pulling at it. The piece of cheese slowly moves in the direction indicated by the arrow *A*. You may think that while the front row is pulling the cheese forward, the back row is pushing it also forward and the ants at the sides are helping their mates. But this is not at all so. Take a knife and separate the back row. Immediately the piece of cheese begins to move forward much faster. This shows that the eleven ants in the back row were pulling the cheese

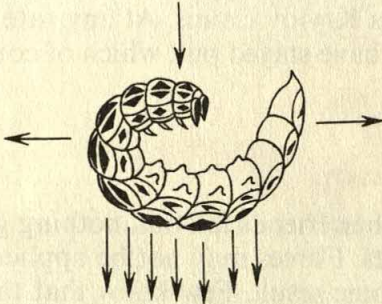


Fig. 143

Ants dragging a caterpillar

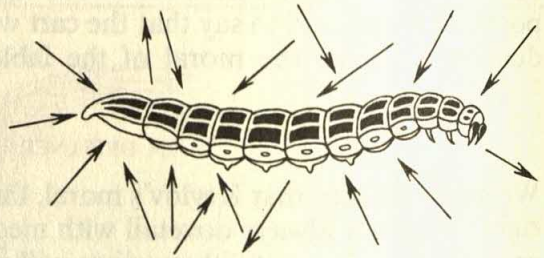


Fig. 144

How ants work. The arrows show the approximate direction of the efforts of each ant

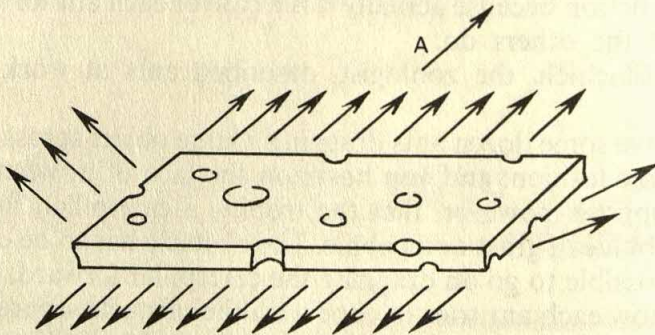


Fig. 145

How ants drag a piece of cheese to their ant-hill, to which arrow *A* points

backward and not pushing it forward. Each of them was plainly trying to deliver the piece of cheese to the ant-hill by pulling it backward, which clearly shows that far from helping the front row the back row was assiduously hampering them, countering their exertions. Actually, the exertions of four ants would have been quite enough to pull the cheese forward, but since they do not coordinate

their actions at all, it needs 25 ants to push the cheese forward.

Mark Twain happened to note this singular "cooperation" between ants. When describing an encounter between two ants, one of which had chanced upon the leg of a grasshopper, he wrote:

"... they take hold of opposite ends of that grasshopper leg and begin to tug with all their might in opposite directions. ... They decide that something is wrong, they can't make out what. ... Mutual recriminations follow. ... They warm up, and the dispute ends in a fight. ... They make up and go to work again in the same old insane way, but the crippled ant is at a disadvantage; tug as he may, the other one drags off the booty and him at the end of it. Instead of giving up, he hangs on. ..." Though Twain was poking fun, he was absolutely right when he remarked that:

"He does not work, except when people are looking, and only then when the observer has a green naturalistic look and seems to be taking notes."

CRUSHING AN EGG-SHELL

One of the philosophical problems, which that "mighty intellect", Kifa Mokievich, a character from the novel *Dead Souls* by the great 19th-century Russian writer Gogol, racked his brains to solve was the following: "Suppose elephants were born in eggs. Wouldn't the egg-shell be very thick? I wager that even a cannon ball wouldn't pierce it and that a new firing weapon would have to be invented."

I'd wager that Gogol's philosopher would have gasped with amazement had he been told that the ordinary *egg-shell* is not so fragile as would seem. It's pretty hard to crush an egg between one's palms in the way shown in Fig. 146. You would have to exert quite an effort. (If you ever try it, beware of the shell splinters.)

Why is the egg-shell so strong? Solely because of its curved shape, which explains too the strength of all vaults and arches.

Figure 147 shows a small stone window arch. Load S (the weight of the masonry above it) pressing down on the wedge-shaped brick in the middle of the arch exerts a force designated by the arrow A . However the crowning brick can't fall down because of its wedge-shaped form; it merely presses against its neighbours. Force A is thus resolved, according to the parallelogram law, into two forces designated by the arrows C and B . These two forces are offset by the resistance offered by the adjacent bricks, which in turn are sandwiched between the others. Hence the force pressing down on the arch from above won't crush

it. On the other hand, it is rather easy to ruin the arch by pressing up from inwards. No wonder, because while the wedge-shaped form of the bricks prevents them from falling out *downwards*, it can't prevent them from being pushed *upwards*.

Our egg-shell is also an arch only one that is curved on every side. *Outside* pressure won't break it so easily as you might expect it. You could stand an oak

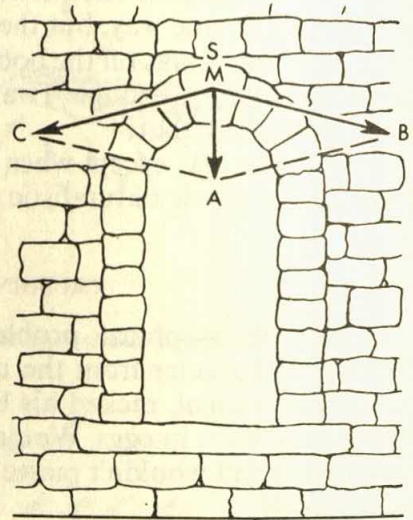
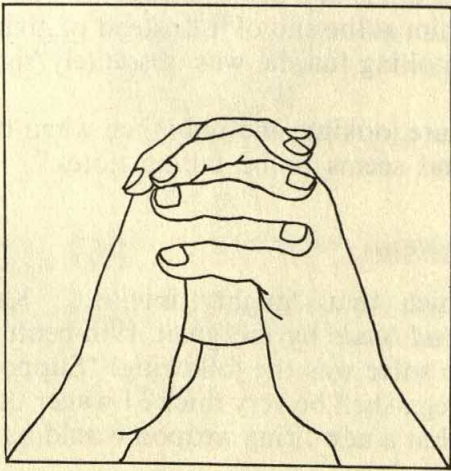


Fig. 146

It takes quite an effort to break an egg this way

Fig. 147

Why an arch is so strong

table by its four legs on four raw eggs and they will not be crushed (to make eggs stand you must mount them on supports of plaster-of-Paris, which easily adheres to the lime egg-shell).

Now you see why a sitting hen need not fear that the eggs will be crushed by the weight of its body. But the weakling chick inside easily shatters the egg-shell from within as it emerges from "Nature's dungeon".

When snapping off the top of the egg by striking at it sideways with a spoon, you can't believe that it so staunchly resists Nature's thrusts. Nature has certainly provided a fine "coat of mail" for the developing embryo inside!

The egg-shell also explains that mysterious strength of the seemingly fragile

electric bulb, which is all the more amazing when one considers that bulbs have *nothing* inside to resist the quite substantial pressure of the outside air. You might be interested to learn that a 10-cm bulb has to resist a combined pressure of more than 75 kg, a full-sized man's weight. Incidentally, it has been experimentally demonstrated that a bulb can withstand a pressure that is even two and a half times greater.

SAILING "CLOSE-HAULED"

How do sailing vessels manage to sail "to the wind", or as seamen say "close-hauled"? True, a seaman will tell you that you can't sail directly against the wind, but nearly against it, at an acute angle to the direction in which the wind is blowing. The angle, however is very small, i. e. about a quarter of a right angle, and it is indeed hard to understand what difference there can be between sailing directly against the wind or at an angle of 22° to it.

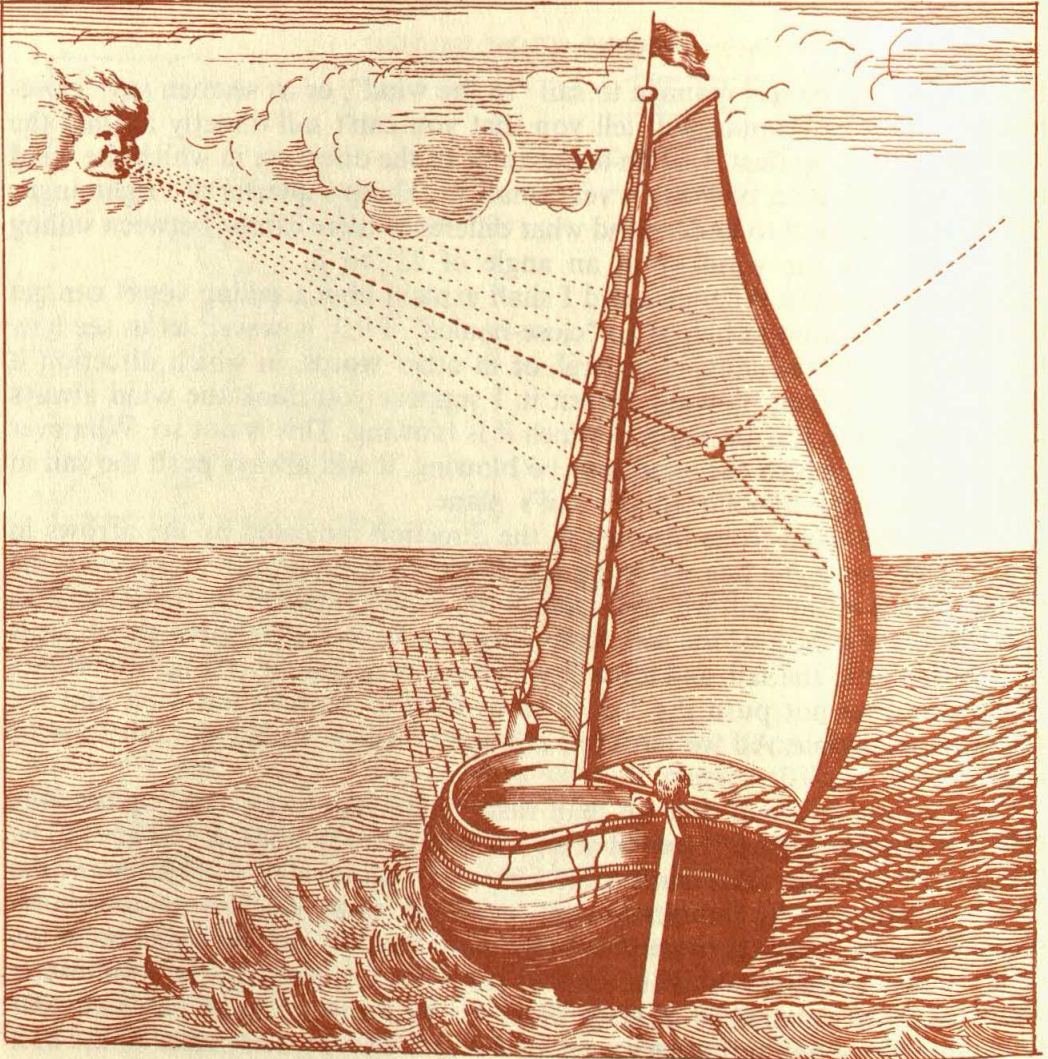
Actually there is a difference and I shall explain how a sailing vessel can get the force of the wind to help it go "close-hauled". First, however, let us see how the wind acts on the sails, in general, or in other words, in which direction it pushes the sail when blowing against it. I suppose you think the wind always pushes the sail in the direction in which it is blowing. This is not so. Whatever the direction in which the wind may be blowing, it will always push the sail in a direction perpendicular to the sail's plane.

Imagine the wind to be blowing in the direction indicated by the arrows in Fig. 149 in which the line AB is the sail. Since the wind presses evenly over the entire surface of the sail, we may replace the wind's pressure by the force R as applied to the centre of the sail. Resolving this force we get force Q , which is perpendicular to the sail, and force P , which is directed along it (Fig. 149, right). The latter does not push the sail at all as friction between the wind and the canvas is negligible. All we have left is force Q which pushes the sail at right angles to it.

Once we are aware of that we shall easily understand why a sailing vessel is able to go nearly against the wind at an acute angle to it. Let KK in Fig. 150 be the vessel's keel line. The wind is blowing at an acute angle to this line in the direction indicated by the arrows. AB is the sail itself, which is set so that its plane bisects the angle between the direction of the keel and the direction of the wind. Figure 150 shows how the force is resolved. The pressure the wind exerts on the sail is designated by force Q , which, as we know, must be perpendicular to the sail. Resolving this force we get force R , which is perpendicular to the keel

and force S , which is directed forward along the boat's keel line. Since the boat's movement in the direction R encounters a strong resistance offered by the water (the keels of sailing vessels go very deep), force R is almost fully offset by the water's resistance. All we have left is force S which, as you see, is directed

Fig. 148



forward and which, consequently, impels the boat forward at an angle, into the teeth of the wind, as it were (one could prove force S is greatest when the sail's plane bisects the angle between the directions of the keel and the wind). Usually this manoeuvre is executed by zigzagging in the way shown in Fig. 151, which in the seamen's lingo is called "tacking".

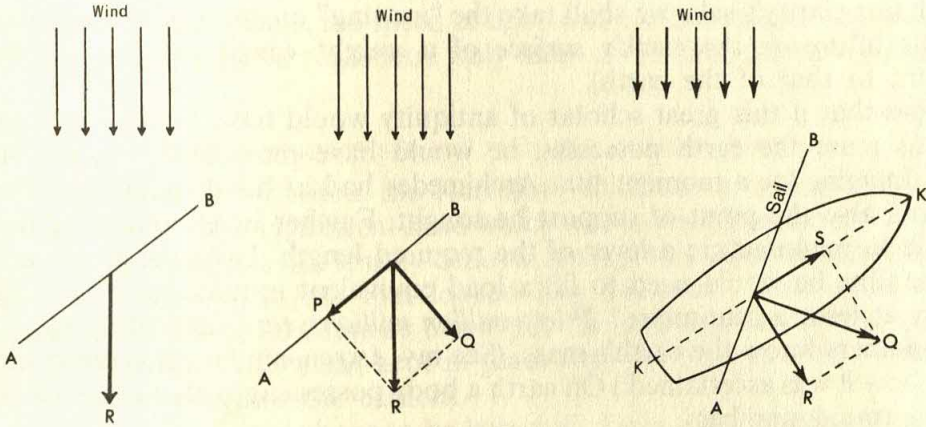


Fig. 149
Fig. 150

Wind will always push a sail at right angles to its plane

How to sail near the wind

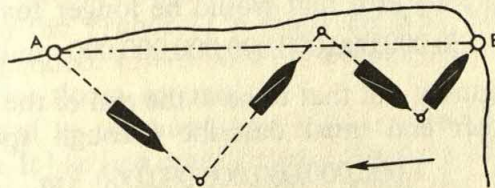


Fig. 151

Yacht tacking

COULD ARCHIMEDES HAVE EVER MOVED THE EARTH?

"Give me where to stand and I will move the earth!" is a saying that legend has ascribed to Archimedes, the genius of antiquity who discovered the laws of the lever. "Archimedes," Plutarch says, "once wrote to King Hiero of Syracuse, whose kinsman and friend he was, that this force could be used to move any weight. Carried away by the power of argument, he added that, were there

another earth, he would go there and lift our own planet from it."

Archimedes knew that by using a lever one could lift the heaviest of weights by applying even the weakest of forces. One had only to apply this force to the lever's longer arm and cause the shorter one to act on the load. He therefore thought that by pressing with his hand on the extremely long arm of a lever he would be able to lift a weight, the mass of which would be equivalent to that of the earth (for clarity's sake we shall take the "moving" or lifting of the earth to mean the lifting *on the earth's surface* of a weight whose mass would be equivalent to that of the earth).

I believe that if this great scholar of antiquity would have known what an enormous mass the earth possesses, he would have most likely "eaten his words". Imagine for a moment that Archimedes had at his disposal "another earth" and also the point of support he sought. Further imagine that he was even able to manufacture a lever of the required length. I wonder if you can guess the time he would need to lift a load equivalent in mass to that of the earth, by at least a centimetre? *Thirty million million years*—and no less!

Astronomers know the earth's mass. (See my *Astronomy for Entertainment** to learn how it was ascertained.) On earth a body possessing such a mass would weigh in round numbers

6,000,000,000,000,000,000 tons.

Supposing a man could lift only 60 kg directly, to "lift the earth" he would need a lever with a long arm that would be longer than the shorter arm by

100,000,000,000,000,000,000 times!

You can easily figure it out that to have the end of the short arm rise by one centimetre, the other end must describe through space the huge arc of

1,000,000,000,000,000,000 km.

That is the colossal distance Archimedes would have had to push the lever to lift the earth by just one centimetre. So how much time would he need? Presuming Archimedes could have lifted 60 kg one metre in one second—the work of almost one horse-power!—to lift the earth by just one centimetre, even then he would need

1,000,000,000,000,000,000 seconds

* Foreign Languages Publishing House, Moscow, 1958.

or 30 million million years. Though he lived to a ripe old age Archimedes and his lever wouldn't have lifted the earth by so much as even the thinnest of hairs.

No artifices would have helped him to cut the time noticeably despite all his brilliance. For according to the "golden rule" of mechanics, the mechanical advantage derived will always be accompanied by a loss in displacement, or, in other words, in time. Even if Archimedes had been able to push the lever with a speed of 300,000 km/s, the speed of light, and Nature's fastest, he would have lifted the earth by one centimetre only after *ten million years* of pushing.

JULES VERNE'S STRONG MAN AND EULER'S FORMULA

Do you remember Matifou, the Herculean character of one of Jules Verne's novels? He had a "magnificent head which was in good proportion to his giant stature. His chest was like smithy bellows, his legs like thick logs, and his hands like real cranes with fists that looked like hammers". One of his exploits described in the novel *Mathias Sandorf* is the amazing case of the good ship *Trabacolo*, which our giant kept in place with his brawny arms. This is how Jules Verne describes the exploit:

"The *Trabacolo* was about to be launched. Only a few wedges were left and some half a dozen carpenters were busy hammering away. Meanwhile a crowd of idlers looked on.

"At that moment a pleasure yacht shot out from beyond the promontory. Since it had to pass by the *Trabacolo* to reach the port, launching operations were temporarily suspended. For otherwise, had the two ships collided, the yacht would have gone down at once.

"All eyes were turned to the handsome vessel, whose white sails gleamed golden in the sunshine. It had just come across when a cry of horror rent the air. The *Trabacolo* shuddered and started to slide down the slips stem forwards.

"Suddenly a man leapt forwards, caught at the tow-lines and, in the twinkling of an eye, wound them round an iron stake driven into the ground. Running the risk of being crushed to pulp, he held on with a superhuman effort for some ten seconds before the tow-lines snapped. However this was enough, the *Trabacolo* barely grazed the yacht as it plunged into the water.

"The hero was none other than our old friend Matifou."

How astonished I imagine Jules Verne would have been had he known that one by no means has to be a giant with the "strength of a tiger" to do what Matifou did. Any resourceful person could do the same.

Mechanics tells us that a piece of rope wound around a drum produces when

sliding a great deal of friction, which increases in geometric progression to the increase, in arithmetic progression, of the number of turns. This means that even a little child could hold a tremendous load by means of a rope wound three or four times around a post. At river ports teen-agers use this method to bring to a halt boats with hundreds of passengers on board. It isn't superhuman strength, but friction that helps.

The famous 18th-century mathematician Euler established the proportion by which friction increases depending on the number of turns. For those undaunted by algebra's laconic lingo, here is Euler's most instructive formula, to wit: $F = fe^{ka}$, where F is the force against which we direct our effort f , e is the natural logarithm base 2.718..., k is the coefficient of friction of rope on stake, and α is the "angle of turns", or the ratio between the length of the arc covered by the rope to its radius.

Applying this formula to Jules Verne's case, we get a staggering result. In the case in question F is the vessel's pull as it slides down the slip. From the novel we know that the ship weighed 50 tons. Presuming that the tilt of the slip was 1/10, it was not the ship's full weight that bore down on the rope but only a tenth of it, i. e. five tons or 5,000 kg. Let us take k , the coefficient of the rope's friction on the iron stake to be 1/3. It is easy to find α , since we know that Matifou wound the rope around the stake only three times. In that case

$$\alpha = \frac{3 \times 2\pi r}{r} = 6\pi,$$

where r is the radius of the stake. Back now to Euler's formula to get the equation:

$$5,000 = f \times 2.72^{6\pi \times 1/3} = f \times 2.72^{2\pi}$$

whence f (the effort we must make) can be determined by using logarithms. Thus,

$$\log 5,000 = \log f + 2\pi \log 2.72$$

whence

$$f = 9.3 \text{ kg.}$$

So to hold the ship the giant had to pull at the rope with a force of only 10 kg.

Now don't think the 10 kg mentioned merely a theoretical figure and that actually you would have to exert a much greater effort. On the contrary, the figure is even greater than it should be because when you have a *hemp rope* wound around a *wooden stake*, the coefficient of friction k is bigger and your

effort f would be ridiculously small. All we must hope for is that the rope wouldn't snap from the strain. Then a little child, using a piece of the rope wound around a stake three or four times, could outvie Jules Verne's strong man.

WHY DO KNOTS HOLD?

In everyday life we often unsuspectingly derive advantages from *Euler's formula*. After all what is a knot if not a piece of twine wound around a small cylinder, the role of which in this case is played by another part of the same piece of twine? The strength of different knots, used by seamen or otherwise, depends exclusively on friction, which is enhanced several-fold by the string being wound around itself—just as the rope was wound around the stake. You can verify my statement by tracing the bends of a knotted string. The more bends, the greater the number of times the string is wound around itself, the greater the “angle of turns”, and, consequently, the firmer the knot.

A tailor unconsciously applies the same principle when he sews on a button. He winds the thread many times around the stitch through the cloth and then snaps it off. As long as the thread is strong enough the button will hold on. Again the familiar rule applies: the number of turns increases in arithmetic progression, while the strength, with which the button holds, increases in geometric progression. In the absence of friction we wouldn't be able to have buttons on our clothes, their weight would cause the thread to unwind and they would drop off.

SUPPOSING THERE WERE NO FRICTION

You have seen the varied, at times, unexpected ways in which friction exhibits itself. Friction, incidentally, is the star actor in cases where we don't even guess that it's there. If friction were suddenly to vanish, many things we are so accustomed to would go all awry.

The French physicist Guillaume has given us a very picturesque description of the role that friction plays:

“You have all happened to walk along icy pavements and no doubt remember how hard it was to keep your balance. How many funny jiggles you had to make! This makes us admit that the earth on which we live and walk usually has that precious property, thanks to which we keep steady without any particular effort. It's the same when we cycle along a slippery road or when a horse slips on asphalt and falls. It is by studying these things that we discover

the consequences of friction. Engineers try the best to rid machines of it and they're doing the right thing. In applied mechanics friction is regarded as most undesirable – and again quite rightly ... but for a very narrow special field. In all other cases we must be grateful to friction. It enables us to walk, sit and work unafraid that books and inkpots would slip off onto the floor or that tables would slide until they bumped into a corner, or that pens would slip out of our fingers.

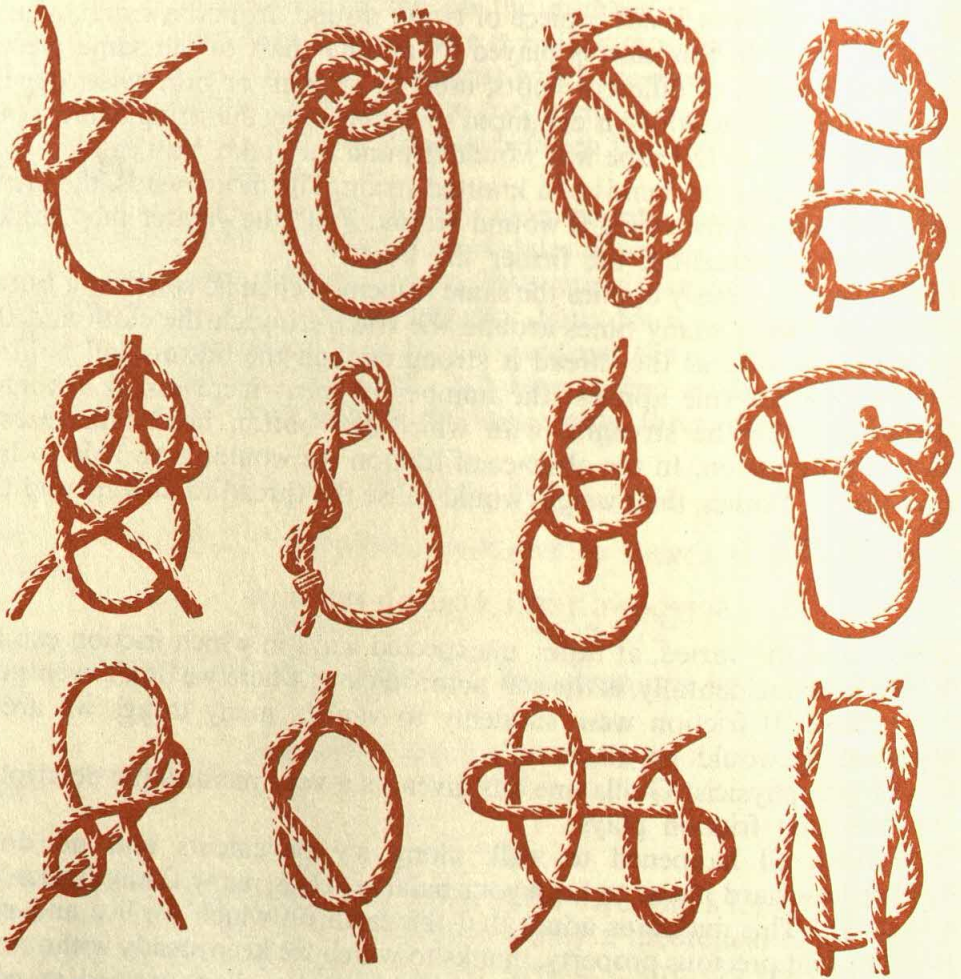


Fig. 152

"Friction is so common that with the exception of a few rare cases we never have to invoke it: it comes of its own accord. Friction makes for stability. Carpenters level floors so that tables and chairs stay put. All the crockery and glassware, we lay a table with, remain where they are without us having to worry about them, as long as we aren't on a ship tossing in a pitching sea. Now imagine we could get rid of friction completely. Then nothing, be it a huge slab of stone or a tiny grain of sand, would ever stay put. Everything would slide and roll until all bodies reached one and the same level. If we had no friction the earth would resemble a smooth ball, the shape of a drop of water."

Add to this that in the absence of friction nails and screws would slip out of walls, we wouldn't be able to hold a thing, no whirlwind would ever stop, and no sound would ever cease, continuing as an endless echo bouncing back from the walls of a room, for instance, without growing any weaker.

Icy pavements show us how tremendously important friction is. When we go out of doors in such weather, we find ourselves in a helpless plight: we are always afraid to fall. Here are some instructive newspaper clippings for December 1927:

"London, 21. Due to very icy weather street and tram traffic in London has been experiencing noticeable difficulties. Some 1,400 people have been hospitalized with fractures."

"The petrol burst into flames and completely destroyed three cars which had collided with two tramcars near Hyde Park."

"Paris, 21. There have been many accidents in Paris and its suburbs due to icy weather."

However, the negligible friction that we get on ice finds a good technical application. The ordinary sledge is one example. A still better instance was afforded by the so-called ice-ways made to haul felled timber to the railway station or rafting place. On such a road with rails of smooth, slippery ice two horses can pull a sledge carrying as much as 70 tons.

PHYSICAL CAUSES OF THE *CHELYUSKIN* DISASTER

I hope however, that I haven't made you jump at the conclusion that friction on ice is always negligible. Even at a near-zero temperature it can rather often be pretty great. A thorough study had been made of the friction of Arctic ice on the steel skin of icebreaker hulls. The coefficient proved to be unexpectedly big, 0.2, as much as the friction of iron on iron. To realize the importance of this coefficient for icebreakers, we shall examine Fig. 153, which shows the direction

of the forces acting on the hull MN , when ice is pressing against it. Force P , the ice's pressure, is resolved into two forces: R , which is perpendicular to the hull, and F , which is directed at a tangent to the hull. The angle between P and R is equal to the angle α of the side's inclination to the vertical plane. Force Q , the friction of ice on the hull, is equal to R multiplied by the coefficient of friction, 0.2, meaning that $Q = 0.2R$. When Q is smaller than F , the latter pulls the

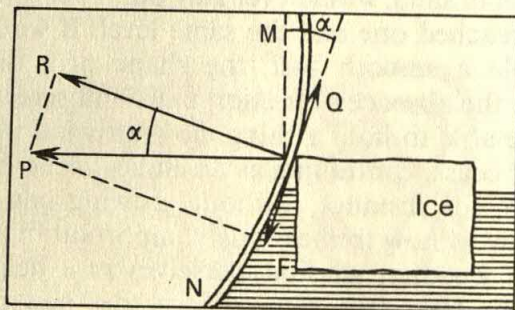


Fig. 153

Forces that act on the vessel's hull MN , when ice presses against it

pressing ice under the water, with the result that the ice slides alongside the hull without doing any damage. But should Q be greater than F , friction will prevent the ice from sliding alongside the hull and after some time the ice may dent and even crush the hull. When is Q less than F ? F is clearly equal to $R \tan \alpha$, consequently, we should have the inequality: $Q < R \tan \alpha$; and since $Q = 0.2R$, the inequality $Q < F$ yields another inequality:

$$0.2R < R \tan \alpha$$

or

$$\tan \alpha > 0.2.$$

Now we use the tables to find the angle, the tangent of which is 0.2: it is 11° . Consequently, Q is less than F where α is greater than 11° . This tells us what inclination of the sides to the vertical plane guarantees safe progress through ice. It must not be less than 11° .

Now back to the *Chelyuskin* disaster. This ship (it wasn't an icebreaker) successfully voyaged the entire Northern Sea Route but was jammed by ice in Bering Strait. The drifting ice carried the *Chelyuskin* northwards and finally crushed it (in February 1934). Many may still remember the two-month *Chelyuskin* Odyssey and the rescue of its crew by Soviet airmen.

Here is a description of the disaster itself. "The strong plating did not yield at once," expedition chief Otto Schmidt reported by radio. "We could see the ice pressing into the hull and the plates above it bulging. The ice pressed on, slowly but inexorably. The steel plates burst at the seam and all the rivets flew out. In an instant the port side was peeled off from prow to stern."

By now you ought to understand what caused the disaster. The conclusion is that the sides of ships built for voyaging in icy seas must have a minimum inclination of 11° .

SELF-BALANCING STICK

Balance a smooth stick on your outstretched forefingers as shown in Fig. 154. Now move your fingers towards each other until they come together. The stick still balances. You can repeat the trick, changing the initial position of your fingers, but the result will always be the same, whatever you use—a ruler, a walking stick, a broom, or a billiard cue. The stick balances.

Why?

First of all you must realize that since the stick balances when the fingers come together, they must consequently be right under the stick's centre of gravity (a body balances when the perpendicular from the centre of gravity falls within the supporting base). When the fingers are parted, a greater pressure is exerted on the finger closer to the stick's centre of gravity. The greater the pressure, the greater the friction. Consequently, the finger closer to the centre of gravity experiences a greater friction than the finger further away. That is why the finger closer to the centre of gravity does not slide beneath the stick. The finger that does slide is the one further away from the centre of gravity. As soon as one finger approaches the centre of gravity the other one begins to slide until, finally, the two fingers come together. As only one of the fingers, the one further from the centre of gravity, moves each time, it is only natural to see them eventually come together right beneath the stick's centre of gravity.

Repeat this experiment with a broom (Fig. 155, top). Then ask yourself: Suppose we cut the broom in half where it balances when the fingers come together, and place each piece on the scale pans (Fig. 155, bottom). Which would be heavier, that with the stick or that with the broom? You might think that since the two parts balanced before on your fingers they ought to balance again on the scales. Actually the pan with the broom is heavier. The answer is simple enough. Realize that when you balanced the broom on your fingers, the forces

exerted by the weights of both parts were applied to the unequal arms of a lever. On the scales, though, the same forces are applied to the two ends of an equal-armed lever.

For the "Science for Entertainment" pavilion in Leningrad's Recreation Park I ordered a set of sticks with differently situated centres of gravity. These sticks

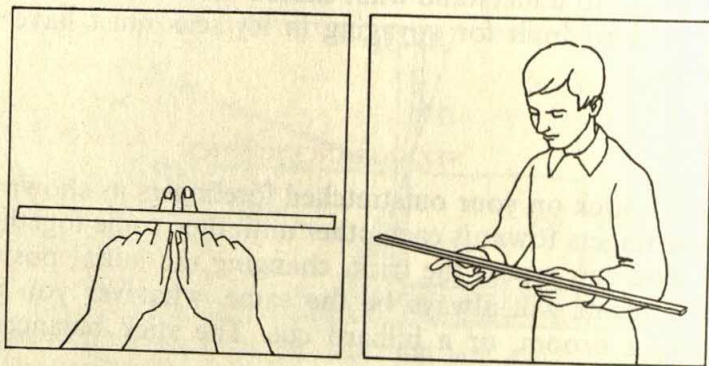


Fig. 154 Ruler experiment

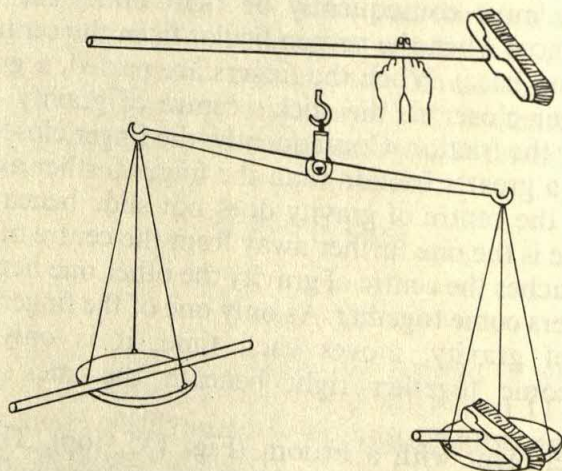


Fig. 155 Same experiment but with a broom. Why don't the scales balance?

could be unscrewed into two usually unequal parts, exactly at the centre of gravity. Visitors were surprised to see that when these two pieces were placed on scales the shorter part proved to be heavier than the longer one.

Chapter

Rotation

13

WHY DOES NOT A SPINNING TOP TOPPLE OVER?

Few of the thousands who have spun a top in their childhood will give, I imagine, the right answer. Indeed, why doesn't a gyrating top, be it upright or even inclined, topple over, as one might expect it to do? What is it that keeps it in its seemingly unstable position? After all wouldn't gravity affect it?

Here we have a rather curious interaction of forces. Now since the theory relating to the spinning top is no simple affair, I shan't bother to explain it but merely furnish the main reason.

Figure 156 depicts a top spinning in the direction designated by the two arrows. Pay heed to segment *A* and its opposite *B*. Segment *A* seeks to move *away from you* while segment *B* seeks to do the opposite. Watch how *A* and *B* move when you tilt the top *towards yourself*. *A* moves upwards and *B* downwards: the two segments receive an impetus at right angles to their own motion. But since in its rapid rotation the circumferential speed of the segments is very great, the insignificant speed that you impart to it will, when added to the great circumferential speed of a point, produce a resultant speed of practically the same value as that of the circumferential speed and thus the top's motion hardly changes. Now you will understand why the top seems to resist attempts to push it over. The greater the top's mass and the more rapidly it rotates, the greater the resistance it offers to efforts to topple it.

The explanation is directly linked with the laws of inertia. Every particle in the top moves along a circular orbit in a plane perpendicular to the axis of rotation. In conformity with the laws of inertia this particle seeks at every moment to veer off its circular orbit on to a straight line tangential to the orbit. However, since every tangential path is situated in the same plane as the circumference itself, every particle always tries to contain its motion within the plane perpendicular to the axis of rotation. This means that all planes in the top perpendicular to the axis of rotation try to stay put in their original position in space and that, consequently, the common perpendicular to them (the axis of rotation itself) also seeks to retain its original direction.

I shan't examine all the motions of the top that are produced when an

external force is brought to bear, as it would call for a too detailed, and hence, probably, boring explanation. I merely wish to tell you why every rotating body seeks to prevent the direction of its axis of rotation from changing.

This property is widely drawn upon in modern engineering. Navigators and airmen employ sundry gyroscopic devices such as compasses and gyroscopes that are all based on the gyroscope principle. Rotation imparts stability to shells

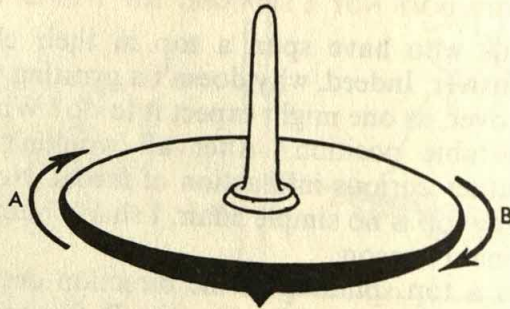


Fig. 156

Why doesn't the spinning top fall?

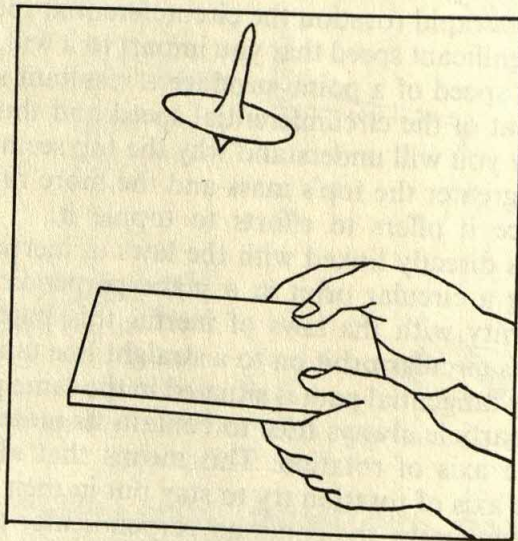


Fig. 157

A spinning top hit upwards retains the initial direction of its axis

and bullets and can also be drawn upon to ensure stability in flight in the case of such space vehicles as satellites and rockets. These are the advantages that are to be derived from what one would have thought just a simple toy.

JUGGLING

Many of the amazing and varied tricks that jugglers perform are also based on the property of rotating bodies to retain the direction of the axis of rotation. Let

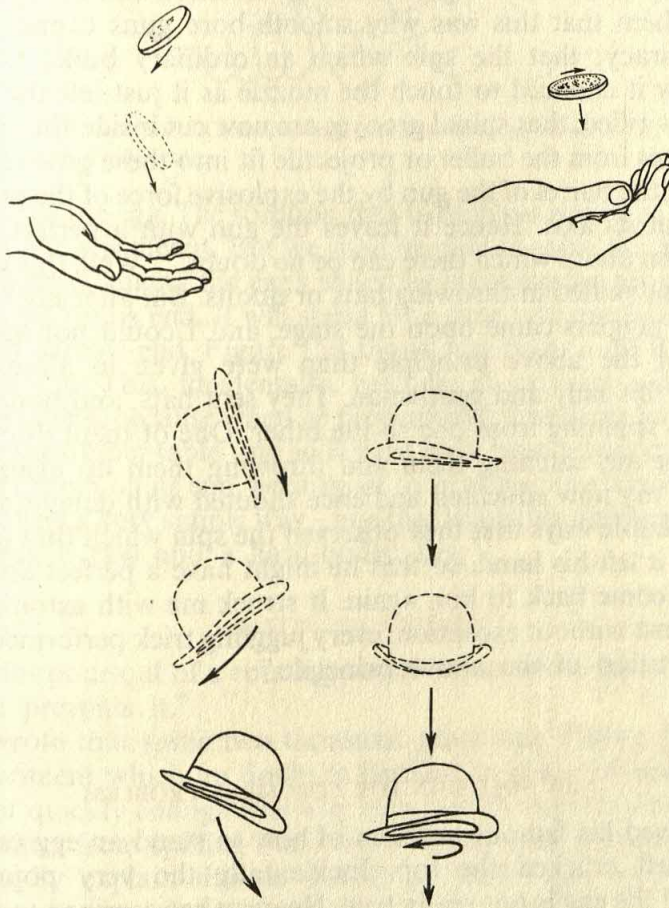


Fig. 158

You will catch the hat much more easily if you give it a twirl before throwing it up

me now quote from that fascinating book called *Spinning Tops* by Prof. John Perry, a British physicist.

"I once showed some experiments on spinning tops to a coffee-drinking, tobacco-smoking audience in that most excellent institution, the Victoria Music Hall in London.... I impressed my audience as strongly as I could with the above fact, that if one wants to throw a quoit with certainty as to how it will alight, one gives it a spin; if one wants to throw a hoop or a hat to somebody to catch upon a stick, one gives the hoop or hat a spin; the disinclination of a spinning body to let its axis get altered in direction can always be depended upon. I told them that this was why smooth-bore guns cannot be depended upon for accuracy; that the spin which an ordinary bullet took depended greatly on how it chanced to touch the muzzle as it just left the gun, whereas barrels are now rifled, that spiral grooves are now cut inside the barrel of a gun, and excrescences from the bullet or projectile fit into these grooves, so that as it is forced along the barrel of the gun by the explosive force of the powder, it must also spin about its axis. Hence it leaves the gun with a perfectly well-known spinning motion about which there can be no doubt. ... Well, this was all I could do, for I am not skilled in throwing hats or quoits. But after my address was finished ... two jugglers came upon the stage, and I could not have had better illustrations of the above principle than were given in almost every trick performed by this lady and gentleman. They sent hats, and hoops, and plates, and umbrellas spinning from one to the other. One of them threw a stream of knives into the air, catching them and throwing them up again with perfect precision, and my now educated audience shouted with delight and showed in other unmistakable ways that they observed the spin which that juggler gave to every knife as it left his hand, so that he might have a perfect knowledge as to how it would come back to him again. It struck me with astonishment at the time that, almost without exception, every juggling trick performed that evening was an illustration of the above principle."

NEW SOLUTION FOR COLUMBUS PROBLEM

Columbus solved his famous problem of how to stand an egg on its end very simply. He just cracked the top. Incidentally the very popular myth of Columbus and the egg is not really true. Hearsay has ascribed to the celebrated explorer what another man did much earlier and for a totally different reason. This was the Italian architect Brunelleschi who built the tremendous dome of

the Florentine Cathedral and who claimed that "My dome will keep in place just as reliably as this egg stands on its narrow end."

Actually Columbus' solution is all wrong. When he cracked the egg Columbus changed its *form*, which means that it was already not an egg but a different body that he caused to stand on its end. The crux of the problem lies precisely in the egg-shaped form. As soon as we change the shape, we substitute

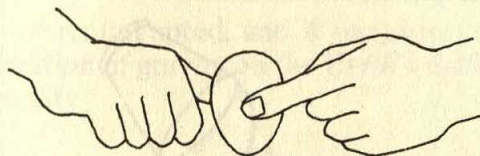


Fig. 159

How to solve Columbus' egg problem. The egg stands on its end when spun

another body for the egg. The solution that Columbus provided is really not for the body which it was meant. But we shall be able to solve the great navigator's problem without changing the egg's shape by invoking the property of the top. Just spin the egg on its end. It will stand for a time without falling down on its broad or even narrow end. Figure 159 shows you how to do it. Be sure to use only a boiled egg. This, incidentally, can't be at variance with the terms of Columbus' problem, because when he propounded it he must have taken an egg straight from the dinner table, and so it must have been a boiled one. You won't get a raw egg to spin on its end, because of its brake-acting liquid contents. This incidentally offers a very simple way—one that many housewives know—of how to tell between a raw and a hard-boiled egg.

GRAVITY "DESTROYED"

"Water will not pour out of a rotating vessel—even when the vessel is bottoms up. Rotation prevents it."

Aristotle wrote that some two thousand years ago. Figure 160 depicts this effective experiment which no doubt is familiar to many of you. If you swing a pail of water quickly enough (the way shown in the figure) you will be able to prevent the water from spilling out, even when the pail is turned bottoms up.

People usually explain this as due to a "centrifugal force", which they understand as an imagined force supposedly applied to the body and responsible for its tendency to shoot away from the centre of gravity. This "force" is nonexistent; the tendency mentioned is nothing else than

a manifestation of *inertia* and every inertia-caused motion needs no force to get it going. Physicists understand the centrifugal force as something entirely different—as the actual force with which a rotating body pulls at a string holding it or presses against its curvilinear orbit. This force is applied not to a moving body but to the *obstacle* that prevents it from moving rectilinearly—a string, the rails of a curved track section, etc.

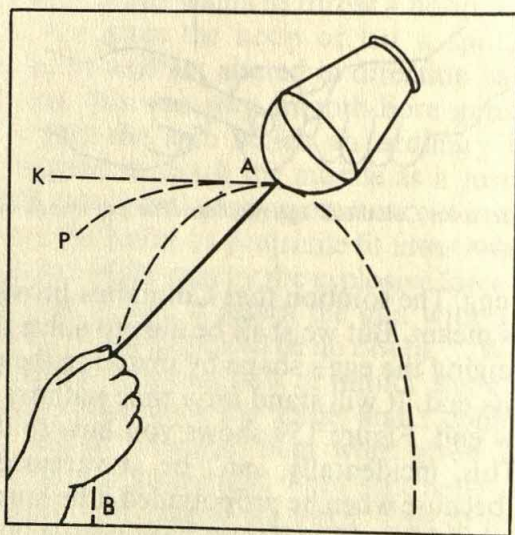


Fig. 160

Why doesn't the water spill out?

Back now to our swinging pail. Let us see if we can find the reasons for this phenomenon, without resorting at all to the ambiguous conception of the “centrifugal force”. Ask yourself: If I make a hole in the pail, in which direction will the water spurt out? If there were no force of gravity it would, by inertia, spill out at the tangent AK to the circumference AB (Fig. 160). Gravity however will make it bend to describe the parabolic curve AK . If the circumferential speed is large enough, the curve will lie outside the circumference AB , showing the direction the water in the swinging pail would take, were it not obstructed by the pail. That shows you that the water does not at all seek to move vertically downwards, which is why it doesn't spill out. It would spill out only if the top of the pail were to face in the direction of its rotation.

Reckon now the speed with which we must rotate the pail so that the water would not spill down. The centripetal acceleration of the rotating pail must be

no less than the acceleration of gravity. Then the path which the water in the pail will seek to follow will lie outside the circumference described by the pail and at no point will the water lag behind the pail. The formula we must employ to calculate the centripetal acceleration W is

$$W = \frac{v^2}{R},$$

in which v is the circumferential speed, and R the radius of the circular orbit. Since the surface acceleration of gravity on the Earth's surface is $g = 9.8 \text{ m/sec}^2$, we thus get the inequality

$$\frac{v^2}{R} \geq 9.8$$

Presuming that R is equal to 70 cm,

$$\frac{v^2}{0.7} \geq 9.8 \text{ and } v \geq \sqrt{0.7 \times 9.8}; v \geq 2.6 \text{ m/s.}$$

To obtain a circumferential speed of this order we must make about one and a half turns every second. This is quite feasible. Our experiment will cause us no particular difficulty.

Engineers draw on the tendency of liquids to press on the walls of a vessel in which they are rotated around a horizontal axis, for what is called *centrifugal casting*. The essential point here is that a heterogeneous liquid stratifies according to specific gravities, with the heavier and lighter components disposing themselves respectively further away from and closer to the axis of rotation. As a result all the gases that molten metal contains and which produce blowholes, seep out into the casting's central hollow channel. Castings produced by this method have good structure and density and are free from blowholes. The method is cheaper than ordinary pressure die casting and requires no intricate equipment.

YOU AS GALILEO

People who like heavy sensations may derive some amusement from a very original attraction called the "devil's swing". There was one in Leningrad once. Since I never tried it, I shall take the liberty of quoting from Fedo's collection of scientific amusements to describe it.

"The swing is suspended to a firm horizontal bar spanning the room at

a certain height from the floor. After everybody has taken his seat the attendant locks the door, removes the board used to mount the swing and, after telling the people on it that he will now take them on a short air trip, gives the swing a push. Then he stands at the back very much like a footman on a carriage, or goes out. Meanwhile the swing goes higher and higher until it finally describes a full circle. The swing goes faster and faster, quite noticeably, and the people on

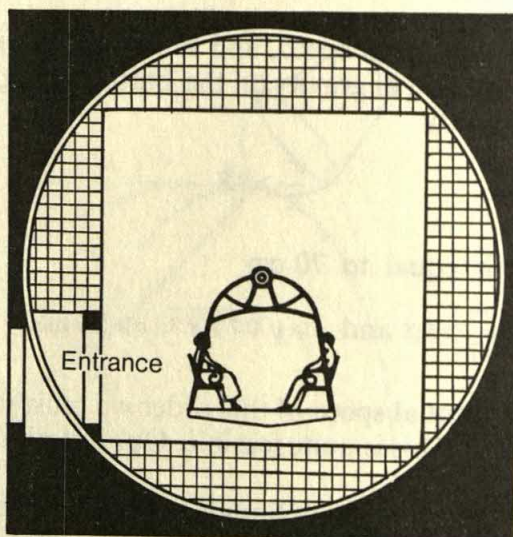


Fig. 161 Devil's swing

it experience an unquestionable sensation—even though most were forewarned—thinking themselves to be flying through space upside down and involuntarily grip at their seats so as not to fall out. Then the swinging diminishes until the swing finally comes to a complete halt a few seconds later.

“Actually the swing was *stationary all the time*. It was the room itself which with the aid of a very simple mechanism was made to revolve around the people seated on the swing. Pieces of furniture are attached to the floor or walls. The lamp, welded onto the table so as to turn easily, had an electric bulb shielded by a large shade. The *attendant* who seemed to be pushing, actually did no more than to make the swinging accord with the room's slight oscillations and only pretended to be pushing. The entire setting makes for a very successful deception.”

As you see the secret is as easy as pie. But I am sure that you succumb to the

illusion even though you now know all about it because it is so strong.

Pushkin has a little poem called "Motion":

*"There is no motion"—quoth the bearded sage.**

*His interlocutor** in answer started walking;*

An apt reply—more eloquent than talking

Or mincing words upon the printed page.

However, gentlemen, that most amusing case

Reminds me of another, somewhat trite;

Although the Sun seems moving on clear days,

Yet it was stubborn Galileo who was right.

Among the people seated on the swing and not initiated into its secrets you would be a Galileo—only in reverse. While Galileo argued that the sun and stars were stationary and that we ourselves were revolving around them contrary to appearances, you would argue that the swing was stationary and that the entire room was revolving around it. Most likely you too would experience Galileo's sad lot, and would be regarded as a decrier of the seemingly self-obvious. ...

TAKE UP THE POINT WITH ME

Do you think it will be easy for you to prove your point? If you do, you're mistaken. Suppose you are seated on the "devil's swing" and want to convince your neighbours that they are labouring under a delusion. I suggest you take up the point with me. Before we begin, let us wait until the swing seems to be describing a full circle. There is one condition: you must stay seated on the swing while we argue. We'll take everything we need in advance.

You: How can you doubt that it is the room which is revolving and that we are stationary? After all, if our swing really turned upside down, we would fall out. We certainly couldn't hang in the air upside down. But since we aren't falling out, that means that it is the room which is turning and not the swing.

I: Remember the water in the rotating pail. It didn't spill out, did it, even though the pail was upturned? Or take the cyclist in the "looping the loop" attraction. He doesn't fall either, even though he rides with his head upside down.

* The Greek philosopher Xenon, who lived circa 500 B.C. and who claimed that everything in the world was stationary. "We thought things were moving," he alleged, "only because of deceptive sensory illusions."

** Diogenes.

You: Let us then figure out the centripetal acceleration to see whether it is big enough to prevent us from falling out. Since we know how far away we are from the axis of rotation and how many turns we are making each second, we can easily deduce from the formula. ...

I: Don't bother. The attendant told me that we would be making quite enough turns to explain the whole thing as I say. So, whether you figure it out or not, it won't help.

You: But I haven't lost hopes of convincing you. As you see, the water in the glass doesn't spill out. But, I suppose, you will again refer to the rotating pail. Go ahead. I have a plumb-line here, and I see that it points down all the time. If we were rotating and the room were stationary, the plumb-line would swing with us as it would always point down.

I: You are mistaken. If we were rotating fast enough the plumb-line ought to be thrust away from the axis all the time in the direction of the radius of rotation, or, in other words, it should point at our feet. And that is exactly what it does.

HOW TO CLINCH THE ARGUMENT

This is what you should do to convince your opponents. Take a spring balance with you when you seat yourself on the swing, place a weight of one kilogramme, say, on its pan, and watch the pointer. The fact that it will remain constant proves your point.

After all, if we were indeed circling about the axis together with the spring balance, the weight would be affected, apart from the force of gravity, also by the centrifugal force, tending at the bottom to add to and at the top to subtract from, the weight. But since the balance pointer remains constant, the weight neither *increasing* nor *reducing*, consequently, it's the room that is turning and not we ourselves.

"BEWITCHED BALL"

One enterprising American started at a public amusement park an extremely interesting and instructive merry-go-round. The people who went into this revolving ball-shaped room experienced sensations which one would come across only in the Land of Nod, or in a fairy-tale world.

First recollect what happens to you when you find yourself standing on the edge of a fast spinning round platform. The rotation tries to send you flying off; and the further away you are from the middle of the whirligig the more of a "push" you get. Now shut your eyes. You seem to be balancing with difficulty

on an inclined – not horizontal! – plane. Why? Let us see what forces act on our body in this particular case (Fig. 162). Rotation tries to throw us off while gravity pulls us down. The two forces combine (according to the rule of the parallelogram) to produce a resultant *inclined downwards*. The faster the spin, the bigger the resultant and the more obtuse the angle.

Imagine now that the edge of the platform is tipped upwards and that you are

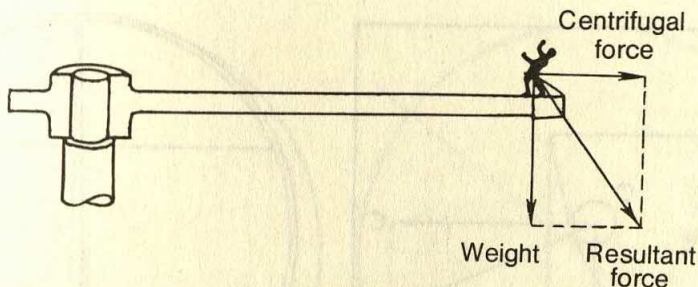


Fig. 162

What one would feel on the edge of a revolving platform

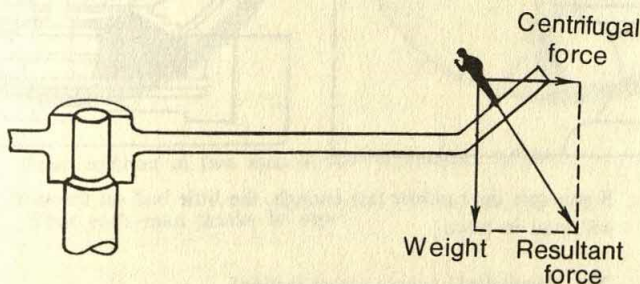


Fig. 163

You won't fall standing on the inclined edge of a revolving platform

standing on it (Fig. 163). When the platform isn't moving you won't be able to stand there: you will surely slide down or even fall. But it will be quite different for you when the platform is rotating. Then, provided the platform is spinning quickly enough, this inclined plane will seem horizontal to you because the resultant force of the centrifugal push and gravitational pull will likewise be inclined, only now at right angles to the tipped edge. (This, incidentally, explains why on curved sections of railway track, the outer rail is a bit higher than the inner one. This also explains why racing tracks are steeped inwards and why racers are able to drive along a heavily inclined circular wall.)

If you curve up the edge of the whirligig so that, at a definite speed, *every* surface point of it will be at right angles to the resultant force the person standing on it will think he is on a flat floor, wherever he is. Mathematicians have found this curved surface to be that of a geometrical body called a *paraboloid*. One can produce it by quickly twirling a glass half full of water around a vertical axis. In this case the water at the rim will rise while that in the

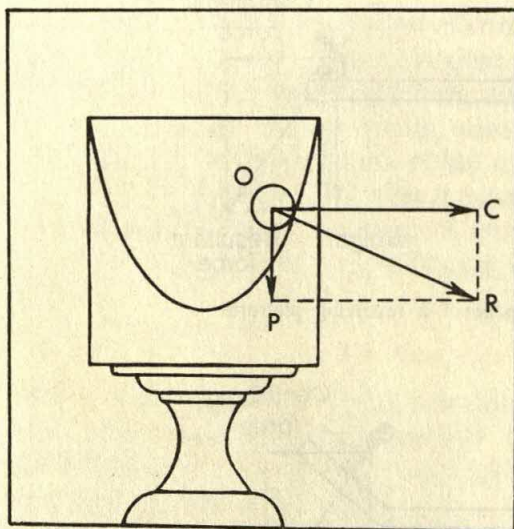


Fig. 164

If you spin the tumbler fast enough, the little ball on the side will stay in place

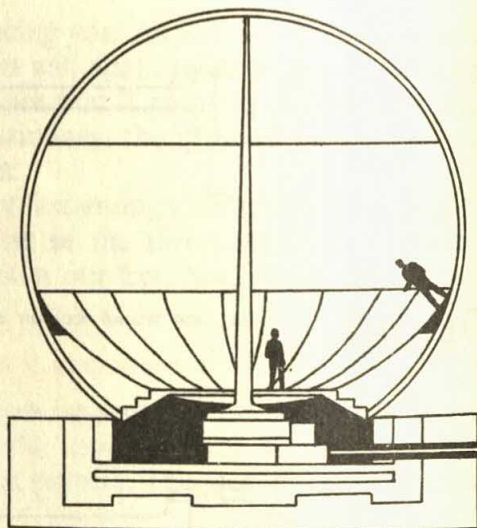


Fig. 165

The "bewitched" sphere (cross-section)

centre will sink, with the result that its surface will assume the form of a paraboloid. If we were to use some molten wax instead of water and spin the glass until the wax set, we would get an exact paraboloid. When twirled at a definite velocity, the surface of such a solid would present a horizontal plane, and a little ball on it would not roll off but stay put (Fig. 164), wherever placed.

Now you will easily understand how the "bewitched" sphere is designed. Its bottom (Fig. 165) is a large revolving platform shaped as a paraboloid. Though spun very smoothly by means of a concealed mechanism, the people inside would feel their heads go into a whirl if the furnishings of the "sphere" room were not spinning together with them. To make you think that the platform isn't

moving, it is placed inside a large opaque sphere twirling around as fast as the platform itself.

Now what would you see and feel inside it? When it rotates, the floor under your feet would seem flat wherever you stood: on the axis itself where the floor is really horizontal, or at edge, where it is inclined at 45° . Your eye clearly sees the concavity of the floor but your muscles make you feel that you are standing

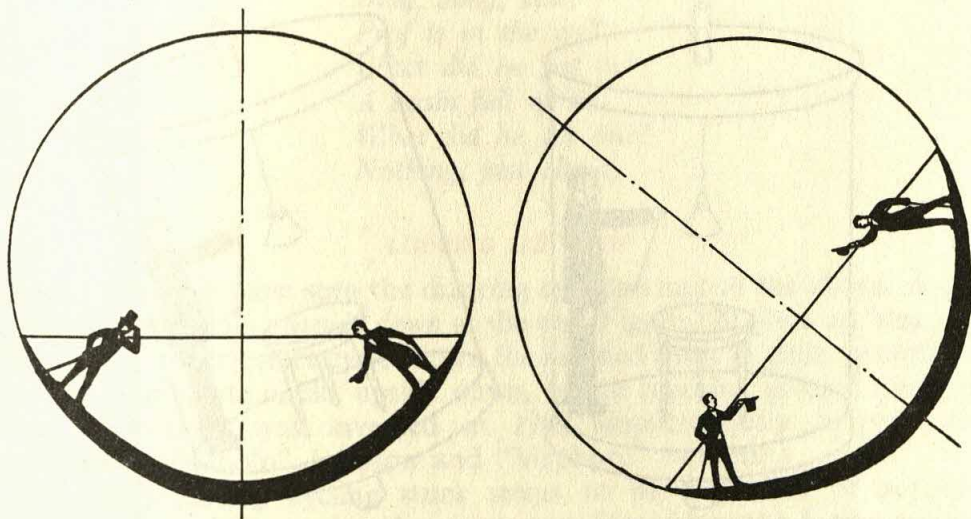


Fig. 166

True position of two men in the "bewitched" sphere

Fig. 167

What each man thinks he sees

on an even flat floor. What the two senses register is most contradictory. When you walk from edge to edge of the platform it will seem to you as if the entire sphere had swung over under your weight with the ease of a soap bubble, despite its enormity. While you will think you are standing on a flat floor all the time, the other people in this "bewitched" sphere will seem to be crawling up and down the walls like flies (Figs. 166 and 167). Water spilled on the floor would spread out evenly over its concave surface and you would think that you had before you an inclined wall of water.

All your habitual notions of gravity would be gone. An airman making a turn would experience the same. Flying at a speed of 200 km/h along a curved route with a radius of 500 m he would see the ground "loom" and tip at an angle of 16° .

In the German city of Goettingen a similar rotating laboratory was built for scientific purposes. This was a cylindrical room (Fig. 168) 3 m across, which did 50 revolutions per second. As its floor was flat the observer standing by its wall thought that the spinning room had leaned backward and that he himself was half lying on an inclined wall (Fig. 169).

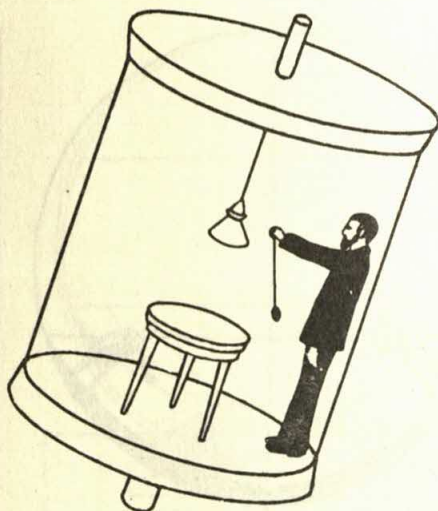
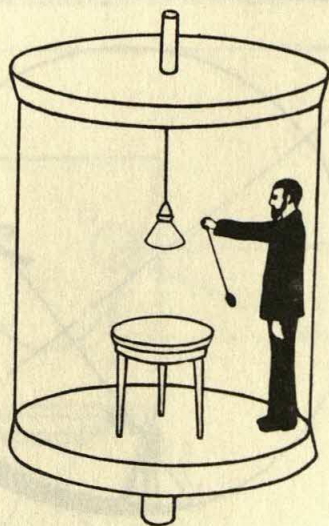


Fig. 168

Spinning laboratory. True position

Fig. 169

Spinning laboratory. Apparent position

LIQUID TELESCOPE

The best kind of mirror for a reflecting telescope is a parabolic one, precisely the form the surface of a liquid assumes in a twirling vessel. Telescope designers take great pains to produce a mirror of this shape, devoting years on end to its manufacture. The American physicist Wood got round the difficulty by devising a liquid mirror. He spun mercury around in a wide-mouthed vessel and obtained an ideal parabolic surface which could well act as a mirror since mercury excellently reflects light. Wood mounted the telescope in a shallow well. The driving belt was used to rotate the vessel containing the mercury and the reflection of Wood's face. The telescope, however, had its drawbacks. The slightest jolt wrinkled the liquid mirror's surface and distorted the image.

Despite its tempting simplicity Wood's mercury telescope failed to find practical application. Neither the inventor himself nor contemporary physicists took it seriously. Here, for instance, is a note that A. G. Webster, the head of the physics department of one American university, jotted down after he had seen this original device:

*Ding, dong, bell,
Prof is in the well,
What did he put in?
A basin full of tin.
What did he get out?
Nothing, just about.*

LOOPING THE LOOP

Some of you may have seen the dizzying cycling stunt at the circus. A cyclist loops the loop, riding *upside down* at the top. Figure 170 gives an idea of this attraction. The performer cycles down the inclined track to glide up swiftly and describe a complete circle, upside down, before reaching ground safely once more. (The stunt was invented in 1902 simultaneously by two circus performers—"Diabolo" Johnson and "Mephisto" Noisette.)

This brain-teasing cycling stunt seems to be the acme of acrobatics. Perplexed, the public wonder what mysterious force keeps the daring performer from falling down and breaking his neck. The sceptics suspect a cunning ruse. But there is really nothing supernatural about it all. Mechanics provides a beautiful explanation. A billiard ball rolling down the same track would perform the trick just as well. At school physics labs you might come across baby "loop-the-loops".

To test the stability of the entire arrangement "Mephisto", the cycling celebrity, had used a heavy iron ball of the same weight as he himself plus the bicycle. Only if everything went well did he risk the stunt himself.

You will have guessed by now, of course, that this odd stunt is based on the same principle as that underlying our earlier experiment with the spinning pail of water. To safely shoot the danger zone at the top of the loop the cyclist must work up the adequate speed which depends on the height from which the cyclist takes off. The least allowable speed depends on the radius of the loop itself. This tells you why the stunt doesn't always work out. One must compute accurately enough the height for the take-off, because otherwise the cyclist may break his neck.

CIRCUS MATHEMATICS

I very well know that a string of what would seem dry formulas, "as dry as dry could be," will scare away some lovers of physics. But shunning the mathematical aspect, such people simply rob themselves of the pleasure they might derive by predicting the course of events and determining the conditions

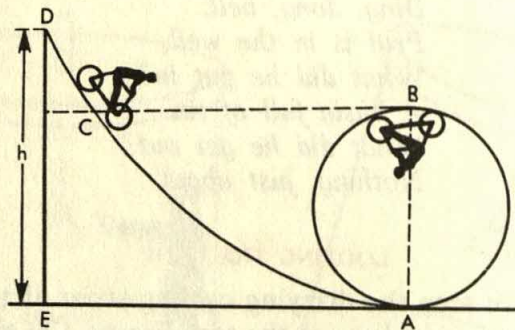


Fig. 170

Looping the loop, computation diagram

required. In the case in question I believe a couple of formulas or so will be quite enough to determine with sufficient accuracy the conditions required to perform successfully such a sensational stunt as the "loop-the-loop".

Here they are. First of all let me designate the values we shall have to deal with. Thus h will be the *height* of the cyclist's take-off, x — the part of h above the top point of the loop. Figure 170 shows us that $x = h - AB$, r is the radius of the loop itself, m is the total *mass* of the performer together with his bicycle (their weight will be expressed as mg , with g being the *acceleration of gravity* which is known to be 9.8 m/sec) and, finally, v the *speed* of the cyclist at the top of the loop.

We can put together two equations from all these values.

(1) Since we know from mechanics that the bicycle's speed at point C of the inclined track, which is at the same level as B (this is the position at the bottom of Fig. 170) is equal to its speed at point B at the top of the loop, our first speed is expressed (we may disregard the energy of the spinning rims of the bicycle wheels as it scarcely affects the result at all) $v = \sqrt{2gx}$ or $v^2 = 2gx$; consequently, the cyclist's speed v at point B is equal to $\sqrt{2gx}$, that is $v^2 = 2gx$.

(2) To prevent the cyclist from falling on reaching point B centripetal acceleration must be greater than the acceleration of gravity or, in other words,

$v^2/r > g$, $v^2 > gr$ and since we know that $v^2 = 2gx$, consequently, $2gx > gr$ or $x > r/2$.

So to successfully perform this perplexing stunt the top segment of the inclined section of the track must be higher than the top point of the loop by more than half its radius. The angle at which the track is inclined is not important. The important thing is that the take-off point be more than a quarter of the loop's diameter higher than the highest point of the loop. For a loop of 16 m in diameter the cyclist must start from a height of at least 20 m. If he doesn't he simply won't be able to loop the loop, falling down before he reaches its highest point.

Note that we have disregarded the effect of friction on the bicycle, and consider the speeds at points *C* and *B* identical. For that reason we must not make the track too long or sloping, as then, due to friction, the speed the bicycle will have by the time it reaches point *B* will be less than at point *C*.

Further note that for this stunt the cyclist does not pedal, letting the machine gather momentum by itself. He cannot and must not accelerate or decelerate his motion. All he must do is to stay in the middle of the track as the slightest deviation may toss him off. The speed with which he loops the loop is great. In the case of a 16-m loop, the cyclist will do the loop in three seconds—the equivalent of a speed of 60 km/h. It is of course hard to steer a bicycle moving with such a great speed. Actually the cyclist doesn't have to worry about that: he may safely trust the laws of mechanics. "In itself this cycling stunt," a booklet by a professional cyclist tells us, "presents no hazard, provided the arrangement is sturdy and correctly designed. The cyclist himself is the sole hazard. Should his hands shake, should he grow excited and lose his head or should he go giddy all of a sudden, anything might happen."

The famous "Nesterov loop" and other aerobatic tricks are likewise based on the same principle. Of paramount importance in looping the loop is the airman's skilful piloting and adequate starting speed.

"SHORT WEIGHT"

A certain crank once said that he knew how to "short-weight" customers without cheating them. His idea was to buy goods at the equator and sell them nearer to the poles. It has long been known that at the equator things weigh less than they do at the poles. An article weighing one kilogramme at the equator would weigh five grammes more at the poles. One, however, must use not the ordinary type of scales but a spring balance which would furthermore be made

or rather calibrated at the equator. Otherwise one would derive no advantage at all. The article would grow heavier, but so would the weights used in weighing. If we buy a ton of gold in Peru and sell it in Iceland we can make a profit of sorts—provided transportation is free.

Now though I don't think anyone could line his pocket by trading in this fashion, actually our crank was right. Gravity does really increase the further away we get from the equator. This takes place because at the equator due to the earth's rotation, bodies describe the biggest circles and also because at the equator the earth bulges as it were. However the main reason for "short weight" is the earth's rotation. It is this that makes an article weigh at the equator $1/290$ th less than at the poles.

The difference in weight when transporting a light article from one latitude to another is negligible, but in the case of extremely heavy objects it may be rather impressive. I suppose you never knew that a train weighing sixty tons in Moscow grows 60 kilogrammes heavier when it reaches Arkhangelsk and sixty kilogrammes lighter when it gets to Odessa. There was a time when Spitzbergen shipped as much as 300,000 tons of coal every year to southern ports. Were this amount delivered to some equatorial port, one would have found himself 1,200 tons short—naturally, provided the load were reweighed on delivery by means of a spring balance brought from Spitzbergen. A battleship that weighs 20,000 tons in Arkhangelsk becomes some 80 tons lighter in equatorial waters. We never notice this, however, because everything else, including the water in the ocean too, grows correspondingly lighter. That, incidentally, is why a ship draws the same water at the equator as in the Arctic Ocean: though it becomes lighter, the water it displaces grows lighter by exactly the same amount.

If the earth were to rotate faster than it does now—in other words, if we had a day of not 24 hours but only of 4—the difference in the weight of articles at the equator and at the poles would be much more pronounced. In that case a weight of one kilogramme at the poles would weigh only 875 grammes at the equator. This is roughly the sort of conditions we have on the planet Saturn: near its poles all objects weigh one-sixth more than they do at its equator.

Since centripetal acceleration increases in direct proportion to the square of velocity we shall easily be able to figure out how fast the earth should rotate at the equator for this centripetal acceleration to increase by 290 times or, in other words, balance the force of gravity. This would take place if the earth rotated nearly 17 times faster than now (17 times 17 is almost 290). Then bodies would no longer exert any pressure and *would weigh nothing*. On Saturn the same thing would happen, if it rotated but 2.5 times faster than now.

Chapter 14

Gravitation

IS THE FORCE OF GRAVITY SIGNIFICANT?

“Were we not to see falling bodies every minute, we would count it a most surprising thing,” wrote the famous French astronomer Arago. By force of habit we regard gravity, the attraction the Earth has for everything on it, natural and common. But when we are told that objects also attract *each other*, we can hardly believe it, since, generally, we never notice it.

Why is it, indeed, that the law of gravitation does not manifest itself always? Why do we never see tables, water-melons, or people attracting one another? Because for small objects the force of attraction is exceedingly small. Here is a graphic instance. Two persons at a distance of two metres apart do pull at each other. But the force exerted is minute, being under 0.01 mg for people of average weight. In other words, two persons pull at each other with the same force that a 0.00001-gramme weight exerts on the scale pan. Only the extremely sensitive type of scales that scientists use in their laboratories will be able to register such a tiny weight. It goes without saying that this force will never affect us, being completely offset by the friction between our soles and the floor. To push a person standing on a wooden floor—where the friction between his soles and the floor is equivalent to 30 per cent of his weight—you must exert a force of at least 20 kg. And to compare that with the negligible pull of the hundredth of a milligramme is simply ridiculous. A milligramme is a thousandth of a gramme: a gramme is a thousandth of a kilogramme, consequently 0.01 mg is exactly half of a *thousand millionth* of the force needed to pull a person away. Small wonder that in ordinary circumstances we never notice the mutual attraction that exists between objects.

But if friction were nonexistent, there would be nothing to prevent even the faintest of pulls from bringing bodies together. In our case of a force of 0.01 mg, however, the *speed* with which the two persons would gravitate towards each other would be negligible. In the absence of friction two persons, 2 metres apart, would draw closer to each other by 3 cm in the first hour, by 9 cm in the next hour, and by 15 cm in the third hour; as you see, speed increases, the closer the

two draw together, nevertheless it would take another five hours before the two persons would be drawn together.

Gravity is evident in cases when friction presents no obstacles, or, in other words, in the case of bodies at rest. It will act on a weight hanging on a piece of thread, causing it to dangle vertically down. However should there be some massive object hard by, it will pull the weight towards itself, making the thread

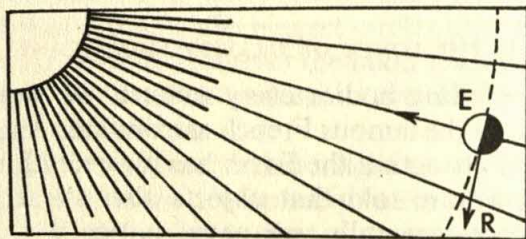


Fig. 171

Sun's pull curves the earth's (E) trajectory. Inertia would make the earth strike off at the tangent ER

deviate slightly from the vertical in the direction of the resultant between gravity and the pull of the massive object. This was first observed by Maskelyne in 1775 near a big mountain in Scotland. He compared the deflection of the plumb-line with the direction towards the celestial pole on either side of the mountain. Subsequent more elaborate experiments conducted with the aid of specially devised scales, enabled scientists accurately to gauge the force of gravity.

The force of attraction between small masses is negligible. As the masses increase, so does the force of attraction accordingly, in direct proportion to their product. Many, however, are prone to exaggerate this force. A certain scientist (true, not a physicist but a zoologist) tried to assure me that the frequently observed mutual attraction between ships at sea was due to gravitation. A reckoning will show at once that gravitation has no share in it. Two 25,000-ton battleships will attract each other with a force of only 400 g, when they are 100 metres apart. This is naturally far too little to cause the ships to move. We shall explain the real cause of this mysterious affinity between ships in the next chapter but one, dealing with the properties of liquids.

Though negligible in the case of small masses, gravitation proves to be quite a force when we have to do with the colossal masses of the celestial objects. Even the distant planet of Neptune, right out on the rim of the solar system attracts the Earth towards itself with a force of 18 million tons. Despite the tremendous distance between us and the Sun, it is only gravitation that keeps

the Earth from straying off its orbit. Were the Sun to cease exert its attraction, this planet of ours would dash off at a tangent to its orbit to race headlong into the infinite reaches of space.

STEEL EARTH-SUN CABLE

Imagine for a while that the Sun's powerful attraction had indeed ceased to exist and that the Earth was faced with the fantastically horrible prospect of being lost in the bleak and murky depths of the universe. Imagine further that a group of engineers had found a way of saving the situation, that they had thought of substituting for the invisible "hawser" of gravitation a sturdy steel cable that would keep the earth on its round-the-Sun orbit. After all what could be stronger than steel which can stand a pull of 100 kg to every sq mm? Suppose you have a thick steel column five metres across. Since its cross-section has an area of 20,000,000 sq mm, this column will break only under a weight of 2,000,000 tons. Suppose next that this column would stretch all the way from the Earth to the Sun and be clamped down firmly at both ends. Do you know how many of these columns would be needed to hold the Earth on its orbit? One million million! To get a clear picture of this dense forest of steel columns studding all the continents and oceans let me add that if they were evenly distributed over that side of the earth turned towards the sun, the space between two neighbouring columns would scarcely be any larger in area than the column itself. When you think of the force that one would need to break this vast jungle of steel columns you will finally realize how mighty is the invisible force that attracts the Earth to the Sun.

This stupendous force manifests itself by curving the Earth's path, swinging it away from a tangent by 3 mm every second. That is the only reason why the Earth travels along a locked elliptical orbit. Isn't it amazing to think what a gigantic force is required to shift the Earth merely by 3 mm (the height of this line) every second? This just shows you how tremendous the Earth's *mass* is, if such a monstrous force is able to shift it only by 3 mm.

CAN WE RID OURSELVES OF THE FORCE OF GRAVITY?

We have just been wondering what would happen were there no mutual attraction between the Sun and the Earth I told you that in that particular case the Earth, having shaken off the invisible chains of attraction, would race headlong into the depths of the universe. What would happen to us and

everything around us here on our planet, if the force of gravity suddenly disappeared? There would be nothing to pin us down and so the slightest push would send us hurtling out into space. We really wouldn't even need a push, since the Earth's rotation would be quite enough to hurl into space every feebly cohering thing.

H. G. Wells chose this as the theme for his novel *The First Men in the Moon*, in which, describing a fantastic journey to the Moon, he produced a very original and clever means for interplanetary travel. Wells' main character is a scientist who invents a special alloy with the curious property of being impervious to forces of gravity. When a screen, made of this alloy, was placed between the earth and an object, the planet's pull was rendered null and disappeared and the object was immediately attracted by other bodies. Wells called this alloy Cavorite after the name of its fictitious inventor.

"Now all know substances are 'transparent' to gravitation. You can use screens of various sorts to cut off the light or heat, or electrical influence of the Sun, or the warmth of the Earth from anything; you can screen things by sheets of metal from Marconi's rays, but nothing will cut off the gravitational attraction of the Sun or the gravitational attraction of the Earth. Yet why there should be nothing is hard to say. Cavor did not see why such a substance should not exist, and... he believed he might be able to manufacture this possible substance opaque to gravitation....

"Any one with the merest germ of an imagination will understand the extraordinary possibilities of such a substance. ... For example, if one wanted to lift a weight, however enormous, one had only to get a sheet of this substance beneath it and one might lift it with a straw."

Using this wonderful alloy, Cavor and his friend built a spaceship on which they undertook a daring journey to the Moon. Their vehicle was a very simple affair: it had no engine, being propelled solely by the gravitational attraction of the celestial bodies. Wells describes the spaceship as follows:

"Imagine a sphere, large enough to hold two people and their luggage. It will be made of steel, lined with thick glass; it will contain a proper store of solidified air, concentrated food, water distilling apparatus, and so forth, and enamelled, as it were, on the outer steel—Cavorite. The inner glass sphere can be airtight, and, except for the manhole, continuous, and the steel sphere can be made in sections, each section capable of rolling up after the fashion of a roller blind. These can easily be worked by springs, and released and checked by electricity conveyed by platinum wires fused through the glass. All that is merely a question of detail. So you see, that except for the thickness of the blind rollers,

the Cavorite exterior of the sphere will consist of windows or blinds, whichever you like to call them. Well, when all these windows or blinds are shut, no light, no gravitation, no radiant energy of any sort will get at the inside of the sphere, it will fly on through space in a straight line, as you say. But open a window, imagine one of the windows open. Then at once any heavy body that chances to be in that direction will attract us. ...

“Practically we shall be able to tack about in space just as we wish.”

HOW CAVOR AND HIS FRIEND FLEW TO THE MOON

Wells furnishes a very interesting description of the spaceship's departure. The vehicle's thin outer skin of Cavorite renders it completely weightless and thus able to shoot up to the top of the ocean of air—much like a cork released at the bottom of a lake. It then continues further (don't forget the inertia of the Earth's rotation!) on its free flight through space beyond the boundary of the atmosphere. When Cavor and his friend found themselves in space they manipulated shutters and drew on the gravitational attraction now of the Sun, now of the Earth, and now of the Moon, until they finally reached our satellite. Later on one of the travellers returned to the Earth in the same projectile.

In this book I shall not bother to analyze Wells' project. Let us, on the contrary, take Wells' story at its face value for a time and go with Cavor and his friend to the Moon.

LUNAR HALF-HOUR

What did they experience in a world with a force of gravity that is much weaker than the Earth's? Read the story as told by one of the earthmen. They have just landed on the Moon.

“I went on unscrewing. ... I knelt, and then seated myself at the edge of the manhole, peering over it. Beneath, within a yard of my face, lay the untrodden snow of the Moon. ... Cavor... stretched out his hand for his blanket, thrust his head through its central hole, and wrapped it about him. He sat down on the edge of the manhole, he let his feet drop until they were within six inches of the lunar ground. He hesitated for a moment, then thrust himself forwards ... and stood upon the untrodden soil of the Moon.

“As he stepped forward he was refracted grotesquely by the edge of the glass. He stood for a moment looking this way and that. Then he drew himself together and leaped.

“The glass distorted everything, but it seemed to me even then to be an

extremely big leap. . . . He seemed twenty or thirty feet off. He was standing high upon a rocky mass and gesticulating back to me. Perhaps he was shouting—but the sound did not reach me. But how the deuce had he done this?...

"In a puzzled state of mind, I too dropped through the manhole. I stood up. Just in front of me the snow-drift had fallen away and made a sort of ditch. I made a step and jumped.

"I found myself flying through the air, saw the rock on which he stood coming to meet me, clutched it and clung in a state of infinite amazement. . . . Cavor bent down and shouted in piping tones for me to be careful. I had forgotten that on the Moon . . . my weight was barely a sixth what it was on the Earth. But now that fact insisted on being remembered. . . .

"With a guarded effort I raised myself to the top, and moving as cautiously as a rheumatic patient, stood up beside him under the blaze of the Sun. The sphere lay behind us on its dwindling snow-drift thirty feet away. . . .

"Look!" said I, turning, and behold, Cavor had vanished.

"For an instant I stood transfixed. Then I made a hasty step to look over the verge of the rock. But in my surprise at his disappearance I forgot once more that we were on the Moon. The thrust of my foot that I made in striding would have carried me a yard on the Earth; on the Moon it carried me six—a good five yards over the edge. For the moment the thing had something of the effect of those nightmares when one falls and falls. For while one falls sixteen feet in the first second of a fall on the Earth, on the Moon one falls two, and with only a sixth of one's weight. I fell, or rather I jumped down, about ten yards I supposed. It seemed to take quite a long time, five or six seconds, I should think. I floated through the air and fell like a feather, knee-deep in a snow-drift in the bottom of a gully of blue-grey, white-veined rock.

"I looked about me. 'Cavor!' I cried, but no Cavor was visible.

"Cavor!" I cried louder. . . .

"Then I saw him. He was laughing and gesticulating to attract my attention. He was on a bare patch of rock twenty or thirty yards away. I could not hear his voice, but 'Jump!' said his gestures. I hesitated, the distance seemed enormous. Yet I reflected that surely I must be able to clear a greater distance than Cavor.

"I made a step back, gathered myself together, and leaped with all my might, I seemed to shoot right up in the air as if I should never come down. . . .

"It was horrible and delightful, and as wild as a nightmare, to go flying off in this fashion. I realized my leap had been altogether too violent. I blew clean over Cavor's head."

LUNAR SHOOTING

The following episode from *On the Moon*, a novel by the celebrated Soviet inventor K. E. Tsiolkovsky, will tell us how the force of gravity affects motion. Because of the Earth's atmosphere, which impedes the motion of all bodies in it, we fail to see the simple laws of falling bodies; they are complicated by sundry additional factors. The Moon, however, hasn't got any atmosphere, and would make a fine laboratory to study falling bodies – provided we could get to it and do scientific research there.

Now let me give the floor to Tsiolkovsky with the explanation that the two persons talking are on the Moon and at the moment wish to see what the flight of a bullet fired from a gun would be like there.

“‘But will gunpowder do its job here?’

“‘In a void the effect of explosives should be even greater than in air, as the latter prevents them from expanding. As for oxygen, they contain as much as they need.’

“‘Let's aim the rifle vertically to make it easier for us to find the bullet later.’

“‘There was a flash and a slight plop (the kind of sound one would hear transmitted through the ground and human bodies and not through the air of which the moon has none) and the ground quivered.

“‘Where's the wad? It ought to be hard by.’

“‘The wad has gone up with the bullet and will most likely keep up with it. Back on the Earth the atmosphere prevents the wad from winging after the lead bullet. Here on the Moon a feather will fall and fly up in the same manner as a stone. Suppose you pluck a feather from your pillow while I take a little iron ball. You will be able to throw your feather and hit a thing that is even far away, just as easily as I will with my little ball, which, considering its small weight, I'll be able to throw as far as some 400 metres. You'll be able to throw your feather just as far. True, you won't kill anyone with it. You won't even feel it when you throw it. So let us throw projectiles with all our might – I think we're about the same in that respect – at one target – that red chunk of granite, for instance. ...’

“‘The feather slightly outflung the iron ball, as if drawn on by a strong whirlwind.

“‘What can have happened? It's already three minutes since we fired the shot but the bullet still hasn't come back.’

“‘Have patience for a couple of minutes. You'll probably see it coming back then.’

"And indeed, a couple of minutes later we felt the ground quiver and saw the wad bouncing near us.

"The bullet certainly flew quite a time. How high did it get?"

"Some 70 kilometres up—all because of the small gravitational pull and the absence of air drag."

Suppose we check this statement. If we take the rather modest figure of 500 m/s for the bullet's muzzle velocity (with modern rifles it is one and a half times more) it would rise above the Earth, *in the absence of an atmosphere*, to

$$h = \frac{v^2}{2g} = \frac{500^2}{2 \times 10} = 12,500 \text{ m}$$

or 12.5 km. However since the Moon's gravitational pull is but a sixth of the Earth's, g will be six times smaller and consequently the bullet will go up to $12.5 \times 6 = 75 \text{ km}$.

BOTTOMLESS WELL

So far we know very little as to what takes place deep down inside the Earth's bowels. Some think a molten mass lies beneath the solid crust at the top which is supposed to be a hundred kilometres thick. Others believe the Earth to be solid all the way through. It is hard to say who is right. The deepest well drilled has not been more than 7.5 km down, while the deepest mine sunk and down which man has gone is only 3.3 km down*.

The Earth's radius meanwhile is 6,400 km. We would be able to say for sure if we could drill a hole right through the Earth along its diameter. Unfortunately our present well-drilling equipment can't do that—even though all the wells drilled so far add up to more than the Earth's diameter in length.

In the 18th century the mathematician Maupertuis and the philosopher Voltaire dreamed of tunnelling right through the Earth, and later the French astronomer Flammarion brought up the project again—true on a more modest scale.

Of course no tunnel of this nature has been dug yet; however we shall suppose it has been dug, in order to deal with a curious problem. What do you think would happen if you fell into such a bottomless well (discount air drag for the time being)? You won't crash into the bottom, because there isn't one. But

* A gold mine in Boxburg, the Transvaal, South Africa, which moreover has its mouth 1,600 m above sea level, meaning that it is only 1,700 m down from sea level.—Ed.

where would you stop? It wouldn't be in the centre of the earth because by the time you reached that point your velocity would be so great (about 8 km/s) that you would simply overshoot and continue to fall, gradually slowing down, until you reached the outlet at the opposite end. Here you must grab the edge for dear life, because otherwise you would again shoot back to the other end. If you again failed to grab the edge, you would simply swing on endlessly, like

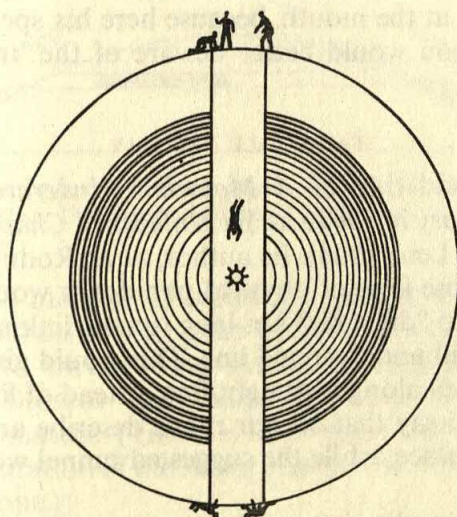


Fig. 172

Should you ever chance to fall into a shaft drilled through the earth's centre you would bob endlessly pendulum-like from end to end. It would take you 84 minutes to get from end to end

a pendulum, of course, provided air drag is disregarded (if we did take it into account, oscillation would gradually damp and you would finally wind up in the centre of the Earth).

Now how long would it take you to bob from end to end and back? The answer is: 84 minutes 24 seconds, or roughly an hour and a half.

"That would be so," Flammarion continues, "if our well were dug from pole to pole along the axis. As soon as we shift the opening to any other latitude in Europe, Asia or Africa, we must take the Earth's rotation into account. We know that every point of the Earth does 465 m/s at the equator and 300 m/s at the latitude of Paris. Since circumferential velocity *increases* the further away we are from the axis of rotation, a plumb-line dropped in a well will deflect

eastward from the vertical. If we dug our bottomless well at the equator, we should have to make it either very wide or greatly inclined, because a body dropped into it from the surface would fly way east of the centre of the Earth.

"Further if the mouth were on a South-American plateau two kilometres above sea level, while the outlet were at ocean level, anybody inadvertently falling into the opening would fly out at the other end two kilometres up. However if both openings were at ocean level, you could grab the person by the hand when he appears at the mouth, because here his speed would be nothing. In the previous case you would better beware of the 'traveller hurtling by'."

FAIRY-TALE RAILWAY

A booklet with the odd title of *A Motorless Underground, St. Petersburg-Moscow Railway, Fantasy in Three as Yet Unfinished Chapters* was once put out in St. Petersburg (now Leningrad). Its author, A. A. Rodnykh, suggested a very witty project which those fond of physical paradoxes would find not devoid of interest. His idea was to "dig a 600-km-long tunnel, linking up the two capitals by an absolutely straight underground line. This would give us for the first time the opportunity to travel along a straight line instead of following curved paths as now." (He wishes to say that all our roads describe arcs, as they follow the curve of the Earth's surface, while the suggested tunnel would follow a straight line, along a chord.)

This project – if ever realized – would possess a unique characteristic. In this tunnel a train would *move by itself*. Recall the well that struck right through the earth. This Leningrad-Moscow tunnel would be a somewhat similar affair, the difference being that it would follow not the diameter but a chord. True, a cursory glance at Fig. 173 might suggest that since the tunnel is horizontal, there is no reason for gravity to propel the train. That is simply an optical illusion: as soon as you mentally trace radii to the two ends of the tunnel (the radius will show the perpendicular) you will realize that the tunnel is not at all at right angles to them, or in other words that it is not horizontal but inclined.

In such a slanting tunnel every object should swing, due to gravity, to and fro like a pendulum, hugging to the bottom. Inside it a train would move by itself along the rails, its weight doing the work of a locomotive. At first the train will move very slowly, but with every new second its speed would increase, to reach soon a figure so incredible, that the air in the tunnel would offer noticeable resistance. However, let us forget for a while this annoying circumstance which has blocked the realization of so many fascinating projects and see what will

happen to our train. Its speed will be so great (many times that of a cannon ball) when it reaches the middle of the tunnel that it will overshoot it and almost reach the other end. I say "almost" because of friction; were there no friction our train would go all the way from Leningrad to Moscow by itself without a locomotive. It has been reckoned that it would take the train to get from end to end the same amount of time as it took the person who fell into the

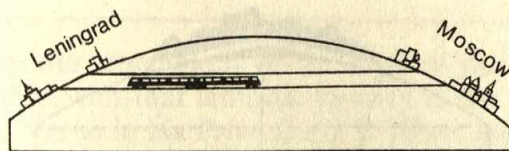


Fig. 173

In this Leningrad-Moscow tunnel trains would need no locomotive. Their own weight would impel them to speed to and fro

pole-to-pole tunnel, 42 minutes 12 seconds, a period of time which curiously enough does not depend on how long the tunnel is. It would take us the same 42 minutes 12 seconds to travel along similar tunnels between Moscow and Leningrad, between Moscow and Vladivostok or between Moscow and Melbourne, for that matter. (There is one more curious point about the bottomless well: the duration of the swing depends not on the *size* of the planet, but on its *density* alone.)

In this tunnel any other conveyance, be it a motorcar, a cart or anything else, would behave in the same manner. Indeed a fairy-tale road. Itself stationary, it is able to make anything on wheels race along it from end to end and moreover with unimaginable speed!

HOW TO DIG TUNNELS

Figure 174 shows three ways of digging a tunnel. Now tell me which of the three is the horizontal one? It is neither the upper nor lower; it is the one in the middle that traces an arc. At every point this middle tunnel will be at right angles to the vertical, or to the Earth's radius. It is horizontal as its curve fully accords with the curve of the Earth's surface.

Long tunnels are usually dug as shown at the top of Fig. 174—along straight lines which swing out at a tangent to the Earth's surface from the two ends. This tunnel first goes *upwards* and then slants *downwards*. It is very convenient since water does not collect in it, but flows by gravity towards the ends.

A tunnel dug strictly horizontally would be shaped as an arc. Water would not flow out of it, as it would be in a state of equilibrium at every point. When such a tunnel is more than 15 km long (the Simplon tunnel, for instance, is 20 km long) a person standing at one end would not see a person standing at the other. He would see nothing but the ceiling of the tunnel as its central point would be 4 metres higher than its two terminals.

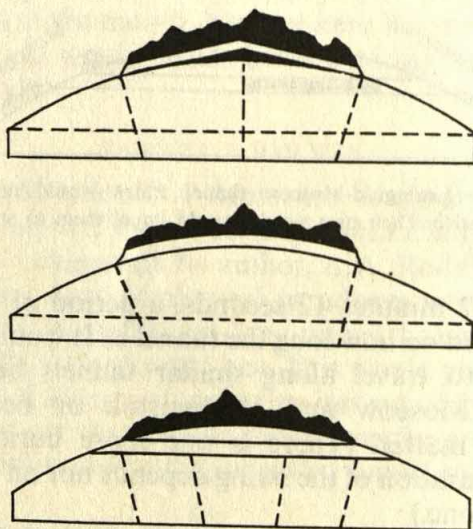


Fig. 174

Three ways of tunnelling through mountains

Finally, if we were to dig the tunnel as a straight line between the two terminals, it would gradually slope down towards the middle. In such a tunnel, far from flowing out, water would, on the contrary, gather in the middle, which would be the lowest part. On the other hand a person standing at one end would see his friend at the other end, as you may deduce from the figure. (Incidentally, while all horizontal lines *curve*, and can by no means be straight, vertical lines, on the contrary, can only be straight.)

Chapter Travelling in a Projectile 15

Before winding up our discussions of the laws of motion and gravitational attraction, let us deal with that fantastic journey to the moon so fascinatingly described by Jules Verne in his *From Earth to Moon* and *Around the Moon*. If you have read these books you will most likely remember that after the close of the Civil War the members of the Baltimore Cannon Club decided out of enforced idleness to cast a huge cannon and to shoot at the moon an enormous hollow projectile with passengers inside. Could this ever be done? And firstly, could we ever impart to bodies a velocity great enough for them to escape from the earth never to return?

NEWTON'S MOUNTAIN

Newton, the genius who discovered the universal law of gravitational attraction, wrote in his *Principia*, that due to gravity any stone we throw up into the air veers away from a straight path and falls back on the earth, describing a curvilinear trajectory. However, if we impart a greater velocity to the stone, it flies much further and it may very well happen that it might describe an arc of some ten, one hundred, or one thousand miles and finally break away from the earth's fetters never to return. Suppose AFB in Fig. 175 is the earth's surface, C its centre, while UD , UE , UF and UG are the curved trajectories described by an object thrown horizontally from a very tall mountain with increasing velocities. (We shall disregard air resistance.) In the case of a smaller initial velocity, the object describes the curve UD , in the case of a higher velocity, the curve UE , and in the case of still greater velocities, the curves UF and UG . Provided the initial velocity is adequate, our object will circumvent the earth and return to its starting point at the top of the mountain, and since its velocity will now be *identical* with the initial velocity, it will continue along the same orbit.

If we had a gun on this mountain, the cannon balls it fired would, provided the starting velocity was high enough, never fall back on earth again but girdle the globe endlessly. It is easy enough to figure out (see Chapter 2) that this

would happen when we have a muzzle velocity of about 8 km/s. A projectile fired at this speed would orbit the earth as a satellite to race along 17 times faster than any point on the equator and have a period of revolution of 1 hour 24 minutes. When the muzzle velocity is greater, the missile no longer travels round the earth on a circular orbit; it follows a more or less elongated elliptical orbit, shooting out far away from the earth. When the initial velocity is still

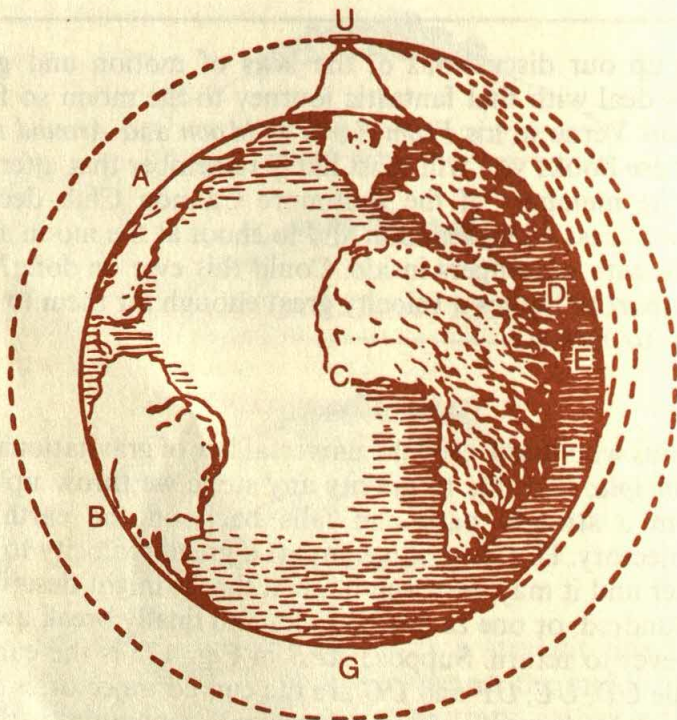


Fig. 175

How stones would fall when ejected horizontally and with great speed from the top of a mountain

greater, about 11 km/s, the missile will escape forever into space. (Note that we have been speaking of the motion of projectiles in a *void*, not in air.)

Let us now see whether we could fly to the moon as Jules Verne suggests. Modern guns impart a muzzle velocity of not more than 2 km/s, which is only a fifth of the speed we require to fly out to the moon. The Baltimore cannoneers thought, however, that if they cast a giant cannon and used a tremendous charge, they would be able to obtain a high enough velocity to shoot their projectile to the moon.

FANTASTIC GUN

So the members of the Baltimore Cannon Club had cast an enormous gun a quarter of a kilometre long, which was vertically bedded in the ground. Then a huge 8-ton projectile with a passenger cabin was made. The charge consisted of 160 tons of nitro-cotton. When the gun was fired, the projectile received, according to Jules Verne, a starting velocity of 16 km/s, which air drag reduced to 11 km/s, quite enough to fly on to the moon after quitting the earth's atmosphere. That is what Jules Verne thought.

Let us now see whether physics bears him out.

Jules Verne's project is vulnerable but not at the point where readers usually think it to be. In the first place one can prove that gun powder will never be able to impart to artillery projectiles a velocity of more than 3 km/s.

Furthermore, Jules Verne ignored air drag which, considering the tremendous velocities involved, should be pretty great. At any rate, it would change the trajectory completely. However, in addition to all that there are other serious objections to a moon flight in a cannon ball. It is what lies in store for the passengers themselves, that presents the main stumbling-block.

Don't think the actual journey is dangerous. As long as they survive the firing moment, they will have nothing more to worry about. The colossal speed with which they would be hurtling through space in their projectile would be just as harmless for them as for us earthmen is the still greater speed with which our planet races around the sun.

HEAVY HAT

The moment of the greatest peril is the few hundredths of a second when the projectile is accelerating in the gun's bore, because in this negligible interval, the velocity is supposed to increase from zero to 16 km/s. No wonder Jules Verne's cannoneers looked forward to that moment with such trepidation. Barbicane was quite right when he said that the very first moment of flight would be just as dangerous for the passengers inside, were they not inside but in front of the missile. Indeed, when the gun is fired, the cabin floor should strike at the passengers from below with the same force as a projectile would strike at anything in its path. Jules Verne's cannoneers made light of this peril thinking that at worst they would get off with a rush of blood to the head. ...

Actually it's much more serious than that. In the barrel the projectile accelerates, its velocity increases by the constant pressure of the gases that the gunpowder gives off when ignited. In the negligible fraction of a second this

speed increases, as I have already remarked, from zero to 16 km/s. Let us suppose for simplicity's sake that acceleration is uniform. In that case the acceleration required to increase the projectile's velocity to 16 km/s in so short a time would be in the vicinity of 600 km/s a second (we shall figure it out later).

This figure is fatal, as you will well realize when I tell you that the usual acceleration of surface gravity is only 10 m/s^2 . (Let me add that the acceleration of a racing car from starting point is not more than $2\text{-}3 \text{ m/s}^2$, while the acceleration of a train smoothly pulling out is only 1 m/s^2 .) It hence follows that at the firing moment everything inside the cabin would press down with 60,000 times its true weight. This means that the passengers would grow several dozen thousand times heavier, which would crush them to pulp at once. Mr. Barbicane's top-hat alone would have weighed at least 15 tons when the gun was fired—more than enough to crush its owner.

True, Jules Verne describes several measures taken to soften the impact. The projectile was fitted out with spring guards and a double water-filled floor. This stretches the impact interval and hence the rapidity with which the speed increases is reduced. But considering the tremendous forces that we have to deal with in this case, the advantage thus derived is insignificant. Only a fraction would be sliced off the force pinning the passengers to the floor. I personally don't think it makes the slightest difference whether the hat would weigh 15 or 14 tons; it would steam-roller you in either case.

HOW TO SOFTEN IMPACT

Mechanics tells us how we can reduce the fatal increase of velocity. We must make the cannon *many times longer*, very much longer if we want the force of "artificial" gravity inside the projectile to equal earth gravity at the firing moment. According to a rough-and-ready reckoning we would have to make the gun at least 6,000 km long. This means that Jules Verne's *Columbiad* would have reached the earth's centre. Only then would the passengers have experienced no particularly unpleasant sensations. They would have merely felt twice as heavy, since the slow increase in speed would have added an apparent weight of the same magnitude to their own.

Incidentally over a short interval of time the human organism can stand up to a several-fold increase in weight without any harmful effect. When we abruptly change our course, our roller-coasting, our weight noticeably increases during these short periods; our body presses down harder on the sled. We can safely bear a threefold increase in weight. Supposing that we could safely stand up

even to a tenfold increase in weight over a short period of time, it would be enough to cast a gun “only” 600 km long, which, even then, wouldn’t help since it is technically impossible to make such a gun.

Only provided we were able to abide by all these conditions, we could think of realizing Jules Verne’s project. (We dealt in Chapter 2 with a serious omission which the French science-fiction novelist was guilty of when he ventured to describe the conditions of life inside the projectile after it had been shot out and was flying to the moon. He forgot the state of weightlessness that would set in when every object inside the projectile would likewise weigh nothing, as the force of gravity would impart an identical acceleration both to the projectile and every object inside it—see further “The Chapter Jules Verne Did Not Write”).

FOR ALL WHO LIKE MATHEMATICS

Some of you would most likely wish to check up on the figures given above. Here are the reckonings—which, true, are only approximate as they are based on the supposition that in the gun barrel the projectile moved with a uniform acceleration (actually acceleration is not uniform).

We shall need the following two equations for uniformly accelerated motion: velocity v after t seconds is equal to at , where a is the acceleration. In other words $v = at$;

the path S covered in t seconds is determined by the equation

$$S = \frac{at^2}{2}.$$

We shall now proceed to determine the acceleration of the projectile in the *Columbiad*’s barrel. From the novel we know its length, 210 metres, i.e. S , the path that the projectile covers. We also know the ultimate velocity: $v = 16,000$ m/s. We are now able to determine t , the time the projectile moved in the barrel (presuming, naturally, that we are dealing with a uniformly accelerated motion). So,

$$v = at = 16,000 \text{ m/s}, \quad 210 \text{ m} = S = \frac{at \cdot t}{2} = \frac{16,000 \text{ m/s} \cdot t}{2} = 8,000 \text{ m/s} \cdot t,$$

whence

$$t = \frac{210 \text{ m}}{8,000 \text{ m/s}} \approx 1/40 \text{ s}.$$

We thus find that it took only $1/40$ of a second for the projectile to travel the length of the barrel.

Substituting $t = 1/40$ in the equation $v = at$, we get:

$$16,000 = 1/40a, \text{ whence } a = 640,000 \text{ m/s}^2.$$

As we see the acceleration of the projectile inside the cannon was $640,000 \text{ m/s}^2$, or $64,000$ times more than the acceleration of gravity. How long should the gun be then, for the projectile's acceleration to be only ten times more than the acceleration of gravity, to wit: 100 m/s^2 ?

This is a problem which must be solved in reverse order to the one we just solved. We know that a is 100 m/s^2 , and that v is $11,000 \text{ m/s}$ (which will be quite sufficient in the absence of air drag).

From the equation $v = at$ we get $11,000 = 100t$, whence $t = 110 \text{ s}$.

From the equation

$$s = \frac{at^2}{2} = \frac{at \cdot t}{2}$$

we find that the gun should be

$$\frac{11,000 \times 110}{2} = 605,000 \text{ m,}$$

or 605 km long.

In this way do we deduce the figures that shatter the fascinating project of Jules Verne's cannoneers.*

* Everything in this chapter is unquestionably right. As for the practical aspect of space flight you will have probably read about it elsewhere.—Ed.

Chapter

Liquids and Gases

16

SEA IN WHICH ONE NEVER SINKS

There is such a sea in a country with a very ancient history. This, of course, is the famous Dead Sea in Palestine. Its water is so salty that nothing can live in it. Due to the local scorching rainless climate the surface water evaporates. Note, though, that it is only water as such which evaporates. The salt dissolved in it remains making the water still saltier. This explains why the Dead Sea has a salt content not of two or three per cent (by weight) as most seas and oceans, but of 27 per cent and even more; the salt content increases with depth.

Thus a quarter of the Dead Sea is made up of the salt dissolved in its water. This sea has been estimated to have a total of 40 million tons of salt.

The water of the Dead Sea exhibits a very curious property precisely because of its saltiness. Since it is much heavier than ordinary sea water, you will never sink in it because your body is much lighter.

We weigh noticeably less than an equal volume of very salty water. Hence, according to the law of buoyancy we would never drown in the Dead Sea; we would pop up to the surface just like an ordinary egg in salt water, which, incidentally, sinks in fresh water.

Mark Twain, the famous American humorist, visited the Dead Sea, and in one of his books he wittily describes the unusual sensations that he and his companions experienced when they bathed in it.

"It was a funny bath. We could not sink, one could stretch himself at full length on his back, with his arms on his breast, and all of his body above a line drawn from the corner of his jaw past the middle of his side, the middle of his leg and through his anklebone, would remain out of water. He could lift his head clear out if he chose. . . . You can lie comfortably on your back, with your head out, and your legs out from your knees down... you can sit, with your knees drawn up to your chin and your arms clasped around them, but you are bound to turn over presently, because you are top-heavy in that position. You can stand up straight in water that is over your head, and from the middle of your breast upward you will not be wet. But you cannot remain so. The water will

soon float your feet to the surface. You cannot swim on your back and make the progress of any consequences, because your feet stick away above the surface, and there is nothing to propel yourself with but your heels. If you swim on your face, you kick up the water like a sternwheel boat. You make no headway. A horse is so top-heavy that he can neither swim nor stand up in the Dead Sea. He turns over on his side at once."

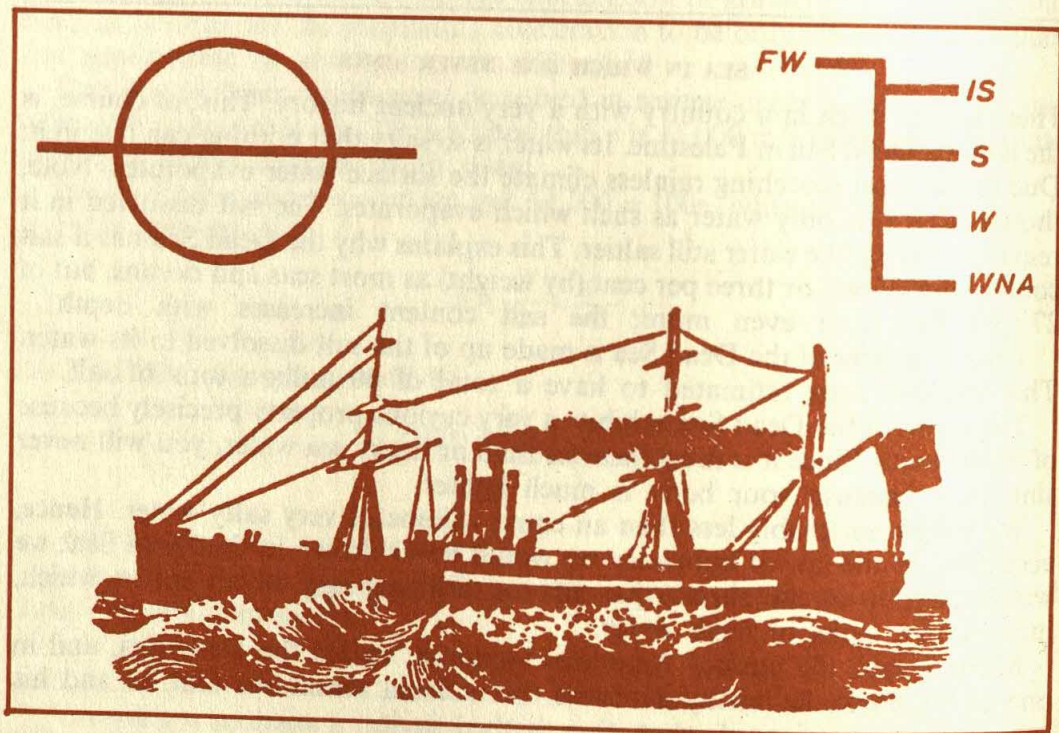


Fig. 176

Cargo marks on a ship's water-line. Top right: same marks enlarged

The water of the Kara Bogaz Gol, a gulf in the Caspian, and of Lake Elton, with its 27-per-cent salt content, exhibits the same unusual properties. (Incidentally, the specific density of the water in the Kara Bogaz Gol is 1.18. "In this dense water one may swim effortlessly and will never sink however hard one may try to violate Archimedes' principle," the explorer Pelsh has noted in this connection.)

Patients taking salt-water baths experience something very similar to what

we have just described. When the water is very salty, as at the Staraya Russa spa, for instance, the patient has to make quite an effort to keep submerged. I heard one lady patient at Staraya Russa complain with disgust that the water "was pushing her out of her bath" and she seemed to think that the management was to blame.

The salt content of the water in different seas varies, due to which ships do not draw identically everywhere. Some of you have probably seen the so-called "Lloyd mark" near the water-line on a ship's hull, which designates submergence limits in water of different densities. For instance, the load mark in Fig. 176 stands for the limit of submergence, which is:

FW in fresh water,

IS in the Indian Ocean in summer time,

S in salt water in summer,

W in salt water in winter,

WNA in the North Atlantic in winter.

Russia introduced these marks as obligatory in 1909.

Let me note in conclusion that there is a variety of water, which even in its pure state with no admixtures is much heavier than ordinary water. Its specific density is 1.1, or 10% more than of ordinary water. In a swimming pool filled with this water even the novice would never drown. Called *heavy* water its chemical formula is D_2O (its hydrogen component is made of atoms twice as heavy as those of ordinary hydrogen and designated by the letter D). There is an insignificant quantity of "heavy" water in ordinary water, about eight grammes to every pail.

The "heavy" water of the D_2O type (there are seventeen possible types altogether) is now obtained in almost its pure form with but a 0.05% admixture of ordinary water. "Heavy" water is extensively used in nuclear technology and, in particular, in atomic reactors. It is obtained commercially and in large quantities from ordinary water.

HOW AN ICEBREAKER WORKS

Do the following experiment when you take a bath. Before getting out pull the plug out but stay prone for a while. As more and more of your body emerges from the water, you feel it grow heavier and heavier. This is a most graphic illustration showing how you regain weight lost in water (remember how much lighter you felt in the bath-tub when it was full). When a whale involuntarily engages in such experiments, being stranded in shallow waters during an

outgoing tide, the consequences are fatal. The whale is crushed to death by its own monstrous weight. No wonder whales can live only in water. Buoyancy saves from gravity's lethal effect.

Now what can all this have to do with icebreakers, you might wonder? The job an icebreaker does is based on the same physical principle. Since that part of the ship jutting out of the water is no longer offset by the water's buoying force, it acquires its "dry" weight. Don't think the icebreaker cuts through ice merely by exerting an endless pressure with its bow. An ordinary ice boat does, but only when the ice is not very thick.

Real icebreakers, like *Krasin* and *Yermak* and the atomic-powered *Lenin*, work quite differently. The icebreaker brings its bow to bear on the surface of the ice, for which purpose the underwater part of the bow is greatly slanted. As it climbs out of the water, the bow "acquires" its full weight (as much as 800 tons in the case of the *Yermak*) and thus crushes through the ice. To increase pressure, water is often pumped into tanks in the icebreaker's bow.

This method is used when the ice is not too thick. Thicker ice is forced to yield by *ramming*. The icebreaker backs away and then goes full steam ahead, bang into the barrier of ice. Now it is not the ship's weight but the kinetic energy of its motion that is brought into play. The ship is actually used as a kind of battering ram. The blows are so powerful that even solid walls of ice, several metres high, crumble. Here is how the polar explorer N. Markov, who took part in the famous 1932 expedition aboard the *Sibiryakov*, describes the way the ship broke through the ice:

"It was among hundreds of solid ice-packs in the midst of huge icefields that the *Sibiryakov* began its 52-hour battle. For 13 full watches, the engine telegraph rang from 'full steam reverse' to 'full steam ahead', as the vessel rammed the ice, crushed it with its bow, climbed out to break it down and then backed away to strike again. The ice, three-quarters of a metre thick, gave way with difficulty. Each new blow took us only a third of the ship's length."

WHERE TO LOOK FOR FOUNDERED SHIPS

Even many seamen think that ships wrecked at sea never sink to the bottom but hang suspended at a certain depth, where the water supposedly "reaches the appropriate density due to the pressure of upper layers".

The author of *Twenty Thousand Leagues Under the Sea* also subscribed to this view. In one place Jules Verne describes a wreck suspended immobile in the

depths. In another chapter he reminds us of ships "rotting as they hang freely suspended in the water".

Is this right?

One might think there is some reason for such statements, since the pressure that the water exerts deep down in the ocean is indeed tremendous. At ten metres down, the water exerts a pressure of 1 kg to every sq cm of the submerged body. At 20 metres down, this is already 2 kg, at 100 metres, 10 kg, and at 1,000 metres, 100 kg.

We know that in many places the ocean bed lies several kilometres deep, reaching to more than 11 km down at the deepest spots (the Marianne depression in the Pacific). You will easily realize what colossal pressures both the water and everything in it should be subjected to at such tremendous depths.

If we push a corked but empty bottle down to a great depth and then pull it out again, we will find it full of water with the cork inside—all because of the pressure that the water exerts deep down. In his *The Ocean*, the celebrated oceanographer John Murray describes the following experiment. Three glass tubes of different sizes, sealed at both ends, were wrapped in a cloth and placed in a copper cylinder which had holes in it to let the water through. The cylinder was sent down to 5 km and then pulled out. When the cloth was unwrapped, a snow-like mass of crushed glass was found. Pieces of wood sent down to similar depths sunk like bricks later, so heavily compressed were they.

Hence it seems only natural to expect that this terrific pressure should make the water at great depths so dense that even heavy objects would not sink any further, in the same way as an iron weight does not sink in mercury. This is a totally erroneous notion. Experiments have shown that water, like all liquids in general, yields very little to compression. Under pressure of one kilogramme to every square centimetre it will compress only by a twenty-two-thousandth of its volume, and the rate of compression increases by the same degree with every extra kilogramme of pressure. We must make water eight times denser than it is for iron to float in it. But to make it just twice as dense, or, in other words, compress it to half its present volume, one must exert a pressure of 11,000 kg/cm². Provided that in general were possible, we would get a pressure of that order only at a depth of 110 km.

Thus it is clear that any noticeable compression at great ocean depths is out of the question, because even at the deepest spot water loses only five per cent of its volume due to compression. (The British physicist Tate has reckoned that if

gravity were suddenly to cease and water become weightless, the level of the water in the oceans would rise by an average of 35 metres as the gravity-compressed water would regain its normal volume. Berger has noted that in this case "the ocean would flood 5 million sq km of dry land which is dry land only because the water in the oceans is compressed".) This would scarcely have any effect on buoyancy—all the more so since all solid objects at these depths are subjected to the same pressure and are consequently compressed too.

There need be no doubt, therefore, that wrecked ships sink to the ocean bottom. "Anything that will sink to the bottom of a tumbler of water," Murray says, "will practically sink to the bottom of the deepest ocean."

I have heard the following objection. If you carefully immerse a glass *bottom up*, it may stay thus, as it will displace an amount of water weighing as much as the glass itself weighs. A heavier metal tumbler might stay in this position, even below water level, without sinking to the bottom. So it is claimed that a capsized cruiser or any other ship might also stop halfway down. If the air in the ship's compartments has no escape, the ship may sink to a certain depth and stay there. After all quite a few ships sink with their keels pointing upwards. Couldn't it be possible that some of them might have not reached the bottom and are still suspended in the murky ocean depths? And though the slightest push would be enough to disturb their equilibrium, righten them, fill them with water and send them to the bottom, could one expect jolts in the ocean depths, that domain of eternal silence and tranquility, where even the worst of storms has no repercussions?

All these arguments are based on a physical error. An overturned glass *does not submerge by itself*. It must be made to do so *by some external force* in the same way as a piece of wood or an empty corked bottle. So will an overturned ship remain afloat—never to find itself halfway between top and bottom.

HOW THE DREAMS OF JULES VERNE AND H. G. WELLS CAME TRUE

Present-day submarines even beat Jules Verne's fantastic *Nautilus* on some points. True, their speed is half as much, only 24 knots instead of Jules Verne's 50, and the longest voyage they can make is a round-the-world one, whereas Captian Nemo did twice as much. On the other hand, the *Nautilus* had a displacement of only 1,500 tons, a crew of some thirty men and was able to lie submerged for no longer than 48 hours. The 3,200 ton submarine *Surcouff*,

which the French Navy built in 1929, had a crew of 150 and could lie submerged for as long as 120 hours without surfacing.*

The *Surcouff* was able to cruise from France to Madagascar without calling on a single port on the way. As far as all the comforts and amenities were concerned, it probably rivalled Captain Nemo's ship, meanwhile boasting the unquestionable advantage of a waterproof upper-deck hangar for a reconnaissance seaplane. Further note that Jules Verne did not equip his *Nautilus* with a periscope through which the people inside the submarine can view the surface from under the water.

Only on one count will the submarines we make still be a long way inferior to Jules Verne's ship: the depth of submergence. However, on this point Jules Verne's imagination stretched beyond the bounds of truth. "Captain Nemo", we read in one place, "went down to 3, 4, 5, 7, 9 and 10 thousand metres below the ocean level." Once the *Nautilus* submerged to the unprecedented depth of 16,000 metres. "I felt," the hero says, "the rivets of the submarine's iron plates shudder and saw its portholes bulge inwards as they yielded to the water's pressure. Had our ship not been as sturdy as a solid cast object, it would have been crushed to pulp instantaneously." He had good reason for such fears because at 16 km down (if such depths really existed) the pressure of the water should reach

$$16,000 : 10 = 1,600 \text{ kg/cm}^2$$

or 1,600 technical atmospheres. While it wouldn't crush iron, it would unquestionably dent it.

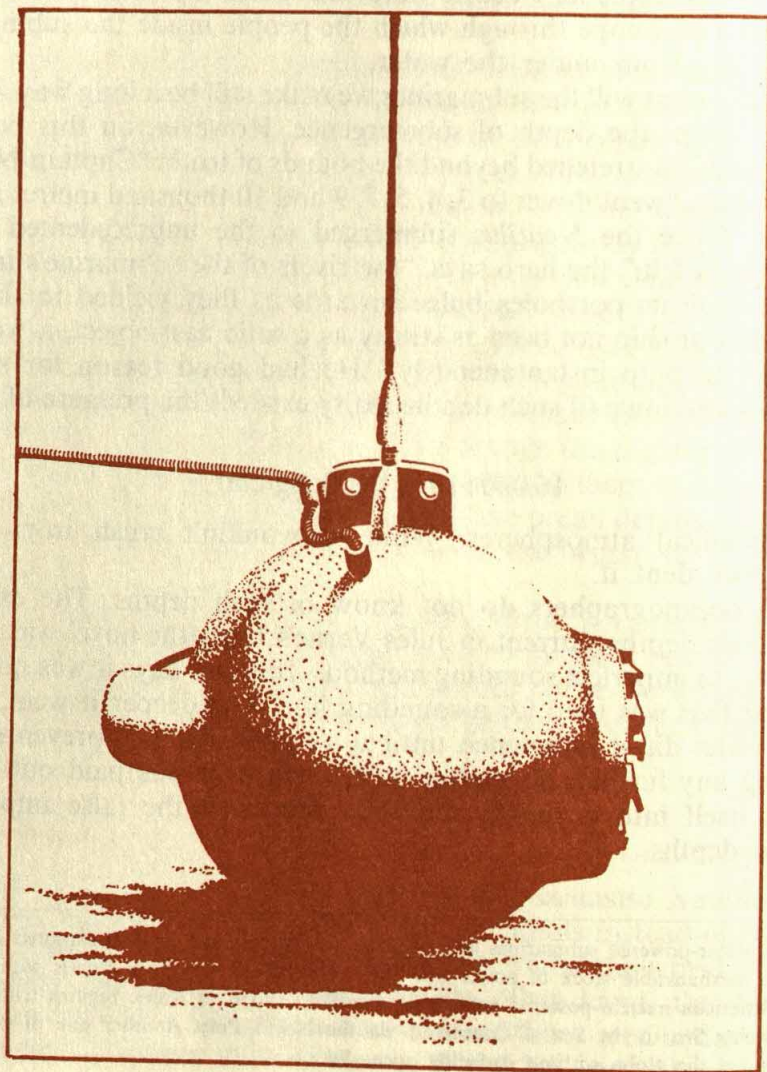
However, oceanographers do not know of such depths. The exaggerated notion of ocean depths, current in Jules Verne's time (the novel was written in 1869) was due to imperfect sounding methods. In those days it was not wire but a hemp rope that was used for a sounding line. The deeper it went, the more friction on water did it experience, until at a certain depth it prevented the line from sinking any further, no matter how much of it was paid out. The rope merely got itself into a tangle and thus produced the false impression of tremendous depths.

* Modern nuclear-powered submarines give us a free choice of routes at little explored sea and ocean depths. The inexhaustible stock of power that they carry allow very long cruises without surfacing. Thus, the American nuclear-powered submarine *Nautilus* cruised in Arctic regions without surfacing from the Bering Sea to the Sea of Greenland via the North Pole. Another one of the same class circumnavigated the globe without surfacing once.—Ed.

Modern submarines can stand a pressure of not more than 25 atmospheres, which means that they can submerge to no deeper than 250 m. Greater depths have been reached in a special diving apparatus called a bathysphere (Fig. 177), which is specially devised for the study of life in the ocean depths. It resembles

Fig. 177

Steel-plated bathysphere in which William Beebe reached the depth of 923 m in 1934



not Jules Verne's *Nautilus* but rather H. G. Wells' invention in his *The Sea Raiders*, which describes the adventures of a man who went 9 km down to the ocean floor in a thick-walled steel sphere. The apparatus submerged without a cable but with a stock of ballast. On reaching the ocean bed the ballast was jettisoned and the sphere rushed up to the surface. In bathyspheres scientists have reached depths of more than 900 metres. The bathysphere is lowered on the cable from the ship with which the underwater "traveller" maintains contact by telephone.*

HOW THE SADKO WAS REFLOATED

Every year, especially in times of war, thousands of ships, big and small, get wrecked. In the last twenty to thirty years the more valuable and accessible of these hulks have been refloated. Soviet engineers and divers of the Special-Purpose Underwater Work Administration have won world fame by successfully raising more than 150 big vessels, largest among which was the icebreaker *Sadko*, wrecked in 1916 in the White Sea due to its skipper's negligence. After 17 years on the sea bottom this fine ship was raised and refloated.

The technique was based wholly on the rule of Archimedes. At 25 metres down divers drilled twelve tunnels in the sea floor beneath the shipwrecked icebreaker and passed through each sturdy steel cables the ends of which were attached to deliberately submerged pontoons. These pontoons shown in Fig. 178 were hollow watertight iron cylinders 11 m long and 5.5 m in diameter, each weighing—empty—50 tons, and having a volume of about 250 cu m. Since it is quite plain that an empty pontoon cannot sink; weighing only 50 tons and displacing 250 tons of water it must have a lifting capacity of $250 - 50 = 200$ tons, it had to be filled with water to submerge.

After the ends of the steel cables were lashed tight to the submerged pontoons (Fig. 178), compressed air was pumped into each of them. At 25 metres down, water exerts a pressure of $25/10 + 1$, i.e. 3.5 atmospheres. Air was pumped in under a pressure of about 4 atm, and, consequently, evacuated the pontoons.

* Later another kind of deep-water diving apparatus called the bathyscaphe was devised in France under the guidance of engineer Willm, and in Italy by the Belgian, Professor Piccard. They differ from bathyspheres in that they can travel at great depths, whereas bathyspheres are strained by the linking cable. At first Piccard went down to more than three kilometres. Then the Frenchmen Guillaume and Willm reached the depth of 4,050 m. In November 1959 a bathyscaphe went down to 5,670 m but even this was not the limit. On January 9, 1960 Piccard went down to 7,300 metres and on January 23 he reached the bottom of the Marianne depression, 11.5 km deep and believed to be the deepest spot in the world.

The water pushed them up to the surface with tremendous force. The twelve pontoons used had a total lifting capacity of $200 \times 12 = 2,400$ tons, but since this was more than the *Sadko* weighed, not all the water was pumped out, so as to do the job more smoothly.

However, the ship was actually surfaced only after several abortive attempts. "We had four failures before we proved successful," T. I. Bobritsky, the engineer

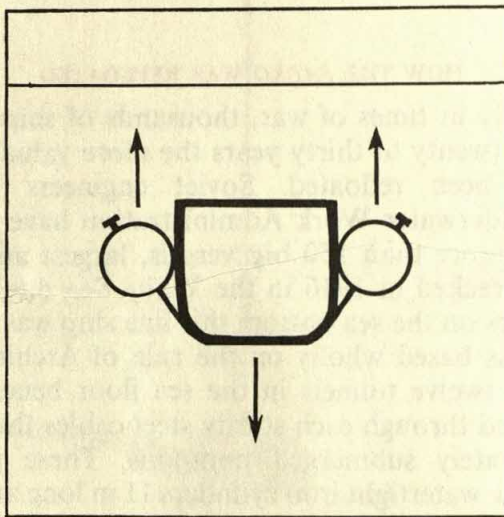


Fig. 178

How the *Sadko* was raised. The icebreaker, the pontoons and the lifting chains are given in cross-section

in charge of the job, wrote. "Three times, as we waited with bated breath for the ship to appear, we saw instead of the icebreaker the pontoons and the snapped cables and hoses whirling in a chaos of breakers and foam. The icebreaker itself came up and sank twice before it was finally floated."

PERPETUAL MOTION WATER MACHINE

Among the countless projects for a perpetual motion machine many were based on buoyancy. One was a 20 metre tall tower filled with water, which had a sturdy cable running like an endless belt through pulleys attached to top and bottom. Fastened to the cable were 14 empty cube-shaped boxes, each a metre high, made of sheets of iron riveted together to prevent water from seeping in. Figure 179 gives a picture of this tower and its cross-section.

How was it supposed to work? Everyone familiar with the Archimedes principle will gather that in water the boxes try to surface as they are buoyed up by a force equal to the weight of the water they themselves displace, or, in other words, by the weight of 1 cu m of water multiplied by the number of boxes submerged. The figures show us that six boxes are always submerged. Consequently the buoyant force is equal to the weight of six cu m of water, or

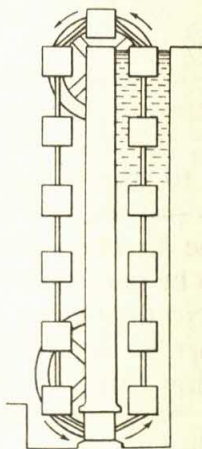
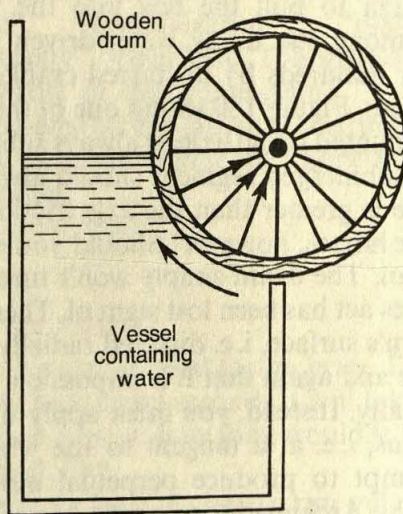


Fig. 179

Cross-section of the tower

Fig. 180

Another project for a water-driven "perpetual motion" machine



six tons. Meanwhile the boxes are pulled down by their own weight, which, however, is offset by the other six cubes freely suspended on the outer side of the cable.

Thus, the cable should be pulled upwards by a force of 6 tons, which should apparently compel the cable to turn endlessly and perform at every turn the work of

$$6,000 \times 20 = 120,000 \text{ kgm.}$$

Hence, if we stud the country with these towers we should be able to make them do an unlimited amount of work, enough at any rate to meet all economic requirements, as they would turn rotors of dynamos and produce any amount of electricity.

However, let us analyze this project. We shall see that the cable will not move at all. Indeed, for the cable to keep on moving, the boxes must dive into the water in the tower from the bottom and re-emerge at the top. But to dive in, each box must *overcome the pressure of a 20-m column of water*. The pressure this column exerts on a square metre of box area is 20 tons, the weight of 20 cu m of water. Meanwhile we have an upward pull of only 6 tons, which is definitely not enough to pull the box into the water.

Among the many water-driven “perpetual motion” machines invented in their hundreds by ill-starred cranks one will find some very simple but witty devices. Figure 180 shows one of them. Part of the wooden drum shown, which is mounted on an axle, is always submerged. If the Archimedes principle is valid, the submerged segment should always seek to surface; and since the buoying force is greater than the axle friction, the drum ought to spin endlessly. Hold your horses, however! Should you ever try to copy this project, you are bound to fail. The drum simply won't turn. Why? Because the direction in which the forces act has been lost sight of. These forces will always be perpendicular to the drum's surface, i. e. directed radially towards the axle. No doubt you have seen time and again that it is impossible to make a wheel turn by applying an effort radially. Instead, you must apply the effort in a direction perpendicular to the radius, i. e. at a tangent to the wheel's circumference. Now you see why the attempt to produce perpetual motion has again failed.

The Archimedes principle has supplied an endless host of perpetual motion cracks with tempting food for thought, inducing them to invent sundry artful devices to exploit the apparent loss of weight so as to obtain a perpetual source of mechanical energy. However, none of these attempts has ever been – nor ever could be – crowned with success.

WHO INVENTED THE WORD “GAS”?

“Gas” is a word scientists invented along with many other words such as “thermometer”, “electricity”, “galvanometer”, “telephone” and first of all, “atmosphere”. Of all invented words, “gas” is unquestionably the shortest. It was Galileo's contemporary the Dutch chemist and physician Helmont (1577-1644) who derived the word from the Greek word “chaos”. Having found air to consist of two parts, of which one maintains combustion and is consumed, while the other doesn't, Helmont wrote: “I have called this vapour *gas*, because it scarcely differs from the *chaos* of the ancients.” (“Chaos” originally meant a chasm.) However, for long this newly coined word failed to catch on. It was

revived by the famous Lavoisier only in 1789, to gain wide currency when the Montgolfier brothers made their sensational balloon flights.

Lomonosov, the celebrated 18th-century Russian scientist, coined another term for gaseous bodies, he called them "resilient liquids", a term which incidentally was still in use when I went to school. I might note that Lomonosov introduced into Russian several new standard scientific terms such as "atmosphere", "barometer", "airpump", "crystallization", "matter", "manometer", "micrometer", "optics", "electricity", "ether", etc. This genius and father of the natural sciences in Russia wrote in this connection:

"I was compelled to look for new words to name certain physical instruments, actions and natural things. These words may seem odd at first but I hope that in time with usage they will grow more familiar."

Lomonosov's prediction, I might add, came true.

A SEEMINGLY SIMPLE TASK

A vessel big enough to hold 30 tea-glassfuls of water is filled to the brim. Place a glass under its tap and, watch in hand, note how many seconds it will take to fill up. Suppose it is half a minute. My question now is: how long would it take the vessel to run dry if the tap were turned on?

Doesn't it seem simple? If it takes half a minute for one glass to run out, you may think it should consequently take only a quarter of an hour for the entire vessel to empty.

Try it and see. You'll find that the vessel will empty only in half an hour. How come? After all, it seemed so simple. Yes, but wrong!

Note that the *rate* with which the water runs out is not constant throughout. After the first glass is filled, the second will take longer to fill, because there will be less water in the vessel and, its level having gone down, it will exert a smaller pressure. For the same reason it will take the third glass still longer to fill up, and so on and so forth.

The speed with which any liquid pours out of a hole in the wall of an open-mouthed vessel with an open top is in direct proportion to the height of the column of liquid above the hole. Torricelli, Galileo's brilliant pupil, was the first to note this dependence which he expressed in the simple formula:

$$v = \sqrt{2gh},$$

where v is the speed with which the liquid pours out, g is the acceleration of gravity, and h is the height of the column of liquid above the orifice. From this

formula it follows that the speed with which the liquid spills out does not at all depend on its *density*. When the column height is the same, light alcohol and heavy mercury will pour out with the same speed (Fig. 181). Furthermore on the moon, whose gravity is but a sixth of the earth's, it will take roughly two and a half times more to fill a glass than here on earth.

However, back to our problem. If after the vessel feeds twenty glasses, the

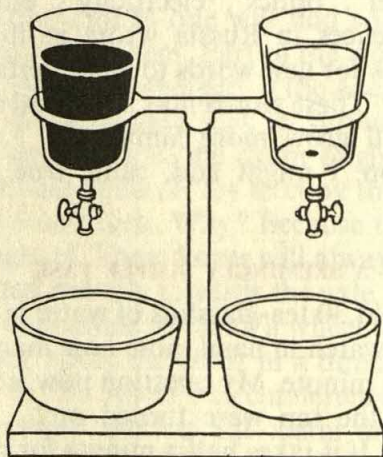


Fig. 181

Which of the two—mercury or alcohol—will pour out sooner?
The levels in both vessels are identical

water level (counting from the tap) drops to a *quarter* of the full vessel, it will take the 21st glass *twice* as long to fill up as the first glass. If later on the level of the water is down to a ninth, it will take already *thrice* as much time to fill up the last few glasses. Using the calculus to solve the problem, we find that the time required to let the vessel run dry is *twice* as much as the time needed for the same amount of liquid to pour out were the level of water above the top to remain constant.

THE TANK PROBLEM

From what I have just said it is one step to the notorious tank problem that one finds in every single collection of arithmetical and algebraic problems. No doubt, you all remember those classic scholastically dry problems of this order:

“The tank has two pipes, one leading in and the other out. The first needs five hours to fill the tank to the brim, and the second ten hours to drain in dry

(Fig. 182). How long will it take the tank to fill up when the stop-cocks are out of both pipes?"

This problem has a venerable history, dating right back some twenty centuries to Heron of Alexandria. Here is one of his problems.

Four fountains are there and a reservoir vast.

In but one day the first doth fill it to the brim.

The second two days and nights must play to do the same.

The third takes thrice the time as did the first.

The fourth comes last with four days and nights.

Now tell me when the reservoir will fill,

When all four play at once.

It is two thousand years now that the tank problem has been posed and—such is the force of habit!—has been solved *wrongly* in all this time. After our tank problem, you should realize why. Indeed, what is the solution given? The following for the tank one mentioned above. In one hour it is claimed the first pipe fills a fifth of the tank, while the second drains a tenth of it. Consequently, with both pipes open the tub should fill up every hour by $1/5 - 1/10 = 1/10$, which means that it should take ten hours for the tank to fill to the brim. This is the wrong way of going about it, though. Whereas the water may be considered to be flowing in under a constant and consequently uniform pressure, it *flows out* under the pressure exerted by a changing level; hence the flow is *not uniform*. From the fact that it takes the second pipe ten hours to drain the tank it does not at all follow that a tenth of the water in the tank flows out with every hour. We shall never solve this problem correctly with the help of elementary mathematics, and so all problems dealing with tanks and the *outflow* of water really have no place in collections of arithmetical problems.

AMAZING VESSEL

Could we have a vessel from which water would keep flowing out evenly without slowing down to a trickle, even though its level inside would drop? I suppose that now you will think this impossible to accomplish. But it can be done. The bottle depicted in Fig. 183 is one such amazing vessel. It is an ordinary bottle with a narrow mouth, having a glass tube inserted through the cork. When you open tap C, below the end of the tube, the liquid flows out evenly until the level of the water inside the vessel drops below the end of the tube. By pushing the tube down almost to tap level you can cause all the liquid

above the tap to flow out uniformly, even though in a mere trickle.

How does this come about? Try to trace in the mind's eye what happens in the vessel when you open tap *C* to let the water out. It is first of all the level of the water in the top tube that falls to the bottom of it; only afterwards does the level of the water in the vessel itself descend and outside air enters through the now empty tube. As the water flows out, its level in the vessel drops. Meanwhile

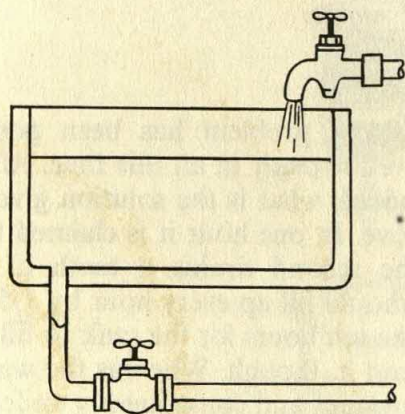
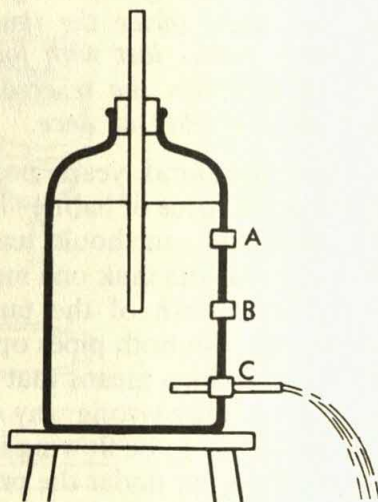


Fig. 182

The tank problem

Fig. 183

Cross-section of "Mariotte's bottle". The water flows out in a steady jet



the air from outside enters through the glass tube to join the rarefied air beneath the water, bubbles up and gathers above the water in the upper part of the bottle. Now at the entire level of tap *B*, the pressure is equal to atmospheric pressure. Consequently the water flows out through tap *C* merely owing to the pressure exerted by the *BC* layer of water, since atmospheric pressure both inside and outside the bottle is identical. As the height of the *BC* layer stays constant, no wonder the water flows out with a uniform speed all the time.

Now try to answer this question. How quickly will the water flow out if plug *B*, which is level with the tube end, is pulled out? Surprisingly enough, we find that *it won't flow out at all*, provided, of course, the hole is small enough to be disregarded, because otherwise the water will flow out due to the pressure of the thin upper layer which is just as high as the hole is wide. Actually both inside

and outside the pressure is the same as atmospheric pressure and so there is nothing to cause the water to flow out. But if we pull out plug *A*, which is *above* the end of the tube, we shall see the outer air entering the bottle instead of water flowing out. Why? For the very simple reason that inside this part of the vessel the pressure of the air is *less* than the outside atmospheric pressure.

This vessel, which has such unusual properties, was invented by the famous physicist Mariotte and has hence come to be known as "Mariotte's bottle."

LOAD OF AIR

In the mid-seventeenth century, the citizens of Regensburg and the German princes with the Emperor at their head, witnessed the following wonder. Sixteen horses in teams of eight apiece tried might and main to pull apart two copper hemispheres joined together by "nothingness", air itself, and failed. So did Burgomaster Otto von Guericke, the "German Galileo" as he is sometimes called, show for everyone to see that air was not at all "nothing", that it possessed weight and that it exerted a considerable pressure on everything on earth.

This experiment was staged in great ceremony on May 8th, 1654. The learned burgomaster was able to interest everyone in his studies, despite the political confusion and devastating wars at the time.

Though you will find a description of it in practically every textbook on physics, I'm sure you won't be averse to hearing the story from Guericke himself. A fat volume describing a long series of his experiments was put in Latin in Amsterdam in 1672. Like all books of the period it had a very rambling title. Here it is:

OTTO von GUERICKE

The so-called new Magdeburg experiments with
AIRLESS SPACE

originally described by KASPAR SCHOTT,
Professor of Mathematics of Würzburg University.

Published by the author himself,
in a more comprehensive form and supplemented with
various new experiments.

It is Chapter 23 that deals with the experiment mentioned. Here it is:
"An experiment demonstrating that the pressure of air can join two hemispheres so firmly together, that even sixteen horses will not pull them apart.
"I ordered two copper hemispheres of three quarters of a Magdeburg ell

[equal to 550 mm] across. Actually they were only 67/100 ell across, since the craftsmen, as is their habit, could not make exactly what was required. The two hemispheres were quite identical. One had a stopcock to evacuate the inside air and prevent the outside air from entering. The two hemispheres also had four rings attached to lash on the ropes fastened to the harnesses of the horses. I also ordered that a leather ring be made which I soaked in a mixture of paraffine and



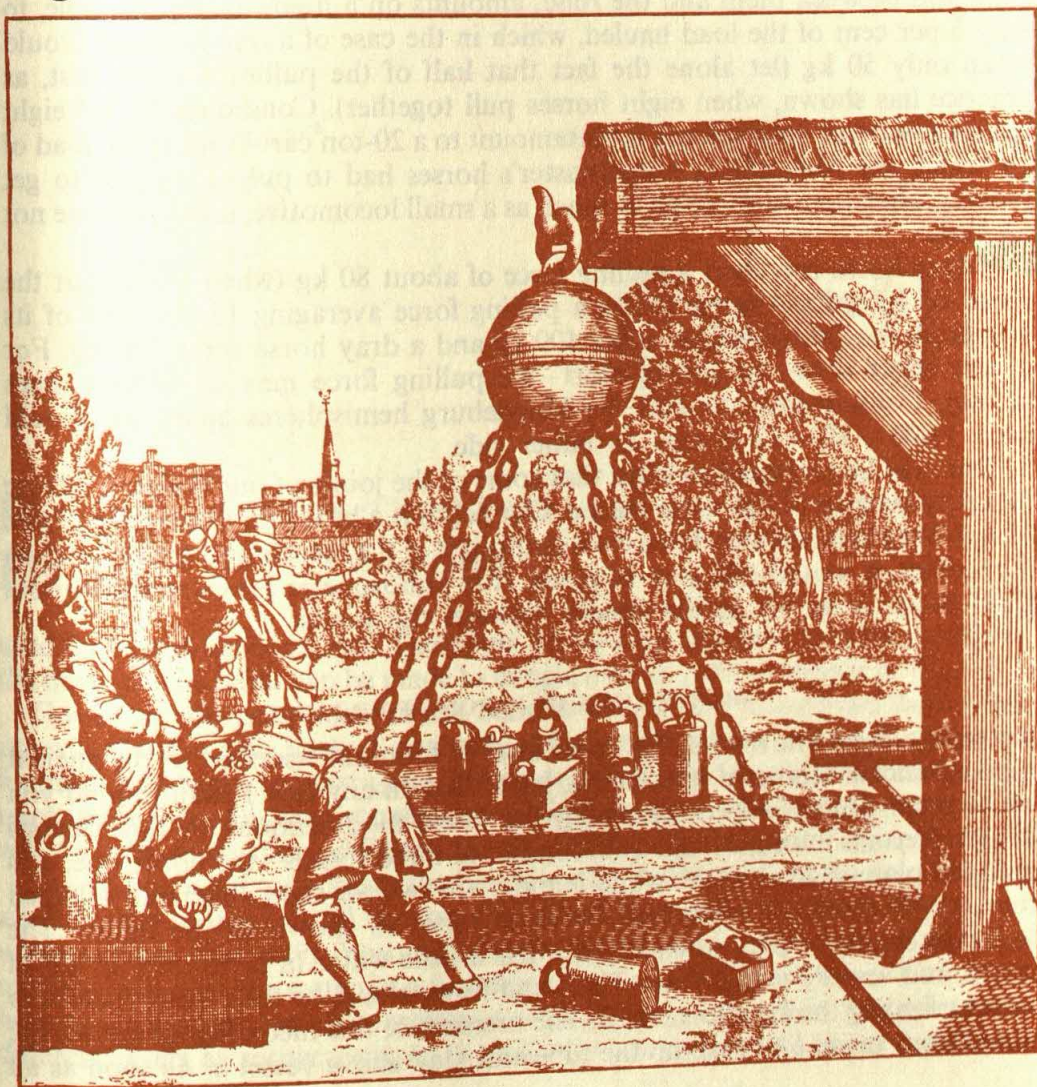
Fig. 184

turpentine. This I placed between the two hemispheres to prevent any air from entering. The nozzle of an air pump was then inserted in the stopcock, and the air inside the sphere was evacuated. The force with which the two hemispheres adhered to each other through the leather ring was then revealed. The pressure of the outer air glued them so tightly together that sixteen horses failed to pull them apart, or did so with great difficulty. When the hemispheres yielded to the horses' pull and came apart, there was a loud report as if a shot had been fired. However, one turn of the stopcock to let the air enter freely was enough to easily pull the hemispheres apart with one's hands."

A simple reckoning will show why so great a force (eight horses from each side) had to be exerted to pull the two halves of the empty sphere apart. Air exerts a pressure of about 1 kg/cm^2 . The area of a circle with a diameter of 0.67 ell (37 cm) is $1,060 \text{ cm}^2$. (We take the area of a circle and not the surface of the

hemisphere, because atmospheric pressure is equal to the indicated value only when it acts on a surface at right angles, being less for an inclined surface. In the case in question we take the right-angled *projection* of the sphere's surface, or, in other words, the area of the great circle.) Consequently, atmospheric pressure

Fig. 185



on each hemisphere should exceed 1,000 kg or one ton. This means the two eight-horse teams must have pulled with a one-ton force to counteract the pressure of the outer air.

Now one ton does not seem so very much for so many horses. However, don't forget that when horses pull a one-ton load, they have to overcome a force not of one ton, but much less. This force, the friction between the wheels and the axles and between them and the road, amounts on a highway, for example, to only 5 per cent of the load hauled, which in the case of a one-ton load would mean only 50 kg (let alone the fact that half of the pulling force is lost, as practice has shown, when eight horses pull together). Consequently, for eight horses a one-ton pulling force is tantamount to a 20-ton cart. That is the load of air which the Magdeburg burgomaster's horses had to pull. They had to get moving what seemed to weigh as much as a small locomotive, moreover one not on rails.

A dray horse can exert a pulling force of about 80 kg (when moving at the speed of 4 km/h). A horse exerts a pulling force averaging 15 per cent of its weight. A race-horse weighs some 400 kg and a dray horse some 750 kg. For a very short time—the initial effort—the pulling force may be several times greater. Consequently, to pull the Magdeburg hemispheres apart, we should need $1,000 \div 80 = 13$ horses on either side.

You may be surprised to learn that some of the joints of our skeleton adhere precisely because of this same reason. Our pelvis is a beautiful illustration to the Magdeburg hemispheres. Even if we stripped it of the muscle and gristle binding it together, it would still stay in place. It is atmospheric pressure which does that—there is no air in the spaces between the joints.

MODIFICATION OF HERON'S FOUNTAIN

You most likely know what the usual kind of fountain, ascribed to the ancient mathematician Heron of Alexandria, looks like. In any case I shall remind you of its main points before describing the latest modifications of this curious device. Heron's fountain (Fig. 186) consists of three vessels—the upper one, *a*, is an open plate-shaped affair, while *b* and *c* are two air-tight spherically-shaped retorts. All three are connected by three tubes as shown in the figure. The fountain begins to play when vessel *a* has a little water in it, vessel *b* is full of water, and vessel *c* is full of air. The water flows along the tube from vessel *a* to vessel *c* forcing the air into vessel *b*. The pressure of this incoming air causes the water from vessel *b* to rush up the tube and play above vessel *a*. As soon as all

the water runs out of vessel *b*, the fountain ceases to play. That was how the fountain worked in Heron's times.

More recently, one Italian physics master, whose school lab's meagre furnishings prodded him to display ingenuity, simplified the fountain and introduced modifications which every one of you could easily reproduce with the simplest of means (Fig. 188). In place of spherical retorts and glass or metal pipes he

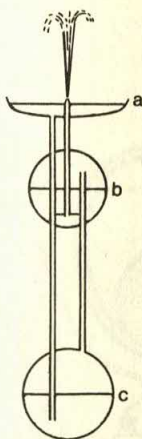


Fig. 186 Cross-section of Heron's fountain

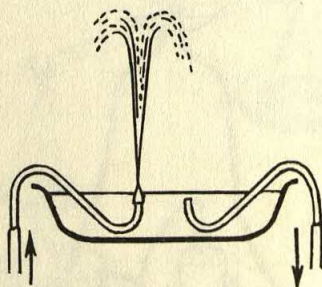


Fig. 187 Variant for the upper vessel

used flasks and rubber tubes. The upper vessel does not have to have a hole in the bottom. The tubes can be made to dangle over the rim as shown in Fig. 187.

This is far more convenient to use, because after all the water from flask *b* has run via vessel *a* into flask *c*, you may simply interchange *b* and *c* and your fountain will begin to play again. However, when you do that, don't forget to reset the nozzle. Another convenience is that we may rearrange the vessels at will to see how their different levels affect the height of the spray.

Should you want to increase the height of the fountain by a number of times, all you have to do is to fill the two flasks with mercury and water, in place of water and air (Fig. 189). You will clearly see that as it flows from *c* to *b* the mercury will oust the water in a fountain. Knowing that mercury is 13.5 times heavier than water, we may reckon the height of the fountain. Designate the different levels as respectively h_1 , h_2 and h_3 . Let us now see what forces the

mercury to flow from c (Fig. 189) to b . The mercury in the connecting tube is subjected to pressure from two sides. One is the pressure exerted by h_2 , the difference between the levels of the columns of mercury (which is tantamount to the pressure of a column of water 13.5 times taller, that is $13.5 h_2$) plus the pressure exerted by the column of water h_1 . Such is the pressure exerted from the right. On the left a pressure is exerted by the column of water h_3 . As a result

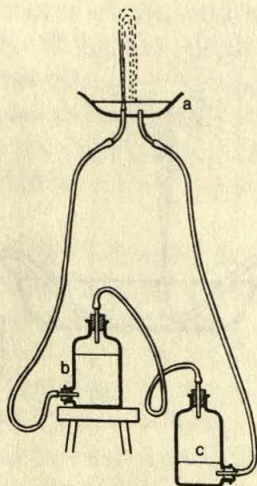
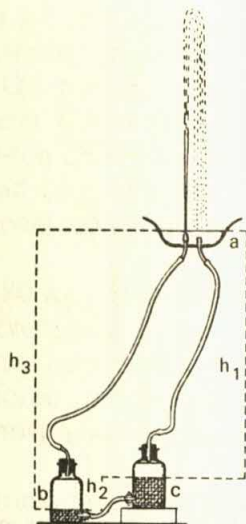


Fig. 188

Cross-section of a modern modification of Heron's fountain

Fig. 189

Cross-section of a mercury-pressure fountain. The jet shoots up to a height ten times greater than the difference between the mercury levels



there acts upon the mercury a force of $13.5 h_2 + h_1 - h_3$. But since $h_3 - h_1 = h_2$, we replace $h_1 - h_3$ by $-h_2$ to get $13.5 h_2 - h_2$, i. e. $12.5 h_2$. Hence the mercury is forced into flask b by the pressure of a column of water equal in height to $12.5 h_2$. Theoretically the fountain should thus play to a height equal to the difference between the mercury levels of the two flasks multiplied by 12.5. However, because of friction the actual height is a little less.

However, this device conveniently affords a rather high fountain. To get a 10-metre height it is quite enough to place one of the flasks roughly a metre higher than the other. Curiously enough the raising of vessel a further up above the flasks with the mercury does not at all affect, as our reckoning shows, the height of the fountain.

“DON’T GET WET”

Back in the 17th and 18th centuries, noblemen amused themselves with the following instructive toy. This was either a mug or a small pitcher with a fanciful pattern of big holes at the top (Fig. 190). Aristocrats would offer such a mug full of wine to a guest from the lower classes, at whose expense a laugh could be had

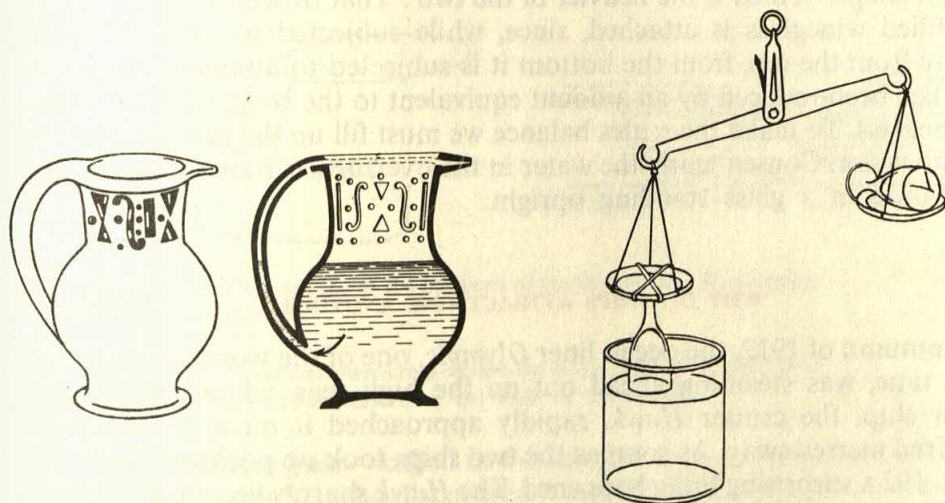


Fig. 190

“Don’t get wet” 18th-century drinking vessel and its secret

Fig. 191

Which pan is heavier?

with impunity. And, indeed, how is one to drink from it? One can’t tip it because then the wine would flow out through the many holes in the top and not a drop would reach one’s lips.

However, all who knew the secret (shown in Fig. 190 on the right) stopped up hole *B* with a finger, and sucked in the liquid through the spout without tilting the vessel. In this way the wine rises up through hole *E*, up the channel inside the handle and thence along its continuation *C* inside the upper rim of the mug till it reaches the spout. These potter’s jokes were made in the Soviet Union not so long ago. I myself have seen some of them, with the words “Drink, but don’t get wet” inscribed on them.

HOW MUCH WILL THE WATER IN AN OVERTURNED GLASS WEIGH?

Nothing, you will say, as the water will surely pour out. But suppose it doesn't? We can make water stay in an overturned glass without pouring out. Figure 191 shows you how this is done. The overturned wineglass, attached to the bottom of one of the pans, is full of water which does not pour out, as the rim of the glass is immersed in a jar of water. The other pan holds an empty wineglass of identical shape. Which is the heavier of the two? That to which the overturned water-filled wineglass is attached, since, while subjected to full atmospheric pressure from the top, from the bottom it is subjected to atmospheric pressure which has been reduced by an amount equivalent to the weight of the water in the wineglass. To make the scales balance we must fill up the glass on the other pan with water. Consequently the water in the overturned glass weighs as much as it would in a glass standing upright.

WHY DO SHIPS ATTRACT ONE ANOTHER?

In the autumn of 1912, the ocean liner *Olympic*, one of the world's biggest ships at the time, was steaming ahead out on the high seas, when another much smaller ship, the cruiser *Hawk*, rapidly approached it on a parallel course a hundred metres away. As soon as the two ships took up positions as depicted in Fig. 192 a surprising thing happened. The *Hawk* sharply veered off its course, as if obeying some invisible force, turned towards the big liner and heedless of the helm rammed into it. The impact was so great that it made a big gash in the *Olympic's* hull. A tribunal examined this queer case and found the *Olympic's* skipper guilty, as, according to its ruling, he had failed to issue orders to yield the right of passage to the *Hawk*. Consequently, the tribunal, as you can gather, saw nothing extraordinary about it all, attributing the accident to the skipper's negligence. Actually this was the result of a totally unforeseen circumstance, a case of the mutual attraction of ships at sea.

This must have taken place before, too, with two ships on a parallel course. But when ships were small, their mutual attraction was not so much in evidence. However, now that floating cities are plying the oceans, it is far more noticeable and warship commanders duly reckon with it when manoeuvring. It was most likely to blame for the many smaller boats that collided with bigger ships, when cruising in their vicinity.

What causes this attraction? Newton's law of universal gravitation has, of course, nothing at all to do with it. We already know from Chapter 14 that this

attraction is negligible. There is a totally different cause: it derives from the laws that govern the flow of fluids in pipes and channels. One can prove that in the case of a fluid flowing through a channel with narrower and wider parts, it will flow faster through the narrower part and exert a smaller pressure on the channel's walls than in the wider parts, where its flow is calmer and its pressure on the walls greater (Fig. 193). This is called the *Bernoulli principle*.

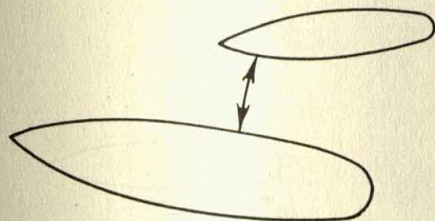


Fig. 192

Diagram shows the positions of the *Olympic* and *Hawk* before collision

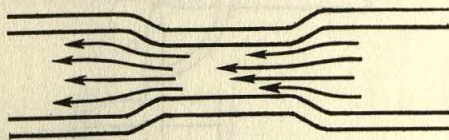


Fig. 193

In the narrower cross-section the water flows faster and exerts a smaller pressure on the walls of the channel

The same holds for *gases*—called in this case, however, the *Clément-Desormes effect*, after the physicists who discovered it and often known as the “aerostatical paradox”. It is said that this phenomenon was discovered accidentally in the following circumstances. At one French mine, a collier was told to cover up with a board the outlet of a shaft through which the compressed air was fed into the mine. The miner had a hard job battling with the jet of air coming out of the shaft. All of a sudden the board banged the shaft tight so violently that had it not been large enough, it would have been pulled into the ventilation shaft together with the scared workman. Incidentally this characteristic feature of the flow of gases explains how an atomizer works.

When we blow into pipe *a* (Fig. 194), which tapers off into a nozzle, the pressure of the air in it decreases. As a result above nozzle *b* air pressure is less: that is why atmospheric pressure forces the liquid in the glass to rush up the pipe. As it comes out of the nozzle, the liquid is atomized in the jet of air.

Now we shall understand why ships attract each other. In the case of two ships on a parallel course, we have a channel of water between them, the difference being that whereas in an ordinary channel the walls remain stationary and the water moves, here the water remains “stationary” and the “walls” move.

This difference, however, does not at all change the action of the forces. In the narrower parts of the moving channel the water exerts a smaller pressure on the "walls" than elsewhere. In other words the sides of the ships facing each other are subjected to a smaller pressure than the two outer sides. What happens then? The pressure of the water on the outer sides causes the ships to move towards each other, with the smaller boat, naturally, moving much faster. The

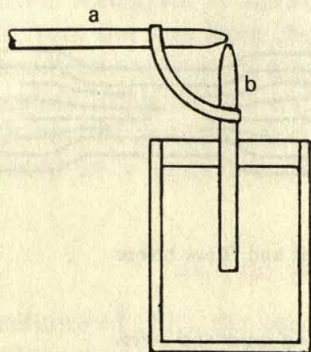
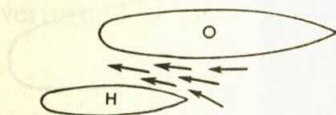


Fig. 194

Principle of the atomizer

Fig. 195

Flows between two ships in motion



bigger boat hardly seems to move. That is why attraction is so strong when a big boat rapidly bypasses a small one.

So to sum up: the mutual attraction of ships is due to the suction of flowing water. This also explains the danger that rapids and the suction of whirlpools present to bathers. It has been reckoned that a stream of water, moving with the moderate speed of one metre a second, attracts a person with the force of 30 kg. It is not so easy to resist so strong a force especially in water, when your own weight prevents you from keeping your balance. Finally, the suction of a swift train is also due to the same Bernoulli principle. A train dashing along with the speed of 50 km/h will attract a bystander with a force of about 8 kg.

The layman knows very little about the phenomena associated with the Bernoulli principle—though they are none so seldom. Therefore I think it would be of benefit to dwell on this in greater detail. The following is an extract from an article on the subject written for a popular-science magazine.

THE BERNOULLI PRINCIPLE AND ITS CONSEQUENCES

This principle, first stated by Bernoulli in 1726, is: in an air or water flow pressure is great when velocity is small and vice versa. There are, of course, some limitations but we shall not deal with them here.

Figure 196 illustrates the principle.

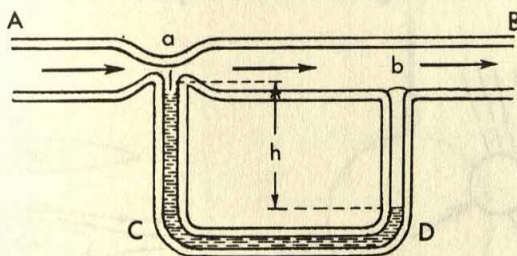


Fig. 196

Illustration of the Bernoulli principle. In the "bottle-neck" (a) of the tube AB pressure is less than in the broader part (b)

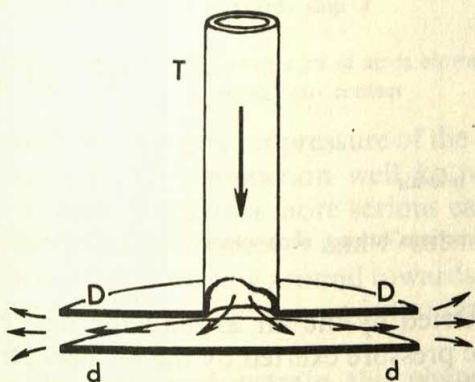


Fig. 197

The discs experiment

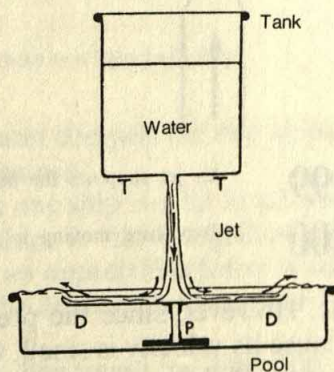


Fig. 198

Disc DD rises along rod P when a jet of water comes down on it

Air is blown in via tube AB. In the "bottleneck" a the velocity of the air is great, in the broader part b it is small. Where the velocity is great, pressure is small and vice versa. Owing to the lower pressure at point a, the liquid in tube C rises, meanwhile, the increased pressure at point b forces down the liquid in tube D.

In Figure 197 tube T is mounted on disc DD ; air is blown in via T and further past the nonfastened disc dd (to simplify the experiment take a used spool and a paper disc, kept in position by means of a pin inserted into the spool's hole). The air between the two discs possesses great velocity which rapidly diminishes the nearer it is to the rims, since the cross-section of the air flow quickly grows and the inertia of the air flowing out from the space between the discs has to be

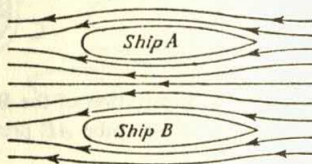
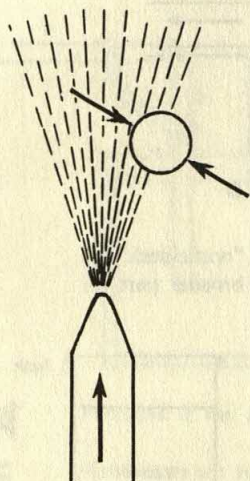


Fig. 199

Air jet supports the little ball in mid-air

Fig. 200

Two ships moving in parallel directions attract each other

overcome. However, since the pressure exerted by the air around the disc is great because its velocity is small, while the pressure exerted by the air between the discs is small, because its velocity, on the contrary, is great, the pressure of the outer air, being the greater, forces the discs together with an intensity that is the more powerful, the more intensively air is blown in through T .

Figure 198 is practically identical with Fig. 197, only it deals with water. The fast moving water on top of disc DD maintains a lower level, rising to the higher level of the placid water in the tank only when overlapping the disc. The placid water, hence, exerts a greater pressure than the moving water on top the disc, and as a result the disc rises. (The disc is kept in position by rod P .)

Figure 199 depicts a small pith ball floating in a jet of air. The air strikes at the ball and prevents it from falling. Meanwhile, should the ball pop aside, the

outer air, whose pressure is greater since its velocity is smaller, returns it to the jet.

Figure 200 depicts two ships on a parallel course in placid water, or standing still in flowing water, which amounts to the same thing. In between the vessels the velocity of the narrower flow is greater than that of the outer water and, consequently, the pressure exerted by the water in this place is less, with the

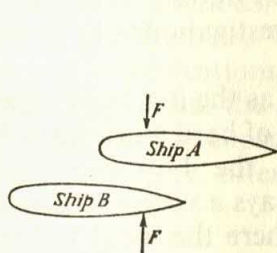


Fig. 201

When the ships move forward, ship *B* veers nosewards towards ship *A*

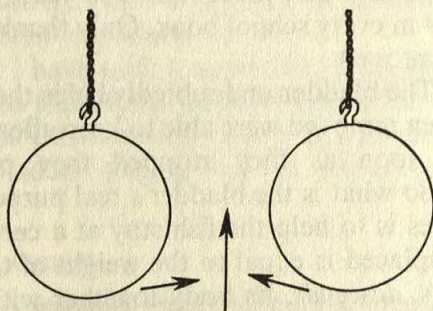


Fig. 202

When a jet of air is blown between these two light balls they swing into contact

result that the greater pressure of the outer water compels the two ships to draw together—a phenomenon well known to seamen.

Figure 201 gives a more serious case when one ship is a bit in advance of the other. The two forces F and F causing the ships to move together, try to turn them, with *B* veering around towards *A* with an appreciable force. A collision is inevitable as the movement is too rapid for the helmsman to manage to change the course.

One can demonstrate the phenomenon illustrated in Fig. 200 also by blowing air between two light rubber balls suspended as in Fig. 202. When this is done, they swing into contact.

WHY FISH HAVE BLADDERS

What does the bladder do for a fish? It is usually said—and, as one would think, with good reason—that the fish inflates its bladder to ascend to the surface: this supposedly increases the body volume and thus the weight of the water displaced presumably becomes greater than the fish's own weight. Buoyancy

causes the fish to rise. When the fish wants to stop ascending, or to descend, it supposedly compresses its bladder, thus reducing its body volume and, consequently, the volume of the water displaced, and sinks again in conformity with the Archimedes principle.

This vulgarized notion of the purport of the fish's bladder dates back to the 17th century and was first postulated in 1675 by Prof. Borelli of the Florentine Academy. For more than 200 years it was accepted unreservedly, and thus set out in every school book. Only thanks to recent investigations was it completely disproved.

The bladder undoubtedly helps the fish to swim, as the fish from which it had been removed were able to keep afloat only by dint of hard work with their fins; as soon as they stopped they plummeted to the bottom like stones.

So what is the bladder's real purpose then? It plays a very limited role. All it does is to help the fish stay at a certain depth, where the weight of the water displaced is equal to the weight of the fish itself. When the fish, by moving its fins, *descends*, its body together with the bladder is compressed by the great pressure of the surrounding water. This reduces the weight of the water displaced to less than that of the fish itself and thus the fish sinks. The lower it goes the greater the pressure becomes, rising by one atmosphere with every ten metres. This compresses the fish's body still more, making the fish sink more rapidly.

The same process, only in reverse, takes place when the fish lifts itself up by fin-work from the layer of water where it was in a state of equilibrium. Now surrounding pressure diminishes; but the fish's bladder (wherein the pressure offset that of the surrounding water) causes its body volume to increase and thus by buoyed up. The higher up the fish goes the more bloated its body becomes, and the more rapidly does it ascend. The fish cannot halt its ascent by "compressing its bladder", as the walls of this bladder have no muscles.

The following experiment has confirmed the fact of *passive* expansion of a fish's body volume. A chloroformed bleak was placed in a sealed water-filled jar in which an intensified pressure, approaching that at a certain depth in a natural body of water, was maintained. On the surface the fish lay passively with its belly up. When pushed a little down, it again floated up to the top. When pushed down nearer to the bottom, it sank right to the bottom. In between these two levels, it remained in a state of equilibrium, neither sinking further nor surfacing. Recall what I have just told you about the passive expansion and compression of the bladder and you will realize why.

So, in defiance of the common notion, a fish can't compress or expand its

bladder at will. Its volume varies but does so passively, due to increased or reduced outer pressure (in conformity with the Boyle-Mariotte law). This varying volume only harms the fish as it makes it either rush faster and faster up or dive rapidly down. In short, the bladder helps the fish to preserve its equilibrium when it isn't moving, but the equilibrium is *unstable*. Such is the true role of the fish's bladder—as far as swimming is concerned. We don't know whether it has any other functions, so far the bladder is still a mystery. It is only its hydrostatic role that has been satisfactorily explained so far.

Fishermen's observations confirm what I have said. It sometimes happens in deep-water fishing that the fish manages to slip off the hook or out of the net. However, contrary to expectation, it doesn't dive back to where it was caught but rushes up, very often with the bladder jutting out of its mouth.

WAVES AND WHIRLS

The elementary laws of physics fail to explain many common physical processes. Even such a frequently observed phenomenon as sea waves on a windy day finds no full explanation within the limits of school physics. What causes waves in calm water when a boat cuts through it? Why do flags flutter on a breezy day? Why is seaside sand wave-shaped? Why does the smoke from a chimney stack curl?

To explain all these and other similar phenomena we must know the peculiar features of *whirling* flow of fluids and gases. Since school textbooks hardly mention this at all, here are a few salient points.

Imagine a fluid flowing through a pipe. When all the particles in the fluid move through the pipe along parallel lines, we have the simplest type of fluid flow, the calm or *laminary* flow as physicists call it. However, this is not so frequent. On the contrary, far oftener does a fluid flow through pipes in a disquiet state, with vortices spreading from the pipe's walls to its axis. This is the vortical or *turbulent* flow which we observe in water-mains, provided we discount thin pipes where we have a laminar flow. This turbulent flow is observed every time the velocity of the flow of the fluid in a pipe of a given diameter reaches a certain magnitude called the *critical* velocity. (The critical velocity for a definite fluid is directly proportional to its viscosity and inversely proportional to its density and the diameter of the pipe through which it is flowing.)

We can render observable the vortices which a liquid makes while flowing through a pipe by adding to a transparent fluid in a glass pipe some amount of light powder, such as lycopodium powder, for instance. We shall then be able to

clearly discern the vortices spreading from the pipe's walls to its axis.

This characteristic feature of the turbulent flow is used to advantage in refrigerators and freezers. A fluid moving in a turbulent flow through a pipe with cooled walls brings all its particles into contact with these cold walls much sooner than if it were flowing otherwise. One must realize that fluids as such are poor conductors of heat and, in the absence of intermixing, cool or warm up

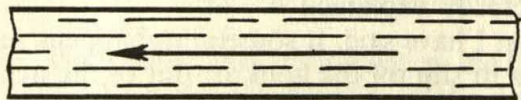


Fig. 203

The calm, laminar flow of a fluid in a pipe

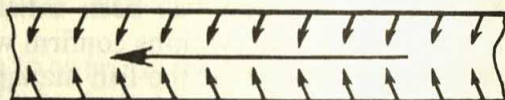


Fig. 204

The disquiet, turbulent flow of a fluid in a pipe

very slowly. The blood and the tissues around it are able to exchange heat and substances so vigorously precisely because the flow of blood through the blood vessels is turbulent and not laminar.

All that has been said of fluids in pipes goes for open canals and streams too, as here the water moves turbulently. When we take exact measurements of the velocity of a river's flow, our instruments register pulsations, especially near the bottom, which point to a constantly changing direction of the flow, or, in other words, to turbulence. The water particles in a river move not only along its course, as is usually thought, but also away from its banks to the middle. Therefore to claim that deep down in a river the water maintains a constant round-the-year temperature of 4°C above zero is wrong. Due to intermixing, the temperature of the flowing water near the bottom of a river (but not a lake) is the same as at the surface.

The vortical flow at the river bottom carries away the light sand and produces "waves" in the sand. You will see the same on a beach paved by the tide (Fig. 205). Were the near-bottom flow steady the sandy bed would be even.

So to sum up: we shall find a turbulent flow on the surface of all bodies washed by water. That it exists is illustrated, for instance, by the snaking motions of a rope, of which one end is tied fast and the other dangling freely in the direction of the flow. How is this motion produced? A vortex arises near a section of the rope and pulls at it. The very next instant, another vortex appears to pull at it in the opposite direction, thus combining with the first to produce the snaking motion (Fig. 206).

Let us now turn from fluids to gases; from water to air. No doubt you have seen whirlwinds snatch up dust and straw from the ground. That is a manifestation of the turbulent flow of the air near the ground. When the air flows along the surface of water, "humps" appear, causing waves or ripples wherever vortices arise due to a drop in atmospheric pressure. The same thing is responsible for the sand "waves" in a desert or on the dune slopes.

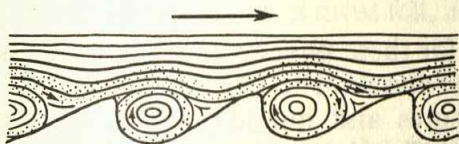


Fig. 205

Turbulence causes sand waves on a sea beach

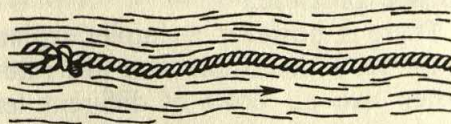


Fig. 206

Turbulence causes a rope to snake in flowing water

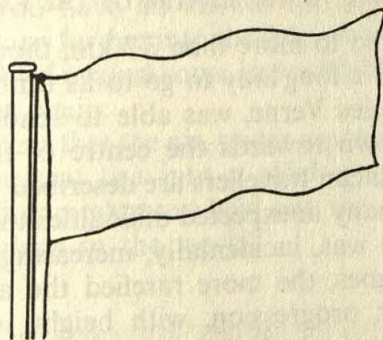


Fig. 207

Flag fluttering in a breeze

Now you will understand why a flag flutters in a breeze. This is identical with the rope-in-the-water case. The weather-cock never points in one constant direction on a windy day, but swivels obedient to air turbulence. The clouds of smoke emerging from a factory chimney stack are of a similar turbulent origin. The gases from the furnace swirl up the chimney and continue to whirl by inertia for some time after they escape from the chimney.

Air turbulence is extremely important for aircraft. Airplane wings are shaped so as to fill up the rarefied air space beneath and enhance the vortices above. This produces a combination of buoyancy (from below) and suction (from

above). This is similar to what takes place when birds soar with outspread wings.

What does the wind do, when it blows against a roof? Its vortical motions cause the air above the roof to rarefy, and in trying to offset pressure, the air, beneath the roof, presses on it. As a result we often see the wind carrying away a light, loosely fastened roof. This also explains why on a very windy day, large shop windows bulge out due to inside pressure. (They are not shattered by outside pressure.)

There is, however, a simpler explanation for these phenomena. They are due to the reduction of pressure in air flows. (See above "The Bernoulli Principle".) When two air flows of different temperatures and humidities take parallel courses, vortices arise in each. Incidentally, this is the main reason for the different shapes clouds assume. This all shows you how wide is the range of phenomena associated with vortical flows.

JOURNEY TO THE CENTRE OF THE EARTH

Nobody has ever descended to more than 3.3 km, though the earth's radius is 6,400 km and there is still a long way to go to its centre. Only that ingenious science-fiction novelist, Jules Verne, was able to send his eccentric professor with his nephew way down towards the centre of the earth. The amazing adventures of the subterranean travellers are described in *Journey to the Centre of the Earth*. One of the many unexpected difficulties that the professor and his nephew had to cope with was, incidentally, increasing air density. You know that the higher up one goes, the more rarefied the air becomes, its density diminishing in geometric progression, with height increasing in arithmetic progression. On the contrary, the lower one descends beneath ocean level, the denser the air becomes under the pressure of the above-lying layers. The professor and his nephew couldn't help noticing this, naturally, and this is what they had to say to each other after they reached the depth of 12 leagues or 48 km.

"Now," he said, "consult the manometer. What does it indicate?"

"Considerable pressure."

"Well, then, you see in descending gradually we get accustomed to the density of the atmosphere, and are not the least affected by it."

"Not in the least, except a little pain in the ears."

"That is nothing, and you can get rid of it at once by breathing very quickly for a minute."

“Quite so,” said I, determined not to contradict him again. “There is a positive pleasure even in feeling one self getting into a denser atmosphere. Have you noticed the wonderful clearness of sound here?”

“Yes, indeed. A deaf man would soon get his hearing again.”

“But this density will of course increase?”

“Yes, according to a somewhat indefinite law. It is true that the intensity of the weight will diminish in proportion as we descend. You know that it is on the surface that its action is most felt, and at the centre of the globe objects have no longer any weight?”

“I know that; but tell me, in the end will not the air acquire the density of water?”

“Undoubtedly, under the pressure of 710 atmospheres.”

“And lower still?”

“Lower still of course the density will increase still more.”

“How shall we descend, then?”

“Well, we must put stones in our pockets.”

“I declare, uncle, you have an answer for everything.”

“I did not dare to go any further into the field of hypothesis, for I should have been sure to have stumbled against some impossibility, which would have made the professor start out again.

“But it was quite evident that the air, under a pressure of possibly a thousand atmospheres, would pass at last into a solid state; and in that case, even supposing that our bodies might have held out, we should be forced to stop in spite of all the reasonings in the world.”

IMAGINATION AND MATHEMATICS

Let us verify Jules Verne’s statement. We shall see that the novelist was wrong and we won’t have to descend into the bowels of the earth either to discover his mistake. All we must do is to equip ourselves with a pencil and a piece of paper.

Firstly, let us try to find how far down we must go for atmospheric pressure to increase by a thousandth. Normal atmospheric pressure is always equal to the weight of a 760-mm column of mercury. If we were living in mercury we would have to descend by only $760/1,000 = 0.76$ mm for pressure to increase by a thousandth. Actually, we shall have to descend much further, as many times deeper as air is lighter than mercury, or 10,500 times more, to be exact. So for pressure to increase by a thousandth we must descend not 0.76 mm (as in mercury) but $0.76 \times 10,500$, almost 8 metres. With every 8 metres down,

pressure will increase by one-thousandth (since each subsequent 8-metre air layer will be denser than the previous one and the absolute physical increase in pressure will also be greater than in the foregoing layer, which is what it should really be as this is a thousandth of a larger amount). Wherever we would be, at the top of the world (22 km), on Mount Everest (9 km) or near sea level, we must make an 8-metre descent for atmospheric pressure to increase by a thousandth. This will give us the following table showing how atmospheric pressure increases with depth:

at ground level, pressure = 760 mm = normal
at 8 m down, pressure = 1.001 of normal
at 2×8 m down, pressure = $(1.001)^2$ of normal
at 3×8 m down, pressure = $(1.001)^3$ of normal
at 4×8 m down, pressure = $(1.001)^4$ of normal

So, at $n \times 8$ m down, atmospheric pressure will be greater than the normal by $(1.001)^n$ times; and while pressure is not very great, air density will increase at the same rate (the law of Mariotte).

Now Jules Verne tells us that the professor and his nephew descended only to 48 km. Consequently, we may discount the decrease in gravity and the related reduction in the weight of the air. So how great was the pressure that Jules Verne's subterranean travellers experienced at the depth of 48 km or 48,000 m? In our formula n is equal to $48,000 \div 8 = 6,000$. We must therefore calculate $1.001^{6,000}$. Since the multiplication of 1.001 by itself 6,000 times is a rather tedious and time-consuming task we shall address ourselves to logarithms—of which the great French astronomer Laplace justly said that by cutting the amount of labour consumed they double the lifetime of the reckoner. (Any of you who dislike logarithms may change your mind after you read the following extract from Laplace's *Exposition du système du monde*: "The invention of logarithms, reducing several months of reckoning to a few days of work, doubles as it were the lifetime of an astronomer, saving him from the fallacies and fatigue always attendant upon long calculations. The human mind may pride itself upon this achievement, all the more so, since it derives wholly from the human mind. In technology, man draws upon the materials and forces of surrounding nature to multiply his power. Logarithms, however, are the product solely of his own mind.") Using logarithms, we find

$$\log x = 6,000 \times \log 1.001 = 6,000 \times 0.00043 = 2.6.$$

From the logarithm of 2.6 we learn that x is equal to 400.

So at the depth of 48 km atmospheric pressure is 400 times greater than

normal. Under this pressure the density of the air would increase, as experiments have shown, by 315 times. We can hardly believe, therefore, that Jules Verne's subterranean travellers felt nothing more than "a pain in the ears". However, Jules Verne goes on to say that they went down still further—to the depth of 120 km and even 325 km. At such depths atmospheric pressure must have reached monstrous proportions. Meanwhile, we know that human beings can bear without harm an atmospheric pressure of not more than 3 to 4 atmospheres.

Using the same formula to estimate the depth at which air would become as dense as water, that is 770 times denser, we would get 53 km. This would be wrong, however, for in the realm of big pressures the density of gases is no longer in direct proportion to pressure, Mariotte's law is valid only for pressures of not more than several hundred atmospheres. Here is a table of experimentally demonstrated air densities:

Pressure		Density
200	atmospheres	190
400	»	315
600	»	387
1,500	»	513
1,800	»	540
2,100	»	564

As we see, the increase in density quite noticeably lags behind the increase in pressure. In vain did Jules Verne's professor believe that he would reach a depth where air would be denser than water. He would have never reached that depth, since air becomes as dense as water only under a pressure of 3,000 atmospheres. Beyond that pressure, it scarcely compresses at all. Moreover, we shall never be able to solidify air by pressure alone, unless we "freeze" it to a temperature of 146°C below zero.

To be just, one must note that Jules Verne published this novel long before the facts I have given you were made known. But though this exonerates the author, it doesn't make his story true.

Let us draw once again on the above-mentioned formula to estimate how far down a human being could go without doing himself any harm. The greatest atmospheric pressure we can stand is 3 atmospheres. Let x designate the depth we are looking for. We can thus write the equation

$$(1.001)^{x/8} = 3$$

whence, with the aid of logarithms, we learn that x is 8.9 km.

Hence, anyone of us could safely descend, without risk to life, to the depth of almost 9 km. Were the Pacific suddenly to dry up, we would be able to live practically everywhere on its bed.

IN A DEEP MINE

Who has got nearest to the centre of the earth – not, of course, in the umagination of a science-fiction novelist but in real fact? Miners, of course. We know (see Chapter 14) that the world's deepest mine is in South Africa. It is more than 3 km deep – that's the depth to which people have gone, because drills have bored down to even 7.5 km. This is what the French writer Dr. Luque Durten had to say after visiting a mine of Morro Velho (about 2,300 m deep).

"The famous gold mines of Morro Velho are some four hundred kilometres away from Rio de Janeiro. Here a British firm is mining gold at a depth to which man never descended before.

"The gold seam slants down and the mine follows it in six steps. The vertical shafts resemble wells and the horizontal workings, tunnels. It is extremely characteristic of modern society that the deepest mine dug in the earth's crust, man's boldest attempt to probe into the bowels of the earth, was undertaken in search of gold.

"Don canvas overalls and a leather jacket. Keep your eyes well open, the tiniest pebble dropping into the well may hit you hard. One of the mine captains will accompany you. You enter the first well-lit tunnel to shiver in the icy wind of only four degrees above zero coming from the ventilation system used to cool the deeper workings.

"You ride down the first seven-hundred-metre shaft in a cramped metal cage and find yourself in a second tunnel. You then go down the next shaft. Meanwhile the air grows warmer. You are already below sea level.

"In the next shaft the air burns your face. Perspiring freely and crouching beneath the low vaulted ceiling, you make for the roar of the drilling machines. Here miners, stripped to the waist and sweating profusely, work in clouds of thick dust. The water bottle makes round after round, endlessly. Don't touch the chunks of ore just hewn off. They run a temperature of 57°.

"What is the net result of this abominable and abhorrent reality? Some ten kilogrammes of gold a day."

In describing the actual physical conditions at the bottom of the mine and the intensified exploitation of the miners, the French writer notes the high temperature but says nothing about the pressure. Let us then try to find out how

much it would be at the depth of 2,300 m. Were the temperature there the same as at ground level, then, according to the familiar formula, the air density should increase by

$$(1.001)^{2,300/8} = 1.33 \text{ times.}$$

Actually, the temperature does not remain constant; it increases. Consequently, the air density does not rise so significantly. In the long run, the air at the bottom of the mine differs in density from that at ground level as the density of the air on a blazing hot summer day does from that of the icy air of winter time. That explains why visitors to the mine fail to notice anything.

Of much greater importance, on the other hand, is the considerable humidity of the air in such deep mines, which at high temperatures renders conditions intolerable. At a mine near Johannesburg, in South Africa (2,553 m deep), 100 per cent humidity is registered at 50° of heat. To combat this, air conditioning has been introduced; the cooling effect of the installation is equivalent to the presence of 2,000 tons of ice.

IN A STRATOSPHERE BALLOON

So far we have been travelling—in the mind's eye, of course—into the depths of the earth in which we were assisted by a formula showing the dependence of pressure on depth. Let us now ascend and, using the same formula, see how atmospheric pressure changes at great altitudes. Naturally, we shall have to rewrite the formula which will now read:

$$p = 0.999^{h/8},$$

where p is the pressure in atmospheres, and h the altitude in metres. The decimal fraction of 0.999 has replaced our previous figure of 1.001, because with every 8 metres pressure, instead of increasing by 0.001, will, on the contrary, *decrease* by 0.001.

Now, firstly, how high up must we go to halve atmospheric pressure? In this case p will be 0.5 and we shall be finding the altitude h . Our equation will be

$$0.5 = 0.999^{h/8},$$

which those of you familiar with logarithms will easily be able to solve. The answer is $h = 5.6$ km, the height at which atmospheric pressure should be half the normal.

Let us now ascend still higher and follow in the wake of the intrepid Soviet aeronauts who reached the altitude of 19 and 22 km, respectively, heights already in what is called the stratosphere. That is why balloons used for such ascents are known as stratosphere balloons. It was the Soviet stratosphere balloons *USSR* and *Osoviakhim-I* which in 1933 and 1934 set world altitude records of 19 and 22 km, respectively.

Let us now see what the air pressure would be like at these great heights. At 19 km it should be $0.999^{19,000/8} = 0.095$ atm = 72 mm, and at 22 km, $0.999^{22,000/8} = 0.066$ atm = 50 mm, of the mercury column.

However, according to the records other pressures were registered, to wit 50 mm at 19 km and 45 mm at 22 km. Where did we go astray?

Mariotte's law is quite valid for gases at such small pressures. Our omission was that we considered the air temperature constant throughout. Actually it drops noticeably with height. It is held that on the average the temperature drops by 6.5°C with every kilometre. This continues up to 11 km, beyond which the temperature remains constant at 56°C below zero for quite a considerable stretch further up. Taking this circumstance into account (which we cannot do with the means of elementary mathematics at our disposal) we would get results far closer to the real thing. For the same reason must you treat the results we obtained when gauging atmospheric pressure in deep mines as also approximate.

Chapter Heat 17

FANS

When ladies fan themselves, they naturally feel refreshed. One might think that this occupation would be absolutely harmless for all others present, that they must be only grateful to the ladies for cooling the air. Let us see whether this is really so.

Why do we feel cooler when we fan ourselves? The air in direct contact with our face warms up. It is this warm invisible mask of air that "heats" the face, or in other words, prevents it from shedding any more heat. When the air around is still, this warm mask is but very slowly pushed up by the cool heavier air. When we fan away this warm mask, our face comes into contact with more and more new portions of nonwarmed air, to which it sheds its warmth. That is how we cool ourselves.

Consequently, when fanning themselves, the ladies continually whisk the warmed mask of air, replacing it with nonwarmed air. This portion of air warms up to be again whisked away and replaced by still another portion of nonwarmed air.

Fanning thus accelerates air mixing and helps to quickly equalize the temperature throughout the room. In other words, it refreshes the possessor of the fan at the expense of the cooler air enveloping the other people present. Then there is one more circumstance of significance in fanning, which I shall now proceed to tell you about.

WHY WINDS MAKE US FEEL THE COLD MORE

You all know, of course, that in calm weather frosts don't bite so cruelly as they do in windy weather, but I suppose, not all of you clearly realize why. It is only the *living beings* that feel the cold more in a wind. It does not cause the thermometer to drop. The reason you feel the cold so keenly on a windy frosty day is, first of all, because the wind takes far more warmth away from the face

(and from the body generally) than in calm weather, when the enveloping layer of air warmed up by the body is not so rapidly ousted by a new portion of cold air. The stronger the wind, the greater the mass of air that comes into contact with your skin every minute and, consequently, the greater the amount of warmth taken away from your body every minute. This alone is already enough to make you feel the cold.

But there is also another reason. Our skin always gives off moisture, even in cold air. To perspire we must have warmth. This warmth is derived from our body and from its enveloping layer of air. When the air is still, perspiration is slow since the layer of air adjacent to the skin is soon saturated with vapour (and in damp air, evaporation is not so intensive). But when the surrounding air is in motion and more and more new portions of it come into contact with the skin, perspiration is more profuse, requiring plenty of heat, which is taken away from the body.

How great is the wind's cooling effect? It depends on the wind's velocity and the air temperature. Generally speaking, it is much more significant than usually thought. Here is an illustration to show how greatly a wind reduces the body's skin temperature. Suppose the temperature of the air is 4°C above zero and that, for the time being, there is no wind. Then the body's skin temperature is 31°C . A light breeze of 2 m/s, in which flags hardly flutter and leaves don't rustle at all, will cool the skin by 7° . A wind causing a flag to flutter, that is one having a speed of 6 m/s, would already cool the skin by 22° right down to just 9° above zero.

Consequently, to gauge just how much a frost will affect us, it is not enough to go by the temperature alone; we must take wind velocity in account as well. The same degree of frost is harder to bear in Leningrad than in Moscow, because the average wind velocity on Baltic shores is 6 m/s, while in Moscow it is only 4.5 m/s. It is still easier to stand a frost near Lake Baikal, where the average wind velocity is only 1.3 m/s. That is why the famous East Siberian frosts are far from being so harsh as we, being accustomed to the relatively strong winds of Europe, may think. On the contrary, East Siberia is distinguished by its almost complete absence of windy weather, especially in winter time.

THE DESERT'S SCORCHING BREATH

After what I have just said you may argue that on a blazing hot day a wind should refresh us. Why then do travellers speak of the *desert's scorching breath*? The contradiction is due to the fact that in tropical climes the air is usually

warmer than the body. No wonder that these winds make it still hotter for people. This is a case when the air, instead of robbing the body of its warmth, on the contrary warms it up. Therefore the greater the mass of air that comes into contact with the body every minute, the more keenly we feel the heat, and though the wind increases the intensity of evaporation, this fails to help. That explains why desert folk wear warm robes and fur hats.

DO VEILS WARM?

This is another problem for everyday physics. Ladies claim that veils give them warmth and that without them they would feel cold. Upon examining these flimsy affairs with their often rather big mesh, some gentlemen believe the claim the ladies make is but a trick of their imagination.

I think you, now that you have read my previous explanation, will put more stock in such claims. However big the mesh, air will penetrate a veil more slowly. The layer of air directly around the face warms up and the veil prevents the wind from whisking this warm mask away. Therefore when the ladies tell you that the veil keeps the face warm when out strolling on a breezy day with the temperature just a few degrees below zero—you can believe them.

COOLERS

You have most likely seen, heard or read of these unglazed earthenware vessels with their curious property of being able to cool whatever they hold. They are common with southern nations being known as the "alcarraza" in Spain and the "goula" in Egypt, etc.

Their secret is very simple. As it seeps through the earthenware walls, the liquid slowly evaporates robbing both the vessel and its liquid contents of their heat ("latent heat of vaporization").

However, travellers in the southern countries wrongly claim that these vessels cool their contents considerably. This effect depends on a number of factors. The hotter the surrounding air, the faster and more profuse the evaporation of the liquid moistening the outer wall of the vessel and, consequently, the more greatly is the liquid in the jar cooled. Humidity likewise plays a definite role. Should it be great, evaporation will be slow and the vessel will hardly cool its contents at all. On the contrary, in dry air evaporation is very intensive, and the cooling effect is greater. A wind will also accelerate evaporation and thus enhance the cooling effect; a fact you may have noticed when wearing a wet

dress on a warm but windy day. The coolers can lower the temperature by not more than 5° . On a blazingly hot southern day, when the temperature is sometimes as much as 33°C , water in the cooling vessel will be 28° . As you see the cooling effect is practically nil, and it is not really for these purposes that these vessels are used. They are successfully used to keep *cold water* cold.

We might try to reckon the cooling effect of a cooler. Suppose this vessel can hold 5 litres of water and that, furthermore, 0.1 litre has evaporated. To evaporate 1 litre (1 kg) you would need on a hot day (33°C) 580 calories. With us it was 0.1 kg that evaporated; consequently, we needed 58 calories. If all this heat were taken from the water in the jar alone, its temperature would drop by $58/5$ or by some 12° . However, most of the heat required for evaporation is taken from the walls of the jar itself and from the air around it. Furthermore, during the cooling process the water in the vessel is simultaneously warmed by the warm air around the jar. Hence, the actual reduction in temperature, that is, the cooling effect, reaches barely half our figure.

It is hard to say where the cooling effect is greater—in the sun or in the shade. The sun's heat accelerates evaporation but also increases the influx of warmth. I think the best place for a cooler is a draughty place in the shade.

"ICEBOX" WITHOUT ICE

A food cooler or an "icebox" without ice, is also based on the cooling effect that evaporation produces. It is a very simple affair: a wooden box, one of zinc-plated iron would be still better, with shelves inside for the food. On top place a tall vessel with cold water. Then dip in the tail end of a piece of canvas draped down the back of the box with its other end dipped in a vessel below the bottom shelf. The canvas soaks in the water from the vessel on top; meanwhile the water slowly evaporates as it moves through the canvas as through a wick, cooling all the compartments of the "icebox". This contraption should naturally be placed in the coolest spot in the room and every evening you should change the water so that it grow still colder during the night. It goes without saying, that the two vessels and the piece of canvas must be spotlessly clean.

THE GREATEST HEAT ONE CAN BEAR

Man can stand heat much better than is usually thought. In southern latitudes he can bear up under a temperature noticeably above what we in moderate zones will scarcely tolerate. In Central Australia the summer temperature often

risers to 46°C in the shade. There have even been cases when the temperature has jumped to 55°C in the shade. In the cabins of ships going through the Red Sea to the Persian Gulf the temperature has risen to 50° and more, despite continual ventilation.

The highest natural temperature ever observed in the world has been not more than 57°C . It has been registered in the "Valley of Death" in California. In Central Asia, the hottest place in the USSR, the temperature has never risen to more than 50°C .

You have probably guessed that the above-mentioned temperatures are all, of course, in the shade. Let me tell you why. The point is that it is only in the shade that a thermometer will register the right temperature of the *air*. After all if it were exposed to the sun, it might be heated up to a much greater temperature than that of the surrounding air. In short, there is no point in referring to readings of a thermometer exposed to the sun, when speaking of heat waves.

Experiments have been staged to determine the highest temperature the human body could bear. It has been found that when we warm up gradually in *dry air*, we can bear a temperature even above boiling point (100°C), as much as 160°C , as was demonstrated by the British physicists Blagden and Centry who for the sake of experiment spent hours on end in a heated bakery furnace. "You boil eggs and fry a steak in the air of a place where people could stay without doing any harm to themselves," Tyndall has noted in this connection.

Where does the explanation lie? In that our body actually repels this temperature, keeping down close to normal. It resists the heat by abundantly exuding sweat. This sweat absorbs much of the warmth from the layer of air directly enveloping the body, thus adequately lowering the temperature. The only essentials that need to be observed are for the body not to come into direct contact with the source of heat and for the air itself to be absolutely dry.

In Central Asia it is far easier to stand a heat of 37°C than a 24°C heat-wave in Leningrad. This of course is because of the very humid air in Leningrad and of the very dry air in Central Asia where rains are very few and far between.

THERMOMETER OR BAROMETER?

As legend has it a certain Simple Simon did not dare to take a bath because, as he explained it, he had "stuck a barometer in the bath and it pointed to stormy weather".

Don't think it is always so easy, however, to distinguish between barometers and thermometers. There are types of thermometers or rather thermoscopes

which we would have every justification for calling barometers and vice versa. An apposite illustration is afforded by the thermoscope that Heron of Alexandria invented (Fig. 208). In the sunshine the air in the upper part of the retort expands to press on the water and forces it to flow along the bent pipe, from the end of which it drips through a funnel to collect in the box below. In cold weather, on the contrary, air resilience in the sphere diminishes and the

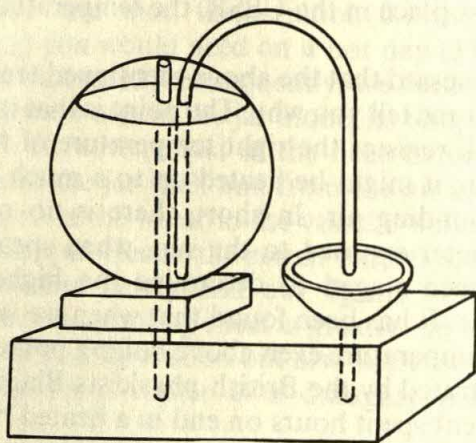


Fig. 208

Heron's thermoscope

water in the bottom box is forced out by external air pressure up the straight pipe back into the sphere.

This instrument, however, reacts to varying barometric pressure; when external atmospheric pressure drops, the inside air, retaining its previous, higher pressure, expands, thus forcing part of the water up through the bent pipe and into the funnel. On the other hand, when external atmospheric pressure increases, part of the water from the bottom box is thereby forced into the retort. Each degree of difference in temperature will produce a similar difference in the volume of air inside the sphere ($760/273$ which is about a 2.5 mm difference in the height of the barometric column of mercury). In Moscow barometric fluctuations register 20 and more millimetres. This corresponds to 8°C on Heron's thermoscope, which means that this fall in atmospheric pressure may easily be taken for an 8° rise in temperature. As you see this ancient thermoscope could well serve as a baroscope. We once had on sale water barometers which could have also served as thermometers, however this was something that neither the buyer nor even the inventor ever suspected.

WHAT IS THE LAMP GLASS FOR?

Few know the long road that the lamp glass had to take before it reached its present shape. For thousands of years people used a flame without any glass guard for purposes of lighting. It needed the genius of Leonardo da Vinci (1452-1519) to introduce this major development. Leonardo da Vinci, however, used metal instead of glass and another three centuries passed before the transparent glass cylinder was introduced. As you see, the lamp glass is the product of the ingenuity of dozens of generations.

What is it used for? I doubt whether any one of you would be able to provide the correct answer. The role of guarding the flame from the wind is but of secondary importance. The main purpose is to enhance the flame's *brilliance*, to accelerate the process of combustion. In other words, it acts as a chimney: it brings more air to the flame and thereby increases the draught.

Let us analyze this. The flame warms up the air column inside the glass much faster than the air around the lamp. Warming up and thus growing lighter, the air is pushed upwards (in conformity with Archimedes principle) by the heavier cooler air which enters from the bottom through the holes in the burner. We thus have a constant upward flow of air, a draft which takes away the products of combustion and brings in fresh air all the time. The taller the glass, the greater the difference in weight between the heated and the unheated air, and the more vigorous hence the influx of fresh air and, consequently, the process of combustion. This explains incidentally why factory chimneys are so tall.

It is curious to note that Leonardo da Vinci had a very clear notion of these things. In his manuscripts we find the following remark: "Wherever fire appears, an air current is induced around it: it is this air current that feeds and adds to the fire".

WHY DOES A FLAME NEVER EXTINGUISH ITSELF?

As soon as we stop to analyze the process of combustion we involuntarily ask ourselves: why does the flame never go out of its own accord? After all, combustion produces carbon dioxide and water vapour—two *noncombustibles*, which naturally cannot maintain combustion. Consequently, the moment it starts burning, a flame ought to be enclosed by noncombustibles, which in turn bar the intake of air. We know that without air combustion cannot continue and, consequently, the flame ought to go out.

But why doesn't this happen? Why does combustion go on until all the fuel is burnt out? Only because gases expand when heated and so become lighter. That is the only reason why the heated-up products of combustion do not remain

where produced, that is, right in the flame's neighbourhood, but are immediately chased upwards by the clean incoming air. If the rule of Archimedes were not valid for gases, or if there were no such thing as gravity, every flame, after burning for a little while, would go out of its own accord.

It is easy to see how fatal the products of combustion are for a flame. You often invoke this point—without even suspecting it—to snuff out the flame. How do you put out a paraffin lamp for instance? You blow in from the top, in other words, you chase down towards the flame the noncombustible products of its combustion: as a result the flame dies as there is no more fresh air.

THE CHAPTER JULES VERNE DIDN'T WRITE

Jules Verne related in great detail the adventures of three brave travellers inside the moon-bound projectile. But he forgot to tell us how Michel Ardan did the cooking in these very unusual conditions. Most likely he didn't think cooking in space of any interest. So much the worse for the novelist. The thing is that inside the projectile, racing through space, *everything becomes weightless* (see Chapter 2 for detailed explanations of this highly interesting point). Jules Verne, regrettably enough, gave this the go-by, for, after all, one must agree that cooking in a kitchen that weighs nothing presents a science-fiction novelist with plenty of scope for imagination. Let me then try to make up to the best of my ability for what the talented author of *Journey to the Moon* missed. And don't forget that in the projectile there is no *gravity*, that not a single thing *weighs even a fraction of an ounce*.

BREAKFAST IN WEIGHTLESSNESS

"We have not breakfasted as yet, my friends," Michel Ardan remarked. "And though we've lost our weight, I don't suppose we've lost our appetite. So, my friends, I'll now cook for you a weightless breakfast which will, I'm certain, offer the lightest dishes ever prepared."

And without waiting for a reply, the Frenchman began his gastronomic ministrations.

"Our water bottle is pretending to be empty," Ardan muttered to himself, as he endeavoured to uncork the big bottle. "But you won't fool me. I know why you're so light. There, I've got the cork out. Now go ahead and pour your weightless content into the pot!"

He tilted the bottle this way and that but the water wouldn't pour out. "You're toiling in vain, my dear Ardan," said Nicoll, as he came to his help.

"You must realize that in our projectile, where we have no gravity at all, water will never pour out! You must *shake* it out as if it were condensed syrup".

Ardan at once clapped the bottom of the tilted bottle. How surprised he was when a ball of water, the size of a fist, flew out of the bottle's neck.

"What's happened to the water?" exclaimed Ardan in astonishment. "I didn't expect this! Please tell me, my learned friends, what has happened?"

"That is merely a *drop* of water, my dear Ardan. In a weightless world with no gravity drops of liquid will assume any size. After all, it is thanks to gravity that liquids assume the form of the vessels that hold them, spill out in a stream, and so on. Since we are weightless, the liquid is left to its own inner molecular forces and so quite naturally assumes the form of a sphere, as the oil did in Plateau's famous experiment."

"I don't care a bit for your Plateau and his experiments! I must boil some water for the consommé and no molecular forces, I swear, will stop me!" the Frenchman declaimed in a temper.

He assailed the bottle furiously, endeavouring to shake the water out into the pot which hovered in the air, but everything seemed to be against him. The big drops of water crept about the pot as soon as they came into contact with it: they slid over onto the outside and soon the pot was enveloped in a thick layer of water. To boil the water in this state was out of the question.

"There is an illuminating experiment to demonstrate the great force of cohesion," the imperturbable Nicoll calmly told the enraged Frenchman. "Don't get so excited. You are dealing with an ordinary case of the wetting of solid bodies, only in this instance gravity is not interfering, and so we can see the entire process."

"It's a great pity that it isn't interfering!" Ardan heatedly objected. "And whether it's wetting or something else, I must have the water *inside* and not *around* the pot. Look at it! No chef would ever consent to prepare consommé in these conditions!"

"You can easily stop that, if it's in your way," Mr. Barbicane inserted in a placatory tone. "Remember that water does not wet bodies covered with a thin film of grease. Grease your pot on the outside and you'll be able to keep the water inside."

"Well, that's what I call real scientific learning," the overjoyed Ardan exclaimed, as he took this advice. Then he lit the gas burner, wanting to put the pot on to boil, but again everything seemed to be against him. Now it was the gas burner that was acting capriciously. Its flame flickered for half a minute and

went out. Ardan was bewildered. He nursed the flame but all his efforts were to no avail. The flame wouldn't burn.

"Barbican! Nicoll! Isn't there a way of making this obstinate flame burn as it should, according to the laws of your physics and the gas company's regulations?" the dejected Frenchman appealed to his friends.

"There's nothing at all unusual or unexpected about it," Nicoll explained. "The flame is really burning as it should according to the laws of physics. As for the gas company's regulations, I suppose the firm would go to the dogs were there no gravity. As you know, combustion produces carbon dioxide and water vapour—gases that don't burn. Ordinarily these products of combustion don't keep near the flame because since they are warm and are consequently lighter, the fresh incoming air replaces them. But as we have no gravity here the products of combustion stay where produced. They envelop the flame and shut out fresh air. That is why the flame is so pale and goes out so quickly. Fire extinguishers by-the-by work precisely in this manner, surrounding the flame with a noncombustible gas."

"That means," the Frenchman interjected, "that if Mother Earth had no gravity, there would be no need for fire brigades, and fires would go out of their own accord, suffocated by their own breath? Is that right?"

"Quite. Meanwhile, to help prepare the consommé, light the burner once again and let's blow on the flame. In this way I think we can induce an artificial draught and make the flame burn as it would back home."

This was done. Ardan lit the burner once again and began cooking, meanwhile watching, not without a pinch of malice, how Nicoll and Barbican alternately blew and fanned the flame to keep it burning. Deep down in his heart, the Frenchman thought that his friends and their science were wholly to blame for all this trouble.

"Ha-ha! You're very good as chimneys, I must say," Ardan vivaciously remarked. "I feel very sorry for you, my learned friends, but if you want to have breakfast hot you'll have to obey the laws of your physics."

A quarter of an hour passed. Then half an hour and then an hour. The pot showed no signs of boiling.

"You'll have to be patient, my dear Ardan. Ordinary water that has weight heats up rapidly. Why? Only because its different layers mix. The heated and, consequently, lighter lower layers are pushed up by the colder heavier upper layers and as a result the whole of the liquid quickly grows hot. Have you ever tried to heat up water from the top? Then the different layers won't mix because the heated layers remain still. Water is a very bad conductor of heat, as you

know. Its conductivity is actually negligible. You can cause water to boil at the top, while having lumps of ice at the bottom. But here, in conditions of weightlessness, it makes no difference from which end we warm up the water. The different layers of water in the pot won't mix and the water should warm up very slowly. If you want to make it warm up faster, you must keep on stirring it."

Nicoll warned Ardan not to bring the water up to boiling point but to keep it a bit below that. At boiling point, he explained, there would be much steam. As in conditions of weightlessness, it would have a specific gravity equal to that of water, both would be nil, it would mix with the water and form a homogeneous foam.

Ardan was most annoyed when he untied the bag with the peas. He shook it slightly and the peas tumbled out into the air in all directions, bouncing on and off the walls. They nearly caused a great misfortune. Nicoll accidentally inhaled one of them and was almost suffocated. To ward off the danger and rid themselves of the perilous peas, our friends assiduously began to trap them with a butterfly net that Ardan had providentially taken along to "collect lunar butterflies".

Cooking in these conditions presented quite a formidable task. Ardan rightly remarked that in this contingency even a real chef would have thrown up the sponge. He also had quite an ordeal when he set about frying the steak. He had to clamp the meat down with a fork, because the resilient vapours of the frying oil beneath it kept on causing the half-done meat to bounce "up", if one could use a word like that in a place where one has neither "up" nor "down".

The process of eating in this weightless world also presented an extremely queer spectacle. They hung suspended in mid air in diverse poses—not devoid incidentally of a certain note of extravagance—and kept on bumping their heads. Sitting was naturally out of the question. Chairs, couches, benches and the like are absolutely useless in a weightless world. Actually there would have been no need for a table, had not Ardan insisted upon having a real "breakfast table".

It was hard to cook the consommé but still harder to eat it. To begin with Ardan couldn't pour the weightless liquid out. The labours of a whole morning were almost lost, when, forgetting that the soup was weightless, he vexedly thumped the bottom of the overturned pot to get the obstinate soup out. A huge ball-shaped drop flew out—the soup itself! Ardan had to display a juggler's skill to trap and get back in the pot the consommé he had prepared with such difficulty.

Spoons failed to help: the soup wettened the spoon up to the finger-tips drooping from it like a solid veil. The three friends then greased their spoons with butter to prevent wettening, but that didn't help either. The soup assumed the form of a little ball and they couldn't get this weightless pill into their mouths.

Finally, Nicoll found a way out. He rolled some waxed paper into tubes and the three travellers sucked the soup up through them. They used the same method to drink water, wine, and all other liquids. (Many who read a previous edition of this book wrote to me wondering how one could drink in a weightless world even with the aid of the method suggested. After all the air in the projectile weighed nothing and, consequently, could not exert any pressure, which should thus make drinking by the sucking in of a liquid impossible.)

Queerly enough, this view had some currency in the press. But it is quite obvious that in these conditions the weightlessness of air has no effect on pressure. Air exerts pressure in a closed space, not at all because it has weight but because, as a gaseous body, it tries to expand without end. In *unclosed* spaces on our planet it is *gravity* that is the barrier to expansion and it was this customary interrelation that misled my critics.)

WHY DOES WATER PUT OUT FIRE?

Though a simple question not all supply the right answer. I hope you won't take it amiss if I stop to explain briefly what water actually does to fire. Firstly, as soon as it comes into contact with the burning object, water turns into steam, in which process it deprives the burning object of much of its heat. After all, to transform boiling water into steam we need five odd times more heat than is required to heat the same amount of cold water to boiling point. Secondly, the steam thus produced occupies a space hundreds of times bigger in volume than the water giving rise to it. The steam envelops the burning object and keeps fresh air away. Without air combustion is impossible.

To cause water to act as a still better extinguisher of fires, gunpowder is sometimes added to it. There is logic in this paradox. Gunpowder burns out quickly, giving off in the process a large quantity of noncombustible gas. This gas envelops the burning object and complicates combustion.

FIGHTING FIRE WITH FIRE

You most likely know that the best and sometimes only way of fighting a forest or prairie fire is to set fire to the forest or prairie from the other side. The second fire moves towards the first, and, by destroying combustible material, deprives it of fuel. As soon as they meet, the two walls of fire die, devouring each other, as it were.



Fig. 209

Fighting fire with fire

Most likely many of you have read of this in Fenimore Cooper's *Prairie*. Surely, you haven't forgotten that tense and dramatic moment of suspense when the old trapper saves the travellers from a fiery death? Here is the extract.

"...the old man ... suddenly assumed a decided air. ...

"'It is time to be acting,' he said ...

"'You have come to your recollections too late, miserable old man,' cried Middleton; 'the flames are within a quarter of a mile of us, and the wind is bringing them down in this quarter with dreadful rapidity.'

"'Anon! the flames! I care but little for the flames... Come, lads, come. ... Put hands upon this short and withered grass where me stand, and lay bare the 'arth'... A very few moments sufficed to lay bare a spot of some twenty feet in diameter. Into one edge of this little area the trapper brought the females, directing Middleton and Paul to cover their light and inflammable dresses with the blankets of the party. So soon as this precaution was observed, the old man approached the opposite margin of the grass, which still environed them in a tall and dangerous circle, and selecting a handful of the driest of the herbage, he

placed it over the pan of his rifle. The light combustible kindled at the flash. Then he placed the little flame in a bed of the standing fog, and withdrawing from the spot to the center of the ring, he patiently awaited the result.

"The subtle element seized with avidity upon its new fuel, and in a moment forked flames were gliding among the grass. ...

"'Now,' said the old man, holding up a finger, and laughing in his peculiarly silent manner, 'you shall see fire fight fire. ...'

"'But is this not fatal?' cried the amazed Middleton; 'are you not bringing the enemy nearer to us instead of avoiding it?'... As the fire gained strength and heat, it began to spread on three sides, dying of itself on the fourth, for want of aliment. As it increased and the sullen roaring announced its power, it cleared everything before it, leaving the black and smoking soil far more naked than if the scythe had swept the place. The situation of the fugitives would have still been hazardous had not the area enlarged as the flame encircled them. But by advancing to the spot where the trapper had kindled the grass, they avoided the heat, and in a very few moments the flames began to recede in every quarter, leaving them enveloped in a cloud of smoke, but perfectly safe from the torrent of fire that was still furiously rolling onward.

"The spectators regarded the simple expedient of the trapper with that species of wonder, with which the courtiers of Ferdinand are said to have viewed the manner in which Columbus made the egg stand on its end. ..."

Incidentally this method of fighting forest and prairie fires is not so simple as it may seem at first glance. Only a very skilled hand at it may use it. A novice would only make matters worse.

You will understand what I am driving at if you ask yourself: why did the fire, which the trapper lit, run towards the other fire and not contrariwise? After all the wind was blowing into the faces of the travellers and was driving the flames towards them. Shouldn't the fire that the trapper started have gone the other way? In that case the travellers would have found themselves hemmed in by a circle of flames and would have certainly perished.

So what was the trapper's secret? In that he knew a simple law of physics. Though the wind was blowing from the burning prairie into the faces of the travellers, in front of them, right near the flames, a reverse air current was blowing towards the fire. Indeed, warmed up by the fire below, the air above it grows lighter and is pushed up by cooler fresh air flowing in from the prairie. This explains why near the fire's fringes the draught is directed towards it.

The fire-fighting fire must be started when the original fire has drawn close enough for one to feel this draught. That is why the trapper didn't hurry, calmly

waiting for the necessary moment. Had he fired the grass too early, before the counter-draught had set in, his fire would have spread in the opposite direction and would have placed the travellers in a hopeless predicament. Too late would be just as fatal because then the fire would be too close.

CAN WE BOIL WATER IN BOILING WATER?

Take a small bottle or a jar, fill it with water and put it in a pot full of water placed on fire, but so that it does not touch the bottom. To abide by the last condition, you will have to suspend it in a wire loop. One would think that when the water in the *pot* boils, the water in the jar should boil too. However, no matter how long you wait, that won't happen. The water in the jar will be very hot, but it won't boil. Boiling water, we find, is not hot enough to boil water.

This comes as quite a surprise, doesn't it? However, it should be expected. After all, to bring water up to boil, it is not enough to heat it up to 100°C . It needs more heat to transform water into its next state, steam.

Pure water boils at 100°C . In ordinary conditions it never rises above this temperature, however much we heat it. This means that the source of heat we are using to heat the water in the jar has a temperature of 100°C and no more and thus can heat the water in the jar also up to 100°C , and no more. As soon as the temperatures equalize, *the water in the pot can no longer impart any more heat to the water in the jar.*

To sum up: by heating water in the jar in this way we shall not be able to give it that extra amount of heat which is required to transform it into steam. (Each gram of water heated up to 100°C requires another 500 odd calories to turn into steam.) That is why the water in the jar doesn't boil, though it is hot.

You might want to know what difference there is between the water in the jar and the water in the pot. After all the water is the same in both vessels: the only difference is that the water in the jar is separated from the water in the pot by a wall of glass. Then why isn't it affected in the same way as the water in the pot? Precisely because this wall of glass prevents the water in the jar from participating in the currents that mix all the water in the pot. Every particle of water in the pot will come into direct contact with the pot's bottom. Meanwhile the water in the jar will come into contact only with the boiling water in the pot.

So, as we have noticed, it is impossible to boil water in pure boiling water. But as soon as you add some salt to it, the picture changes; salt water boils not at 100°C but at a somewhat higher temperature, and, consequently, can bring the pure water in the jar to boil.

CAN WE BOIL WATER IN SNOW?

Well, you will say, if boiling water can't do the trick, how dare we speak of snow? Don't jump at conclusions, though. Do the following experiment first, using that same glass jar which we employed in the previous experiment. Fill half of it with water and immerse it in boiling *salty water*. As soon as the water

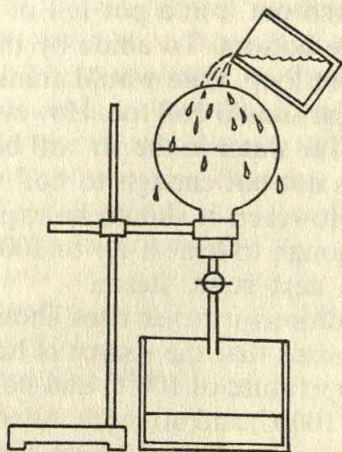


Fig. 210

Water boiling in a retort after cold water has been poured over it

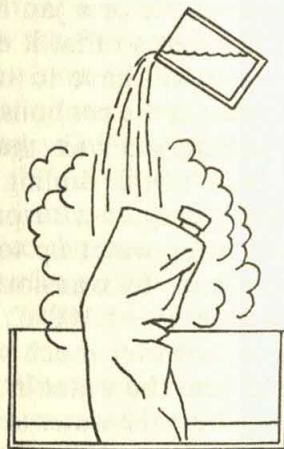


Fig. 211

What happens to a tin can when unexpectedly cooled

in the jar boils, take it out and quickly cork it tightly. Now turn it over and wait for the boiling to stop. Then pour a little boiling water over it. The water inside won't boil. But you need only put a little snow on the bottom of the jar or even pour a little cold water over it, as is shown in Fig. 210, for the water in the jar to start boiling at once. Snow has done what boiling water failed to do!

This is all the more mysterious because when you touch the jar with a finger, you will not find it very hot. Still you will see the water inside boiling. The answer lies in the fact that the snow cools the walls of the jar. The steam inside condenses into drops of water. But since the air in the jar was pushed out when the water boiled, now the water in it is subjected to a much smaller pressure. You already know that at a lower pressure liquids boil at a lower temperature. Consequently, we have boiling water in the jar but boiling water that isn't hot.

If the walls of the jar are very thin, the sudden condensation of the steam inside may produce something like a minor explosion. Failing to encounter an adequate resistance from inside the jar, the pressure exerted by the outer air may crush it. (Incidentally, the word "explosion" is not a happy term or phrase in this case.) It is therefore better to take a spherically shaped jar, a retort, for instance, so that the outer air press on its arched sections.

It is safest of all to stage this experiment with a tin can. After boiling some amount of water in it, screw the top tight and pour cold water over it. The tin containing the steam will be crushed by the pressure of the outer air as this steam has condensed into water in the process of cooling. The tin will seem to have been struck at with a heavy hammer (Fig. 211).

"BAROMETER SOUP"

In his *A Tramp Abroad* Mark Twain describes the following event, naturally a fictitious one, that happened during mountain climbing in the Alps.

"Our distresses being at an end, I now determined to rest the men in camp and give the scientific department of the Expedition a chance. First, I made a barometric observation, to get our altitude, but I could not perceive that there was any result. I knew, by my scientific reading, that either thermometers or barometers ought to be boiled, to make them accurate; I did not know which it was, so I boiled both. There was still no result; so I examined these instruments and discovered that they possessed radical blemishes: the barometer had no hand but the brass pointer and the ball of the thermometer was stuffed with tinfoil. ...

"I hunted up another barometer; it was new and perfect. I boiled it half an hour in a pot of bean soup which the cooks were making. The result was unexpected: the instrument was not affected at all, but there was such a strong barometer taste to the soup that the head cook, who was a most conscientious person, changed its name in the bill of fare. The dish was so greatly liked by all, that I ordered the cook to have barometer soup every day. It was believed that the barometer might eventually be injured, but I did not care for that. I had demonstrated to my satisfaction that it could not tell how high a mountain was, therefore I had no real use for it."

But joking apart, let us try to answer the question as to what we should have really "boiled"—the thermometer or the barometer? The answer is: the thermometer. And here is why.

We have seen from previous experience that the lower the pressure exerted on

water, the lower the temperature at which it boils. Since atmospheric pressure decreases the higher up you go, consequently, the lower should the temperature be at which water boils. Here is a table showing the temperatures at which pure water boils under different atmospheric pressures.

Temperature at which water boils, Centigrade	Barometric pressure, mm
101	787.7
100	760
98	707
96	657.5
94	611
92	567
90	525.5
88	487
86	450

At Berne in Switzerland, where the mean atmospheric pressure is 713 mm, water boils in an open-mouthed vessel already at 97.5°C, while on top of Mont Blanc, where the barometer registers a pressure of 424 mm, water boils at a temperature of only 84.5°C. With every kilometre up, the temperature at which water boils drops by 3°C. Consequently, if we measure the temperature at which water boils, or, to use Mark Twain's expression, "boil the thermometer," *by addressing ourselves to the appropriate table* we shall be able to find the altitude. To do that we must, of course, have the table that Mark Twain "simply" forgot.

The instruments used for this purpose – they are called hypsometers – are just as easy to carry as metal barometers, but give a far more accurate reading.

Of course, a barometer will also tell us how high up we are, as it doesn't have to be "boiled" to register atmospheric pressure and, after all, the higher up we go the lower pressure gets. In this case, we shall again need a table to show how atmospheric pressure drops the more we ascend from sea level or know, at least, the appropriate formula. The humorist, however, confused everything and so decided to "cook barometer soup."

IS BOILING WATER ALWAYS HOT?

The brave batman Ben-Zouf, whom you might remember from Jules Verne's *Hector Servadac*, was firmly convinced that boiling water would always be

scaldingly hot wherever it was boiled. I imagine he would have stuck to his guns to the end of his days had he not found himself with Servadac on a comet. This capricious celestial body collided with Mother Earth to slice off a chunk with our two heroes on it and carry it along with it on its elliptical orbit. That was when the batman found out for the first time in his life that boiling water was not identically hot everywhere. He made this discovery unexpectedly when preparing breakfast.

"Ben-Zouf filled the pot with water and put it on to boil. In his hands he held the eggs. They seemed to him to be empty inside, being as light as feathers.

"When in under two minutes the pot began to boil, Ben-Zouf exclaimed:

"Faith, how hot the fire must be!"

"It is not the fire that is hotter," Servadac returned after brief thought, "but the water that boils sooner."

"He then took the Centigrade thermometer down from the wall and dipped it into the boiling water. It showed exactly sixty-six degrees.

"God save us," the captain cried, "water is boiling at sixty-six degrees instead of one hundred!"

"Well, captain?"

"So let me advise you, Ben-Zouf, to boil the eggs for a quarter of an hour."

"They will be hard-boiled then."

"No, my friend, on the contrary, they will be just about right."

"Evidently this was all because the height of the atmosphere had diminished. The column of air pressing on the ground had grown shorter by about a third, which explained why the water, being subjected to a smaller pressure, boiled at sixty-six degrees instead of one hundred. This would have also happened on a mountain peak eleven kilometres above sea level. If the captain had had a barometer on hand, it would have indicated this lessening of atmospheric pressure."

We shan't question their observations. They claim that water boiled at 66°C and we shall accept it at face value. But it is extremely doubtful whether the two men would have felt so fit in the rarefied atmosphere around them.

Jules Verne quite rightly notes that we would see water boiling at this temperature at the height of 11,000 m. At this altitude, according to calculations, water should really boil at 66°C (as we noted earlier, the temperature at which water boils drops by 3°C with every kilometre up and so to get water boil at a temperature of 66° one must ascend $34 \div 3 \approx 11$ km). In this case atmospheric pressure should be only 190 mm of the mercury column which is exactly a quarter of normal atmospheric pressure. It is practically

impossible to breathe air rarefied to such an extent. After all this altitude is already in the stratosphere. We know that pilots who reached this height without oxygen masks lost consciousness. Meanwhile Servadac and his batman felt more or less fit. It is a jolly good thing that Servadac did not have a barometer on hand; otherwise Jules Verne would have had to make it register not the figure which it should have shown according to the laws of physics.

Had our two heroes found themselves not on the imagined comet but on Mars, for instance, where atmospheric pressure is no more than 60-70 mm, they would have drunk still colder boiling water, heated up to only 45°C .

Conversely, very hot boiling water can be obtained at the bottom of deep mines where atmospheric pressure is much greater than at ground-level. At 300 m down water boils at 101°C , and at 600 m down already at 102°C .

When pressure is greatly increased, water boils even in the boiler of a steam engine. At 14 atm, for instance, water boils at a temperature of 200°C . On the contrary, under the bell jar of an air-pump one could get water to boil at ordinary room temperature, in which case the "boiling water" would be only 20°C hot.

HOT ICE

We have just been speaking of cool boiling water. But there is still a more surprising thing—*hot ice*. We have grown accustomed to the idea that water cannot exist in a solid state at a temperature above 0°C . However, the physicist Bridgman demonstrated that this is not at all so. Under very high pressures water solidifies and stays in that state at temperatures way above 0°C . Generally speaking, Bridgman proved that there could be more than one kind of ice.

The ice he called "Ice No. 5" is obtained under the monstrous pressure of 20,600 atm, and stays solid at a temperature of 76°C . It would scorch our fingertips, provided, of course, that we would be able to touch it. We can't do that, however, because it is formed under a powerful press in a vessel with very thick walls made of the best grades of steel. We can't even see it and all that we know about its properties has been learned indirectly.

It is curious to note that this "hot ice" is denser than ordinary ice and even denser than water. It has a specific gravity of 1.05. It would sink in water, whereas ordinary ice, as you well know, floats.

COLD FROM COAL

The obtaining of cold, not heat, from coal is not at all a fantasy. It is effected daily at factories which make what is called "dry ice". Here the coal is burned in

boiler-drums, the smoke it gives off is purified and the carbon dioxide it contains trapped in an alkaline solution. The pure carbon dioxide subsequently separated by heating is then cooled and compressed and liquefied under a pressure of 70 atmospheres. This is the selfsame liquid carbon dioxide that is shipped in thick-walled cylinders to factories making fizzy drinks or that is used for industrial purposes. It is cold enough to freeze ground, as was done when the Moscow Underground Railway was built. However, there are many cases in which we need solid carbon dioxide or what is known as dry ice.

Dry ice is derived from liquid carbon dioxide by fast vaporization under a reduced pressure. Outwardly, chunks of dry ice sooner resemble pressed snow than ice and, generally speaking, differ greatly from solidified water. This ice is heavier than ordinary ice and sinks in water. Despite its extremely low temperature— -78°C below zero—you won't feel the cold, provided you hold it gingerly, because the carbon dioxide gas which forms as soon as the piece comes into contact with our warm finger-tips, protects the skin from the cold. Only if you clasp a chunk of dry ice tight, will you run the risk of freezing your fingers.

The name "dry ice" is exceedingly apt as it emphasizes its salient physical characteristic. It is, indeed, never wet and will never wetten anything it comes into contact with. Warmed, it immediately turns into gas, skipping the liquid state, because carbon dioxide cannot exist in a liquid state at a pressure of but one atmosphere.

This characteristic feature of dry ice, plus its low temperature, makes it an invaluable cooling agent for practical purposes. The products preserved with its aid never grow damp and are furthermore protected from spoilage—from mildew and mould—by the carbon dioxide gas that obstructs the development of microorganisms. Neither will insects or rodents be able to live in such an atmosphere. Finally, carbon dioxide provides a reliable aid for fighting fire. A few lumps of dry ice thrown into burning petrol extinguish the flames at once. This has all added to its popularity in both industry and the household.

Chapter 18

Magnetism and Electricity

"LOVING STONE"

Such is the poetic name the Chinese have bestowed on natural magnets. *Chu shi*, the "loving stone", the Chinese say, attracts iron as a tender mother will draw her children to her bosom. Curiously enough, the French, a people living at the other end of the Old World, have a similar name for the magnet. They call it *aimant* which means both *magnet* and *loving*.

The *loving* power of natural magnets is small and the Greek name for the magnet, "Hercules' stone", is, consequently, rather naive. If a natural magnet's moderate power of attraction had wondered the ancient Hellenes, I wonder how amazed they would have been to see the modern magnets used at iron and steel plants, magnets able to lift huge chunks weighing several tons. True, these are not natural magnets, but electromagnets, or, in other words, hunks of iron magnetized by an electric current flowing through the coil wound round them. However, both cases manifest one and the same sort of attraction, magnetism.

Don't think that a magnet attracts only iron and nothing else. There are some other metals which a powerful magnet will attract, though with not so great a force. These are nickel, cobalt, manganese, aluminium, gold, silver, and platinum. The properties possessed by so-called diamagnetic bodies such as zinc, lead, sulphur, and bismuth, are still more remarkable. These metals are repelled by a powerful magnet.

A magnet can also attract, or repel, liquids and gases. True it must be very powerful in order to exert any influence. For example, a magnet can attract pure oxygen. If we were to fill a soap bubble with oxygen and place it between the poles of a powerful electromagnet, its invisible magnetic forces would distend the soap bubble between the two poles quite noticeably. Placed between the poles of a powerful magnet the flame of a candle will also change its habitual form and clearly exhibit a sensitivity to magnetic power.

THE COMPASS PROBLEM

We have grown accustomed to thinking that a compass needle always points with one end North and the other South. Therefore, the following question might seem absurd: where in the world will a magnetic needle point North with both ends? My next question may seem just as absurd: where in the world will a compass needle point South with both ends?

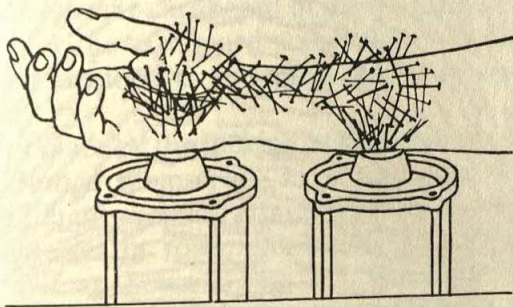


Fig. 212

Magnetic forces in the arm

I bet you'll claim that there can't be any places like that on our planet. However, they do exist. If you recollect that the earth's magnetic poles do not coincide with its geographical poles, you will have probably guessed what places I mean. Where will the needle of a compass point when at the South geographical pole? One end will point to the closest magnetic pole and the other to the opposite magnetic pole. But whichever way you go from the South geographical pole, you will always be going *North*, there is, indeed, no other way to go, except North. Consequently, there the compass needle will point North with both ends. Similarly will the needle of a compass at the North geographical pole point with both ends South.

LINES OF MAGNETIC FORCES

Figure 212 shows a curious phenomenon reproduced from a photograph. It shows a great many nails sticking out like bristles from an arm resting on the poles of an electromagnet. The arm itself does not sense any magnetic attraction at all. Meanwhile the magnetic forces pass through it invisibly, causing the iron

nails to obey them and dispose themselves in a regular pattern exhibiting the direction of the magnetic forces.

Since we have no magnetic organ of sense, we can only guess at the existence of the magnetic forces emanating from a magnet. (It would not be devoid of interest to wonder what we would really feel if we did have a magnetic sensitivity. Kreidel managed to impart a sort of magnetic sensitivity to crawfish.

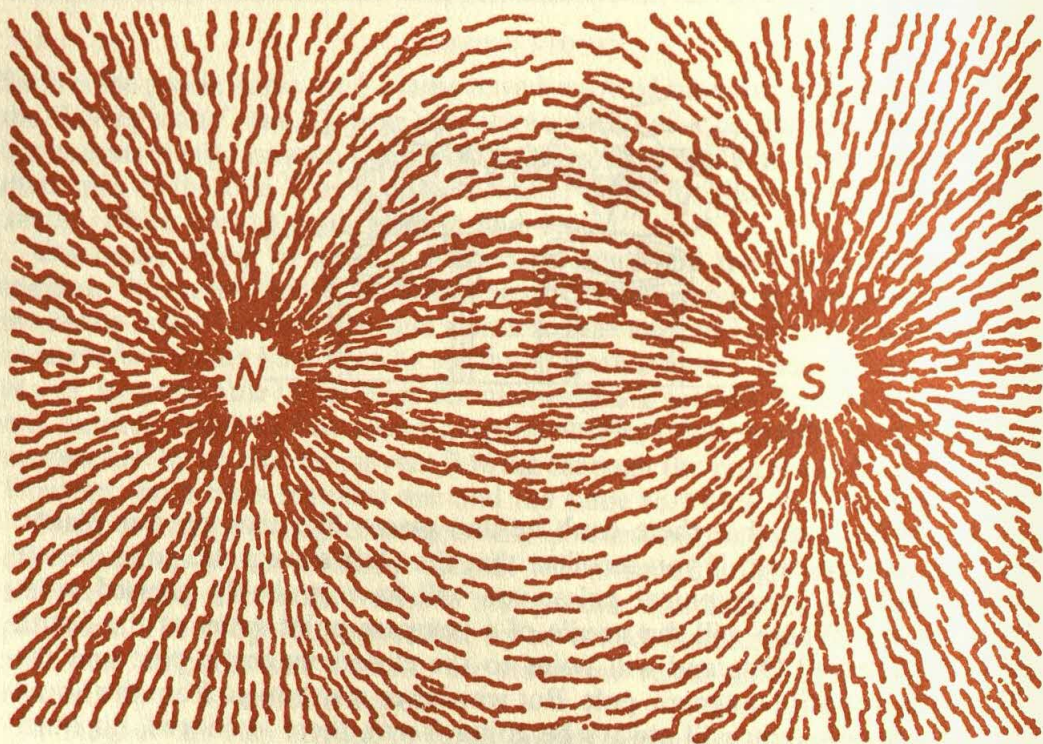


Fig. 213

Pattern of iron filings on a piece of cardboard, under which a magnet has been placed. Reproduced from a photograph

He noticed that young crawfish poked tiny pebbles into their auditory organs, which tended to weigh on the sensitive hair comprising a component part of their balancing organ. The human ear also has similar pebbles or stones which are called otoliths. They are located near the main auditory organ. Acting in the vertical direction, these stones point to the direction of the force of gravity. Kreidel was able unnoticeably to insert iron filings instead of these stones into

the ears of the crawfish. When a magnet was brought up, the crawfish disposed itself in a plane perpendicular to the resultant of the magnetic force and force of gravity.

"Of late a modification of these experiments has been staged on a human being. Kehler glued minute iron filings to the ear drum, the result being that the ear received the oscillations of magnetic force as a sound." [Prof. O. Wiener.] It is, however, simple enough to detect indirectly the pattern of the alignment of these forces. This is best done by using small iron filings.

Take a piece of smooth cardboard or a glass plate and sprinkle filings over it in a thin layer. Then place the cardboard or glass with the filings on top of a bar magnet and gently flick the cardboard with a finger. Since the magnetic forces pass "freely through cardboard and glass, the iron filings will be magnetized.

When jolted out of place by the flicking of the cardboard, the magnetic forces cause them to rearrange themselves, as a magnetic needle would at each particular point, i. e. lengthwise along the magnetic lines of force. As a result the filings dispose themselves in rows, graphically revealing the pattern of the invisible magnetic lines, as shown in Fig. 213. The magnetic forces produce an intricate system of curves, which strike out radially from each pole of the magnet and link up to form, now short, now long arcs between the two poles. The filings show what a physicist pictures in his mind and what invisibly surrounds every single magnet. The closer to the poles, the thicker and more distinct the lines are. Further away they grow hazier, well illustrating the weakening of magnetic forces of attraction with distance.

HOW IS STEEL MAGNETIZED?

To answer this often-asked question, we must first of all understand the difference between a magnet and a nonmagnetic bar of steel. Every atom of iron in a bar of steel, whether magnetized or not, may be imagined as a tiny magnet. In a nonmagnetic state these baby magnets are haphazardly orientated, with their poles completely neutralizing each other (Fig. 214a). In a magnet, on the contrary, all the tiny magnetic units are disposed in a regular pattern in which like poles are set in the same direction, as is shown in Fig. 214b.

Now what happens in a bar of steel when magnetized? The magnet's attractive forces cause the magnetic particles in the steel bar to line up with their South or North poles pointing in one and the same direction. Figure 214c provides a graphic apposite illustration. The magnetic units swing round at first

with their south poles pointing to the magnet's north pole, then, when the magnet is moved further, they orientate themselves in the direction of its movement, their south poles turned inward.

This shows how one uses a magnet to magnetize steel. One must place one pole of the magnet on the end of a bar of steel and, pressing, move it to the other end. This is one of the simplest and oldest ways of magnetizing steel, suitable,

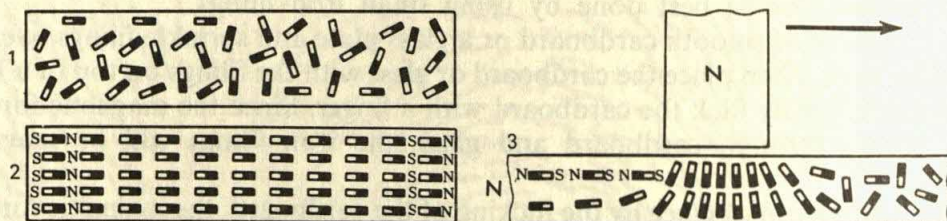


Fig. 214

Disposition of the atom magnets in a nonmagnetized piece of steel (a); same in a magnetized piece of steel (b); the effect of the pole of a magnet on the atom magnets of magnetized steel (c)

however, only for obtaining small and feeble magnets. Powerful magnets are obtained by drawing on the properties of electric currents.

GIANT ELECTROMAGNETS

At iron and steel mills you may see electromagnetic cranes lifting huge loads. They render an inestimable service, as they can hoist and transport, without any special attachment, huge chunks of iron or machine parts weighing dozens of tons. They can also carry, unpacked and uncrated, sheet iron, wire, nails, metal scrap and other materials, which it would take much time and energy to transport in any other way. At one iron and steel plant four magnetic cranes, each carrying ten rails at once, do the job of 200 workers.

I have already mentioned that you do not have to attach these loads to the crane, because while electric currents pass through the coil of the electromagnet, nothing will ever drop down. However, should the line break there is bound to be an accident, and there were such accidents when lifting electromagnets were first introduced. "At one American plant," we read in a technical journal, "an electromagnet was carrying iron ingots from the train to the furnace. Suddenly there was a mishap at the Niagara waterfalls power station supplying the

electricity and the line went dead. The mass of metal broke away from the electromagnet and crushed to pulp a worker below. To prevent a repetition of such accidents and also save on electricity consumption special gadgets are supplied. As soon as the lifting magnet has snatched up the items to be carried, they are caught up from beneath by huge steel pincers and while the load is being shifted from place to place the electric current is switched off."

It might have struck you as very convenient to carry *hot* iron bars in this way. Unfortunately, iron is susceptible to a magnet's attractive force only up to a certain temperature. Red-hot iron loses its magnetic properties. A magnet heated up to the temperature of 800°C no longer possesses its magnetic properties.

Electromagnets are widely used at modern metal-working establishments to hold in place or move items of iron, steel, or pig iron, and hundreds of various devices have evolved to simplify and speed up operations.

MAGNETIC TRICKS

Sometimes circus magicians also resort to electromagnets; one can well imagine how effective these tricks should be. Dary, the author of the well-known book *Electricity and Its Use*, recounts the following story which a French magician told him about a performance in Algeria. The trick made a tremendous impression upon the audience who knew nothing about electricity; they thought that they were seeing a real miracle.

"I had on the stage," the magician's story went, "a small iron-tipped box with a handle on top. I invited a strong man to step forth. In response an Arab of medium height but sturdily built, a sort of local Hercules, came up. He walked up cheerfully, grinning slyly the while, and stopped opposite me.

"'Are you strong?' I asked, looking at him from tip to toe.

"'Yes,' said he.

"'Are you sure you will always be strong?'

"'Certainly,' came the answer.

"'You're wrong,' I said. 'In the twinkling of an eye I can rob you of your strength and you will grow as weak as a little child.'

"The Arab gave a disbelieving grin.

"'Come here,' I said, 'and lift up this box.'

"The Arab bent over, lifted it up and then inquired:

"'Is that all?'

“‘You just wait a moment,’ said I. ‘Assuming a serious mien I made a commanding gesture and solemnly uttered:

“‘You are now weaker than a woman. Lift that box once again.’

“Undaunted by my magic passes, the Arab again bent over and took hold of the box. However, this time it resisted. Despite his desperate efforts, it remained as if rooted to the spot. He strained himself might and main, exerting a force enough to lift an enormous load. But, it was all to no avail. Exhausted, puffing, and crimson with shame, he gave up. Now he believed in my magic.”

The secret was simple enough. The iron-tipped box stood on a platform that was actually the pole of a powerful electromagnet.

It was easy enough to lift the box while the current was off, but as soon as the current flowed through the coil, even three strong men would have failed to lift it.

MAGNET IN AGRICULTURE

Still more curious is the service that magnets render in agriculture. They help the farmer to separate the seeds of cultivated plants from the seeds of weeds.

Weeds have hairy seeds that cling to the wool of passing animals and thus spread to long distances away from the mother plant. The farmer has availed himself of this characteristic feature which weeds have evolved in the aeons of their struggle for survival, to separate the hairy weed seeds by means of a magnet from the smooth seeds of such useful plants as flax, clover and alfalfa. The contaminated mixture of seeds is sprinkled with finely grated iron filings which adhere to the hairy seeds of weeds. As soon as they find themselves in the field of a sufficiently powerful electromagnet, the seeds separate, the magnet attracting all seeds to which the soft iron filings have adhered.

MAGNETIC FLYING MACHINE

At the beginning of this book I had occasion to refer to Cyrano de Bergerac's amusing *History of Lunar and Solar States*. He happens to describe a curious flying machine based on magnetic attraction which one of his characters used to travel to the moon. Here is the extract:

“I ordered a light cart to be made of iron. As soon as I was comfortably seated, I began to toss up a magnetic ball. My iron cart at once ascended in its wake. Every time I reached the ball, I threw it up still further. The cart ascended even when I simply lifted the ball. After I had thrown the ball up time and again, the cart lifted me to a place from whence I began my descent on the moon. And

since, at this moment, I held fast to the magnetic ball, the cart pressed closely to me. Not to break my neck on the descent, I threw the ball up to delay the cart's fall by its attraction. At a distance of some six or seven hundred yards from the moon's surface, I began throwing up the ball at right angles to the direction of my descent until the cart drew quite near. Then I jumped out to the sand below."

Everyone—including Cyrano de Bergerac himself—must have realized that his project was utterly unfeasible. But I am not sure all will be able to say why. Is it because you can't throw a magnet up while sitting in an iron cart? Or because the cart will not be attracted by the magnet? Or is it something else?

Let me tell you that you *could* throw a magnet up and it *would* attract such a cart if powerful enough. However, the flying machine would not move a single inch up.

Have you ever thrown a heavy article ashore from a boat? There is no doubt that, if observant enough, you felt the boat move away from the shore. This happened because while you were imparting an impetus to the object you were throwing in one direction, your muscles compelled your body and the boat with it to recoil. This is a manifestation of that selfsame law of the equality of action and reaction which we have already mentioned more than once. In the throwing up of the magnet you would have the same thing happening. As the man in the cart threw up the magnetic ball, which would cost him quite an effort, as the cart would also attract it, he would inevitably push the cart down. Coming together due to mutual attraction, the cart and the ball would merely regain their initial positions. Hence it is quite clear that even if the cart were as light as a feather, the throwing up of the magnetic ball would only cause it to swing up and down from a definite mean position. We would never get the cart to translate.

In the mid-17th century when Cyrano de Bergerac wrote his book, the law of action and reaction was still unknown. It is therefore doubtful whether the French satirist would have ever been able to state clearly why his amusing project was impracticable.

'MAHOMET'S TOMB'

One day, when an electromagnetic crane was in operation, a worker noted that the electromagnet had attracted a heavy iron ball attached to a short chain riveted to the floor. Since the chain prevented the ball from coming into direct contact with the magnet, leaving a gap, the width of a hand, in between, he saw the unusual sight of a ball and chain jutting vertically up. The magnet was so

powerful that the chain remained in this position, even when the worker climbed it, somewhat like the legendary tomb of Mahomet. (This, incidentally, indicates the electromagnet's tremendous attractive power because a magnet will exert a far weaker force the greater the gap between its pole and the object being attracted. A horse-shoe magnet capable of holding a 100-gram load in direct contact, loses half of its power of attraction when a sheet of paper is

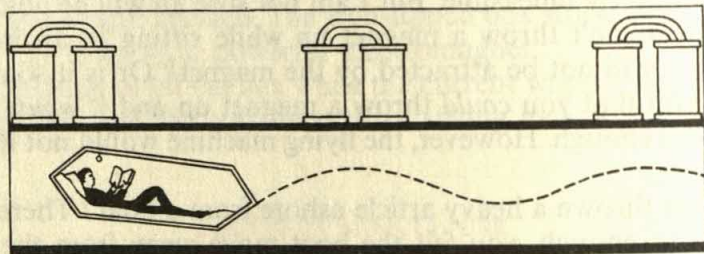


Fig. 215

Frictionless railway designed by Prof. Weinberg

inserted between it and the load. That is why you will never find magnet ends painted, though paint offers protection from corrosion.)

Incidentally, a few words about Mahomet's tomb. Followers of Islam are convinced that the tomb containing the "Prophet's" remains rests on a cushion of air. Could this be possible? "It is said," Euler wrote in his *Letters on Sundry Physical Materials*, "that Mahomet's coffin is suspended in mid air by a magnet. This does not seem improbable because there are manmade magnets capable of lifting as much as 100 pounds." (This was written in 1774 at a time when electromagnets were unknown as yet.)

This explanation is untenable. Were such a method (*attraction of a magnet*) applied, the state of equilibrium could exist only for an instant, because the slightest tremor, even the slightest breath of air, would have been quite enough to upset the balance and the coffin would have either dropped to the floor or ascended to the ceiling. To all practical intents, it is just as impossible to retain it in a state of suspended immobility as it is to place a cone on its vertex, even though the latter is theoretically probable.

However, it is quite possible to simulate the "Mahomet's tomb" phenomenon with the help of a magnet, the difference being that we should have to draw on forces not of mutual *attraction* but of mutual *repulsion*. (Even people who have studied physics are prone to forget that magnets both attract and repel.) Like

poles of magnets repel each other. Two magnetized bars of iron, arranged so that their like poles point to each other, will repel each other. If we chose a magnet of the proper weight, we can easily get it to hover above a second magnet in a state of steady equilibrium without touching the latter. However, we shall have to use nonmagnetic props, made of glass, for instance, to prevent the hovering magnet from swinging into a horizontal plane. Provided these stipulations are observed, we can very well have the Mahomet's tomb of legend suspended in mid air.

Finally, we can achieve this even through a magnetic *attraction*, provided we apply it to a moving object. This, incidentally, is the basic principle of a remarkable project for an electromagnetic, *frictionless* railway (Fig. 215), suggested by the Soviet physicist Prof. B. P. Weinberg. I think it so instructive, that I have made so bold as to dwell on it in greater detail.

ELECTROMAGNETIC TRANSPORTATION

On Weinberg's projected railway the carriages *weigh nothing*, their weight being offset completely by electromagnetic attraction. They neither roll along rails, float on water, nor hover in air. They have no visible means of support, being suspended by the invisible "cables" of powerful magnetic forces. They experience no friction at all and, once set into motion, keep on moving by inertia. No locomotive is required for traction.

This is how the railway works. The carriages are placed in a copper tube that has been thoroughly evacuated to remove air resistance. As they *don't touch the sides of the tube*, they encounter no friction whatever. They are suspended in the middle of the airless tube by the attractive forces of powerful electromagnets, set at definite intervals on top, all along the tube outside, and capable of sending the iron carriages on their way through the tube without touching either "ceiling" or "floor". The electromagnet attracts the carriage moving beneath. But before it has a chance to bump into the "ceiling", it is pulled down by gravity, to be lifted again by the next electromagnet, before it reaches the "floor", thus racing along a smooth wavy trajectory, without friction and jolts. The carriages go through the void much like a planet in space.

The carriages are zeppeline-type cylinders of some 2.5 m long and about 90 cm tall. They are airtight, of course, since they move in a vacuum, and are outfitted with automatic submarine-type air-regeneration systems. They pull out in an entirely novel fashion that can compare only to a cannon shot. They are indeed "shot out" like cannon balls, the difference being that the "cannon"

in this case is an electromagnetic one, based on the property that an electrically energized solenoid is able to pull in an iron plunger with great rapidity, which is the greater, the bigger the coil and the stronger the current. It is this force that shoots out the carriages and since, as we have noticed, there is no friction inside the tube, they continue to move by inertia with the same speed, until stopped by the solenoid at the point of destination.

Here are a few details provided by the author of the project:

"In the experiments I conducted in 1911-13 at the Physics Laboratory at the Tomsk Institute of Technology, I used a copper tube 32 cm in diameter with electromagnets on top and a 10-kg car on a support below. The car was a piece of iron pipe with front and back wheels and a nose-cone to stop it by ramming into a board reinforced by a bag of sand. It could not go faster than about 6 km/h because of restricted space and the fact that the tube was a circle 6.5 m in diameter. I contest, though, that with 3-mile-long solenoids at the point of departure, a speed of 800-1,000 km/h could easily be worked up and maintained without expending any energy, since there is no friction on floor or ceiling to overcome.

"Though the railway, particularly the copper tube, would be rather expensive, no funds would be required to maintain the initial speed or keep a staff of engine-drivers, conductors, etc., and the costs per kilometre would not exceed several thousandths to several hundredths of a kopek; meanwhile a two-tube railway would be able to take daily 15,000 passengers or 10,000 tons in one direction.

MARTIANS FIGHT EARTHMEN

The Roman savant Pliny relates a story current in his day about a magnetic promontory somewhere in India which attracted all iron objects with unusual force. Any unfortunate mariner, whose ship passed close by, was doomed, as his boat would lose all its iron nails and fall to pieces. Later this became one of the Arabian Night legends.

This, of course, is a legend and nothing more. There are magnetic mountains, or rather mountains rich in magnetite. Recall the famous magnetic mountains in the Urals, where the blast furnaces of Magnitogorsk now stand. However, the power of attraction of such mountains is exceedingly faint. There never was on the face of the earth anything of the sort that Pliny describes. And if today we do build ships with no iron or steel parts, this is done not for fear of magnetic rocks but to facilitate the study of terrestrial magnetism.

The science-fiction novelist Kurt Lasswitz took Pliny's legend as the basis for

a story about a master weapon which Martian invaders in the novel *The Two Planets* employ to fight the Earthmen. With this magnetic or rather electromagnetic weapon, the Martians were able to disarm the Earthmen's troops without even engaging with them. Here is the extract describing the "battle".

"The glittering array of horsemen galloped forward. It seemed as if their selfless resolve had finally compelled the formidable foe [the Martians—Y. P.] to retreat. There was a new commotion among the enemy airships. They ascended into the sky as if about to yield.

"At the same time, however, a dark spreading pall that had just appeared above the field, descended. It unfolded like a table-cloth, hemmed in on every side by airships. As soon as the first row of cavalry came beneath the odd machine it reacted with diabolical rapidity. The air was rent with deafening cries of horror. The horses and their riders fell. Meanwhile the air filled with clusters of clattering and rattling pikes, swords and carabines, that whirled up and clung to the strange machine.

"The machine then veered away slightly and dropped its crop of iron onto the ground. It returned twice seeming to collect every weapon in the field. None of the cavalrymen could hold his sword or pike.

"The machine was a new Martian invention. It attracted with an irrepressible force every steel and iron object. The Martians employed their hovering magnet to wrest from the enemy all their weapons, without doing them any harm.

"The aerial magnet floated towards the rows of infantry. In vain did the soldiers clutch at their rifles. Some invincible power plucked them out of their hands. Many who did not let go were themselves lifted into the air. The first regiment was completely disarmed in the matter of a few minutes. The machine then raced after the regiments marching into the city, ready to mete out the same treatment.

"Nor was the artillery spared."

WATCHES AND MAGNETISM

Haven't you the impulse to ask: Couldn't a screen impenetrable to magnetic attraction be found? It could, of course. The Martians' fantastic invention could have been countered had due precautions been taken.

Queerly enough the substance impermeable to magnetic forces is that very same so easily magnetized iron. *Inside* an iron ring a compass needle will not be deflected by a magnet outside the ring. An *iron case* will protect the steel

mechanism of a watch from magnetism. If you put a gold watch on the poles of a powerful horse-shoe magnet, all its steel parts, and, firstly, its fine hair-spring, will be magnetized (provided, of course, that the hair-spring is not made of a special alloy called *invar* which does not magnetize, even though it contains both iron and nickel), and your watch would no longer show the right time. You wouldn't be able to repair the harm done, even if you took the magnet away; the

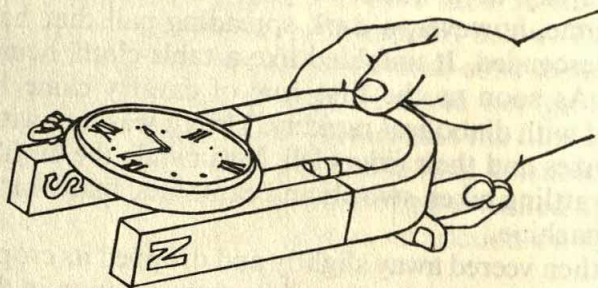


Fig. 216

What protects the steel mechanism of a watch from being magnetized

steel mechanism would stay magnetized and your watch would need to be overhauled fundamentally. So don't experiment with a gold watch in this way. You'll have to pay dearly for it.

However, you can boldly perform this experiment with a watch whose mechanism is contained in an iron or steel case, as these two metals are impervious to magnetic forces. Even if you put it near the coil of a powerful dynamo, it will tick on just as well as it did before. These cheap iron-cased watches are ideal for the electrical engineer or technician.

MAGNETIC PERPETUAL MOTION MACHINE

In attempts to invent a perpetual motion machine the magnet and its powers have played a role of no mean magnitude. Ill-starred perpetual motion machine inventors have tried might and main to apply the magnet to this end. Here is one such project (described back in the 17th century by the Englishman John Wilkins, the Bishop of Chester).

A powerful magnet *A* is placed on top of a pillar (Fig. 217), leaned against which are two inclined grooves *M* and *N*, one above the other. The upper

groove *M* has a small hole *C* at the top, while the lower groove *N* is curved. The inventor presumed that the arrangement would operate as follows. A small iron ball *B* was to be placed on the upper groove. Attracted by magnet *A*, it ought to roll upwards. On reaching the hole, it should fall through on to the lower groove *N*, along which it should roll down, be carried up by inertia along the curve *D*, and find itself again on the upper groove *M*, from whence, again

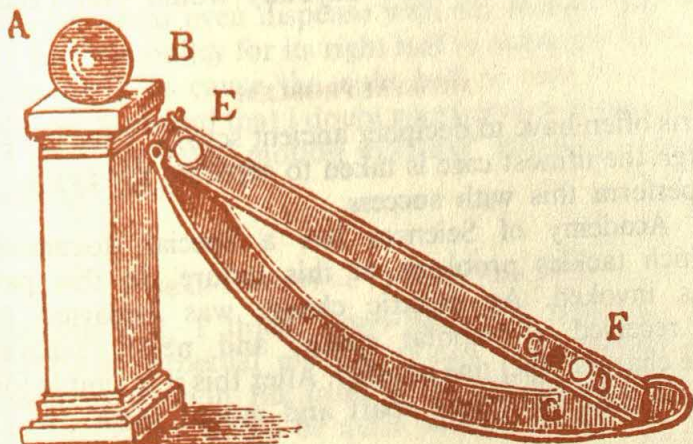


Fig. 217

A fake perpetual motion machine

attracted by the magnet, it should again roll up and drop through the hole, roll down and on to the upper groove, *ad infinitum*. This, the inventor conjectured, would produce perpetual motion.

Where did the inventor go wrong? His fallacy is easy enough to indicate. Why did he think that after rolling down groove *N* the little ball would have enough momentum to climb up curve *D*? This would happen, were the little ball influenced by gravity alone. However, we also have a second force, that of magnetic attraction, which is so powerful that it even compels the ball to ascend from position *B* to position *C*. Consequently, our little ball will not accelerate as it goes down groove *N*. On the contrary, it will roll very slowly down and, even if it should reach the bottom, will not have enough momentum to take the curve.

Sundry modifications of this same project have been put forward time and again. Curiously enough, one even had a patent issued to it. It happened in Germany in 1878, thirty years after the law of the conservation of energy was

published. The inventor had so deftly guised the absurd principle at the root of his magnetic perpetual motion machine that he fooled the patent authority, though according to the regulations no patents are issued for inventions based on principles contrary to the laws of nature. However, the proud possessor of this sole patent of its kind ever issued, must have soon grown disillusioned, as he stopped paying patent duties in two years' time. Now anyone can acquire the "invention". However, I don't think anybody would ever need it.

MUSEUM PROBLEM

Museum experts often have to decipher ancient scrolls. They are so fragile that they tear though the utmost care is taken to separate the pages. The problem was how to perform this with success.

The USSR Academy of Sciences has a special document-restoration laboratory which tackles problems of this nature. In this particular case electricity was invoked. An electric charge was imparted to the MSs.

The pages received a unipolar charge and neatly separated without tearing—as like charges repel one another. After this it is simple for a proficient pair of hands to take the pages apart and mount them.

ONE MORE FAKE PERPETUAL MOTION MACHINE

The idea of coupling a dynamo to an electric motor has become very popular of late with all who want to "solve" the problem of perpetual motion. Every year I'm asked to advise on around half a dozen of these projects, which all boil down in essence to running a belt from the electric motor to the dynamo and wiring the dynamo with the motor. The idea is that if the dynamo be given an initial impulse, the electricity it generates will work the motor, which in turn will set the dynamo in motion. Consequently, as the inventors presume, the two machines will set each other in motion and never stop, until they both wear out.

It seems very tempting, doesn't it? But all who have tried it have found, to their surprise, that it doesn't work, as really was to be expected. Even if both machines had a 100-per cent efficiency factor, they would operate endlessly only in the complete absence of friction. This combination of machines—or assembly, as an engineer might call it—is really one machine which is supposed to make itself go. Of course, in the absence of friction it would move endlessly, just like anything else, but no practical use would ever be derived from it, because as soon as you tried to make it perform some work, it would stop at once.

This would give us perpetual motion but not a perpetual motion machine. All that has just been said would be valid, naturally, were there no friction; since we do have friction, the machine won't go at all.

I wonder why these "perpetual motion" cranks never think of simply joining two pulleys by a belt and spinning one of them. Because, judging by the method of reasoning employed to "justify" the above-mentioned combination, oughtn't we to expect the first pulley to turn the second pulley, and the second pulley the first one? Why, we could even dispense with the second one. Wouldn't it be enough to turn just one pulley for its right half to cause the left half to turn and this left half similarly to cause the right half to turn?

This is so obviously absurd that I doubt whether they would ever bring a glint to the eyes of any "perpetual motion machine" inventor, though he labours under the same delusion.

A NEAR-PERPETUAL MOTION MACHINE

The mathematician will, I think, pooh-pooh the idea of "near-perpetual motion". Either it is perpetual motion or not. "Near-perpetual motion" is actually not perpetual motion. But from the practical angle this can be viewed differently. I believe many would be quite satisfied to have a "near-perpetual motion" machine able to run for at least a thousand years. Man's life span is short and we would look upon a thousand years as eternity. I suppose people with a practical turn of mind would consider the "perpetual motion" machine problem solved, could that be done.

It can be; a thousand-year motion machine has been invented. Everybody can own one, provided he is willing to foot the bill. No patent has been taken for it and it is no secret. Commonly called a "radium clock", it was invented by Prof. Stret in 1903. It is rather simple (Fig. 218). It consists of a small glass tube *A*, with several thousandths of a gram of *radium salts*, suspended from a quartz thread *B* (quartz does not conduct electricity), inside a sealed glass jar, from which the air has been evacuated. Attached to one end of the tube, as in an electroscope, are two narrow strips of gold leaf. Radium, as you may know, emits three types of rays, respectively, alpha, beta and gamma rays. In our case it is the beta rays, as easily capable of passing through glass and comprising a stream of negatively charged particles or electrons, that do the job. The scattered electrons carry away the *negative* charge gradually imparting a *positive* charge to the radium in the tube. This positive charge is then imparted to the strips of gold leaf, causing them, on account of mutual repulsion, to swing

apart, touch the jar's wall, relinquish their charge to strips of electricity-conducting tin foil, appropriately pasted on, and swing together again. With every new electron charge, this process repeats itself, which happens every two or three minutes with the regularity of a pendulum. Hence the name. This continues for years and centuries until the radium decays entirely. This of course is not a perpetual motion machine but merely a gift-motion machine.

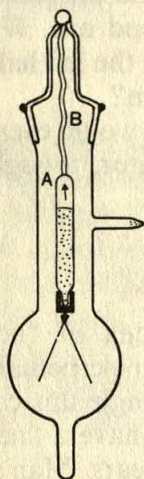


Fig. 218

A radium clock with an almost "perpetual wind" for 1,600 years

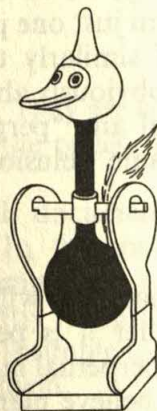


Fig. 219

Insatiable birdie

How long does radium emit rays? Scientists have found that radium has a half-life of 1,600 years. Consequently, a radium clock will be able to go without stopping for at least a thousand years. Only the frequency of oscillations will diminish due to the diminishing electric charge. Had a radium clock of this order been set going when Russia was born as an independent state, it would still be ticking today!

Could this gift-motion machine be used for any practical purposes? Unfortunately, not. Its power, or the amount of work it does every second, is so minute that it will never set any mechanism in motion. To attain tangible results, we would need a far larger stock of radium. Since radium is an extremely rare and very costly element, such a gift-motion machine would be ruinous.

INSATIABLE BIRDIE

There is a Chinese toy which is a perpetual source of astonishment and delight. This is the "insatiable birdie". Put before a drinking bowl, the "birdie" will dip its beak in the water and having "drunk its fill", swing back into its initial upright position. After a while, it slowly leans over to dip its beak in the water

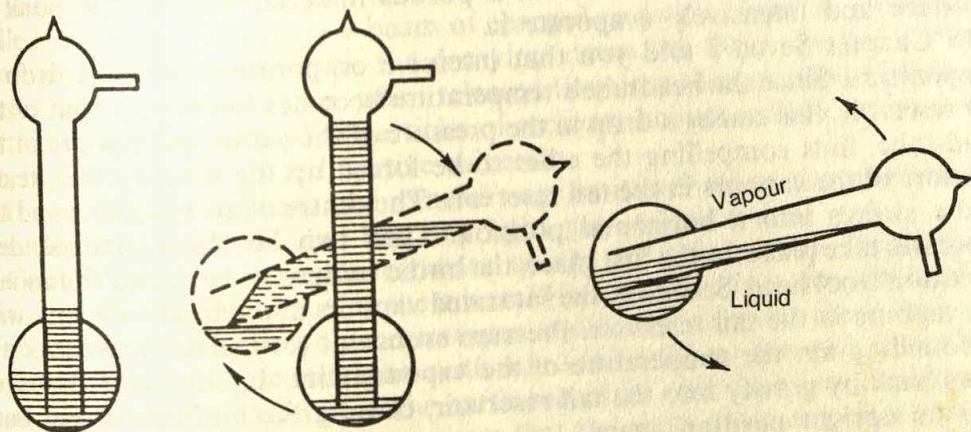


Fig. 220

The birdie's secret

again, "drinks" and swings back. This is a typical gift-motion machine, one, moreover, based on an extremely ingenious principle. Look at Fig. 219. The birdie's "body" consists of a glass tube ending at the top in a little head-shaped sphere, and inserted at the bottom into a broader similarly air-tight reservoir sphere, filled with ether up to a level a bit higher than the open bottom end of the tube.

To cause the birdie to "drink", its head must be wetted with water. For a while we see it still upright—since the ether gradually rise in the tube heavier than the head. Then we see the ether gradually rise in the tube (Fig. 220), finally making the upper part heavier and causing the birdie to lean over and dip its beak in the drinking bowl. When the birdie swings into a horizontal position the tube's open bottom end takes up a position which is above the level of the ether in the bottom reservoir, thus causing the ether in the tube to flow back into the tail reservoir, and the birdie, consequently, to swing back into its initial upright position. This is the mechanical aspect of the problem; as the ether rises and returns, the centre of gravity shifts.

But what compels the ether to rise? Ether easily evaporates at room

temperature, while the pressure that saturated ether vapours exert greatly varies, when the temperature fluctuates.

When the birdie is in its upright position, there are two clearly distinguishable zones of ether vapours. There are the "head" tube and the "tail" reservoir.

Now the "head" possesses the remarkable property of lowering its temperature in comparison with that of the surrounding environment. This can be achieved by making the head of a porous material well able to soak in moisture and intensively evaporate it.

In Chapter Seven I told you that intensive evaporation causes a drop in temperature. Since the headtube's temperature becomes lower than that of the tail reservoir, this causes a drop in the pressure of the saturated vapours in the head-tube, thus compelling the ether to be forced up the tube by the greater pressure of the vapours in the tail reservoir. The centre of gravity shifts and the birdie swings into a horizontal position. Then two absolutely independent processes take place. In the first place, the birdie wettens its beak and thus soaks its cotton wool head. Secondly, the saturated vapours in the head-tube mix with the vapours in the tail reservoir. Pressure evens out (owing to the heat of the surrounding air, the temperature of the vapours rises slightly), and the ether flows back by gravity into the tail reservoir, causing the birdie to swing back into its upright position again.

This "nodding" continues while the cotton wool head is wet and provided the humidity of the surrounding air is not too great.

These two factors will guarantee normal evaporation and the consequential relative drop in the head-tube's temperature. It is thus that the warmth of the surrounding air imparted to the birdie all the time causes it to nod.

HOW OLD IS THE EARTH

A study of the laws governing the decay of radioactive elements has provided scientists with a reliable method for estimating the earth's age.

What is radioactive decay? It is the "spontaneous transformation" of one set of atoms into another, a process not induced by any external factors. It is curious to note that temperature and pressure fluctuations and the like have not the slightest effect on the "speed" of this process (only a temperature of the order of tens of thousands of millions of degrees could have any effect). The elements of uranium, thorium, and actinium, contained in some minerals, are the progenitors of several series of radioactive elements, each of which series is a sequence of spontaneous transformations of radioactive elements. The

ultimate product of these spontaneous transformations in the case of all three elements named is lead. True, this "lead" in each case has a different "atomic weight" than the normal lead. A normal atom of lead is 207 odd times heavier than an atom of hydrogen, while atoms of lead closing the uranium, thorium and actinium series are respectively 206, 208 and 207 times heavier. It is thus quite possible to distinguish between them.

This spontaneous transformation is attended by the emission of what are called alpha rays, which are a beam of charged particles of matter or atoms of the light inert gas helium, by the decaying atoms. As these charged particles possess enormous velocities, when released they lose their positive charge and settle down in the mineral as particles of ordinary helium—which explains why we find helium in all radioactive minerals.

However, the estimation of a mineral's age by its helium content may lead us very far out, since helium—like any light gas—evaporates.

Couldn't a more accurate estimate of age be obtained by checking the amount of lead accumulated in the mineral? In the early 1940s, proceeding from a quantitative evaluation of lead isotopes at different deposits, the British geologist Holmes concluded that the earth was 3,500 million years old. Actually he had ascertained the age not of the earth but of its crust and had furthermore proceeded from the obsolete conjecture that the earth owed its origin to a hot clot of gas torn out of the sun.

In 1951-52 Academician A. P. Vinogradov concluded, after scrupulously analyzing all available data, that it was impossible to estimate the age of the earth's crust on the basis of lead data alone. One could only surmise that it was not more than 5,000 million years old. At the same time minerals were found, whose age has been estimated as 3,000 million years. Proceeding from data concerning the speed with which identical quantities of two uranium isotopes (with the atomic weights of 235 and 238) decay, scientists have put the earth's age between 5,000 and 7,000 million years.

So we may presume that the earth is some 6,000 million years old. This estimate seems to be right because the same figure was deduced, though entirely different methods were used. Naturally 6,000 million years is tremendous compared even with man's history, let alone his life-span.

BIRDS ON THE WIRES

You all know how dangerous it is for a person to touch live tramway or high-tension wires. We know of many cases too, when people and big animals have

been electrocuted by a broken live wire. Why then do birds so calmly perch on live wires with absolute impunity?

To understand this contradiction the following must be taken into account. One must regard the body of the bird, perched on the wire, as the branch line of an electric circuit, whose resistance is tremendous compared with the other branch line of the circuit, namely, the very short distance between the bird's claws.

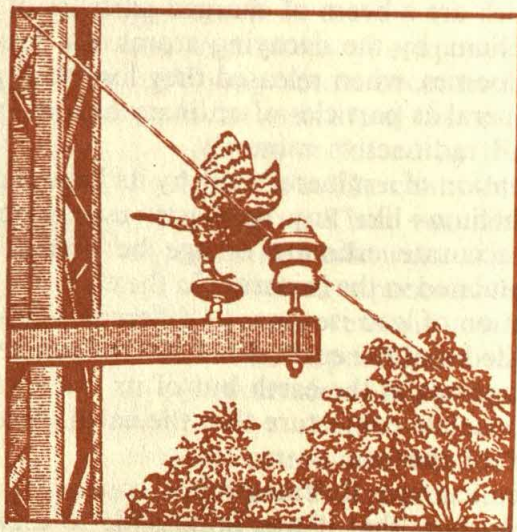


Fig. 221

An isolated bird perch on the support of a high-voltage transmission line

Therefore the intensity of the current passing through the bird's body is negligible and, consequently, harmless. But as soon as the bird on the wire touches the pole with its wing, tail, or bill, or makes a contact with the ground in any other way, it is immediately electrocuted. No doubt you have observed this.

Birds have the habit of pecking at the live wire while perched on the supports of high-tension transmission lines. Since the support is not insulated from the ground, the moment the grounded bird touches the live wire it is electrocuted.

This happens so often that the Germans once took special bird-protection measures installing insulated perches on the supports of high-tension transmission lines, which thus prevented electrocution when the bird chose to peck at the live wire (Fig. 221). Sometimes, to keep the birds away, live wires are enclosed in guards.

IN THE LIGHT OF LIGHTNING

Have you ever happened to observe busy street crossings when a lightning flashes? Imagine for a moment that a thunderstorm has caught you out shopping. Oddly enough, during the flashes of lightning everything, so full of life a moment ago, seems motionless; cars seem to be standing still and you are able to clearly make out every spoke in their wheels.

The reason lies in the negligible fraction of time during which lightning flashes. Like any electric spark lightning is instantaneous, so much so that our usual methods of time-reckoning simply won't do. However, scientists have indirectly established that a flash of lightning lasts less than a thousandth of a second.* In such extremely short stretches of time scarcely anything moves to any noticeable degree. No wonder that in a flash of lightning a busy street seems motionless. After all we see only what lasts less than a thousandth of a second. In this time interval the wheel of a car shifts only a negligible fraction of a millimetre, which our eye cannot catch at all.

HOW MUCH DOES LIGHTNING COST?

In those ancient times when lightning was the prerogative of "divine beings" a question of this order would have been regarded as rank blasphemy. Today, however, when electricity is a commodity that can be gauged and valued like any other, I don't think anyone would take the question of the cost of lightning as bosh and bunkum. Our problem is to reckon the amount of electric energy consumed in a lightning discharge and price it at least on the basis of electricity rates.

The potential of a lightning discharge is about 50 million volts, the maximum intensity of current rating 200,000 amperes (a factor ascertained incidentally by noting the degree to which a steel rod is magnetized by the current that passes through its coil when lightning strikes at a lightning conductor). The wattage is determined by multiplying the number of volts by the number of amperes. As we do this, however, we must not lose sight of the fact that during the discharge the potential drops to zero. Consequently we must take the mean potential or, in other words, half the initial voltage. This gives us discharge wattage of $50,000,000 \times 200,000/2 = 5,000,000,000,000$ watts, or 5,000 million kilowatts.

* There are also cases of flashes of lightning lasting for "as long" as several tens of a second, and of a series of repeated flashes, each bolt whizzing through the "corridor" made by the first, that will keep up for "as long" as one and a half seconds.—Ed.

This impressive row of naughts may lead us to believe that we shall have a similarly astronomical figure representing cost. However, to get kilowatt-hours—which electricity rates are based on—the time factor must also be taken into account. Our lightning discharge lasts about a thousandth of a second, in which interval $5,000,000,000 / (3,600 \times 1,000)$ or about 1,400 kwh are spent. The rate of a kilowatt-hour is 4 kopeks and hence lightning should cost $1,400 \times 4 = 5,600$ kopeks or 56 rubles.

It's astounding, isn't it! Lightning, the energy of which is a hundred times greater than that released when a heavy artillery piece is fired costs but 56 rubles.

It is interesting to note how close electrical engineering has got to the artificial manufacture of lightning. In laboratories scientists have produced a tension of up to ten million volts and have obtained a fifteen-metre-long spark.

THUNDERSTORM AT HOME

It is very easy to make at home a small fountain by using a rubber tube with one end either in a pail of water that has been placed on a chair, or attached to a tap. The other end of the tube must be very narrow if you want to get the fountain to spray. The simplest way to do that is to make a nipple by using a pencil stub from which the lead has been extracted. For convenience's sake you may insert the pencil stub in the end of an overturned funnel as shown in Fig. 222.

Get your fountain to play to about half a metre high, with the spray directed towards the ceiling. Then bring near a stick of sealing wax or an ebonite comb previously rubbed with a piece of cloth. The separate fountain sprays will suddenly merge into a solid column of water that thuds quite loudly on a plate with a sound exceedingly reminiscent of the noise of a thunderstorm. "Unquestionably," the physicist Boyce remarks in this connection, "this is precisely why the raindrops in a thunderstorm are so large". As soon as you withdraw the sealing wax or comb, your fountain will spray again and you will hear the gentle tapping of scattered drops of water.

You may turn this into a parlour trick and cause the uninitiated to believe that your stick of sealing wax is a "magic" wand.

The phenomenon is caused by the induced electrification of the drops of water. The drops near the stick receive a positive charge and the drops further away, a negative charge; mutual attraction thus causes the drops to merge.

There is a much simpler way of detecting the effect electricity has on a jet of

water. Put a comb through your hair and then bring it up to the trickling from a tap. The trickle will become a steady stream and curve noticeably (Fig. 223). This is harder to explain than the previous phenomenon; it is bound up with the change in surface tension under the effects of an electrical charge.

Let me note in passing that the ease with which an electric charge accumulates during friction explains the electrification of belts as they rub against

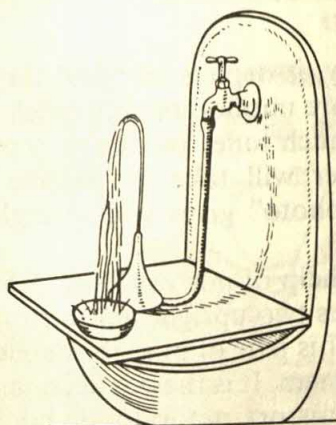
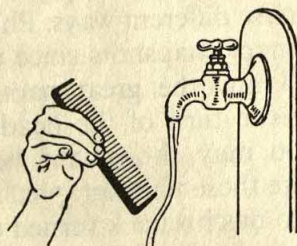


Fig. 222

Thunderstorm in miniature

Fig. 223

The stream of water from the tap bends away when an electrified comb is brought up



publeys. The electric sparks thus emitted sometimes cause fires. To avoid this the belts are thinly plated with silver. This turns them into conductors of electricity, unable to accumulate an electric charge.

Chapter 19

Reflection and Refraction of Light. Vision

QUINTUPLE PHOTO

Figure 224 shows you a photographic curiosity, it depicts one and the same person in five different ways. Photos of this sort are unquestionably much better than ordinary snapshots since they provide a much fuller picture of a person. You all know the great pains a photographer will take to get the most characteristic turn of the head. A "quintuple photo" gives you several from which you may choose the best.

How are these photographs taken? With the help of mirrors (Fig. 225). The sitter, who has his back turned to camera *A*, faces two upright flat mirrors *CC*, set at an angle of one-fifth of 360° , that is, 72° . This pair of mirrors should give four reflections turned differently towards the camera. It is these reflections, plus the sitter, that are photographed. The unframed mirrors, naturally, do not show. To prevent reflection of the camera itself it is screened off by two screens *BB* which are placed so as to leave a small aperture for the lens.

The number of reflections depends on the angle between the two mirrors; the acuter the angle, the greater the number of reflections. If the angle is 90° , which is $360 \div 4$, we get four images; if it is 60° , which is $360 \div 6$, we get six. Should the angle be 45° , which is $360 \div 8$, we get already eight images, and so on and so forth. However, the greater the number of reflections the fainter the image is. That is why photographers usually prefer to confine themselves to a fivefold reflection.

SUN-POWERED MOTORS AND HEATERS

The idea of employing solar energy to heat an engine boiler is most fascinating. A simple reckoning: scientists know how much energy a minute every square centimetre of the top surface of the atmosphere, in places at right angles to the sun's rays, receives from the sun. Since the amount is apparently constant, it has come to be known as the "solar constant". In round numbers it is equal to 1.4 kW/m^2 . This amount of heat which the sun sends us with such faithful regularity does not all reach the earth's surface. About 25% of it is absorbed in

the atmosphere. We may take it for granted that every square centimetre of ground placed perpendicular to the sun's rays gets roughly 1 kJ of energy a second.

Such is the amount of work solar energy could do in optimal conditions, i.e. when its incidence is perpendicular and it is all converted into mechanical energy. However, we have a long way to go yet to achieve this ideal. The



Fig. 224

A quintuple photograph of one and the same face

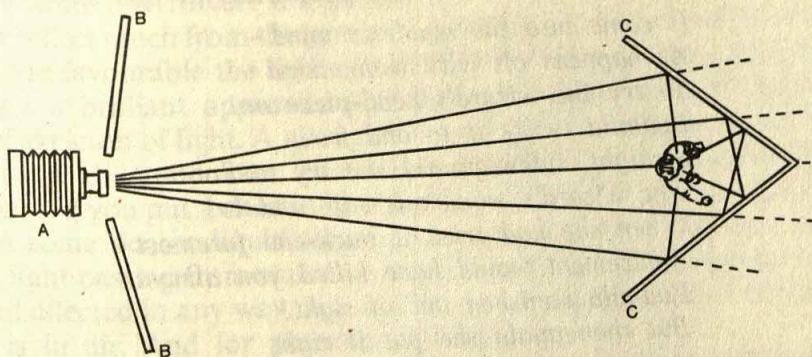


Fig. 225

How to obtain multiple photographs. The sitter is placed between the mirrors CC

efficiency factor obtained so far has not been more than 5-6 per cent, as a rule. The best efficiency factor of 15 per cent has been recorded by Prof. Charles Abbot's sun-powered motor.

It is much easier to employ solar energy not for mechanical work but for heating. In the USSR great attention is paid to this problem. There is a special Sun Institute in Samarkand, which carries on extensive research. Various solar devices, including bath-houses and water heaters, have been devised and tested. The average efficiency factor of solar water heaters is 47 per cent, while the maximum is 61 per cent. One such device tested in Turkmenia was a solar refrigerator, whose cooling batteries ran a temperature of 2-3°C below zero, despite an air temperature of 42°C above zero in the shade. This is the first commercial solar refrigerator of its kind.

Experiments in the sun-powered smelting of sulphur, which has a melting point of 120°C, produced some very fine results. I could also mention solar distillers used along the Caspian and Aral seas to obtain fresh water, a sun-powered pump to replace the primitive Central Asian pumps, sun-driers for drying fruit and fish, a solar kitchen-range, etc. This is a far from complete list of all the different ways in which trapped sunshine may be used. It will definitely play an important role in the economy of Central Asia, the Caucasus, the Crimea, the Volga delta and the Southern Ukraine.

CAP OF INVISIBILITY

There is a hoary legend of a magic cap which renders the wearer invisible. In his *Ruslan and Ludmila*, the celebrated Russian poet Alexander Pushkin provides a classical description of the miraculous properties of this cap:

*It came into the maiden's mind –
As happens oft with womankind –
To try the wizard's head-piece on.
Ludmila twists it to and fro;
Straight, sideways did she try to don
The wizard's wondrous cap, and lo!
When she had tried it back-end foremost –
Amazement would have killed you almost –
Ludmila vanished out of sight!
But then again she put it right
And reappeared. On repetition
Ludmila disappeared anew.*

*"A-ha, my wily old magician,
I owe much gratitude to you.
For hence my freedom I have found
And shall be ever safe and sound!"*

The cap of invisibility was all the captive Ludmila had for protection. She used it to escape the clutches of her Argus-eyed guards, who were able to suspect her presence only by her action.

Many of the wonders of ancient legend have long become facts of everyday life. Science has wrought many a miracle. Today we can drill mountains, trap lightning, and travel by "flying carpets". Couldn't we invent also the cap of invisibility or find some means of making ourselves absolutely invisible? Let us discuss this point.

THE INVISIBLE MAN

In his *The Invisible Man* H.G. Wells would have us believe that it is quite possible to render ourselves invisible. The main character in the novel, whom the author calls the most brilliant physicist the world had ever known, discovered a way of making the human body invisible. In the following passage he describes his method to a doctor acquaintance.

"...visibility depends on the action of the visible bodies on light... You know quite well that either a body absorbs light or it reflects or refracts it or does all these things. If it neither reflects or refracts nor absorbs light, it cannot of itself be visible. You see an opaque red box, for instance, because the colour absorbs some of the light and reflects the rest, all the red part of the light to you. If it did not absorb any particular part of the light, but reflected it all, then it would be a shining white box. Silver! A diamond box would neither absorb much of the light nor reflect much from the general surface, but just here and there where the surfaces are favourable the light would be reflected and refracted, so that you would get a brilliant appearance of flashing reflections and translucencies. A sort of skeleton of light. A glass box would not be so brilliant, not so clearly visible as a diamond box, because there would be less refraction and reflection... if you put a sheet of common white glass in water, still more if you put it in some denser liquid than water, it would vanish almost altogether, because light passing from water to glass is only slightly refracted or reflected, or indeed affected in any way. It is almost as invisible as a jet of coal gas or hydrogen is in air. And for precisely the same reason!

"Yes," said Kemp. "That is plain sailing. Any schoolboy nowadays knows all that."

“And here is another fact any schoolboy will know. If a sheet of glass is smashed and beaten into a powder, it becomes much more visible while it is in the air; it becomes at last an opaque, white powder. This is because the powdering multiplies the surfaces of the glass at which refraction and reflection occur. In the sheet of glass there are only two surfaces, in the powder the light is reflected or refracted by each grain it passes through, and very little gets right through the powder. But if the white, powdered glass is put into water, it forthwith vanishes. The powdered glass and water have much the same refractive index that is, the light undergoes very little refraction or reflection in passing from one to the other’.

“You make the glass invisible by putting it into a liquid of nearly the same refractive index, a transparent thing becomes invisible if it is put in any medium of almost the same refractive index. And if you will consider only a second, you will see also that the powder of glass might be made to vanish in air, if its refractive index could be made the same as that of air. For then there would be no refraction or reflection as the light passed from glass to air.*

“‘Yes, yes,’ said Kemp. ‘But a man’s not powdered glass.’

“‘No,’ said Griffin. ‘He’s more transparent.’

“‘Nonsense.’

“That’s from a doctor. How one forgets! Have you already forgotten your physics in ten years? Just think of all the things that are transparent and seem not to be so! Paper, for instance, is made up of transparent fibres, and it is white and opaque only for the same reason that a powder of glass is white and opaque. Oil white paper, fill up the interstices between the particles with oil, so that there is no longer refraction or reflection except at the surfaces, and it becomes as transparent as glass. And not only paper, but cotton fibre, linen

* We can render an absolutely transparent object completely invisible if we surround it on all sides by walls able to disperse light strictly uniformly. Through a small side aperture our eye will then receive from every point of the object the same amount of light and the object will seem nonexistent, as it will have no sparkle or shadow betraying its presence. Here is how you do it. Make a funnel out of white cardboard half a metre in diameter and mount it as shown in Fig. 226 some distance away from a 25-W bulb. Then insert from below through the funnel’s narrow end a glass rod, keeping it strictly vertical, as the slightest deviation from the vertical will cause it to appear either as a haloed dark thin shadow or as a shadow-fringed pencil of light, interchanging as soon as you give the stick a slight twist. By trial and error get the light to fall uniformly on the stick. Then to the eye, looking at it through a narrow side aperture not more than 1 cm in diameter, it will seem nonexistent. The glass object will be completely invisible, though its refractivity greatly differs from that of air. Another way of making a bit of faceted diamond-cut glass invisible, is to place it in a box coated inside with luminescent paint.

fibre, wool fibre, woody fibre, and *bone, flesh, hair, nails and nerves*, in fact, the whole fabric of a man, except the red of his blood and the dark pigment of hair, are all made up of transparent, colourless tissue—so little suffices to make us visible one to the other....”

Confirmation is afforded by the considerable transparency of the tissues of nonhairy albino animals (their tissues are completely devoid of pigment). One

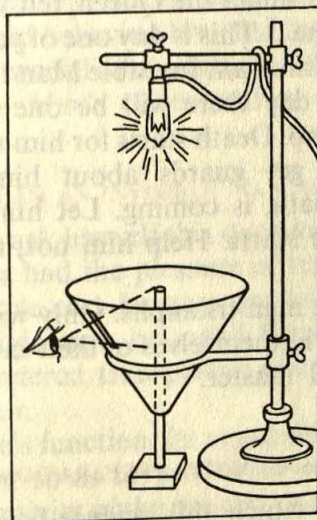


Fig. 226 Invisible glass rod

zoologist who happened to pick up an albino frog near Detskoye Selo in the summer of 1934, describes it as follows: “The thin skin and muscular tissues are transparent and one can see the skeleton and visceral organs through them. The contraction of the heart muscle and intestine movement are particularly well seen through the abdomen.”

Wells’ hero discovered how to make all the tissues of the human organism and even its pigments transparent. He applied his invention to his own body obtaining the spectacular result of total invisibility. Let us now see what happened next to the invisible man.

MIGHT OF INVISIBILITY

Wells demonstrates with extraordinary wit and logic that an invisible man thus acquires almost unlimited power. He is able to enter any place unnoticeably and

steal anything with impunity. Elusive, thanks to invisibility, he successfully fights a whole crowd of armed people. Threatening to smite all who are visible, the invisible man subjugated the population of an entire town. Himself elusive and invulnerable, he strikes down all his opponents despite their every precaution. The invisible man is thus able to issue to the terrified population of his home town an order of the following content:

"Port Burdock is no longer under the Queen, tell your Colonel of Police, and the rest of them; it is under me... This is day one of year one of the new epoch—the Epoch of the Invisible Man. I am Invisible Man the First. To begin with, the rule will be easy. The first day there will be one execution for the sake of example—a man named Kemp. Death starts for him today. He may lock himself away, hide himself away, get guards about him, put on armour if he likes—Death, he unseen Death, is coming. Let him take precautions—it will impress my people... Death starts. Help him not, my people, lest Death fall upon you also."

At the outset, the invisible man triumphs. Only with the greatest of difficulty do the terrorized townsfolk rid themselves of their invisible foe who dreamed of becoming their all-powerful master.

TRANSPARENT PREPARATIONS

Are the physical theses on which this science-fiction novel is based right? Unquestionably yes. In a transparent medium every transparent object becomes invisible when the difference between refractive indices is less than 0.05. Ten years after H. G. Wells' *The Invisible Man* was published, the German anatomist, Prof. W. Spalteholtz, put the writer's idea into practice—true not on living organisms but in the preparation of dead specimens. Such transparent preparations of organs and even whole animals may be seen today in many museums. The transparent preparations method evolved by Prof. Spalteholtz in 1911 is briefly as follows. After treatment (bleaching and washing) the prepared specimen is soaked in methylsalicylate, a colourless liquid with a big refractive index. Specimens of rats and fishes, or various human organs thus prepared, are placed in jars containing the same liquid. However, full transparency is not sought as this would cause the specimens to become absolutely invisible and, consequently, useless for the anatomist. We could achieve full transparency if necessary though.

This is naturally far from Wells' dream of a *live man* so transparent as to be absolutely invisible. Firstly, because we must know how to treat *living* tissue

with this transparency liquid without violating organic functions. Secondly, because Prof. Spalteholtz's preparations are transparent but not invisible. They are invisible only while immersed in liquid of corresponding refractivity. They will become invisible in the air, only when their refractive index is the same as that of the *air*, which is something we are still unable to achieve.

However let us imagine for a moment that with time we shall be able to do this and consequently realize the British novelist's dream. H. G. Wells was so thorough, that one can't help believing him and his thesis that an invisible man must indeed be the most powerful of mortals. This is not at all so. There was one point which *The Invisible Man's* clever author overlooked.

CAN AN INVISIBLE MAN SEE?

Had Wells ever stopped to ask himself this question before he embarked on his novel we would have never had the pleasure of reading his gripping narrative. This upsets the entire apple-cart because *an invisible man must be...blind*.

Why couldn't the invisible man be seen? Because every part of his body, including his eyes, was rendered transparent and possessed a refractive index identical to that of the air.

Let us now recall the eye's function. Its crystalline lens, vitreous humour and other elements refract light so as to produce a retinal image of surrounding objects. But when the refractivity of the eye and that of the air are equal, the sole cause of refraction is removed. Passing from one medium to another of *the same refractivity*, light will not change its direction and, consequently, its rays will be unable to concentrate in one point. Light will pass through the eye of an invisible man without hindrance; its rays will neither be refracted nor retarded, since there is no pigment. To induce a sensation in animals, the rays of light must bring about some changes even of the most insignificant nature; or, in other words, perform certain functions in the eye. Consequently, at least part of the rays must be *retarded*. An absolutely transparent eye will naturally be unable to check rays, otherwise it wouldn't be transparent. All creatures drawing upon transparency for protection have eyes that are not completely transparent, provided they have eyes. "Immediately below the surface," the well-known oceanographer Murray writes, "most animals are transparent and colourless.... When taken from the tow-nets they are often distinguishable *only by their little black eyes*, their blood being devoid of haemoglobin and the entire body perfectly transparent, and, consequently, will fail to produce any mental image."

To sum up: *an invisible man sees nothing*. He will derive no benefit from all his advantages. This formidable claimant to power would have to grope in the darkness begging for alms which nobody would be able to give, as the supplicant would be invisible. Instead of the most powerful of mortals we would have before us a helpless cripple doomed to a miserable existence. (It is quite likely that Wells deliberately omitted this point. In his science-fiction, he often deliberately obscures the basic defect by plentiful realistic detail. In the preface to an American edition of his novels, he directly says that as soon as the trick has been done, everything else must be made to seem common and lifelike. One must stake, he wrote, not on the power of logic, but on the created illusion.)

In other words, if we desired the cap of invisibility, it would be futile for us to copy Wells. Even a successful result would be a sorry one.

PROTECTIVE PAINT

There is, however, another way of acquiring the cap of invisibility. This is to paint objects so as to render them unnoticeable to the eye. Nature supplies countless instances, it draws extensively on this simple means to protect creatures from enemies and help them in their difficult struggle for existence.

What the military call camouflage, zoologists have been calling mimicry ever since Darwin. Fauna affords thousands of instances, we meet them at every step. Most desert denizens have the characteristic yellow colouring of sand, the lion, for instance, or any bird, lizard, spider or worm. Arctic inhabitants, on the contrary—be it the dangerous polar bear or innocuous bear or innocuous loon—all possess a natural white colour making them inconspicuous against the background of snow. Butterflies and caterpillars living on trees have a colouring that simulates bark with surprising accuracy—the praying mantle, for instance.

Every bug and insect collector knows how hard it is to spot specimens because of natural mimicry. Try to find a green grasshopper chirping away at your feet. You will never make it out against the green background.

The same is true of aquatic creatures. Marine animals living amidst brown seaweed all have a protective brown colouring. Among red seaweeds, the dominant protective colouring is red. The fish's silvery scales also serve to protect it both from birds of prey above and the carnivores of the ocean deep. The surface of water is mirror-like both from above and still more so from beneath—"total reflection"—and the fish's silvery scales well merge with this sparkling metallic background. Meanwhile jelly-fish and other transparent sea denizens such as worms, shellfish, molluscs, and the like, have chosen as

protective colouring the total lack of colour, a transparency that renders them invisible in the colourless and transparent world which they inhabit.

Nature's devices are far superior to anything man has ever invented. Many animals are able to adapt their colouring to the changes of nature. The silvery-white ermine, so unnoticeable against the snow, would be easy prey were it not to change its colour when the snow melts. Every spring this white beast dons a new coat of a russety brown, to merge with the ground now bereft of snow, and goes white again in winter.

CAMOUFLAGE

Nature's ingenuity has supplied a lesson or two in the art of camouflage, the use of blending or deceptive coloration. The dressy uniforms of the past, which made battle scenes so colourful, have been completely superseded by the familiar khaki. The steely grey paint of warships ("battleship grey") is also a protective colouring rendering ships inconspicuous on the seas.

In military camouflage we use branches, bizarre-painted designs, smoke and other deceptive expedients to disguise guns, forts, tanks, and ships. Camps are hidden under special nets with tufts of grass. Fighting men put on masking capes.

Military aircraft are likewise camouflaged by having the top painted brown, a dark-green or violet—to blend with the ground and thus be rendered invisible to spotters from above—and the belly daubed a pale blue, pink, or white—to blend with the sky and thus become unnoticeable to ground observers. At 750 m aircraft thus camouflaged are hardly noticeable while at 3,000 m they become invisible. Night bombers are painted black.

An ideal protection suitable for *any* occasion is a *mirror-like* surface capable of reflecting the environment. Then the object automatically becomes mimetic and it is practically impossible to discern it from a distance. The Germans employed this method to camouflage their Zeppelins in the First World War. Their glistening aluminium body reflected the skies and the clouds, making them extremely difficult to spot, unless betrayed by engine noise.

So has the fairy-tale legend of invisibility been realized in practice in nature and warfare.

UNDERWATER EYE

Assume, for a while, that you were able to stay under water for as long as you liked and could keep your eyes open there. Would you be able to see anything?

You might think that since water is transparent nothing should prevent you from seeing just as well as you do in air.

However, recall the blindness of the "invisible man". He cannot see because the refractive indices of his eyes and the air are the same. Under water we find ourselves in roughly the same conditions as the "invisible man" in the air. A few figures to make things clear. The refractive index of water is 1.34. The refractive

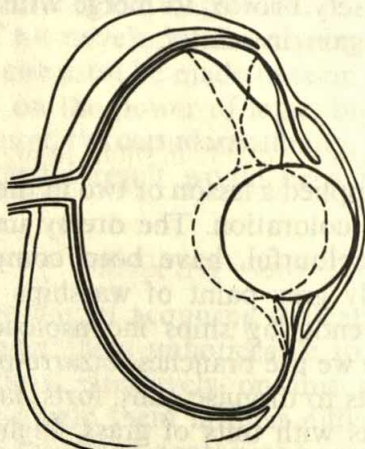


Fig. 227

Cross-section of a fish's eye. The crystalline lens is spherical in shape and it does not change its form during accommodation. Instead, the position changes, as shown by the dotted line

indices for the transparent media of the human eye are: 1.34 for the vitreous humour and cornea; 1.43 for the crystalline lens, and 1.34 for the aqueous humour. As you see the refractivity of the lens is only a tenth greater than that of water, while as far as the other elements of the eye are concerned, the refractive indices are *identical*. That is why under water the rays focus far behind the retina, thus producing an extremely blurred retinal image. Only very short-sighted people can see more or less normally under water.

If you would like to get a clear picture of the way things would appear under water put on a pair of *biconcave* spectacles. These lenses which strongly disperse light will focus all the rays that the eye refracts way beyond the retina, thus producing an extremely blurred image.

But couldn't a person under water use glasses with a big refractive index? Ordinary lenses won't help much, as the refractive index of ordinary glass is 1.5—just a little more than that of water (1.34) and under water their

refractibility will be feeble. One must have special glasses with very great refractivity (so-called heavy flint glass has a refractive index of almost 2). With such glasses you would be able to see more or less distinctly under water (read further about special goggles for divers).

Now you will have realized why a fish's crystalline lens is extremely concave, in fact, spherical; its refractive index is the greatest of all for animal eyes. Were this not so, it would be useless for fish as inhabitants of a greatly refracting transparent environment to have eyes at all.

HOW DO DIVERS SEE?

Many will probably ask: how are divers in their diving suits able to see anything under water, when our eyes hardly refract in the water at all? After all, diving helmets are always equipped with flat, not convex, glasses. Then how could the travellers in Jules Verne's *Nautilus* admire under water scenery through the portholes?

This is easy enough to answer. You must realize that when we dive in without a diving suit and helmet, the water comes into *direct* contact with our eye. In a diving helmet, however (or inside the *Nautilus*) the eye is *separated from the water by a layer of air* (and glass), which essentially changes matters. Emerging from the water and passing through the glass, light first goes through air before it reaches the eye. In conformity with the laws of optics the rays of light from the water that strike the *flat parallel glass* at an angle *do not change their direction* as they go through the glass. But as soon as they pass from the air into the eye, they naturally refract, with the eye performing the same functions as it performs normally. A fine illustration is that we experience no trouble at all in seeing fish in a fish bowl.

LENSES UNDER WATER

Have you ever tried to immerse a magnifying glass in water and look at submerged objects through it? Surprisingly enough in water the magnifying glass hardly magnifies at all. If you were to do the same with a biconcave lens, you would again find that it had lost its powers of diminishing the size of objects. Furthermore, if you were to use not water but a liquid with a refractive index greater than that of glass, a biconvex lens would *diminish* the size of objects, while a biconcave one, on the other hand, would *magnify* them.

You need merely recall the law of the refraction of light to understand why. A magnifying glass magnifies because the lens refracts light to a greater degree

than the surrounding air. However, since the difference between the refractivity of lenses and water is very small, light does not bend much when crossing from the water into the lenses. This is the explanation for the powers of lenses, whether biconvex or biconcave. Monobromo-naphthalene, for instance, has a *greater* refractive index than glass and that is why convex lenses reduce the image in it, while concave ones magnify it. Hollow, or rather air-filled lenses, act

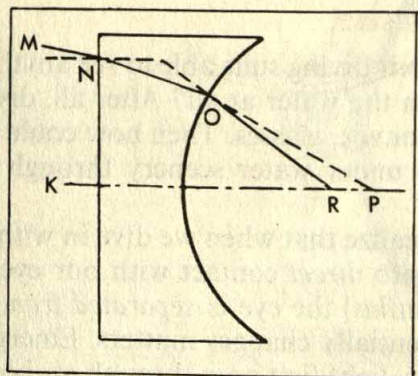


Fig. 228

Divers' goggles are hollow lenses, one side of which is flat and the other concave. As it refracts, the ray *MNOP* swinging away inside the lens from the normal incidence and *veering back* to it (i.e., to *OR*) outside the lens. That is why the lens acts as a collecting glass

Fig. 229

Distorted image of a spoon in a glass of water

similarly under water; concave lenses magnify while convex lenses reduce. Diving goggles are comprized precisely of such air-filled lenses (Fig. 228).

INEXPERIENCED BATHERS

Such people often run great risks merely out of disregard for one noteworthy consequence of the law of refraction. They do not know that refraction seems to elevate everything in the water above its true position. To the eye the bottom of a pond or river seems *raised* by nearly a *third of the depth*. This delusion often

places people in great peril. It is especially important for children and persons of small height to be aware of this, for otherwise a mistake in gauging the depth may prove fatal. The same optical principle of refraction that distorts the image of a spoon in a teaglass (Fig. 229), produces this apparent elevation of the bottom of a pond.

Refraction may be illustrated as follows. Sit your friend at the table so that he

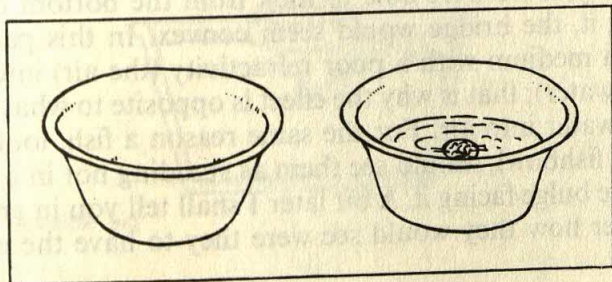


Fig. 230

Coin-in-bowl experiment

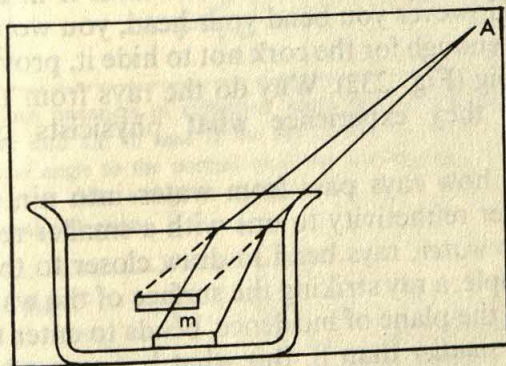


Fig. 231

Why the coin in the experiment illustrated in Fig. 113 seems elevated

cannot see the bottom of a bowl placed in front of him. Place a coin on the bottom of the bowl so that it is hidden from his eye by the side of the bowl. Now ask him not to bend over, and pour some water in the bowl. To his surprise the coin will come completely into view. Remove the water with a syringe and the coin will disappear (Fig. 230).

Figure 231 provides the explanation. To the observer's eye at point A above

the water, coin m seems elevated. The rays are bent and, passing from the water to the air, enter the eye as shown in the figure. The eye thus imagines the coin to be where these lines continue, that is, above its true position. The more the rays are slanted, the higher the coin seems to elevate. That is why, when looking from a boat at the even bottom of a pond, we always think it deepest right beneath us and shallower further off, or, in other words, concave.

On the contrary, if we were able to look from the bottom of a pond at the bridge spanning it, the bridge would seem convex. In this particular case the rays pass from a medium with a poor refractivity (the air) into one with good refractivity (the water); that is why the effect is opposite to what we see when the rays pass from water into air. For the same reason a fish, looking at a row of people outside a fishbowl, should see them as standing not in a straight line but in an arc with the bulge facing it. A bit later I shall tell you in greater detail how fish see, or rather how they would see were they to have the eyes of a human being.

INVISIBLE PIN

Stick a pin into a flat round piece of cork and float it in a bowl with the pin turned downwards. However you bend your head, you won't be able to see the pin, though it is long enough for the cork not to hide it, provided, of course, that the cork is not too big (Fig. 232). Why do the rays from the pin fail to reach your eye? Because they experience what physicists call "total internal reflection".

Figure 233 shows how rays pass from water into air, or, generally, from a medium with greater refractivity to one with a smaller refractivity and back. Passing from *air into water*, rays bend to draw closer to the "perpendicular of incidence"—for example, a ray striking the surface of the water at the angle β to the perpendicular, to the plane of incidence, bends to enter the water already at the angle α which is *smaller* than β . But what happens when the incident ray glides along the water's surface at almost a right angle to the perpendicular? It will enter the water at an angle smaller than a right angle, to wit, 48.5° . It would not enter the water if the angle is bigger than 48.5° , since this angle is "critical" for water. These simple relationships have got to be understood so as to comprehend the absolutely unexpected and extremely curious consequences of the laws of refraction that are discussed below.

We have just learned that rays striking the surface of water at various angles are compressed under the water in a rather compact cone with a spread of $48.5 + 48.5 = 97^\circ$. Let us now see how rays go the other way, *from water into air*

(Fig. 234). According to the laws of optics, the rays will follow the same paths. All the rays confined in the afore-mentioned 97° -cone, will emerge at different angles, spreading out along the entire 180° above-water semicircle.

Where then will an underwater ray, lying outside the afore-mentioned cone, go? *It won't emerge at all, we find, it will reflect from the surface as from a mirror.* Generally speaking, every underwater ray striking the surface at an angle

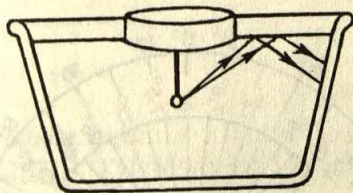


Fig. 232

Invisible pin

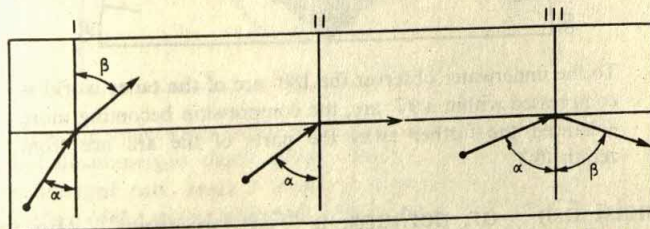


Fig. 233

Various instances of refraction when the ray emerges from water into air. In case *II* the ray strikes the surface at the critical angle to the normal incidence and emerges from the water to slide along its surface. Case *III* is one of total internal reflection

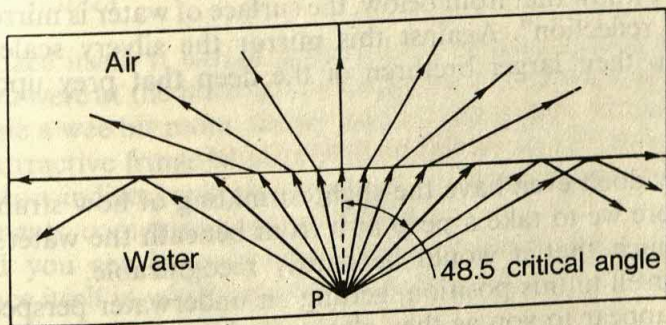


Fig. 234

Rays coming from point P at an angle to the normal incidence greater than the critical angle (48.5° for water) do not emerge from under the water, but are totally reflected inwards

greater than the “critical” – more than 48.5° – will not refract but reflect. As the physicist would say, it undergoes a “total internal reflection”. (The particular reflection is called a *total* one because all incident rays are reflected. Meanwhile even the best of mirrors, for instance, of polished magnesium or silver, reflect only *part* of the incident rays, absorbing the rest. In the circumstances water represents an ideal mirror.)

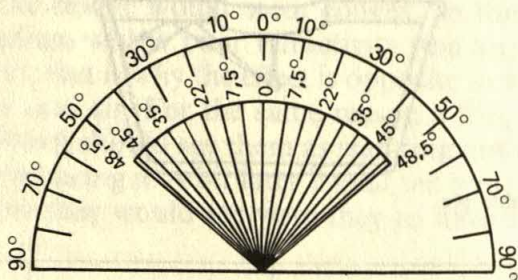


Fig. 235

To the underwater observer the 180° arc of the outer world is compressed within a 97° arc, the compression becoming more enhanced the further away the parts of the arc are from zenith (0°)

For a “physicist fish” – or, perhaps, a “fish-physicist” – the main branch of optics would be the theory of “internal reflection” since it is of prime importance for their underwater vision. Incidentally, the specific features of underwater vision may most likely be associated with the silvery colour of fish scales. Zoologists claim this is due to mimetic adaptation to the water “ceiling” above them. We know that from below, the surface of water is mirror-like due to “total internal reflection”. Against this mirror the silvery scales render fish unnoticeable to their larger brethren of the deep that prey upon them.

UNDERWATER OUTLOOK

I am sure many don’t even have the slightest inkling of how strange the world would seem were we to take a peep at it from beneath the water. It would be distorted so much that it would be hardly recognizable.

Imagine yourself in this position, getting an underwater perspective. Clouds overhead will appear to you as they always do because perpendicular rays do not refract. However, all other objects, the rays from which strike the surface of the water at acute angles, will be distorted. They will seem much shorter, which is accentuated the more, the more acute the angle of incidence is. And no

wonder, since everything spread out in a 180° arc above the water will have to stuff itself into the cramped underwater cone of 97° —nearly half as less—and images are bound to be distorted. All objects from which rays strike the water at the angle of 10° would be so greatly compressed to the view of the underwater observer as to be scarcely distinguishable.

But what would astonish the underwater observer most would be the shape of

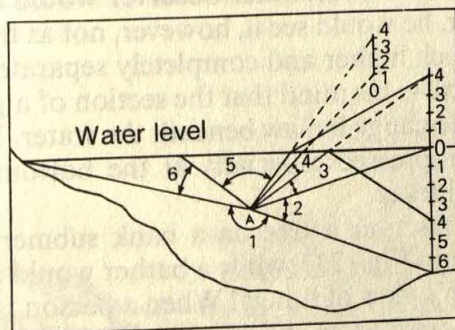


Fig. 236

How the underwater observer with eye at point A would see a half-submerged depth gauge. Angle 2 shows hazily the submerged part; angle 3 shows its reflection from the inner surface of the water; while still higher you see the jutting part of the gauge contracted and furthermore separated from the rest of the rod. Angle 4 gives a reflection of the bottom. Angle 5 gives the whole of the above-water world in the form of a cone. Angle 6 gives a reflection of the bottom from the lower surface of the water. Angle 1 gives a hazy image of the river-bed

the water's surface itself. It would appear to be conical, instead of flat. You would think you were at the bottom of a huge crater with sides inclined to each other at an angle a wee bit more obtuse than a right angle— 97° . At the top you would see an attractive fringe of all colours of the rainbow. This is due to the different refractive indices, and, consequently, "critical" angles of the various colour components comprizing white sunlight.

What would you see beyond this rainbow, haloed fringe? The water's glistening surface itself in which everything *underneath* would be reflected back as in a mirror.

Incidentally anything half in the water, half out, would present a most fantastic sight to the underwater observer.

Suppose you had a depth gauge sticking out of a river (Fig. 236). What would

the underwater observer see at point *A*? Let us divide the observable area of 360° into different sections and discuss each one separately. Within the limits of the angle 1 he would see the river-bed, provided there was enough light. Within the limits of angle 2 he would get an undistorted view of the underwater part of the depth gauge. Roughly within the limits of angle 3, he would see the reflection of this same part of the gauge, only upside down, due to "total internal reflection". A bit higher our underwater observer would see part of the gauge sticking out of the water, he would see it, however, not as the continuation of the underwater part but much higher and completely separated from its lower half. Indeed, it would never cross his mind that the section of a gauge hovering in the air really belonged to the gauge he saw beneath the water. In addition the gauge would seem greatly compressed especially at the bottom, where its divisions would be noticeably thicker.

To our underwater observer a tree on a bank submerged by spring floods should appear as shown in Fig. 237, while a bather would appear as depicted in Fig. 238. Such is the fish's view of things! When a person is wading in a shallow place, fish see him as two separate split personalities: the top one is legless and the bottom one headless but four-legged. The further away he wades from the underwater observer, the more and more does the top of the body seem compressed until, at some distance, only a floating head remains.

Could we ever test this ourselves? By diving in we would see very little, even if we could get ourselves to keep our eyes open. In the first place the water surface would fail to resume its placid state in those few seconds during which we would be able to stay under water, and it is very hard to make anything out on a *rippling* surface. In the second place, as I have already had occasion to note, the refractivity of water is almost the same as that of the transparent elements of our eye and, consequently, our retinal image would be extremely blurred. Nor would observation from inside a diving bell or helmet or through the porthole of a submarine help. Though the observer will be under water, he will not be in the conditions of underwater vision. I explained earlier that before the rays would reach the eye they would have to *pass again through air*, and would undergo reverse refraction—in which case they would either regain their previous direction or veer off at an angle which would not be the same as in the water. That is why observation through the glass portholes of submarines will never provide the correct idea of what underwater vision is really like.

However, there is no need to dive in *ourselves* to get an underwater "outlook". We can simulate it by using a special water-filled photographic camera, having a metal plate with a hole in the middle, in place of the usual lens. Naturally, if all

the space between the aperture and the light-sensitive plate is filled with water, the outer world should appear on the film just as it would to an underwater observer. This, incidentally, was how the American physicist, Professor Wood, took some very curious photographs. We mentioned this picture earlier and also told you why the straight bridge appeared as an arc.

There is one other way of getting an underwater "perspective" at first hand.



Fig. 237

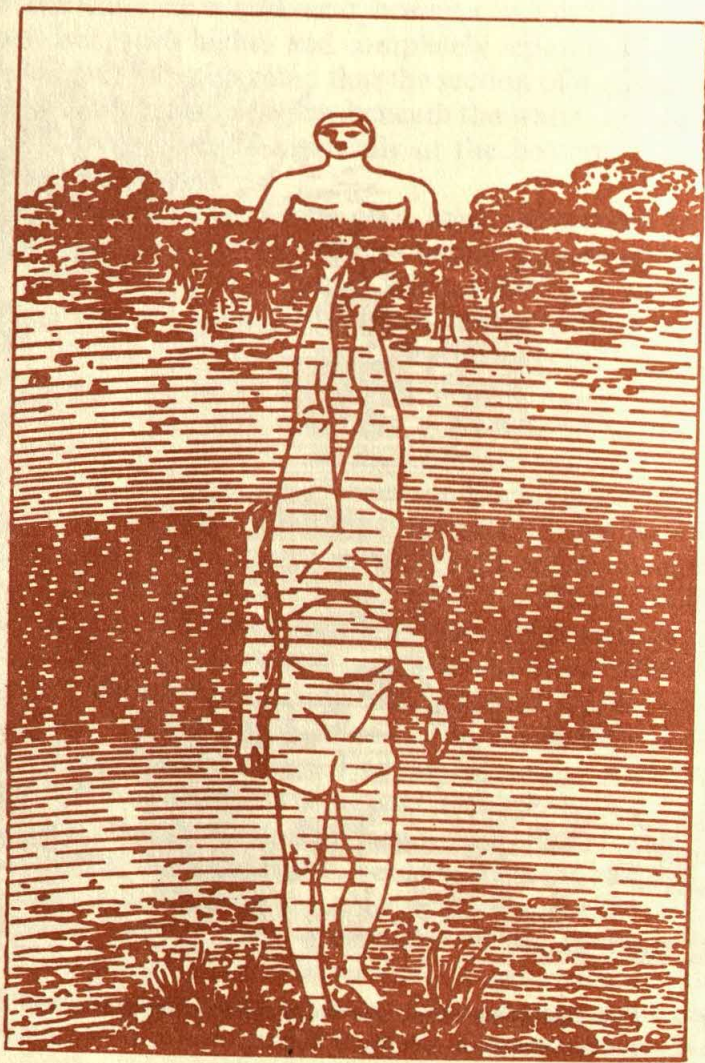
How a partly submerged tree would appear to an underwater observer (compare with Fig. 120)

This is to submerge a mirror in a lake's placid waters and, after tilting it at the required angle, observe in it the reflection of above-water objects. This will corroborate to the last detail the theoretical points we made above.

To sum up. A translucent layer of water distorts to the eye everything that lies

Fig. 238

How a bather up to his chest in the water would appear to an underwater observer (compare with Fig. 120)



beyond, imparting truly fantastic forms and shapes. Any land creature that would suddenly take to living in water, supposing it could do that, would completely fail to recognize its old habitat, as through the transparent water it would present an entirely different sight.

UNDERWATER PALETTE

The American biologist Beebe gives an extremely colourful description of changing tints under water.

"At 9 :41 in the morning we splashed beneath the surface, and often as I have experienced it, the sudden shift from a golden yellow world to a green one was unexpected. After the foam and bubbles passed from the glass, we were bathed in green; our faces, the tanks, the trays, even the blackened walls were tinged. Yet from the deck, we apparently descended into sheer, deep ultramarine. ...

"... the first plunge erases, to the eye, all the comforting, warm rays of the spectrum. The red and the orange are as if they had never been, and soon the yellow is swallowed up in the green. We cherish all these on the surface of the earth and when they are winnowed out at 100 feet or more, although they are only one-sixth of the visible spectrum, yet, in our only one-sixth of the visible spectrum, yet, in our mind, all the rest belongs to chill and night and death.

"The green faded imperceptibly as we went down, and at 200 feet it was impossible to say whether the water was greenish-blue or bluish-green. ...

"At 600 feet the colour appeared to be a dark, luminous blue ... it seemed bright, but was so lacking in actual power that it was useless for reading and writing. ...

"I tried to name the water: blackish-blue, dark grey-blue. It is strange that as the blue goes, it is not replaced by violet—the end of the visible spectrum. That has apparently been absorbed. The last hint of blue tapers into a nameless grey, and this finally into black, but from the present level down, the eye falters, and the mind refuses any articulate colour distinction. The sun is defeated and the colour has gone forever, until a human at last penetrates and flashes a yellow electric ray into what has been jet black for two billion years."

Elsewhere Beebe says the following about the murkiness at great depths:

"A few days ago the water had appeared blacker at 2,500 feet than could be imagined, yet now to this same imagination it seemed to show as blacker than black. It seemed as if all future nights in the upper world must be considered only relative degrees of twilight. I could never again use the word BLACK with any conviction."

BLIND SPOT

If I told you that in your field of vision you have a section you don't see at all, though it's right before your nose, you would probably think I was pulling your leg. Indeed, do we never notice in all our life-time such a signal defect? Here is a simple experiment to show that there really is such a thing.

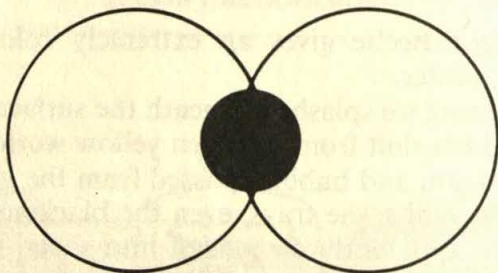


Fig. 239 How to find the blind spot

Hold Fig. 239 some 20 cm away from your right eye, meanwhile cupping your left eye, and look at the cross on the left. Then gradually bring the drawing nearer. At one moment the large black spot at the conjunction of the two circles will vanish without trace. You won't see it, though it will still be within the limits of your field of vision and the *two circles at the right and left will be quite distinct.*

This experiment, which the famous physicist Mariotte first performed somewhat differently in 1668, served to amuse the court of Louis XIV. Mariotte would seat two courtiers two metres apart face to face, and ask them to look with one eye closed at a spot placed somewhat to the side. Each thus saw a headless vis-a-vis.

Strangely enough it was only in the 17th century that man came to know of the blind spot on his retina. This is the area of the retina where the optic nerve enters the eyeball being not yet divided into fine ramifications, and where the retina has no light-sensitive elements.

We never notice this black "hole" in our vision because we have long grown accustomed to it and because our imagination involuntarily makes up for the deficiency. Thus, though we don't see the spot in Fig. 239, we continue the lines mentally and are quite sure that we clearly see their intersection.

Do you wear glasses? Then you might like to try the following experiment. Glue a scrap of paper to one of the lenses – only not quite dead centre. For a few days it will be a nuisance, but after a week or two you will cease to notice it at

all. Incidentally, if you ever happen to crack your glasses and wear them for some time after, you might remember that the crack annoyed you only at the beginning. Habit, and only habit, is again responsible for our being "blind" to our blind spot. Then one must note that the blind spots of the right eye and the left eye correspond to different places in the two fields of vision. Consequently, with two-eyed vision, there is no deficiency in the range they both cover.

Don't think the blind spot is nothing to "write home about". Whenever you look, with one eye closed naturally, at a house, say, some 10 metres away, you fail, on account of the blind spot, to see quite a big portion of its façade of more than a metre across—enough to accommodate a whole window. While if you turned your eye to the heavens you would fail to see a space equal in area to 120 full moons.

HOW BIG WE THINK THE MOON

A few words, by the by, about the moon's visible proportions. Ask your friends how big they think the moon is. You're likely to get a host of different replies. Most will say the moon is as large as a plate, but some might think it the size of a saucer, an apple, or even a cherry. A schoolboy I once knew always thought the moon "as big as a round table covered for twelve" while a certain writer has claimed in a book that the moon is a "yard across".

Why do we differ so much with regard to the size of one and the same thing? Because we *estimate distances* differently and moreover subconsciously. A person who takes the moon to be as large as an apple, imagines it to be much nearer than people who think it the size of a plate or round table.

I noticed before that most think the moon as large as a plate and thereby hangs a tale. If we compute the distance—later I shall tell you how this is done—at which we put the moon with such *apparent* dimensions, we shall find that our distance is not more than 30 metres! (See Minaert's *Light and Colour in Nature* for greater detail about this and other allied matters.) Such is the very modest distance to which we subconsciously remove our nocturnal luminary.

Incidentally, quite a few optical illusions are based on the erroneous estimation of distance. I well remember one to which I succumbed when I was a boy. One spring I went out of town on an outing for the first time in my life. I saw a herd of cows browsing in the meadow. They appeared as pygmies to me; I had misestimated the distance. I have never seen such tiny cows ever since and, naturally, never will. (Adults also succumb to this illusion—as borne out by the following extract from the story "Ploughman" by the 19th-century Russian writer Grigorovich: "The country seemed to fit in the hollow of one's hand. The

trees seemed fast by the bridge; while the cottage, hill and birch thicket now seemed adjacent to the village. Everything—house and orchard and village—resembled playthings, with stalks for trees and the slivers of a mirror for a river.”)

Astronomers define the apparent dimensions of celestial bodies by taking the angle at which they are seen. The “angle of vision” is the angle between two

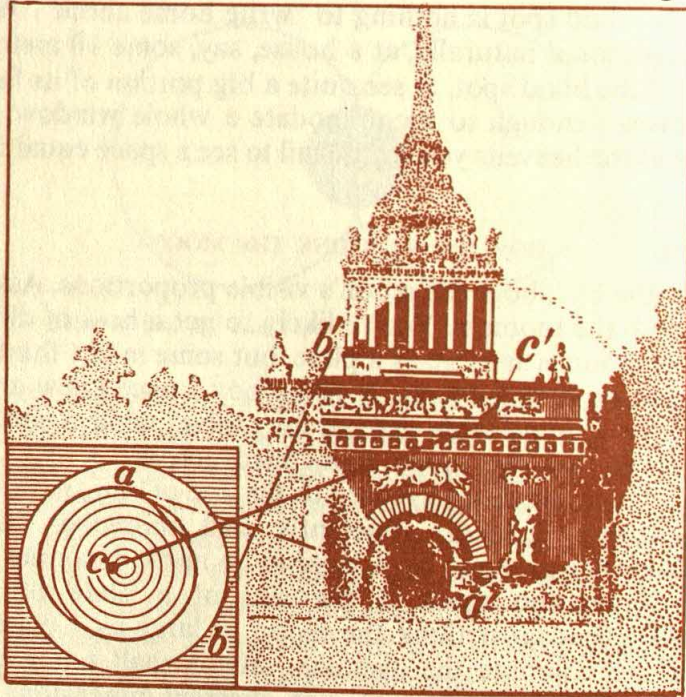


Fig. 240

When looking at the building with one eye, the small section c' of the field of vision, corresponding to the blind spot c of the eye, is not seen at all

straight lines traced to the eye from the extremes of the observed object (Fig. 241). As you all very well know, angles are measured in degrees, minutes, and seconds. When asked about the moon's apparent dimensions, the astronomer won't say that it is as large as an apple or plate. He will say “half a degree”, which means that there is an angle of half a degree between the straight lines from either limb of the lunar disc to our eye. This definition of apparent dimensions is the only correct one as it does not produce misunderstanding.

Geometry teaches us that an object, set away from the eye at a distance 57 times greater than its diameter, is observed at an angle of 1° . For instance, an apple five centimetres in diameter will have an angular value of 1° if held at a distance of 5×57 cm away. At twice that distance it would appear at an angle of half a degree or as large as we see the moon. You can even say that the moon seems to be as large as an apple, provided the latter is 570 cm away.

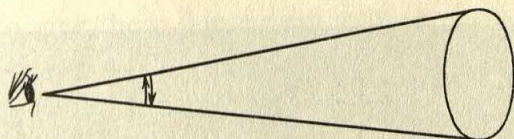


Fig. 241 Angle of vision

Should you want to compare the moon's apparent dimensions to a plate, you will have to move the plate some 30 metres away. Most are loth to believe that the moon seems so small. Well, place a six-penny bit at a distance 114 times greater than its diameter. Though this will be but two metres, it will cover the moon.

If I told you to draw a circle for the lunar disc as seen by the naked eye, you would most likely think the task not concrete enough, as your circle could be big or small, depending on how far it was from the eye. Let us then choose the distance at which we usually hold a book or drawing, that is, the distance of optimal vision, which for the normal eye is 25 cm. Let us see how big a circle, on a page of this book, for example, should be, for its apparent size to equal the moon's disc. The problem is simple enough; all we need do is divide the 25-cm distance by 114. Our result will be tiny, a wee bit more than 2 mm—about the same size as the letter “o” in this book. It's really hard to believe that the moon as well as the sun, which is of equivalent apparent dimensions, seem so small at such a small angle.

You have probably noticed that after you look at the sun for a while, you seem to see for quite a time a jumble of coloured discs. These so-called “optical traces” have the same angular value as the sun but their apparent dimensions change. When you look at the sky, they are as large as the sun itself, but as soon as you look down at the book, the sun's “trace” on the page will occupy a space of no more than the letter “o”, which graphically demonstrates the correctness of our calculations.

APPARENT DIMENSIONS OF CELESTIAL BODIES

If we were to draw, keeping to angular dimensions, the constellation of Ursa Major, the Dipper, we would get the figure depicted in Fig. 242. Looking at it from the distance of optimal vision we would see it as it appears to us in the sky. This, so to speak, would be a map of the constellation with angular dimensions

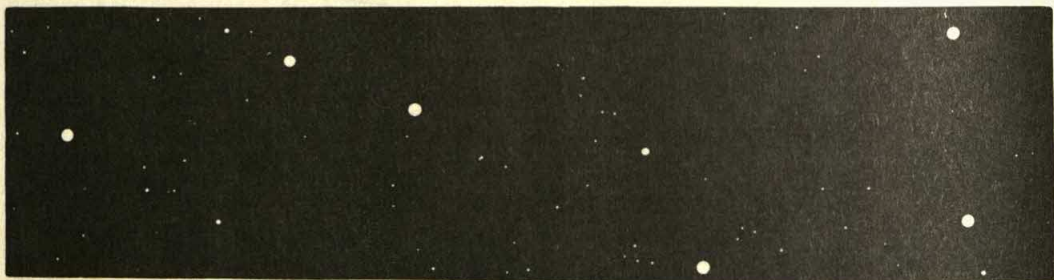


Fig. 242

Dipper constellation with angular dimensions preserved. This figure should be held 25 cm away from the eye

preserved. If you are familiar with the visual impression this constellation produces, that is, not only its *pattern*, but namely the direct *visual impression*, you will get this same impression when looking at the drawing appended. Knowing the angular distance between the main stars of all the constellations (they are given in astronomical calendars and ephemerides) you will be able to give "full-size" drawings for a whole astronomical atlas. To do this you must have some millimetre lined paper and reckon each 4.5 mm as one degree (the areas of the circles representing the stars should be given in proportion to their brilliance).

Let us now turn to the planets. Their apparent dimensions—as of the stars—are so tiny that to unaided vision they seem radiant points of light. No wonder, because no planet, with the exception, perhaps, of Venus during the period of its greatest brilliance, ever appears to the naked eye at an angle of more than $1'$, which is the critical value at which we will be able generally to distinguish an object as a dimensional body (at a smaller angle every object seems just a point).

Here is a table of the dimensions in angular seconds of the different planets; the two figures opposite each planet denote respectively the distances when the planet is closest to, and furthest from, the earth.

<i>Planet</i>	<i>Seconds</i>
Mercury	13-5
Venus	64-10
Mars	25-3.5
Jupiter	50-31
Saturn	20-15
Saturn's rings	48-35

It is impossible to give these dimensions in their "full size". Even a whole angular minute of 60° corresponds, at the distance of optimal vision, to but 0.04 mm, which is too small for the normal eye to see. We shall therefore depict the planetary discs as seen through a telescope with a magnifying power of 100. Figure 243 gives the apparent dimensions of the planets thus magnified. The lower arc is the rim of the moon's or sun's disc as seen through a 100-power telescope. Right above it is Mercury when closest to the earth. Still higher are the different phases of Venus. At its most favourable opposition it is not seen at all as it turns its unlit face towards the earth. (It is seen in this phase only during those extremely rare periods when projected on to the sun's disc as a black circle—the so-called "passage of Venus".) Then comes its visible slender crescent which is biggest of all planetary "discs". In subsequent phases Venus grows smaller and smaller till it becomes a full disc with a diameter only a sixth of that of the crescent.

On top of Venus is Mars, shown on the left as when closest to the earth and on the right as when furthest away. The left-hand disc, let me remind you, is what Mars looks like in a telescope with a magnifying power of 100. Do you think anything could be made out on so small a disc? Imagine it 10 times bigger and you will have some idea of what an astronomer sees when he studies Mars in a very powerful telescope with a magnifying power of 1,000. Again, I ask you, do you think it possible to make out with unquestionable clarity on so small an object such details as the notorious canals or to detect the slight variations in coloration supposedly due to vegetation on the bed of the "seas" of this strange world? No wonder some observers essentially contradict what others seem to see. Some regard as an optical illusion what others claim to discern quite distinctly.*

The giant planet of Jupiter and its satellites occupy an extremely prominent

* Present available information on Mars and other planets is not limited exclusively to data obtained by visual observation alone. Thanks to measurements performed by means of sensitive instruments, we have been able to draw some quite definite and veracious conclusions as to the physical conditions on the planets and their satellites.—Ed.

place in our table. This planet's disc is much greater than those of all the other planets, with the exception of Venus' crescent, while its four main satellites are spread out along a line equal to nearly half the moon's disc.

In the figure Jupiter is shown as when closest to the earth. Finally comes Saturn with its rings and its biggest moon Titan, which are also rather noticeable in most favourable opposition.

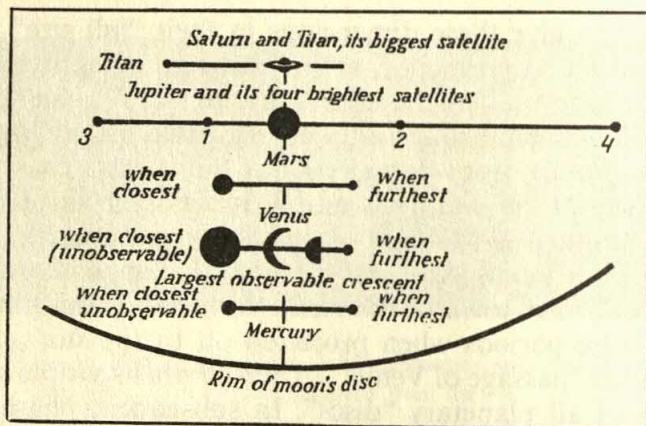


Fig. 243

Hold this diagram 25 cm away from the eye and you will see the planet discs as seen in a telescope with a magnifying power of 100

After all I have said, it should be clear to you that every visible object appears to be the smaller the closer we imagine it. Conversely, if, for some reason, we would exaggerate the distance to the object, the object itself would become correspondingly larger. Let me now regale you with an instructive story by Edgar Allan Poe describing precisely one such optical illusion. Though it seems scarcely true it is not at all a figment of the imagination. I myself succumbed once to practically the same type of illusion and many of you may recall a similar experience.

THE SPHINX

By Edgar Allan Poe

(The story is given with a few minor cuts)

"During the dead reign of cholera in New York, I had accepted the invitation of a relative to spend a fortnight with him in the retirement of his *Cottage ornée*. ... We should have passed the time pleasantly enough, but for the fearful

intelligence which reached us every morning from the populous city. Not a day elapsed which did not bring us news of the decease of some acquaintance. At length we trembled at the approach of every messenger. The very air from the South seemed to us redolent with death. That palsyng thought, indeed, took entire possession of my soul. ... My host was of a less excitable temperament, and, although greatly depressed in spirit, exerted himself to sustain my own. ...

"Near the close of an exceedingly warm day, I was sitting, book in hand, at an open window, commanding through a long vista of the river banks a view of a distant hill. ... My thoughts had been long wandering from the volume before me to the gloom and desolation of the neighbouring city. Uplifting my eyes from the page, they fell upon the naked face of the hill and upon an object—upon some living monster of hideous conformation, which very rapidly made its way from the summit to the bottom, disappearing finally in the dense forest below. As this creature first came in sight, I doubted my own sanity—or at least the evidence of my own eyes—and many minutes passed before I succeeded in convincing myself that I was neither mad nor in a dream. Yet when I describe the monster (which I distinctly saw, and calmly surveyed through the whole period of its progress), my readers, I fear, will feel more difficulty in being convinced of these points than even I did myself.

"Estimating the size of the creature by comparison with the diameter of the large trees near which it passed ... I concluded it to be far larger than any ship of the line in existence. I say ship of the line, because the shape of the monster suggested the idea—the hull of one of our seventy-fours might convey a very tolerable conception of the general outline. The mouth of the animal was situated at the extremity of a proboscis some sixty or seventy feet in length, and about as thick as the body of an ordinary elephant. Near the root of this trunk was an immense quantity of black shaggy hair ... and projecting from this hair downwardly and laterally, sprang two gleaming tusks not unlike those of the wild boar, but of infinitely greater dimension. Extending forward, parallel with the proboscis, and on each side of it, was a gigantic staff, thirty or forty feet in length, formed seemingly of pure crystal, and in shape of a perfect prism—it reflected in the most gorgeous manner the rays of the declining sun. The trunk was fashioned like a wedge with the apex to the earth. From it there were outspread two pairs of wings—each wing nearly one hundred yards in length—one pair being placed above the other, and all thickly covered with metal scales; each scale apparently some ten or twelve feet in diameter. ... But the chief peculiarity of this horrible thing was the representation of a *Death's Head*, which covered nearly the whole surface of its breast, and which was as

accurately traced in glaring white, upon the dark ground of the body, as if it had been there carefully designed by an artist. While I regarded this terrific animal, and more especially the appearance on its breast, with a feeling of horror and awe ... I perceived the huge jaws at the extremity of the proboscis suddenly expand themselves, and from them there proceeded a sound so loud and so expressive of woe, that it struck upon my nerves like a knell, and as the monster disappeared at the foot of the hill, I fell at once, fainting, to the floor.

"Upon recovering, my first impulse, of course, was to inform my friend of what I had seen and heard.... He heard me to the end—at first laughed heartily—and then lapsed into an excessively grave demeanour, as if my insanity was a thing beyond suspicion. At this instant I again had a distinct view of the monster—to which, with a shout of absolute terror, I now directed his attention. He looked eagerly—but maintained that he saw nothing—although I designated minutely the course of the creature, as it made its way down the naked face of the hill.... I threw myself passionately back in my chair, and for some moments buried my face in my hands. When I uncovered my eyes, the apparition was no longer visible.

"My host ... questioned me very vigorously in respect to the conformation of the visionary creature. When I had fully satisfied him on this head, he sighed deeply, as if relieved of some intolerable burden.... stepped to a book-case, and brought forth one of the ordinary synopses of Natural History. Requesting me then to exchange seats with him, that he might the better distinguish the fine print of the volume, he took my arm-chair at the window, and opening the book, resumed his discourse very much in the same tone as before.

"'But for your exceeding minuteness,' he said, 'in describing the monster, I might never have had it in my power to demonstrate to you what it was. In the first place, let me read to you a schoolboy account of the genus *Sphinx*, of the family *Crepuscularia*, of the order *Lapidoptera*, of the class of *Insecta*—or insects. The account runs thus:

"'Four membranous wings covered with little coloured scales of metallic appearance; mouth forming a rolled proboscis, produced by an elongation of the jaws, upon the sides of which are found the rudiments of manibles and downy palpi; the inferior wings retained to the superior by a stiff hair, antennae in the form of an elongated club, prismatic; abdomen pointed. The Death's-headed Sphinx has occasioned much terror among the vulgar, at times, by the melancholy kind of cry which it utters, and the insignia of death which it wears upon its corslet.'

"He here closed the book and leaned forward in the chair, placing himself

accurately in the position which I occupied at the moment of beholding the monster.

“‘Ah, here it is,’ he presently exclaimed – ‘it is reascending the face of the hill, and a very remarkable looking creature I admit it to be. Still, it is by no means so large or so distant as you imagined it; for the fact is ... it wriggles its way up this thread, which some spider has wrought along the window-sash....’” (This butterfly has now been classified as a member of the *Acherontia* family. It is one of the few butterflies able to emit sounds – in this case a whistle resembling the squeaking of a mouse – and the only butterfly to do so with its oral organs. The sound is rather shrill and can be heard many metres away. In this particular case, it may have seemed very loud, as the observer had thought its source to be rather far away, see Chapter Ten “The Tricks Our Ears Play”).

WHY DOES A MICROSCOPE MAGNIFY?

“Because it alters the direction of the rays in a definite way as is described in textbooks on physics,” is the reply one hears most often. This however is but a remote reason having no relation to the real cause. So what really causes the microscope and telescope to magnify?

I learned the answer accidentally, when a schoolboy, and moreover not from any textbook. I happened to notice an extremely curious and perplexing thing. I was sitting near a closed window looking at the brick wall of a house across the road. Suddenly I recoiled in horror. I could clearly see a huge eye several metres wide staring at me from the wall. I hadn’t read Edgar Allan Poe’s story then and did not realize at once that this huge eye was a reflection of my own eye, a reflection I had projected on this wall and had therefore imagined as correspondingly enlarged.

When I finally realized what had happened, I started wondering whether a microscope based on the same optical illusion couldn’t be made. My efforts were abortive, but one good thing ensued – I realized why a microscope magnifies. This is not at all because the object viewed appears to be larger, but because it is viewed at a *much wider angle of vision*, with the result, and this is the most important thing, *that its image occupies a far greater retinal area*.

To help you understand why the angle of vision is so essential, let me refer to a significant feature of our eye. Every object or part of an object, that we observe at an angle of less than one minute, appears to the normal eye as a *point* with no distinguishable shape or elements. When an object is far away or so small that the whole of it, or parts of it, are observed at an angle of vision less than one

minute, we cease to make out its details. This is because at this angle of vision the retinal image of the object or its element covers only one visual cell, with the result that we see a *point* and nothing more.

The microscope and telescope alter the direction the rays from the object under observation take, and thus present it at a greater angle of vision. The retinal image is stretched out to cover more visual cells and we are thus able to

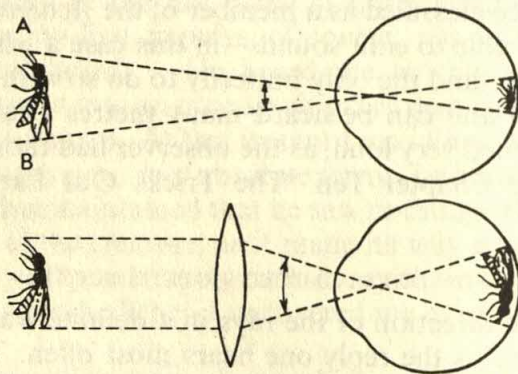


Fig. 244

The lens increases the retinal image

distinguish details which had previously merged into one dot. When people say that a microscope or telescope has a magnifying power of 100, they mean that it presents objects at an angle of vision 100 times greater than the angle at which we would see them without the instrument. If an optical instrument does not increase the angle of vision, *it will not magnify at all, even if we think we are seeing a magnified object.* The eye on the brick wall seemed tremendous, but I did not see *any new detail* in addition to what I saw when looking in a mirror. When low on the horizon, the moon seems much *larger* than high up in heavens; but we fail to detect on this enlarged disc anything new which we didn't notice when our nocturnal luminary was high in the sky.

Taking the case of magnification Edgar Allan Poe describes, we shall again see that no new details were observed in the magnified object. The angle of vision remains constant, and the butterfly is observed at one and the same angle whether removed further away or brought up close to the window. Since the angle of vision does not change, the enlarged object, however staggering, doesn't reveal a single new detail. A faithful realist Edgar Allan Poe remains loyal to nature even on this point. I wonder if you noticed how he describes the "monster" in the wood. The list of the insect's different members does not add

anything new to what this "dead head" had when seen with the unaided eye. Compare the two descriptions – given not without reason – and you will see that they differ only in the metaphors used (ten-foot scales – little scales, giant tusks, stiff hair, etc); there are no new details.

If this were the only way a microscope magnified, scientists would find it useless; it would be nothing more than a curious plaything. However we know this not to be so; we know that the microscope opened up a new world, extending the boundaries of our natural vision.

Now we can explain why the microscope gives us details which Edgar Allan Poe's observer failed to see in his monster butterfly. The microscope gives not just an enlarged image and nothing more; it presents the object *at a greater angle of vision*. Hence the retinal image is *larger*, covering a bigger number of visual cells and thus supplying a bigger number of individual visual impressions. In short, the microscope magnifies not the object but its retinal image.

VISUAL SELF-DECEPTION

We often use the term "optical illusion" or "auditory illusion". However there can be no deception of the *senses*. The philosopher Kant aptly noted in this connection: "The senses do not deceive us. Not because they always rightly pass judgement, but because they don't pass judgement at all."

What then deceives us? Naturally, what passes *judgement* in this case – our brain. Indeed, most optical illusions derive not only from what we *see* but from what we subconsciously still *think* we see; we involuntarily deceive ourselves. This is a deception produced by what we *think* we see or hear, not by what the senses actually register.

Some two thousand years ago Lucretius wrote:

"Our eyes are unable to take cognition of the nature of objects, so do not impose upon them delusions of the mind."

Let us take a commonly known case of an optical illusion. The picture on the left in Fig. 245 seems narrower than that on the right, though both are limited by identical squares. This is because in estimating the *height* of the picture on the left we subconsciously add the gaps between the lines. Therefore it seems to be higher, though actually both are the same. For the same reason the figure on the right seems to have more width than height, and again for the same reason. Fig. 246 seems to have more height than width.

ILLUSIONS USEFUL FOR TAILORS

When you try to apply the optical illusion just described to bigger figures which the eye is unable to take in at one glance, your expectations fail to materialize. You all know that a small fat man in a pin-striped suit in which the stripes are horizontal, seems still fatter. On the contrary, by donning a pin-striped suit in

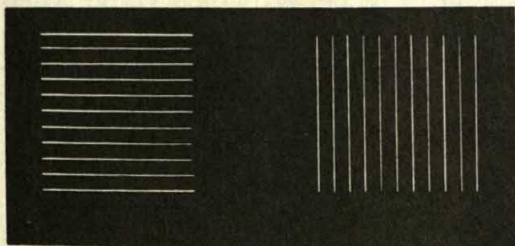
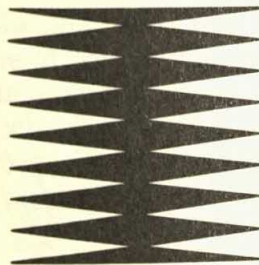


Fig. 245

Which is wider, the right-hand figure or the left-hand one?

Fig. 246

Which is larger, height or width?



which the stripes are vertical, a fat man can make himself appear a bit slimmer.

Why the contradiction? Because we are unable to take in the entire suit at one glance, without moving the eye; as we do that, we involuntarily let our eye travel down the stripes. The effort our eye muscles make in this process compels us subconsciously to magnify the object in the direction the stripes go, as we are accustomed to associating this exertion with notions of larger objects that do not lie completely within the field of vision. On the other hand, when we look at a *small* striped drawing, our eye doesn't move and the muscle does not have to exert itself.

WHICH IS BIGGER?

Which ellipse in Fig. 247 is bigger—the one at the bottom or the inner one on top? The bottom one really seems bigger than that at the top, doesn't it? Actually both are identical. It is only because of the outer fringing ellipse that we get the illusion that the inside ellipse is smaller than the bottom one. This illusion is enhanced furthermore by the entire figure appearing to be not flat but three-dimensional, and shaped as a pail. We involuntarily mentally redraw

ellipses as circles compressed into perspective and the straight side lines as slanting ones standing for the sides of the pail.

In Figure 248 the distance between points *a* and *b* seems bigger than that between points *m* and *n*. The presence of a third straight line, commencing from the same apex, enhances the illusion.

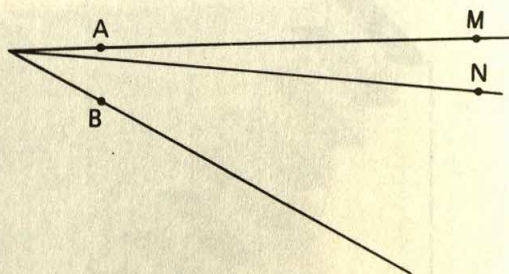
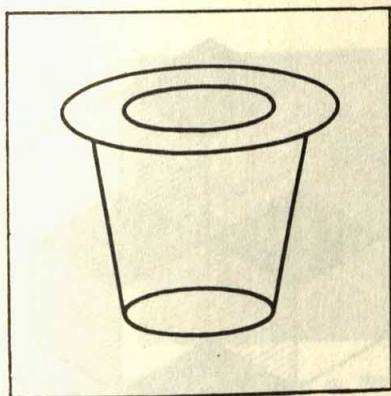


Fig. 247

Which ellipse is bigger, the bottom one or the top inner one?

Fig. 248

Which distance is longer, *ab* or *mn*?

THE POWER OF IMAGINATION

As I have already noticed, most optical illusions depend not only on what we see but also on what we *imagine* we see. "We look with our brain and not with our eyes," physiologists say. You will surely agree with this after an acquaintance with several illusions in which imagination plays a *conscious* role in the process of vision.

Look at Fig. 249. If you were to show it to your friends, you might get three different answers as to what it represents. One might say it is a staircase, another, that it is a niche in a wall, and a third, that it is a strip of paper creased like a concertina and stretched across a white square.

Oddly enough all three answers are right. You yourself will get all three illusions, provided you look at it differently. First, cast your glance at the *left* half of the drawing—you will see a staircase. Then let your eye travel across the drawing from right to left—you will see a niche. Finally, if you let your eye travel slantwise, diagonally from the bottom right-hand corner to the top left-hand corner, you will see a strip of paper creased like a concertina. Incidentally, when

you look too long, your attention will stray and you will get alternately the first, second or third illusion, regardless of what you would really want to see.

Figure 250 presents a similar case.

The illusion Fig. 251 produces is most curious. We involuntarily succumb to the impression that the distance AC is shorter than AB , though actually they are the same.

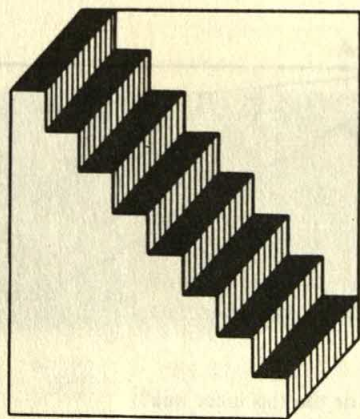


Fig. 249

What is this, a staircase, a niche, or a strip of paper creased like a concertina?

Fig. 250

How are the cubes disposed here? Where do you see two cubes side by side, on top or at the bottom?

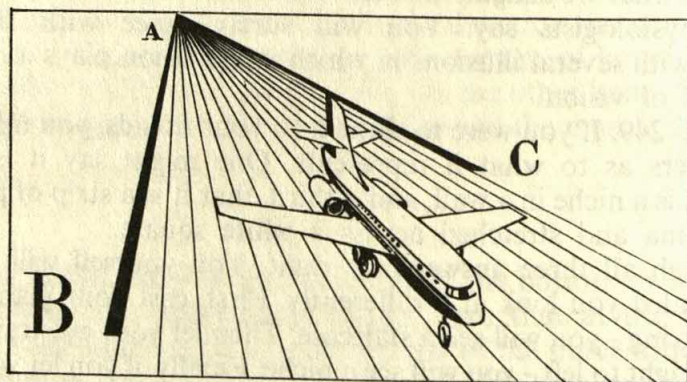
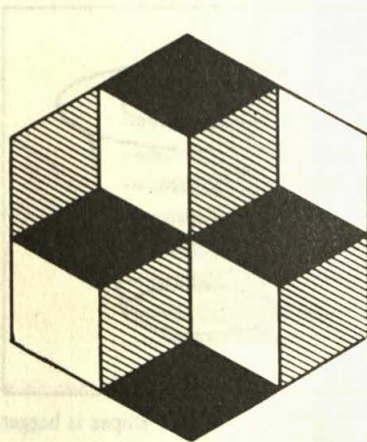


Fig. 251

What is longer, AB or AC ?

MORE OPTICAL ILLUSIONS

We are unable to explain all the optical illusions. We often cannot guess what subconscious conclusions our brain makes to cause one or another optical illusion. Figure 252 distinctly shows two arcs, their bulges facing each other. You hardly believe it, when, by putting a ruler to these "arcs" or looking at them

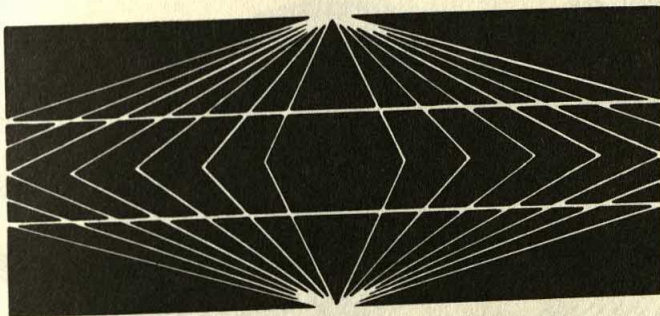


Fig. 252

The two lines in the middle going from right to left are straight parallel lines, though they seem to be arcs with facing bulges. The illusion vanishes when (1) you raise the figure to eye level and look along the lines, or when (2) you place a pencil tip at any point in the figure and concentrate on this point

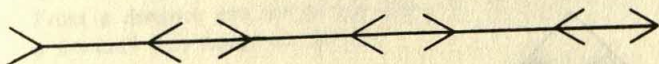


Fig. 253

Is this straight line divided into six equal parts?

lengthwise with the figure at eye level, you find that they are straight. Why the illusion? That is not so easy to explain.

Some more instances of similar illusions. In Figure 253 the straight line seems divided into unequal portions. Measure them and you find they are equal. In Figures 254 and 255 the straight parallel lines seem bent. In Figure 256 the circle seems oval.

It is curious to note that the optical illusions provided in Figs. 253, 254 and 255 cease to deceive if looked at by the light of an electric spark. The illusions are evidently associated with a movement of the eye, which is too slow for the spark's instantaneous flash.

One more highly entertaining illusion known as "the pipe". Look at Fig. 257 and tell me which of the lines are longer, those on the left or those on the right?

The left lines seem longer though actually both are the same (this drawing, incidentally, illustrates the well-known geometrical principle of Cavalieri stating that the areas of the two parts of the "pipe" are equal). Many reasons have been suggested to explain these curious illusions, but they are not very convincing and I shan't bother to adduce them. However, one thing is plain, the illusions derive from the subconscious mind which prevents us from seeing what we really should see.

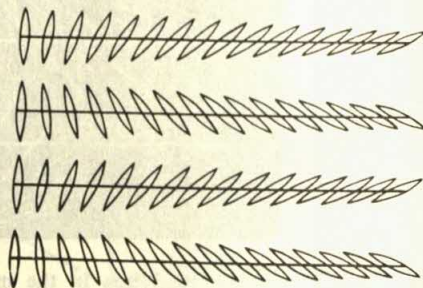
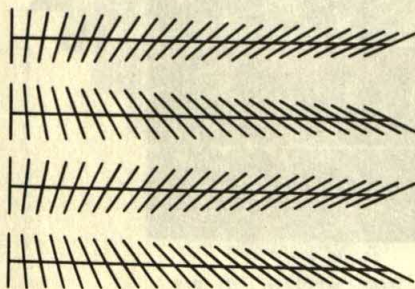


Fig. 254

The parallel lines in this figure don't seem to be parallel

Fig. 255

An illusion similar to the previous figure

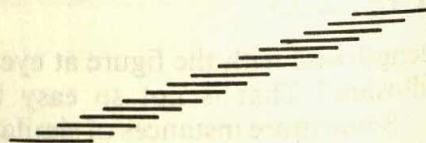
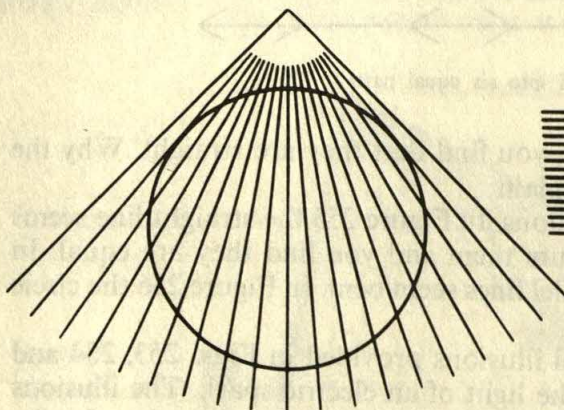


Fig. 256

Is this a circle?

Fig. 257

The pipe illusion. The strokes on the right seem shorter than those on the left, though actually they are identical

WHAT IS THIS?

I doubt whether you would guess at once what Fig. 258 depicts. You would probably dismiss it as a circular piece of black mesh. However, stand the book upright on the table, take some three or four steps back and look again. You see a human eye. Immediately you draw up nearer, you again see nothing but the

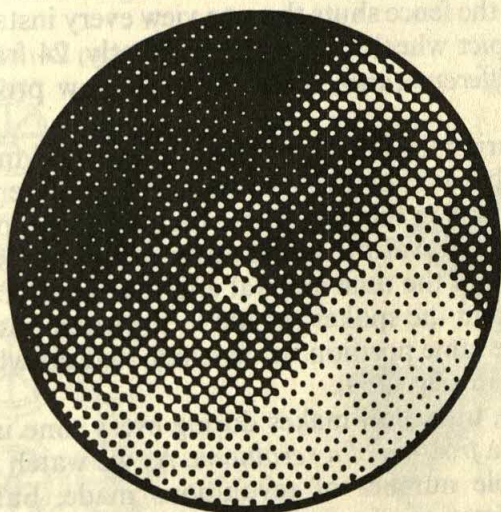


Fig. 258

From a distance you see an eye and part of the nose of a woman's face turned to the left

mesh. You might think it an artful trick by an ingenious engraver. No, this is but a crude instance of the optical illusion we succumb to every time we look at half-tone reproductions. Book and magazine reproductions always seem to present a solid background, but when you peer at them through a magnifying glass you see a similar pattern of dots as shown in Fig. 258. The brain-teaser is part of an ordinary book illustration magnified ten times over. When the gauze is fine it fuses into one solid background already close up, at the distance we usually hold a book when reading. But when the gauze is coarse, it will blend into one solid background only at a much greater distance away. You need only remember all that I said about the angle of vision to realize why this is so.

UNUSUAL WHEELS

Have you ever watched through a crack in a fence or, still better, on the movie screen the wheel spokes of a quickly moving cart or motor-car? You've most

likely noticed a strange circumstance: the motor-car rolls along, but its wheels hardly move, if at all. Sometimes you see them spinning in an opposite direction. This optical illusion is so unusual that it perplexes all who see it for the first time.

Here is the explanation. When watching a spinning wheel through a crack in a fence, we see its spokes not continuously but in a series of regular identical time intervals—since the fence shuts them to view every instant. In the same way a movie film will depict wheel images intermittently, 24 frames a second. This gives rise to *three different cases*, which we shall now proceed to discuss one after the other.

In the first case, during the first time interval, the wheel makes any number of *full revolutions*, whether two or twenty it makes no difference. In this case, the wheel spokes will assume in the next frame the same position as in the previous one. In the next time interval the wheel again makes the same number of *full revolutions* (the length of the time interval and the speed of the motor-car have remained constant), and the spokes remain in the same position. As we see the spokes in one and the same position we conclude that the wheel is not turning at all (middle column in Fig. 259).

In the second case, the wheel makes during every time interval a number of full revolutions plus a *fraction of a revolution*. As we watch the series of images we see not the whole number of revolutions made, but merely a gradual turning—by a small fraction of a revolution each time. As a result we conclude that the wheel is turning slowly, though the motor-car itself may be moving very quickly.

In the third case, the wheel makes an incomplete revolution during the time interval between two frames—just a small fraction less than a complete revolution (315° , for instance, as shown in the third column in Fig. 259). In this case the wheel spoke appears to be turning in the *opposite direction*—an illusion which lasts until the wheel goes faster or slower.

There remains but little to be added. In the first case, for the sake of simplicity, we gave a number of full revolutions; however, since wheel spokes look all alike, it is quite enough for the wheel to turn a whole number of *segments*, between the spokes. The same holds for the other two cases as well.

Then there are, furthermore, the following interesting points. If the wheel rim is marked at some point, we may see the rim moving in one direction and the spokes, which are all alike, in the opposite direction. Should a spoke be marked, we may see the spokes moving in a direction contrary to the mark which will seem to be skipping from spoke to spoke.

When you happen to be watching a feature film or a newsreel, this illusion does not annoy you. But if the film-maker seeks to explain a machine's principle of operation, this optical illusion may lead to serious misunderstandings and even provide a totally distorted picture of how the machine really works.

The attentive movie-goer will easily be able to figure out how many revolutions a wheel is making a second, by counting its spokes. The usual speed

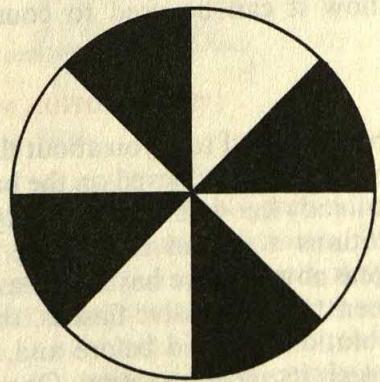
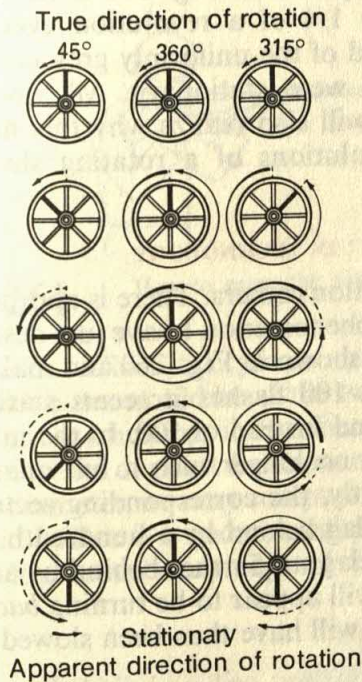


Fig. 259

Clue to the mysterious movement of wheels on a movie screen

Fig. 260

The disc used to determine the speed with which an engine revolves

of film projection is 24 frames a second. In the case of a twelve-spoke wheel, the number of revolutions per second will be equal to $24 \div 12 = 2$, or one whole revolution every half-second. This is the least number of revolutions; it may be greater by any whole number of times – twice as much, three times as much, and so on. By estimating the wheel's diameter we may even try to guess how fast the

motor-car is moving. For a wheel diameter of 80 cm, in the case just described, the motor-car's speed would average 18 km/h—or 36, 54, etc. km/h.

Engineers avail themselves of this optical illusion to count the number of revolutions of quickly rotating shafts. This is how they do it. The luminous power of a bulb consuming a-c current does not stay constant. Every one-hundredth of a second the light dims, though usually we don't see the twinkle. However, imagine that the revolving disc depicted in Fig. 260 is lit by such a bulb. Supposing the disc were to make $1/4$ of a revolution every one-hundredth of a second, we would see, instead of the uniformly grey circle, the black and white segments, as if the disc were stationary. All who have understood the causes of the wheel illusion will also realize why this happens and how it can be used to count the revolutions of a rotating shaft.

"SLOW-MOTION MICROSCOPE" IN TECHNOLOGY

In Chapter One I told you about the slow-motion camera. There is another way this effect can be achieved on the basis of the phenomenon I have just described. You already know that when the type of disc shown in Fig. 260 and making 25 revolutions a second is lit every second by 100 flashes it seems stationary. Imagine now that we have 101 flashes a second instead of 100. In the intervals between two successive flashes, the disc will no longer turn a full quarter of a revolution as it did before and, consequently, the corresponding sector will not reach its initial position. One will see it lag behind by a hundredth of the circumference. In the next flash it will seem to lag still further behind by another hundredth and so on and so forth. The disc will appear to be turning *backward* making one full revolution a second. Motion will have thus been slowed down 25 times.

It is not so hard to guess how one could see the same sort of slow-motion rotation, but going forward and not backward. To do that we must *reduce*, instead of increase, the number of flashes. For instance, with 99 flashes a second, the disc would seem to be going forward, making one revolution a second.

This is what we could call a "slow-motion microscope" with a time-delaying power of 25. We could slow down motion still more. If, for example, we had 999 flashes every 10 seconds or 99.9 per second, our disc would seem to be making one revolution every ten seconds, and we would have achieved a time-delaying power of 250.

Any fast, periodically recurring, motion can thus be slowed down to the

required degree. This provides a handy method for studying the specific features of the motion of very fast mechanisms*.

In conclusion, I shall describe a method employed to measure the speed of a bullet in flight. It is based on the possibility of determining the exact number of revolutions made by a revolving disc. A cardboard drum (Fig. 261) is mounted on a quickly spinning shaft. The marksman fires a bullet and pierces

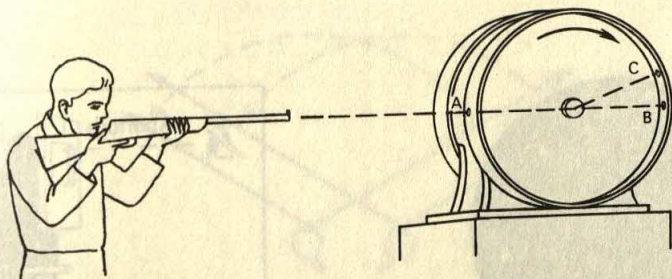


Fig. 261

How to gauge the speed of a bullet in flight

the drum's walls in two places along its diameter. If the drum were stationary the bullet holes would be at the two ends of one and the same diameter. But as the drum was turning, in the time the bullet passed from end to end, it struck point *c* instead of point *b*. Knowing the number of revolutions the drum makes and its diameter, we may compute the bullet's speed on the basis of the value of the arc *bc*. This is a geometrical problem which is more or less simple for all possessing some knowledge of mathematics.

THE NIPKOV DISC

The so-called Nipkov disc, used in the first television sets, was a splendid case of the technical application of an optical illusion. Figure 262 shows a disc with a series of a dozen or so small holes 2 mm in diameter. Set uniformly along a spiral near the outer edge, each hole is 2 mm closer to the centre than its preceding neighbour. Now you might think there is nothing remarkable about it. However, mount it on a shaft, place a small window in front of the disc and a picture of the same size behind (Fig. 263), and spin the disc rapidly. The picture, which the disc had shut to view before, can now be seen quite clearly. As

* The principle just discussed is that of the stroboscope which is used to measure the frequency of rapidly varying processes. It gives exceptional accuracy—for instance, an electronic stroboscope may be only 0.001 per cent out.—Ed.

soon as the disc slows down the picture becomes blurred before it finally vanishes altogether when the disc stops. All you see of the picture now is what you can make out through the tiny, 2-mm hole.

What is the secret of this mysterious disc? Let us revolve the disc slowly and watch each successive hole as it passes the window. The hole furthest from the centre passes near the window's upper rim. When moving quickly enough, it

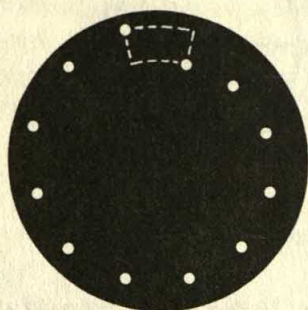


Fig. 262

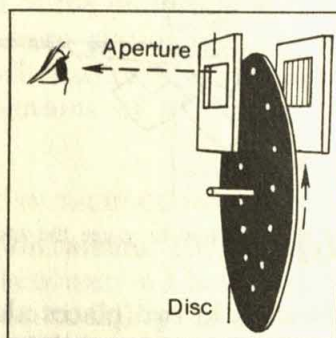


Fig. 263

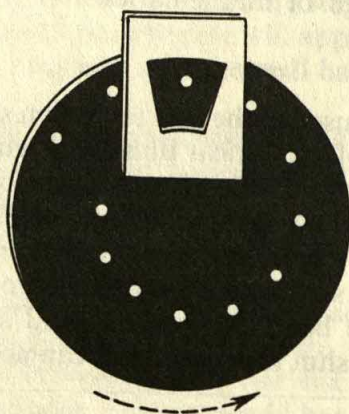


Fig. 264

opens to view a whole strip along the upper edge of the picture. The next hole, which is a bit below the first, opens, in fast passage, a second strip abutting on the first (Fig. 264), the third hole opens to view a third strip abutting on the second, and so on and so forth. When the disc is revolved rapidly enough, we see the entire picture. Opposite our window there seems to be in the disc itself another aperture of the same size.

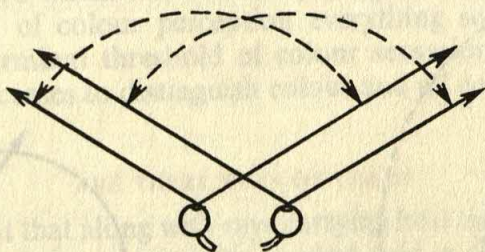


Fig. 265

Field of vision of a man's eyes

This disc is quite easy to make. To spin it you could use a piece of string wound round its shaft, but, of course, it would be better to work it with a small electric motor.

WHY IS A RABBIT CROSS-EYED?

Man is one of the few creatures whose eyes are accommodated to the simultaneous perception of an object. It is only by a wee bit that the right eye's field of vision does not coincide with that of the left eye. Most animals, however, look with each eye separately. What they see lacks the relief to which we are accustomed, but this is made up for by a field of vision which is much wider than ours.

Figure 265 shows man's field of vision. Each eye sees—horizontally—within an angle of 120° , and moreover, both angles almost completely overlap, assuming that the eyes are not moving, of course. Now compare this drawing with Fig. 266 which gives the rabbit's field of vision. Without turning its head, the rabbit sees with its wide-set eyes not only what goes on in front but also behind it. The fields of vision of both eyes link up, both in front and behind. This explains why it is so hard to creep up on a rabbit from behind without scaring it away. On the other hand, from the drawing it is clear that the rabbit can't see at all what is right in front of its nose without turning its head sideways.

Nearly all hooved and ruminant animals possess this property of "all-round

vision". Figure 267 shows the horse's fields of vision. Though they do not converge at the back, it is enough for the horse to turn its head but slightly to see everything behind it. Visual perceptions, true, are not so distinct, but, on the other hand, the animal will not miss the slightest motion. Agile beasts of prey instead of this "all-round" vision, have a "two-eyed" vision, which enables them accurately to estimate the pouncing distance.

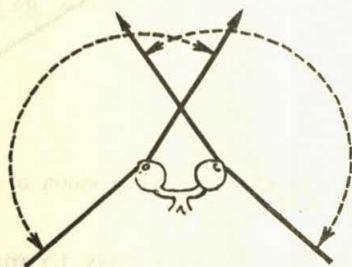
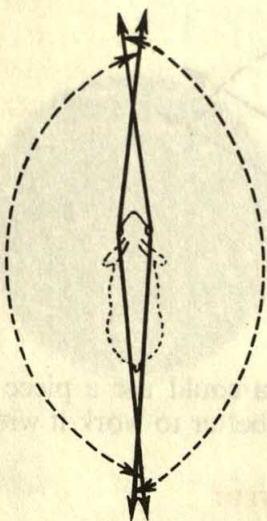


Fig. 266

Field of vision of a rabbit's eyes

Fig. 267

Field of vision of a horse's eyes

WHY ARE ALL CATS GREY WHEN THE CANDLES ARE OUT?

A physicist would say that when the candles are out all cats are black, as in the absence of light nothing is to be seen in general. The proverb does not mean total darkness; rather does it imply that when light is poor we cease to distinguish colour and everything seems grey to us.

Is this really true? Is it really so that in half darkness a red flag and a green leaf will both seem grey? You can easily verify this. If you have ever tried to make out colours in twilight, you must have observed the general more or less darkish grey tinge that every object acquires, regardless of its colour, be it a red blanket, blue wall paper, violet flowers, or green leaves. "The drawn blinds barred the sunshine," we read in Chekhov's story *The Letter*, "and it was

semidark. All the roses in the big bouquet seemed of one colour."

Exact physical experiments have quite confirmed this observation. If you turn a faint white light on a coloured surface or a faint tinted light on a white surface, and gradually increase the candle-power, you will see at first only grey and no other colour. Only when the candle power is intensive enough do you begin to notice colour. This is called the absolute threshold of colour perception.

So the same proverb which exists in many tongues is literally right, because below the threshold of colour perception everything seems grey.

There is also a terminal threshold of colour sensation. When light is too bright, the eye again ceases to distinguish colour and all coloured surfaces seem white.

ARE THERE RAYS OF COLD?

The opinion is current that along with rays carrying heat there are also rays that carry cold. After all a lump of ice seems to shed cold in the same way a stove radiates heat. Does not this suggest that ice radiates rays of cold just as the stove radiates rays of warmth?

This is absolutely wrong. Rays of cold simply don't exist. Articles placed next to ice grow cold, not because there are "rays of cold" but because warm articles radiate more warmth than they themselves receive from the ice. Both the warm article and the cold ice radiate heat. An article warmer than ice sheds more heat than it receives. Since the amount of incoming heat is less than the amount of outgoing heat, the article cools.

There is an effective experiment which may induce us to think that rays of cold really exist. Large concave mirrors are hung opposite each other in a long hall. If we place a powerful source of heat in the focus of one of the mirrors, the rays it emits will be reflected from this mirror to the second mirror, which will again focus them; a piece of black paper at this focus will burst into flame. This graphically demonstrates the existence of heat-carrying rays. However if we place a lump of ice at the focus of the first mirror a thermometer at the focus of the second mirror will register a drop in temperature. Does this really mean that the ice emits rays of cold which the mirror reflects and focuses on the thermometer?

Not at all. Again an explanation can be found which will debunk these mysterious "rays of cold". Due to radiation the thermometer will impart to the ice more warmth than was received from it; this is why the temperature drops. Again we have no reason to believe that rays of cold exist. There is nothing of the sort in nature. All rays impart energy to the absorbing object. Meanwhile objects that emit rays grow colder.

Chapter **Sound Wave Motion** 20

SOUND AND RADIO WAVES

Sound travels with a speed a million times slower than that of light. Since the speed with which radio waves propagate coincides with that of light oscillations, hence sound is a million times slower than a radio signal. This leads to a curious conclusion, the gist of which is explained in the following problem. Who will hear first a pianist's first note—a person in a concert hall seated some ten metres away from the piano, or a radio listener in his partment some one hundred kilometres away from the hall? Strangely enough, the radio listener, even though he is ten thousand times farther away.

Indeed radio waves will travel 100 km in $100/300,000 = 1/3,000$ s; meanwhile sound travels ten metres in $10/340 = 1/34$ s. It follows that it is almost a hundred times faster to transmit sound by radio than to transmit sound through air.

SOUND AND BULLET

When the passengers in Jules Verne's projectile set off for the moon, they were mystified not to hear the roar of the tremendous gun that hurtled them into space. But it could not be otherwise. However deafening the noise, the speed with which it propagated—as any sound in air generally—was only 340 m/s, whereas the projectile whizzed out with a speed of 11,000 m/s. It was only natural that the sound of the shot did not reach the ears of the passengers, as their projectile was moving faster than sound.*

What about real projectiles and bullets? Do they move faster than sound? Or, on the contrary, does sound outrace them to warn the victim of the deadly projectile? Modern rifles impart to bullets a muzzle velocity nearly three times greater than the speed of sound in air—about 900 m/s (the speed of sound at 0° is 332 m/s). True, sound propagates uniformly, while a bullet slows down. However, over most of its trajectory a bullet will fly faster than sound. Hence, if

* Modern aircraft fly much faster than sound.—Ed.

in a skirmish you hear the sound of a shot or the whistle of a bullet, you needn't worry, the *bullet has already missed you*. The bullet will hit its victim before the sound of the shot would reach his ear.

FALSE EXPLOSION

The speed race between a flying object and its sound sometimes involuntarily compels us to draw absolutely erroneous conclusions. A curious illustration is

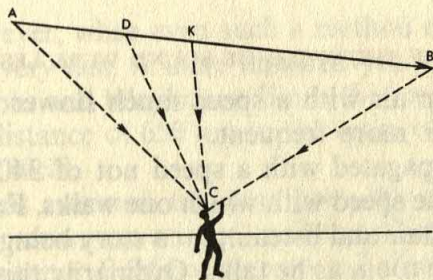


Fig. 268

Imagined explosion of a bolide

afforded by a bolide, or a cannon ball, whizzing by high up above. The bolides that dive into our terrestrial atmosphere for outer space possess a tremendous velocity *dozens of times* greater than the speed of sound, even though they are retarded by atmospheric resistance.

As they cut through the air bolides often produce a noise greatly resembling peals of thunder. Suppose we are at point C (Fig. 268). High up above a bolide is rocketing along the trajectory AB. The sound it produced at point A will reach the ear at point C only when the bolide itself reaches point B. Since the bolide flies much faster than sound, it may reach a certain point D, from which we shall hear its sound, before we hear the sound it made at point A. Therefore we hear first the sound from point D and, only then, the sound from point A. Since the sound from point B reaches us also later than from point D, somewhere above us there should be a point K from which we should hear the bolide's noise soonest. All fond of mathematics will be able to figure out the exact position of this point, provided they determine the relation between the speeds of the bolide and the sound.

As a result what we *hear* will in no way resemble what we *see*. To the eye the bolide will appear first of all at point A from whence it will dash further along the trajectory AB. But to the ear the bolide will seem to be first somewhere

above us at point *K*. Then we will hear simultaneously two sounds fading in opposite directions—from *K* to *A*, and from *K* to *B*. In other words, it will seem to us that the bolide had split into two parts, whizzing away in opposite directions.

Actually there was no explosion at all, which shows you how deceptive auditory impressions may be. Most likely many “eye witness” accounts of bolide explosions derive precisely from this auditory illusion.

IF THE SPEED OF SOUND WERE LESS

If sound propagated in air with a speed much slower than 340 m/s, auditory illusions would be far more frequent.

Suppose sound propagated with a speed not of 340 m/s but of 340 mm/s, which is slower than the speed with which one walks. Further suppose that you are sitting in an arm-chair and listening to a story being told by a friend having the habit of pacing the room as he talks. Ordinarily this would be no obstacle. But if the speed of sound were much less, you would not make head or tail of your friend’s story. His initial utterances would be overtaken by more to mix and produce an incoherent jumble.

Incidentally, when your friend approached, his speech sounds would reach you in *reverse order*. At first you would hear the sounds he had just uttered, then sounds uttered a bit before, and after that sounds uttered still earlier and so on and so forth. This would happen because the person uttering them would be outpacing them and uttering more sounds, meanwhile being all the time in front of the sounds just uttered.

THE SLOWEST CONVERSATION

But if you always thought the real speed of sound in air, a third of a kilometre a second, rapid enough, you will now have to change your mind. Suppose Moscow and Leningrad were linked up, instead of electric telephones, by an ordinary speaking tube, like the one on a steamship which the skipper uses to issue orders to the engine room. You are at the Leningrad end of this 650-km-long tube while your friend is at the Moscow end. You ask a question and wait for an answer. Some five minutes pass, then ten, fifteen, but there is still no reply. You are worried, and think something has happened. Your fears are unwarranted. Your question has *still not reached Moscow*. It is only half-way there. Another quarter of an hour will pass before your friend hears it. But since

his reply will take the same half-hour to get from Moscow to Leningrad, you will hear your questions answered only one hour later.

This is easy to verify. It is 650 km from Leningrad to Moscow. Sound propagates with a speed of $1/3$ km/s. Conversing in this way from morning till night, you would barely manage to exchange a dozen sentences.*

QUICKEST WAY

There was a time, however, when even such a method of relaying news would have been considered very fast. A mere hundred years ago nobody dreamed even of electric telegraphs and telephones. If one then would have been able to transmit news over a distance of 650 km in the space of a few hours, it would have been considered ideal.

When Tsar Paul I was crowned, the story goes, the news of the coronation, which took place in Moscow, was relayed to the northern capital of St. Petersburg in the following manner. Soldiers were posted all along the road between the two capitals at a distance of 200 m apart. As soon as the cathedral bell chimed forth, the nearest soldier fired his gun into the air. As soon as the next soldier heard the shot, he fired his gun. The third did the same, and it thus took only three hours to relay the news to St. Petersburg, 650 km away.

If one could have heard the chiming of Moscow bells in St. Petersburg, this sound, as we already know, would have reached the northern capital half an hour later. This means that two and a half hours of the three hours required to convey the news went for each soldier to hear his neighbour's gun and make the necessary motions to fire his own gun. However short the delay, these thousands of tiny delays added up to two hours and a half.

The old optical telegraph was based on a similar principle. It transmitted light signals to the nearest post, which then relayed them further.

TOM-TOM TELEGRAPH

The relaying of news by sound signals is current even today among tribes of Africa, Central America, and Polynesia. For this purpose special tom-toms, able to transmit sounds over great distances, are used. The signal is repeated in

* The author has evidently deliberately disregarded the fading of sound with distance. You would never be able to conduct a conversation in this manner as the person at the other end of the tube would never hear you.—Ed.

relays and very soon the population of an extensive area are “in the know” (Fig. 269).

When Italy was at war with Abyssinia, the Negus learned very quickly of all Italian troop movements. This puzzled the Italians who had no inkling of the enemy’s tom-toms. When Italy went to war with Abyssinia again, the general mobilization order issued in Addys Ababa was “made public” in the same



Fig. 269 A Fiji native using a tom-tom telegraph

manner and relayed to the remotest villages in the space of a few hours.

Tom-toms were again used during the Anglo-Boer war. They enabled the Kaffirs to relay military information very quickly. The Capelanders learned everything several days before official dispatches came by messenger. Explorers claim that some African tribes have such an excellent system of sound signals, that they may be said to have a much better telegraph than the optical one used in Europe before the present electric one was introduced.

In one magazine I read the following about the tom-tom telegraph. R. Hasselden, the British Museum’s archaeologist, was visiting the town of Ibada in the heart of Nigeria. The steady, dull rhythmic beat of tom-toms could be heard day and night. One morning the scientist heard the Negroes animatedly chattering among themselves. In response to his inquiries the sergeant told him that “a big ship of the white men has sunk and many white men have perished”. Hasselden paid no heed to the rumour at the time. However, three days later he received a telegram (delayed because of disrupted

communications) about the *Lusitania* disaster. Only then did he realize that the Negro grapevine was right and that it had "beat" its way in drum language from Cairo to Ibada. This was all the more surprising, since the tribes that had relayed the news spoke in totally different dialects while some were even at war with one another.

ACOUSTIC CLOUDS AND THE AERIAL ECHO

Sound bounces back not only off solid obstacles but also off clouds. Even absolutely transparent air is able to reflect sound waves in certain circumstances, when for some reason it differs in sound-carrying capacity from the rest of the air mass. This is a phenomenon reminiscent of the "total reflection" in optics. The sound is repelled by an invisible barrier and we hear a mysterious echo whose source is undiscernible.

Tyndall discovered this curious phenomenon by accident, when experimenting with sound signals on the sea shore.

... "The echoes reached us," he wrote, "as if by magic, from the invisible acoustic clouds with which the optically transparent atmosphere was filled."

The famous British physicist gave the name of acoustic clouds to those areas of transparent air which reflected sound, thus producing an "aerial echo". This is what he has to say about it:

"Acoustic clouds, in fact, are incessantly floating or flying through the air. They have nothing whatever to do with ordinary clouds, fogs or haze. The most transparent atmosphere may be filled with them; converting days of extraordinary optical transparency into days of equally extraordinary acoustic opacity...

"The existence of these aerial echoes has been proved both by observation and experiment. They may arise either from air currents differently heated, or from air currents differently saturated with vapour."

SOUNDLESS SOUND

Some people are deaf to such high-pitched sounds as the chirping of a cricket or the squeaking of a bat. Though not deaf generally and having normal auditory organs with no defects, they fail to hear high-pitched tones. Tyndall claims that there are people who can't even hear a sparrow chirruping.

Generally speaking, our ear does not catch every vibration occurring near by. We don't hear any sound when vibrations are less than 16 or more than 15,000-22,000 per second. The terminal threshold of audibility differs for

different people, dropping to as low as 6,000 vibrations per second in the case of old persons. This is why one person will clearly hear a shrill high-pitched note while another won't.

Many insects, the mosquito and cricket, for instance, emit sounds having a pitch corresponding to 20,000 vibrations a second, which to some is audible and to others not. The latter, those insensitive to high-pitched notes, take pleasure in a quietness which for the former is an ear-racking world of shrill sounds. Tyndall had this observation to make about a stroll he and his friend once made in Switzerland:

"In *The Glaciers of the Alps* I have referred to a case of short auditory range, noticed by myself in crossing the Western Alps in company with a friend. The grass at each side of the path swarmed with insects, which to me rent the air with their shrill chirruping. My friend heard nothing of this, the insect-music lying beyond his limit of audition."

The squeak of a bat is one whole octave below the shrill shrieking of insects, as the vibrations produced have only half the frequency. But there are people whose borderline of audibility is still lower and to whom bats are noiseless creatures. On the contrary, dogs, as the famous Soviet physiologist Academician Pavlov experimentally demonstrated, hear tones up to 38,000 vibrations a second.

ULTRASOUNDS IN TECHNOLOGY

Modern physicists and engineers are able to produce "soundless sounds" with a frequency that is much greater than the sounds we have just mentioned. "Ultrasounds" may have vibrations ranging up to as many as 100,000,000,000 a second.

One way of producing ultrasonic vibrations is based on the property of plates cut in a certain manner from quartz crystals to electrify under compression (this is called piezoelectricity). This crystal will alternately contract and expand under the effect of periodic electric charges. In other words, it will vibrate and produce ultrasounds. The crystal is charged by a radio-tube generator with a frequency selected to conform with the so-called own period of the crystal's vibrations.*

* Since quartz crystals are expensive and feebly emit ultrasounds, they are hence used mostly in laboratories. Engineers have evolved for technical uses such synthetic materials as barium titanate ceramics.—Ed.

Though ultrasound is inaudible to us, it exhibits itself in other very manifest ways. If we immerse a vibrating plate in a jar of oil, a 10-cm "hump" will appear on the oil surface, due to ultrasonic sound, and drops of oil will spray up to 40 cm high. If we dip a metre-long glass rod in this oil bath, the hand holding the rod will be badly burned. The vibrating rod end will char a hole through a piece of wood, the energy of the ultrasounds having been transformed into thermal energy.

Scientists both in the Soviet Union and abroad are intensively investigating ultrasound. It strongly affects living organisms, causing the threads of seaweeds to snap, animal cells to burst, and blood cells to disintegrate. One or two minutes of ultrasound treatment is enough to kill small fish and frogs, and to raise an animal's body temperature to as much as 45°C —in the case of mice, for instance. The inaudible ultrasounds, like the invisible ultraviolet rays, are helping doctors to treat sick people.

Ultrasound is widely used in metallurgy, to detect impurities, blowholes, cavities and other inner defects. In ultrasonic fault detection, the metal being tested is greased with oil and subjected to ultrasonic vibrations. The defective area disperses the sound, casting what one might call a sound shadow, which appears in so clear a relief against the even ripples on the oil, that it can even be photographed.*

Ultrasound can be used to test for defects a bar of metal over a metre thick, which is way beyond the reach of X-rays. Moreover it will spot tiny defects of as little as one millimetre in cross-section. There is no question that the future prospects are very promising.**

GIANT'S BASS AND MIDGET'S TREBLE

In the Soviet film *The New Gulliver* the Lilliputians speak in voices highly pitched to correspond with their tiny throats, while the boy-Gulliver, Petya, speaks in a deep voice. Nevertheless, when the picture was being made, it was grown-up actors who spoke for the Lilliputians and a real boy who spoke for

* The method of ultrasonic fault detection was suggested by the Soviet scientist S. Y. Sokolov back in 1928. The special ultrasonic vibration receivers used today dispense with oil and make the process simpler.—*Ed.*

** Ultrasounds exist in nature as well—in the noise of the wind and breakers at sea, for instance. Butterflies, cicades and many other creatures both emit and receive ultrasounds. Bats use ultrasound when in flight as a sort of radar to circumvent obstacles.—*Ed.*

Petya. How was the pitch changed? I was most surprised when film director Ptushko told me that the actors had not tried to change their voices at all. That was done for them by an original method based on the physical characteristics of sound.

To impart a high pitch to Lilliputian speech and a deep voice to Gulliver the actors speaking for the Lilliputians were recorded on a *slow* track while the boy playing Petya was recorded, on the contrary, on a *fast* track. The sound-film, however, was reproduced at the normal speed. You have probably guessed the outcome. Lilliputian speech is received by the audience when vibrations are more *intensive*, thus producing a *rise* in the pitch. Petya's speech, on the contrary, is reproduced at a *slower speed* than normal and, consequently, its tone should *drop*. As a result in *The New Gulliver*, the Lilliputians speak in voices a quint *higher* than that of a normal adult, while the boy-Gulliver speaks in a tone a quint *below* the normal.

Thus was a slow-motion method used to produce a sound effect. One will often hear this, incidentally, when a gramophone record is played at a speed faster or slower than indicated.

READING A DAILY TWICE A DAY

The problem we are now going to discuss may seem, at first glance, to have nothing to do with either sound in particular, or physics in general. Still I would like you to pay heed to it, since it will facilitate understanding of what is to come later. In all likelihood you may have encountered another version of the same problem before.

Here it is. Daily, at noon, a train pulls out from Moscow for Vladivostok. Also daily, and again at noon, another train leaves Vladivostok for Moscow. Suppose the entire journey takes ten days. The question is: how many trains will you meet on your way from Vladivostok to Moscow? Most people rush to give the answer: ten. That's wrong though. Besides meeting on the way the ten trains that will leave Moscow after you depart from Vladivostok, you will also meet the trains already on the way at the time you left. Consequently, the right answer is not ten but twenty.

Let us now proceed further. Each Moscow train has on board fresh newspapers. If you are interested in Moscow news, you will naturally buy fresh papers at each stop. How many fresh newspapers then will you buy on your ten-day journey? I imagine that by now you will give the right answer of twenty. After all, each train you meet brings a fresh paper, and since you meet twenty,

that means you read also twenty fresh papers. But since you will be travelling only ten days, *you will be reading a fresh daily twice a day.*

This seems a surprising paradox, doesn't it? And I don't suppose you would believe me unless you ever had a chance to put it to test in practice.

THE TRAIN WHISTLE PROBLEM

If your ear for music is good, you have probably noticed how the pitch—not the loudness, but precisely the pitch—of the locomotive's whistle changes as an approaching train passes. While the two trains were drawing together, the pitch of the whistle was noticeably higher than after the trains had met and receded. If both trains are doing 50 km/h, the difference in the pitch reaches nearly a whole tone.

Why does this happen? The answer is easy to fathom, when you realize that the pitch depends on the frequency of vibrations per second and that you have an analogy with the newspaper problem mentioned above. The whistle of the approaching locomotive emits one and the same sound of a definite frequency. Your ear, however, receives a varying number of vibrations, depending on whether you are approaching, are stationary, or are receding.

In the same manner as on the train journey to Moscow, when you read daily newspaper twice a day, on approaching the source of sound you catch a vibration frequency of a rate *greater than the locomotive whistle's normal rate.* This, however, is no auditory illusion; it is your ear that receives the *increased number of vibrations* and you directly hear a tone of a *higher pitch.* As you move away, you get a smaller number of vibrations and hear a tone of a *lower pitch.*

If this explanation of mine has not satisfied you, try to trace in the mind's eye how the sound waves propagate from the locomotive whistle. Take the *stationary* locomotive (Fig. 270) to begin with. Its whistle emits wave-trains. For simplicity's sake we shall discuss only four wave-trains (see the upper wavy line). From the stationary locomotive they propagate in a definite time interval to one and the same distance in all directions. Wave 0 will reach observer *A* at the same time as observer *B.* Then both *A* and *B* will hear waves 1, 2, 3, etc., simultaneously. The same number of waves strike the ears of both observers every second—which is why both hear one and the same tone.

It would be different were the whistling locomotive to be *moving* from *B* to *A* (the lower wavy line). Suppose at a certain moment the whistle would be at point *C'* and that while it had been emitting the four waves, it had managed to reach point *D.* Now compare the different propagation of the sound waves.

Wave 0 from point C' will reach both observers A' and B' simultaneously. However, the fourth wave, emitted from point D , won't reach them simultaneously, as the distance DA' is less than DB' ; consequently, it will reach A' before B' . The intermediate waves 1 and 2 will also arrive at B' later than at A' , but there will be less difference in time. Consequently, A' will receive the sound waves *more often* than B' and will hear a tone of a *higher pitch*. At the same time,

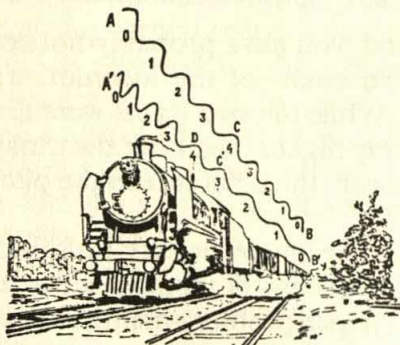


Fig. 270

Train whistle problem. $A-B$: sound waves emitted by a stationary locomotive. $A'-B'$: sound waves emitted by a locomotive moving

as the drawing clearly shows, the length of the waves moving towards A' will be correspondingly shorter than the waves moving in the opposite direction, towards B' .

(The wavy lines of the drawing do not depict the *shape* of the sound waves. Air particles vibrate *longitudinally*, in the direction of the sound, and not transversely. The waves are given *transversely* solely to provide a graphic illustration. The crest of each wave corresponds to the maximum longitudinal contraction.)

THE DOPPLER EFFECT

The phenomenon described above was discovered by the physicist Doppler and ever since has been known after him. It is also observed for light, as light likewise propagates in waves; the increasing frequency appears to the eye as a change in colour, while in the case of sound it is heard as a change in pitch.

The Doppler effect, as it is called, enables astronomers not only to detect whether a star is moving towards or from us, but also to estimate the velocity of this shift. In this case it is the side shift of the dark vertical lines in the spectrum that helps. A close examination of the direction of the shift and its extent, in the

spectrum of a heavenly body, has enabled astronomers to make a whole series of astounding discoveries. Thus the Doppler effect has told us that the bright star of Sirius is receding by 75 km every second. It is so incredibly distant that its recession even by thousands of millions of kilometres would not appreciably affect its apparent brilliance, and most likely we would have never guessed that it was moving away, if not for the Doppler effect.

This fact most glowingly shows physics to be a really all-embracing and *all-inclusive* science. Having evolved a law for *sound* waves, which are as much as several metres long, it then applies it to the infinitesimally small *light* waves, which are only a few ten-thousandths of a millimetre long, in order to calculate the rapid motion of huge suns in the fantastically distant reaches of outer space.

THE CASE OF THE FINE

When Doppler first concluded (in 1842) that the wavelengths of sound and light should change, as the source of emission approached or receded, he boldly postulated that this was precisely why stars were coloured. All stars, he conjectured, were actually white; however, many seemed coloured due to rapid motion in relation to us. Quickly approaching white stars, he reasoned, send us shortened light waves tinted green, blue, or violet. On the contrary, quickly receding white stars seem yellow or red.

Original but unquestionably wrong! For the eye to notice a change in colour due to motion, the stars would have to race with the enormous velocity of tens of thousands of kilometres a second, which even then wouldn't help, as at the same time the blue rays of an approaching white star would change to violet, the green ones would change to blue, while the violet ones would take over from the ultraviolet, and the red ones from the infrareds. In short, we should still have the same old components of white light and, despite the general shift in all the colours in the spectrum, our eye wouldn't notice any change in the general colour.

The shift of the dark lines in the spectra of stars moving towards or from the observer is quite another thing. Sensitive instruments spot them, enabling us to determine the line-of-sight velocities of the stars. A good spectroscope will catch even a one-kilometre-per-second velocity.

The celebrated physicist Robert Wood recollected Doppler's error when the police were about to fine him for jumping a red traffic light. Wood, the story goes, assured the guardian of law and order that when driving fast you would see a red traffic light as a green one. Had the policeman been a bit of a physicist

as well, he could have well told Wood that to see green in place of red, his car must do at least 135 million km/h—a totally incredible speed.

This is how it is calculated. Let l designate the wavelength of the light emitted by the traffic light, l' the wavelength received by Wood in his car, v the car's velocity, and c the velocity of light. Then we may write the following equation: $l/l' = 1 + v/c$. Knowing that the shortest, red, wavelength is 0.0063 mm, while the longest, green, wavelength is 0.0056 mm, and that the velocity of light is 300,000 km/s, we get $0.0063/0.0056 = 1 + v/300,000$, whence the speed of the car is $v = 300,000/8 = 37,500$ km/s, or 135 million km/h. At this speed Wood, in the space of an hour or so, could have put a greater distance between himself and the police than from the earth to the sun. Still, the physicist was fined after all for "speeding".

WITH THE SPEED OF SOUND

What would you hear if you were to move away from a band with the speed of sound? You might think that since a mail-train passenger buys at all stations one and the same paper that was put out on the day of the train's departure, by moving away with the speed of sound from the band, we would hear one and the same note that the orchestra had played when we had just started.

That would be wrong. Since you are moving away with the speed of sound, the sound waves emitted by the band would be in a state of rest with respect to you and would not impinge on your ear drums at all; you would hear nothing and think that the band had stopped playing.

Why did our comparison produce the wrong answer? Simply because we applied the analogy wrongly. After all the passenger could imagine, that is, if he forgot he was travelling, that ever since he had left Moscow, no fresh newspapers had been put out, since he was seeing one and the same newspaper sold all along the line. From his point of view the newspaper offices should have closed down—just as the band had seemed to have stopped playing if we were moving with the speed of sound.

Curiously enough, even scientists sometimes confuse the point, though it is really not so complicated as all that. I remember, when a schoolboy yet, having an argument with an astronomer who disagreed with my solution, and who claimed that when we moved away with the speed of sound we would hear one and the same tone all the time. The line of reasoning he chose was as follows:

"Suppose you have a note of a certain pitch struck," he wrote to me. "It has always had that sound and will always have it. A row of observers in space would hear it in succession and let us suppose, for the sake of argument, just as

loudly. Why then shouldn't we hear it, were we able to hop with the speed of sound or even thought, to the side of any of these observers?"

In exactly the same way he argued that an observer moving away from lightning with the speed of light would always see this lightning.

"Imagine," he wrote, "an endless row of eyes in space. Each successive eye will see the flash in succession. So imagine you visit each eye in succession: quite obviously you will see the flash of lightning all the time."

It goes without saying that neither assertion is right. In the conditions given we would neither hear the note nor see the lightning. The equation mentioned a bit earlier demonstrates that; for if $v = -c$ the wavelength λ will be infinite, which is all the same as saying that it isn't there.

* * *

We have come to the end of *Physics Can Be Fun*. If, now that you have read it, you feel you would like to learn more about this boundless domain of knowledge from which this motley handful of simple facts has been culled, I shall consider my task fulfilled and, happily content, will write
The End

99 Review Questions

1. Can one see from a balloon how the earth rotates?
2. Will a weight, dropped from an airplane, fall vertically?
3. How can we get off moving railway trains with absolute safety?
4. When an icebreaker ploughs through ice, is the force it exerts equal to the ice's resistance?
5. Why does a rocket go up; and will it go up in a void?
6. Do any creatures move like rockets?
7. Does it always happen that forces exerted in different directions fail to make the objects to which they are applied move?
8. Why is an arched ceiling sturdier than a flat one?
9. How does the wind make a yacht go?
10. Would Archimedes have ever been able to lift the earth, even if he had found a point for a fulcrum?
11. Why does a knot hold?
12. Will knots help in the absence of friction?
13. How would we benefit and what would we lose, were there no friction?
14. Balance a broom on the back of a chair. Which part is heavier—the shorter or the longer part?
15. Why doesn't a spinning tectotum topple over?
16. When doesn't water pour out of an overturned glass?
17. When won't an unfettered ball roll down an incline?
18. Where is gravity greater—in London or Cairo?
19. Why do we never see the mutual attraction of objects in a room?
20. How far would you be able to jump on the moon?
21. How high up would a bullet go on the moon when fired vertically upwards with a muzzle velocity of 900 m/s?
22. If you were to drop a weight into a shaft going right through the centre of the earth along its diameter, would it stop in the absence of air resistance?
23. How should one dig a tunnel through a mountain to avoid its flooding by rain?
24. Can you hurtle something into space so that it never comes back?

25. Where would the nonswimmer never sink?
26. How does an icebreaker go through ice?
27. Do shipwrecks reach the ocean bed?
28. On what physical law is the lifting of sunken ships based?
29. What is the tub problem and do arithmetic books provide the correct solution?
30. Can we make water flow out of a vessel in a uniform jet?
31. Would two harnesses of 8 elephants apiece—in place of the two harnesses of 8 horses—have pulled the Magdeburg hemispheres apart? (An elephant is presumably five times stronger than a horse.)
32. What is the working principle of an atomizer?
33. Why do two parallel ships attract each other?
34. What is the role of a fish's bladder?
35. What are the two different fluid flows in physics?
36. Why does smoke curl when coming out of a chimney?
37. Why does a flag flutter in the breeze?
38. Why does desert sand "ripple"?
39. How high up must one go for atmospheric pressure to drop by one-thousandth?
40. Is Mariotte's law applicable to air at a pressure of 500 atmospheres?
41. Is the temperature a thermometer shows in windy weather lower than that in windless weather?
42. Why is a frost worse in windy weather than in quiet weather?
43. Will a wind always refresh us in hot weather?
44. What is the effect of coolers band on?
45. Can you make a cooler without ice?
46. Can you bear a 100°C heat?
47. Why is it easier to bear a 36°C heat wave in Central Asia than a 24°C heat wave in Leningrad?
48. What is the function of glass in the paraffin lamp?
49. Why don't the products of combustion extinguish the flame of a paraffin lamp or a candle?
50. How would a flame burn were there no gravity?
51. How would water heat up on a primus stove were there no gravity?
52. Why does water put fire out?
53. How can we fight fire with fire?
54. Will pure water ever boil in a vessel heated up by boiling water?
55. Will water ever freeze in a bottle immersed in a mixture of water and ice?

56. Can we get water to boil at room temperature?
57. How can we determine atmospheric pressure by using a thermometer?
58. Is there anything like hot ice?
59. Which kind of magnet—natural or man-made—would be more powerful?
60. What other metals besides iron can a magnet attract?
61. Are there any metals which a powerful magnet would be able to repel?
62. Will a magnet affect liquids or gases?
63. Where in the world would a compass needle point North with both ends?
64. What attracts more strongly—the iron the magnet, or the magnet the iron?
65. Which sense organ is susceptible to magnetic forces?
66. Can an electromagnetic crane hoist molten metal?
67. Why are powerful magnets dangerous for gold watches?
68. What is a radium clock?
69. How do we determine the age of the earth and minerals by radioactive decay?
70. Why can birds perch on electric wires with impunity?
71. How long does lightning last?
72. At what angle should we put two mirrors to get seven reflections?
73. What difference is there between a sun-powered motor and a sun-powered heater?
74. What is “helio-engineering”?
75. Why is the crystalline lens of a fish’s eye spherical in shape?
76. Can you read a book with your head under water?
77. Which of the two—a diver in a helmet or a person without goggles—will see better under water?
78. Can we make a biconcave lens magnify and vice versa?
79. Why does the eye see the bottom of a pond as elevated?
80. What is the critical angle?
81. What is total reflection?
82. Do the fish’s silvery scales help it in any way?
83. What is the blind spot and how can we find it?
84. What is the angle of vision?
85. How far away should we hold a six-penny bit for it to hide the full moon?
86. How far apart are the sides of a $1'$ angle 10 metres away from the apex?
87. Jupiter’s diameter is roughly ten times greater than that of the earth. How far away is Jupiter when its disc is observed at an angle of $40''$?
88. How should we understand the expressions: “a microscope makes things 300 times bigger” or “a telescope brings things 500 times closer”?

89. Why do motor-car wheels often seem to be revolving in the opposite direction on a screen?
90. Can we get a quickly spinning object to appear as a stationary one to the eye?
91. Can a rabbit see everything going on around it without turning its head?
92. Is it true that all cats are grey when the candles are out?
93. What propagates faster: a radio signal or sound in air?
94. What moves faster: a rifle bullet or the sound of the shot?
95. What sound vibrations are we unable to hear?
96. Have engineers been able to put "soundless sounds" to any use?
97. What is an "acoustic cloud"?
98. How does the pitch of a whistle of an approaching locomotive change?
99. What would we hear if we were to move away from a band with the speed of sound?

The End





Y. Perelman

20/1



Physics
Can Be Fun