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 straighten up, 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 kilogramme 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 grammes 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 away. In our particular instance, we lifted the kilogramme weight twice the distance away from the centre of the earth; hence attraction grew $2^2=4$ times weaker. If we set the weight at a distance of 12,800 km away from the surface of the earth—three times the earth's radius—the force of attraction would grow $3^2=9$ times weaker, in which case our kilogramme weight would register only 111 grammes on a spring balance.

You might conclude that the deeper down in the earth we were to put our one-kilogramme 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.

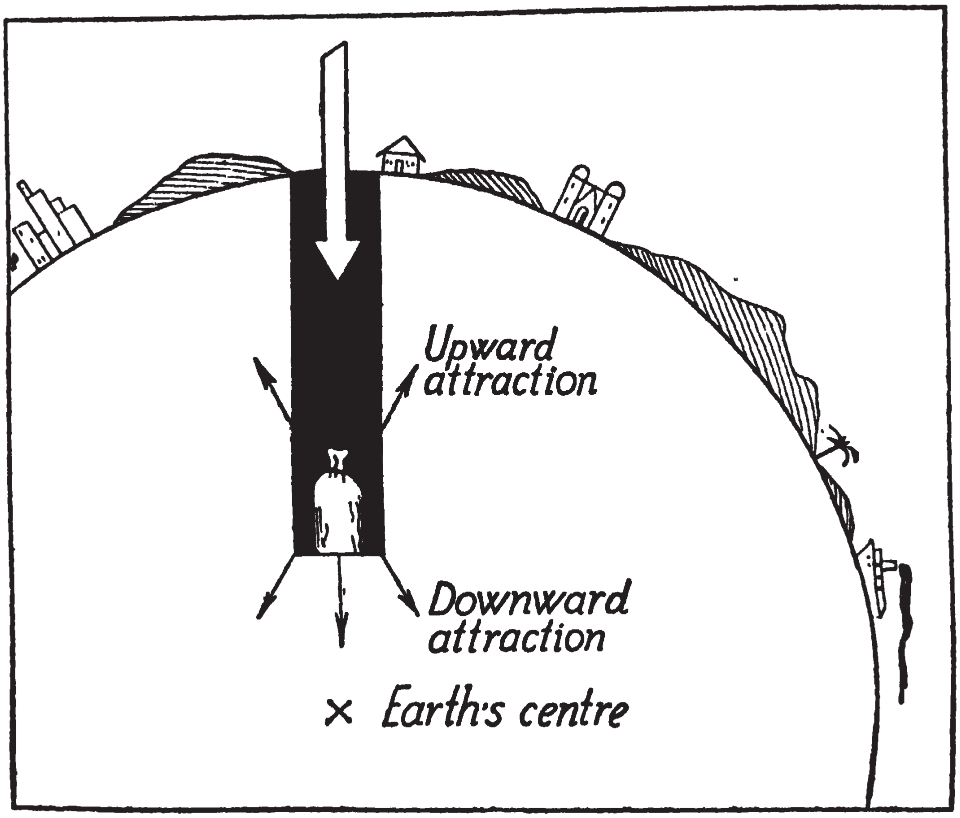

Fig. 23. Gravitational pull lessens the closer we get to the middle of the Earth

This is because now the earth's attracting forces no longer act just on one side of the body but all around it. *Fig. 23* 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, that is of importance. Consequently, the deeper 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 interred (this would stand, 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 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 would be 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 *Mathematical Proofs Concerning Two Fields of a New Science*: "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 well illustrates this point. Place a nutcracker on one of the scale pans, with one arm on the pan and the

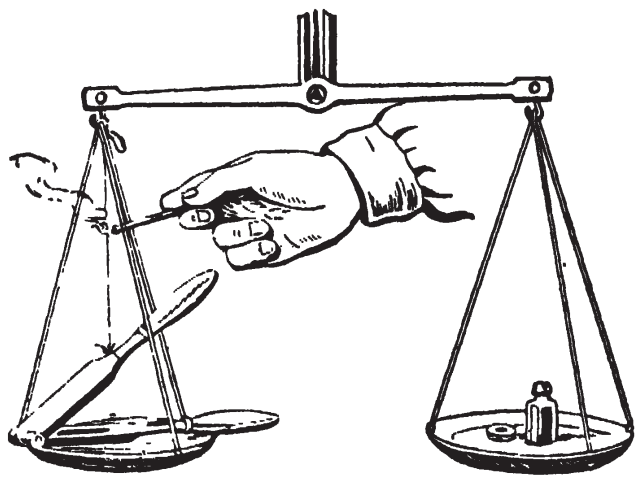

Fig. 24. Falling bodies are weightless

other tied by a piece of thread to the hook of the scale arm (*Fig. 24*). 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. (Today, after Sputnik and Lunik, 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.)

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. 25* which depicts a cross-section of part of the earth. A cannon is mounted on the hilltop at point *A*. 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 same distance away from the ground as it was when fired at point *A*, it means that the shell is

Fig. 25. How to reckon a projectile's "escape" velocity

following a trajectory curved concentrically to the earth's circumference.

All that remains is to reckon the distance AB (*Fig. 25*), 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; h nce OB is 6,370,005 m. Applying Pythagoras's 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 non-locked curve, a parabola, and fly away from the earth never to return (*Fig. 26*). 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

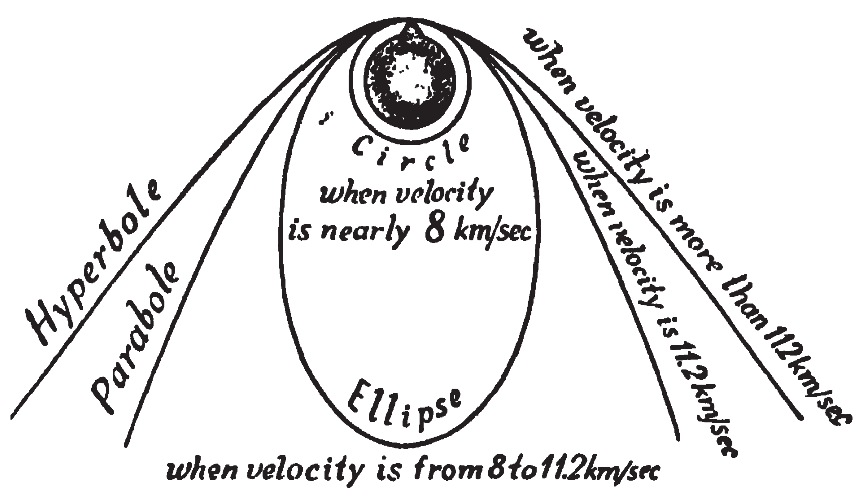

Fig. 26. When a projectile is fired with a starting velocity of 8 km/sec and more

present some quite specific difficulties. Let me refer you, for greater detail, to Book Two of *Physics for Entertainment* and also to *Interplanetary Travel*—another book of mine. (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 remembers 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 void 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 would continue to press down on its floor when it was in space. He forgot that a weight presses down on what supports it only because this support is stationary. But if both object and its support hurtle with the same velocity in space 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 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! (If this problem interests you, we could refer you to the appropriate chapter in A. Sternfeld's *Artificial Earth Satellites*.)

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 Mendeleyev. 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. Tote 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. Tote 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 kilogrammes. Does this amount qualify your arm's muscle-power? Oh, no. Your biceps is much stronger. *Fig. 27* shows how this muscle works. It is attached close to the fulcrum 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.

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 muscular arrangement in animals enables them to move extremities quickly, which is more important than strength in the struggle to survive. Otherwise, we would move around at literally a snail's pace.

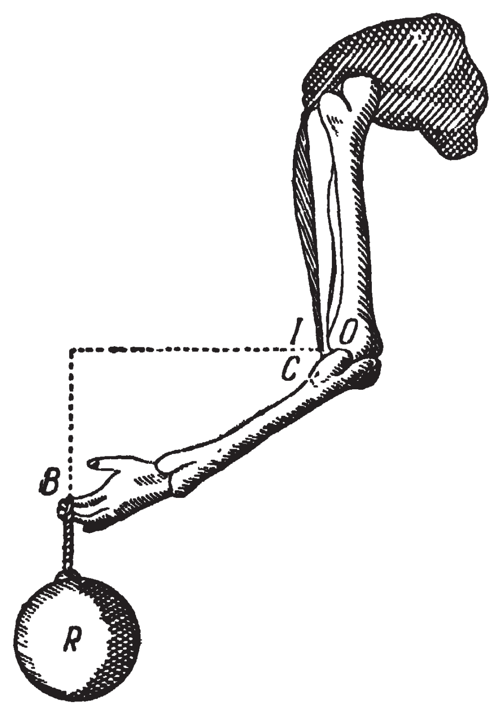

Fig. 27. Forearm *C* acts as a lever. The force acts on point *I*; the fulcrum is at point *O* and the load *R* is being lifted from point *B*. *BO* is roughly eight times longer than *IO*. (This drawing is from an ancient book called *Concerning the Motions of Animals* by the 17th-century Florentine scholar Borelli who was the first to apply the laws of mechanics to physiology.)