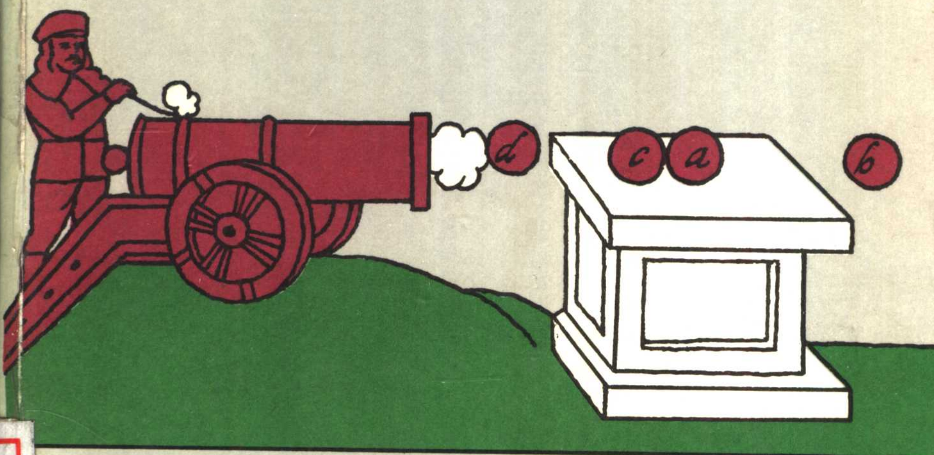
Book 1

Physics for Everyone

L. D. Landau, A. I. Kitaigorodsky



PHYSICAL BODIES

Mir Publishers Moscow

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Book 1

ИЗДАТЕЛЬСТВО · МИР ·

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Физика для всех
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PREFACE TO THE FOURTH RUSSIAN EDITION

After many years I decided to return to an unfinished book that I wrote together with Dau, as his friends called the remarkable scientist and great-hearted man Lev Davidovich Landau. The book was *Physics for Everyone*.

Many readers in letters had reproached me for not continuing the book. But I found it difficult because the book was a truly joint venture.

So here now is a new edition of *Physics for Everyone*, which I have divided into four small books, each one taking the reader deeper into the structure of matter. Hence the titles *Physical Bodies*, *Molecules*, *Electrons*, and *Photons and Nuclei*. The books encompass all the main laws of physics. Perhaps there is a need to continue *Physics for Everyone* and to devote subsequent issues to the basics of various fields of science and technology.

The first two books have undergone only slight changes, but in places the material has been considerably augmented. The other two were written by me.

The careful reader, I realize, will feel the difference. But I have tried to preserve the presentation principles that Dau and I followed. These are the deductive principle and the logical principle rather than the historical. We also felt it would be well to use the language of everyday life and inject some humour. At the same time we did not oversimplify. If the reader wants to fully understand the subject, he must be prepared to read some places many times and pause for thought.

The new edition differs from the old in the following way. When Dau and I wrote the previous book, we viewed it as a kind of primer in physics; we even thought it might compete with school textbooks. Reader's comment and the experience of teachers, however, showed that the users of the book were teachers, engineers, and school students who wanted to make physics their profession. Nobody considered it a textbook. It was thought of as a popular science book intended to broaden knowledge gained at school and to focus attention on questions that for some reason are not included in the physics syllabus.

Therefore, in preparing the new edition I thought of my reader as a person more or less acquainted with physics and thus felt freer in selecting the topics and believed it possible to choose an informal style.

The subject matter of *Physical Bodies* has undergone the least change. It is largely the first half of the previous edition of *Physics for Everyone*.

Since the first book of the new edition contains phenomena that do not require a knowledge of the structure of matter, it was natural to call it *Physical Bodies*. Of course, another possibility was to use, as is usually done, the title *Mechanics* (i.e. the science of motion). But the theory of heat, which is covered in the second book, *Molecules*, also studies motion except that what is moving is the invisible molecules and atoms. So I think the title *Physical Bodies* is a better choice.

Physical Bodies deals largely with the laws of motion and gravitational attraction. These laws will always remain the foundation of physics and for this reason of science as a whole.

September 1977

A. I. Kitaigorodsky

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原书缺页

done in ancient times; the very names of the units testify to this: for example, an "ell" or "cubit" is the distance between the elbow and the fingertips of a stretched-out hand, an "inch" is the width of a thumb at its base. The foot was also used for measurement—hence the name of the length "foot".

Although these units of measurement are very convenient in that they are always part of oneself, their disadvantages are obvious: there are just too many differences between individuals for a hand or a foot to serve as a unit of measurement which does not give rise to controversy.

With the development of trade, the need for agreeing on units of measurement arose. Standards of length and mass were at first established within a separate market, then for a city, later for an entire country and, finally, for the whole world. A standard is a model measure: a ruler, a weight. Governments carefully preserve these standards, and other rulers and weights must be made to correspond exactly to them.

The basic measures of weight and length in tsarist Russia—they were called the pound and the arshin—were first made in 1747. Demands on the accuracy of measurements increased in the 19th century, and these standards turned out to be imperfect. The complicated and responsible task of creating exact standards was carried out from 1893 to 1898 under the guidance of Dmitri Ivanovich Mendeleev. The great chemist considered the establishment of exact standards to be very important. The Central Bureau of Weights and Measures, where the standards are kept and their copies made, was founded at the end of the 19th century on his initiative.

Some distances are expressed in large units, others in smaller ones. As a matter of fact, we wouldn't think of expressing the distance from Moscow to Leningrad in centimetres, or the mass of a railroad train in grams.

People therefore agreed on definite relationships between large and small units. As everyone knows, in the system of units which we use, large units differ from smaller ones by a factor of 10, 100, 1000 or, in general, a power of ten. Such a condition is very convenient and simplifies all computations. However, this convenient system has not been adopted in all countries. Metres, centimetres and kilometres as well as grams and kilograms are still used infrequently in England and the USA in spite of the obviousness of the metric system's conveniences.*

In the 17th century the idea arose of choosing a standard which exists in nature and does not change in the course of years and even centuries. In 1664 Christiaan Huygens proposed that the length of a pendulum making one oscillation a second be taken as the unit of length. About a hundred years later, in 1771, it was suggested that the length of the path of a freely falling body during the first second be regarded as the standard. However, both variants proved to be inconvenient and were not accepted. A revolution was necessary for the emergence of the modern units of measurement—the Great French Revolution gave birth to the kilogram and the metre.

In 1790 the French Assembly created a special commission containing the best physicists and mathematicians for the establishment of a unified system of measurements. From all the suggested variants of a unit of length, the commission chose one-ten-millionth of the Earth's meridian quadrant, calling this unit the *metre*.

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*The following measures of length were officially adopted in England: the nautical mile (equals 1852 m); the ordinary mile (1609 m); the foot (30.48 cm), a foot is equal to 12 inches; an inch is 2.54 cm; a yard, 0.9144 m, is the "tailors' measure" used to mark off the amount of material needed for a suit.
In Anglo-Saxon countries, mass is measured in pounds (454 g). Small fractions of a pound are an ounce (1/16 pound) and a grain (1/7000 pound); these measures are used by druggists in weighing out medicine.

Its standard was made in 1799 and given to the Archives of the Republic for safe keeping.

Soon, however, it became clear that the theoretically correct idea about the advisability of choosing models for our measures by borrowing them from nature cannot be fully carried out in practice. More exact measurements performed in the 19th century showed that the standard made for the metre is approximately 0.08 of a millimetre shorter than one-forty-millionth of the Earth's meridian. It became obvious that new corrections would be introduced as measurement techniques developed. If the definition of the metre as a fraction of the Earth's meridian were to be retained, it would be necessary to make a new standard and recalculate all lengths anew after each new measurement of the meridian. It was therefore decided after discussions at the International Congresses of 1870, 1872 and 1875 to regard the standard of the metre, made in 1799 and now kept at the Bureau of Weights and Measures at Sèvres, near Paris, rather than one-forty-millionth of a meridian, as the unit of length.

Together with the metre, there arose its fractions: one-thousandth, called the *millimetre*, one-millionth, called the *micron*, and the one which is used most frequently, one-hundredth—the *centimetre*.

Let us now say a few words about the *second*. It is much older than the centimetre. There were no disagreements in establishing a unit for measuring time. This is understandable: the alternation of day and night and the eternal revolution of the Sun suggest a natural means of choosing a unit of time. The expression "determine time by means of the Sun" is well known to everyone. When the Sun is high up in the sky, it is noon, and, by measuring the length of the shadow cast by a pole, it is not difficult to determine the moment when it is at its summit. The same instant of the next day can be marked off in the same way. The interval of time which elapses constitutes a day. And the further division of a day into hours, minutes and seconds is all that remains to be done.

The large units of measurement—the year and the day—were given to us by nature itself. But the hour, the minute and the second were devised by man.

The modern division of the day goes far back to antiquity. The sexagesimal, rather than the decimal, number system was prevalent in Babylon. Since 60 is divisible by 12 without any remainder, the Babylonians divided the day into 12 equal parts.

The division of the day into 24 hours was introduced in Ancient Egypt. Minutes and seconds appeared later. The fact that 60 minutes make an hour and 60 seconds make a minute is also a legacy of Babylon's sexagesimal system.

In Ancient Times and the Middle Ages, time was measured with the aid of sun dials, water clocks (by the amount of time required for water to drip out of large vessels) and a series of subtle but rather imprecise devices.

With the aid of modern clocks it is easy to convince oneself that the duration of a day is not exactly the same at all times of the year. It was therefore stipulated that the average solar day for an entire year would be taken as the unit of measurement. One-twenty-fourth of this yearly average interval of time is what we call an hour.

But in establishing units of time—the hour, the minute and the second—by dividing the day into equal parts, we assume that the Earth rotates uniformly. However, lunar-solar ocean tides slow down, although to an insignificant degree, the rotation of the Earth. Thus, our unit of time—the day—is incessantly becoming longer.

This slowing down of the Earth's rotation is so insignificant that only recently, with the invention of atomic clocks measuring intervals of time with great accuracy—up to a millionth of a second—has it become possible to measure it directly. The change in the length of a day amounts to 1-2 milliseconds in 100 years.

But a standard should exclude, when possible, even such an insignificant error. On p. 20 we shall show how this is done.

Weight and Mass

Weight is the force with which a body is attracted by the Earth. This force can be measured with a spring balance. The more the body weighs, the more the spring on which it is suspended will be stretched. With the aid of a weight taken as the unit it is possible to calibrate the spring—make marks which will indicate how much the spring has been stretched by a weight of one, two, three, etc., kilograms. If, after this, a body is suspended on such a scale, we shall be able to find the force (gravity) of its attraction by the Earth, by observing the stretching of the spring (Figure 1.1*a*). For measuring weights, one uses not only stretching but also contracting springs (Figure 1.1*b*). Using springs of various thickness, one can make scales for measuring very large and also very small weights. Not only coarse commercial scales are constructed on the basis of this principle but also precise instruments used for physical measurements.

A calibrated spring can serve for measuring not only the force of the Earth's attraction, i.e. weight, but also other forces. Such an instrument is called a dynamometer, which means a measurer of forces. You may have seen how a dynamometer is used for measuring a person's muscular force. It is also convenient to measure the tractive force of a motor by means of a stretching spring (Figure 1.2).

The weight of a body is one of its very important properties. However, the weight depends not only on the body itself. As a matter of fact, the Earth attracts it. And what if we were on the Moon? It is obvious that

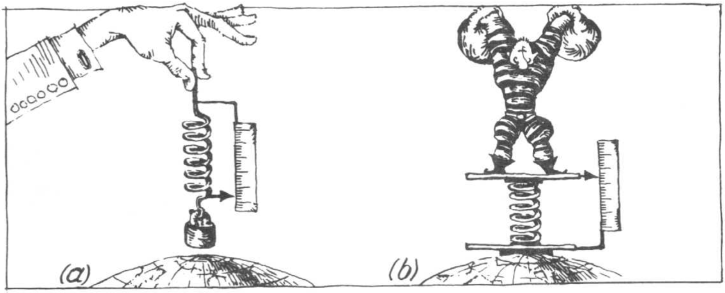

Figure 1.1

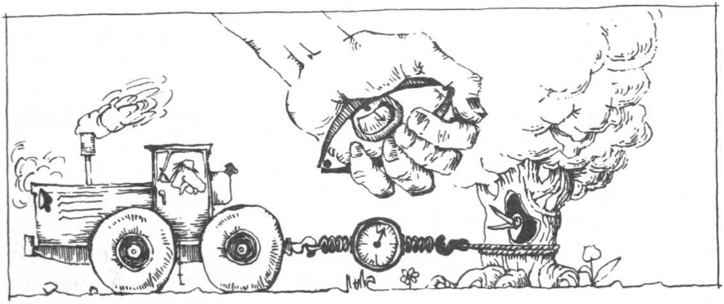

Figure 1.2

its weight would be different—about six times less, as shown by computations. In fact, even on the Earth, weight is different at various latitudes. At a pole, for example, a body weighs 0.5% more than at the equator.

However, for all its changeability, weight possesses a remarkable peculiarity—the ratio of the weights of two bodies remains unchanged under any conditions, as experiments have shown. If two different loads stretch a

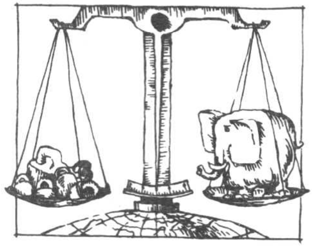

Figure 1.3

spring identically at a pole, this identity is completely preserved even at the equator.

In measuring weight by comparing it with the weight of a standard, we find a new property of bodies, which is called *mass*.

The physical meaning of this new concept—mass—is related in the most intimate way to the identity in comparing weights which we have just noted.

Unlike weight, mass is an invariant property of a body depending on nothing except the given body.

A comparison of weights, i.e. measurement of mass, is most conveniently carried out with the aid of ordinary balance scales (Figure 1.3). We say that the masses of two bodies are equal if the balance scale on whose pans these bodies are placed is in perfect equilibrium. If a load is in equilibrium on a balance scale at the equator, and then the load and the weights are transported to a pole, the load and the weights change their weight identically. Weighing at the pole will therefore yield the same result: the scale will remain balanced.

We can even verify this state of affairs on the Moon. Since the ratio of bodies' weights will not change there either, a load placed on a scale will be balanced by the same weights there. The mass of a body remains the same no matter where it is.

Units of mass and weight are related to the choice of