

Table 1. Masses of Some Common Objects

<i>A. Masses Found on the Balance</i>		<i>B. Some Masses Found by Other Means</i>	
Object	Mass	Object	Mass
A check mark written in pencil	≈ a microgram	A house	≈ 200 tons
A fly wing	50 micrograms	S.S. Queen Elizabeth	several times 10 ⁴ tons
A postage stamp	20 milligrams	Mt. Whitney	≈ 10 ¹² tons
A dime	2.5 grams	The moon	7.35 × 10 ²² kilograms
A nickel	5.0 grams	The earth	5.98 × 10 ²⁴ kilograms
A silver dollar	25 grams	The sun	1.99 × 10 ³⁰ kilograms
A paperback book	200 grams	A red corpuscle	10 ⁻¹³ kilograms (10 ⁻⁴ micrograms)
A pound	453.5924277 grams (legal definition)	A bacterial cell	5 × 10 ⁻¹² kilograms (5 × 10 ⁻³ micrograms)
A pint of water*	473 grams	A molecule of egg-white protein	≈ 10 ⁻²² kilograms
A quart of water	≈ 950 grams	A molecule of stearic acid	8.9 × 10 ⁻²⁵ kilograms
One liter of water	10 ³ grams	A molecule of oxygen	5.3 × 10 ⁻²⁶ kilograms
A metric ton	10 ³ kilograms, about one long ton	An electron	9.1 × 10 ⁻³¹ kilograms

* "A pint's a pound, the world around" (to 5%)

part in a million. In Table 1 a list of a few common objects is presented to give you some idea of their masses. A simple form of balance which you can make yourself will easily measure a tenth of a milligram (or 10⁻⁷ kilogram), and the best laboratory microbalances will measure differences as little as 10⁻¹¹ kilogram (Fig. 7-3), though only for postage-stamp loads. Large balances, rigidly built, sometimes using rather more complicated parts than the simple equal-arm device, will give excellent results for masses up to almost a metric ton. On such a balance we can see a person lose mass with every breath, as he "burns" his food and exhales the gases of combustion, and as water evaporates from the pores of his skin.

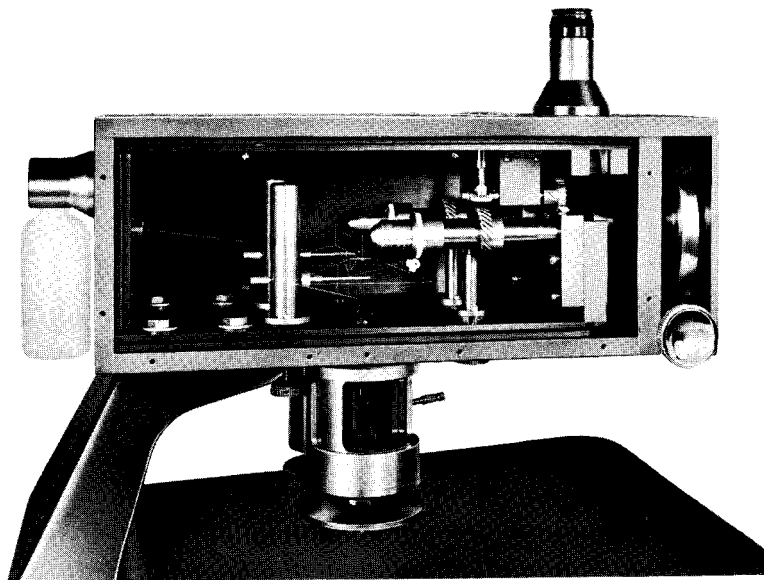
7-3. The Meaning of Mass

The balance is to the measurement of mass what the meter stick is to the measurement of length. It is the direct, defining form of instrument. Gravitational mass is what we measure on the balance; that is its definition. But the balance is not the only means of comparing masses with a standard. We are all able to judge the equality of masses when we "heft" them, one in each hand. Here our senses do not really

perform a balance; we are in fact comparing the set and strain of the muscles of the two hands and arms. We are comparing masses by comparing the relative pull exerted on the two masses by the earth.

We know that the pull of the earth for any given object is not constant. This pull, which we call the weight, varies somewhat from place to place even on the earth's surface. On the moon, we all expect to find the pull toward the surface to be much less than it is on earth, for one and the same chunk of matter. But the shape, the bulk, the physical appearance, and the chemical behavior of that chunk would be unchanged. A hammer, for example, whether it is at home, in the orbiting satellite, or in a lunar station, is the same. It will drive nails into a wall equally well in all three places. Also its mass, defined by a balancing operation, does not change when the hammer is moved to a new location. Unlike the pull toward the ground, the mass remains the same along with the other properties that seem to belong to the hammer itself. Two masses that balance on the earth will also balance anywhere else.

Mass, then, is an unchanging property of a



7-3 (a). An ultra-microbalance. Even the delicate analytical balance is not sufficiently sensitive for some purposes. The balance pictured above, however, is capable of measuring a mass to within 5×10^{-11} kg, although its load is limited to 2×10^{-4} kg. Balances of this type have been made for measuring within 10^{-12} kg, but the maximum load is then decreased to 4×10^{-6} kg. Like a conventional balance, the microbalance consists of a beam supported at the middle with a pan suspended from each end. In this case, however, the beam (the group of fine lines near the center of the picture) is made of light quartz and is supported by a quartz fiber that extends the length of the case.

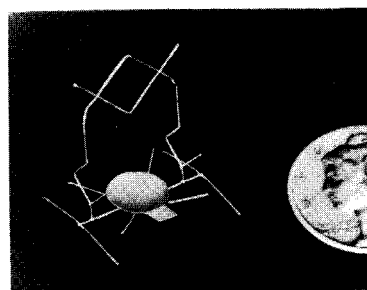
body. The weight of a body — the pull of gravity on it — changes very much indeed when the body is moved from the earth to the moon, or to a satellite. Weight and mass are not the same, and we must be careful not to confuse the two terms. Their relationship will be a topic of Part III. Throughout physics we shall find mass more important than weight.

7-4. Density

The notion of density is a familiar one (Fig. 7-4). Lead is denser than wood. A small volume of lead can have more mass than a larger volume of wood. *Density* is defined as the mass of a sample divided by its volume:

$$\begin{aligned} \text{Density} &= \frac{\text{Mass of sample}}{\text{Volume of sample}} \\ &= \frac{m}{v} \end{aligned}$$

The density of water, for example, is very close to 1 gm/cm^3 or to 1 metric ton (10^3 kg) per cubic meter.



7-3 (b). Some idea of the small size of the quartz-fiber balance can be gained from this photograph, in which one of the pans and its gossamerlike supporting frame are compared with a dime. In use, the pans are suspended in the cylindrical chambers that project below the case as shown at the left. (Photos Courtesy: Microtech Services Co.)

The pans are suspended in the cylindrical chambers projecting below the main case. The mass to be determined is placed on one of the pans. This causes the beam to rotate about its point of support. The beam is then restored to its original position by applying a small amount of twist to the supporting quartz fiber. The amount that the fiber is twisted is recorded on a dial and the mass is then calculated by multiplying the amount of the twist by a constant, known as the calibration factor, that has been determined for the balance. The entire balance is about 40 cm long, 33 cm deep, and 30 cm high. The humidity inside the case is controlled by the device at the left.

7-4. These two mineral specimens — pumice (left) and obsidian, or volcanic glass (right) — are of the same chemical composition and the same mass. Their relative densities are inversely related to their volumes. The obsidian has almost the same density as glass, while the pumice is of such low density that it floats with about 20 per cent of its volume above water. These two materials, which come from volcanic craters, have the same general composition as quartz. The rapidly cooled pumice solidified with spaces in it created by volcanic gases and steam. The slowly cooled obsidian has no spaces.

