2

Volume and Mass

2.1 VOLUME

Suppose that you have some pennies stacked one on top of another in several piles, and that you want to know how many pennies are in each pile. The obvious thing to do is to count them. If you had to count the pennies in many piles, you could speed up the counting in the following way: Make a scale like that shown in Figure 2.1, marking it off in spaces equal to the thickness of one penny. You can then place this scale alongside each pile and read off the number of pennies.

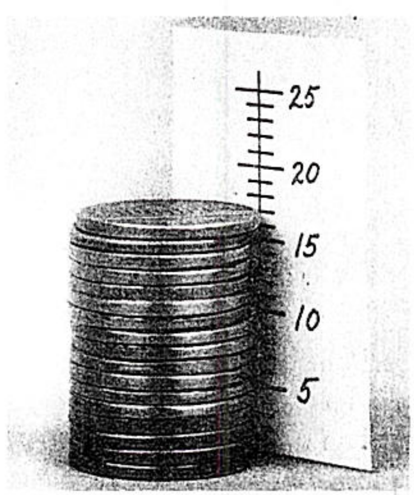

Figure 2.1
A scale for counting the number of pennies in a vertical pile. The distance between marks is the thickness of one penny.

If you want to measure the amount of copper in each pile of pennies, you first have to decide in which unit to measure the amount of copper. If you choose as the unit the amount of copper in one penny, then the amount in the whole pile is expressed by the same number as the number of pennies.

Suppose, now, that you want to find out how much copper there is in a solid rectangular bar of copper. You might think of making a box of the same size and shape as the copper bar and then counting the number of pennies needed to fill the box. This idea will not work, because if you place pennies next to one another in a rectangular box, there will always be some empty space between them.

A better way to measure the amount of copper in the bar is to choose a new unit, such as the volume of a small cube. Suppose

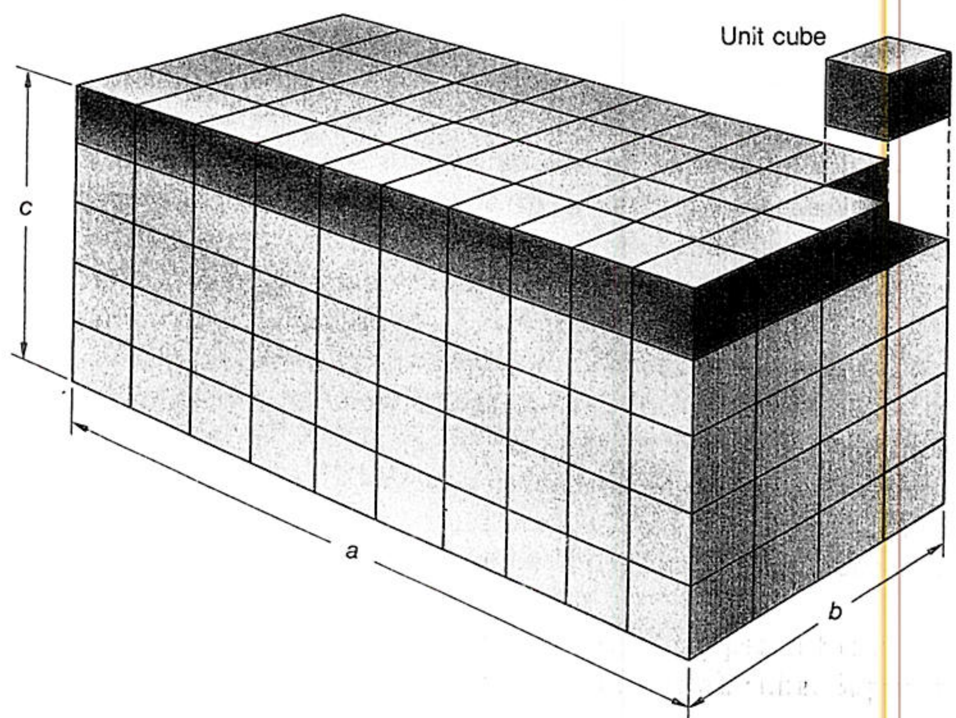

Figure 2.2
A bar of copper 10 cubes long, 4 cubes wide, and 5 cubes high. One layer of the bar contains 10 rows of 4 cubes each, or 10×4 cubes. We see that there are 5 layers in the bar, each containing 10×4 cubes. The total number of unit cubes in the bar is therefore $10 \times 4 \times 5 = 200$ cubes. If the unit cube is 1 cm on an edge, the volume of the bar is 200 cm^3 (cubic centimeters). For any rectangular solid, therefore, the volume is the product of the three dimensions, $a \times b \times c$.

we had a box the same size and shape as the copper bar, and we could fill it with cubes of copper of a size that would fit without air spaces between them. We could simply count the number of cubes to find the amount. Of course, we do not have to count each cube. If *a* cubes fit along the length of the box, *b* along the width, and *c* along the height, then the total number of cubes in the box (and bar) is $a \times b \times c$. (See Figure 2.2.) This is the amount of copper in the solid bar, expressed in units of cubes. As you probably know, this is also the *volume* of the bar, expressed in terms of the volume of the unit cube.

What we choose to be the length of each side of this unit cube is a matter of convenience. We shall choose a unit of length based on the meter (m), the international standard of the metric system. In this case, as in much of our work in this course, we shall use the centimeter (cm). A centimeter is $\frac{1}{100}$ m. Our unit cube would then be the cubic centimeter (cm^3), a small cube 1 cm on an edge.

To sum up, then, we can compare different amounts of the same substance by comparing their volumes—that is, the amounts of space they occupy. When we are dealing with a rectangular solid, we find its volume by measuring its three edges and taking the product of these numbers. We can also calculate the volumes of solids of other regular shapes from measurements of their dimensions, but this requires further knowledge of geometry.

The use of volume to compare amounts of substances is particularly convenient when we deal with liquids, because liquids take the shape of their containers. If we wish to compare the amounts of water contained in two bottles of very

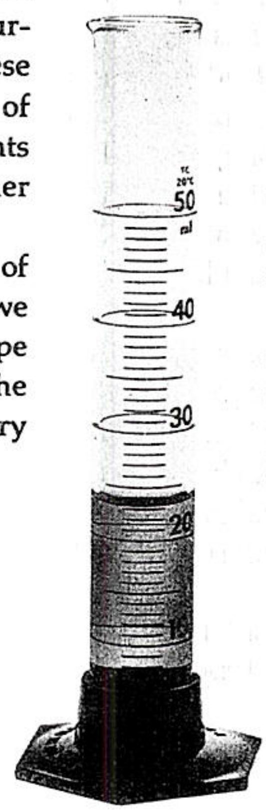

Figure 2.3
A graduated cylinder marked off in units of volume. The cubic-centimeter marks could be made by filling the cylinder with liquid from a small cubic container, 1 cm on an edge, and making a mark at the liquid level each time a containerful of the liquid is poured in. Many graduated cylinders are marked off in milliliters (ml). A milliliter is the same as a cubic centimeter.

different shapes, we simply pour the contents of each separately into a graduated cylinder that has already been marked off with the desired units; we then read off the volumes (Figure 2.3). This way of measuring volume is very much like counting pennies all stacked up in a pile.

We can use the property of a liquid to take any shape when we want to find the volume of a solid of irregular shape, such as a small stone. After pouring some water into a graduated cylinder and reading its volume, we can submerge the stone in the water and read the combined volume of the water and the stone. The difference between the two readings is the volume of the stone.

1† A student has a large number of cubes that measure 1 cm along an edge. If you find it helpful, use a drawing or a set of cubes to answer the following questions.

a) How many cubes will be needed to build a cube that is 2 cm along an edge?

b) How many cubes will be needed to build a cube that is 3 cm along an edge?

c) Express, in cubic centimeters, the volumes of the cubes built in (a) and (b).

2 One rectangular box is 30 cm long, 15 cm wide, and 10 cm deep. A second rectangular box is 25 cm long, 16 cm wide, and 15 cm deep. Which box has the larger volume?

3 Figure A shows a cone-shaped graduate used for measuring the volume of liquids. Why are the divisions not equally spaced?

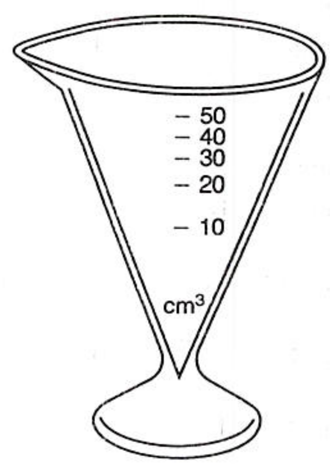

Figure A
For problem 3

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† Answers to problems marked with a dagger are found on pages 293–295.

2.2 READING SCALES

To measure length with a ruler, volume with a graduated cylinder, and temperature with a thermometer, you must be able to read a scale. Therefore, learning how to get all the information a scale can provide is a useful skill.

We shall begin with reading a metric ruler (Figure 2.4). The smallest divisions on such a ruler are 0.1 cm (1 mm) apart. This is a small distance indeed. Nevertheless, when the object you wish to measure has sharp edges, you can see whether the edge falls on one of the lines.

In Figure 2.5, the edge falls between two lines. It is clear that the length is between 4.8 cm and 4.9 cm. To gain more information, estimate the position of the edge. If you cannot tell whether the edge is closer to one line or the other, it is best to report the reading as 4.85 cm, or 48.5 mm.

If the edge is closer to the left line, report the reading as 4.82 cm or 4.83 cm. Either way, you will not be off by more than ±0.02 cm. (The notation ± means "plus or minus.") Similarly, if you decide that the edge is closer to the right line, report the reading as 4.87 cm or 4.88 cm. Again, you will not be off by more than ±0.02 cm. Had you read the scale as 4.8 cm or 4.9 cm, you might have been off by as much as 0.05 cm.

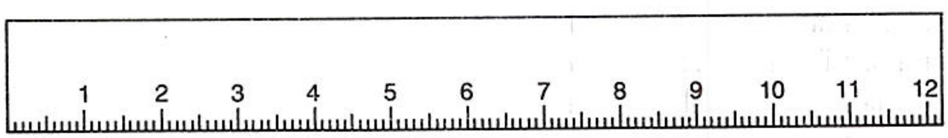

Figure 2.4
A metric ruler. The numbered divisions are centimeters; the small divisions are $\frac{1}{10}$ cm, or millimeters.

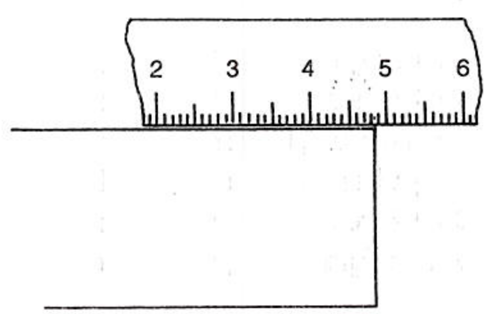

Figure 2.5
Reading the position of the edge of an object. Here the edge falls between two of the millimeter marks.

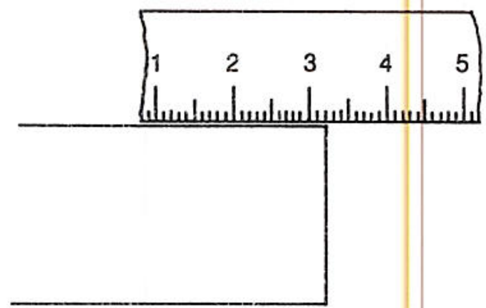

Figure 2.6
Reading the position of the edge of an object. Here the edge falls on one of the millimeter marks.

Suppose that, as far as you can tell, the edge falls on a line (Figure 2.6). Then you should report the reading as 3.20 cm. This will indicate that the reading is closer to 3.20 cm than to either 3.22 cm or 3.18 cm. Here the "0" gives us information that would be lost had you written only 3.2 cm.

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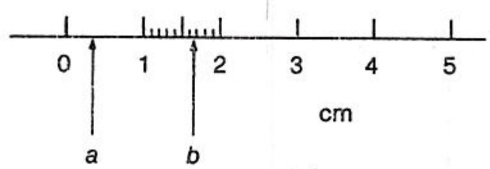
4 The scale in Figure B is in centimeters. Estimate the positions of arrows *a* and *b* to the nearest 0.1 cm. Can you estimate their positions to 0.01 cm? To 0.001 cm?

Figure B
For problem 4



5† What fractions of a cubic centimeter do the smallest divisions on each of the graduated cylinders in Figure C represent?

Figure C
For problem 5

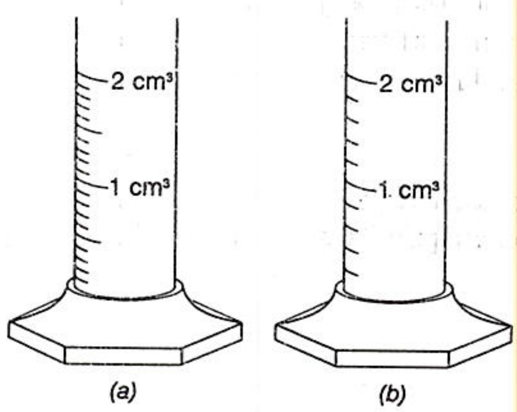
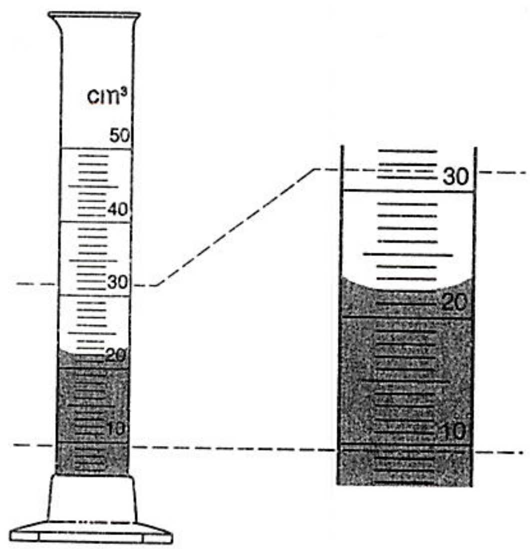


Figure D
For problem 6



6 **A close look at Figure D shows that the top of the liquid contained in the graduated cylinder is not flat but curved. How do you decide how much water is in the cylinder?**

7 **Three students reported the length of a pencil to be 12 cm, 12.0 cm, and 12.00 cm. Do all three readings contain the same information?**

8 **What advantage is there to making graduated cylinders narrow and tall rather than short and wide?**

2.3 EXPERIMENT MEASURING VOLUME BY DISPLACEMENT OF WATER

A granular solid like sand, although it does not flow as well as a liquid, can be measured by the same method. Suppose we have some sand in a cup. We can find how much space it takes up in the cup by simply pouring it into a graduated cylinder. But does the mark it comes to on the scale of the cylinder really show the volume of the sand? What about the air spaces between the loosely packed grains? The graduated cylinder really measures the combined volume of the sand plus the air spaces. However, we can do a simple experiment to find the volume of the sand alone.

Pour some sand into a dry graduated cylinder until it is about two-thirds full.

- What is the volume reading on the scale?

Now pour the sand into a beaker, and pour water into the graduated cylinder until it is about one-third full. Record the volume of the water, and then add the sand to the water.

- What is the volume of sand plus water?
- What is the volume of the sand alone?
- What is the volume of the air space in the sand?
- What fraction of the dry sand is just air space?

The experiment you have just done shows that we must be careful when we talk about the volume of a sample of a dry substance like sand. We must say how the volume was measured. If we

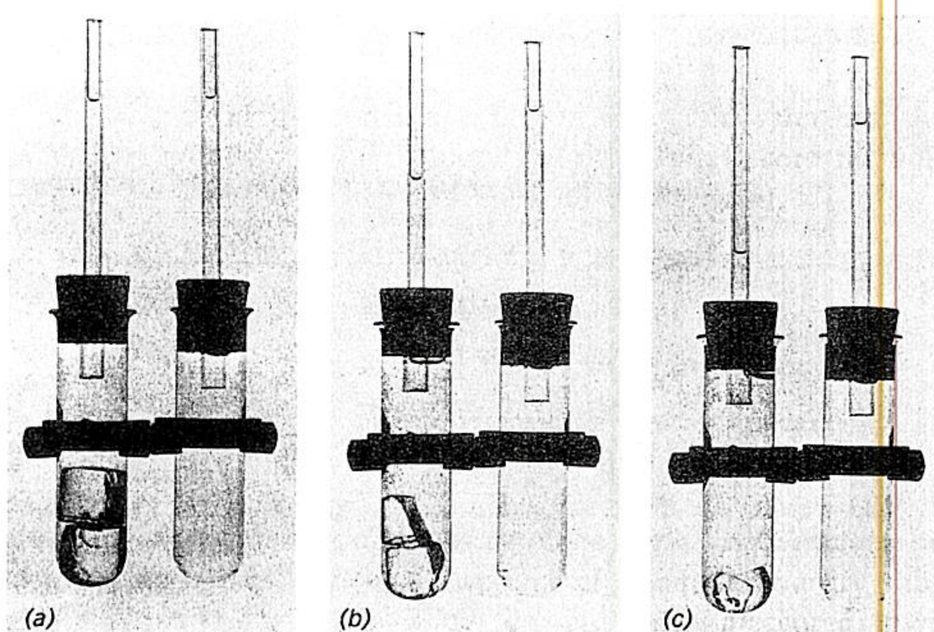


Figure 2.7
(a) A test tube containing only water and another test tube containing water to which two large pieces of rock salt have just been added. *(b)* The same test tubes 30 minutes later, after the salt has begun to dissolve. Notice the decrease in the total volume of the rock salt and water, as shown by the water level in the narrow glass tube. The test tube containing the salt was shaken several times to speed up the dissolving. *(c)* The test tubes after another 30 minutes. The total volume continues to decrease as more salt dissolves.

have a bag of dry sand and want to know how many quart bottles it will fill, we need to know its volume dry. But if we want to know the volume of sand alone, not sand plus air space, then we must do an experiment like the one you have just done. We must measure the volume by liquid displacement.

Whenever we measure the volume of a solid by displacement of water, we make the assumption that the volumes of the solid alone and of the water alone add up to the volume of the solid and water together. This assumption may or may not be correct. This will depend on the kind of solid we have. For example, if you measure the volume of a few chunks of rock salt by the displacement of water, you will see that the total volume of rock salt and water becomes less as the salt dissolves. (See Figure 2.7.)

9† A volume of 50 cm^3 of dry sand is added to 30 cm^3 of water for a total volume of 60 cm^3.

a) What is the volume of water that does *not* go into air spaces between the sand particles?

b) What is the volume of water that does fill air spaces between the sand particles?

c) What is the volume of the air spaces between the particles in the dry sand?

d) What is the volume of the sand particles alone?

e) What fraction of the total volume of the dry sand is sand particles?

10 How would you measure the volume of granulated sugar?

11 How would you measure the volume of a cork stopper?

2.4 SHORTCOMINGS OF VOLUME AS A MEASURE OF MATTER

The experiment shown in Figure 2.7 strongly suggests that volume is not always a good measure of the amount of a substance. Here are some other difficulties: Suppose you wanted to find the amount of gas given off in your distillation of wood. You could measure the volume of gas you produced by filling bottles (displacing the water in them) until no more gas was left. You could thus use one bottle as a unit of volume and express the volume as so many bottles of gas. Or you could collect the gas in inverted water-filled graduated cylinders instead of bottles and express the volume in cubic centimeters.

But if you have ever pumped up a bicycle tire with air, you know that a gas is very compressible. You know that, as you push more and more gas into the tire, its volume remains almost unchanged. Does this mean that the amount of gas in the tire remains almost unchanged, too? If you compressed the gas obtained from the distillation of wood into a smaller volume, would there be less of it?

Finally, can we really use volume to compare the amounts of different substances, some of which may be solids, some liquids, and others gases? Consider again the distillation of wood. Does measuring the volume of the wood splints, the ashes, the liquids, and the gas really tell us how much of each of these substances we have?

2.5 MASS

The limitations of volume as a measure of the amount of matter must have been known to people many centuries ago because they developed a method for measuring the amounts of different substances independently of their volumes. From an Egyptian tomb several thousand years old, archaeologists have recovered a little balance arm of carved stone, with carefully made stone masses (Figure 2.8). It was almost surely used, in the very dawn of history, for the careful measurement of gold dust. Goldsmiths knew even then that the balance was the best way to determine the amount of solid gold they could get from any heap of dust or from any pile of irregularly shaped nuggets.

The balance was hung by the upper loop so that the horizontal bar was divided exactly into two arms of equal length. With no objects suspended from either arm, the balance bar would hang horizontally. When an object was hung from the loop on the end of one arm, it could be balanced by hanging some other objects from the end of the other arm.

No doubt, in using the balance, people soon learned that the bar would remain horizontal even though there were drastic changes in the shapes of the objects being balanced. Dividing a

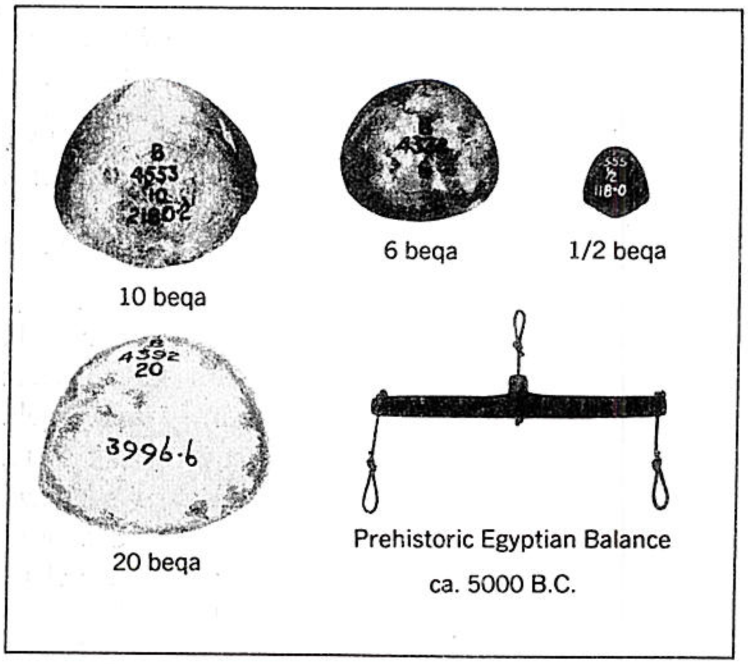


Figure 2.8
This balance, the earliest one known, comes from a prehistoric grave at Naqada, Egypt, and may be 7,000 years old. It uses limestone masses and has a red limestone beam which is 8.5 cm long. (The limestone masses and beam are not shown to the same scale.) Other limestone masses of different numbers of *beqa* (BEK-ah) were also found in these prehistoric graves. Is there any reason why you should not use the *beqa* as your unit of mass? *(Courtesy of Science Museum, London)*

chunk of iron into a number of pieces or filing it into a pile of small grains does not affect the balance. A balance responds to something quite independent of the form of the object. What it responds to we call "mass."

Suppose a piece of gold balances a piece of wood, and the piece of wood balances a piece of brass. Then we say that the masses of all three are equal. If something else balances the piece of brass, it also balances the wood and the gold and therefore has the same mass. The equal-arm balance gives us a way of comparing masses of objects of any kind, regardless of their shape, form, color, or what substance they are made of.

To record masses, we shall need some standard masses with which various other pieces of matter can be compared. This standard mass is arbitrary—any mass, even the ancient Egyptian *beqa*, can be chosen—but people must agree on it. In our work we shall use the gram (g), the fundamental unit of mass in the metric system. The international standard of mass in the metric system is a carefully made cylinder of platinum kept at Sèvres, near Paris, France, that has a mass of 1 kilogram (kg), or 1,000 g. All other kilogram masses are compared, directly or indirectly, with the standard whenever high precision is required. If we were to place a mass of 1 kg on the grocer's scale, the scale would read 2.2 pounds.

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12 When you buy things at the store, are they measured more often by volume or by mass? Give some examples.

13 What is your mass in kg?

2.6 EXPERIMENT THE EQUAL-ARM BALANCE

In later experiments, you will often use an equal-arm balance. The purpose of this experiment is to make you familiar with it and to allow you to develop the necessary skill in using it (Figure 2.9).

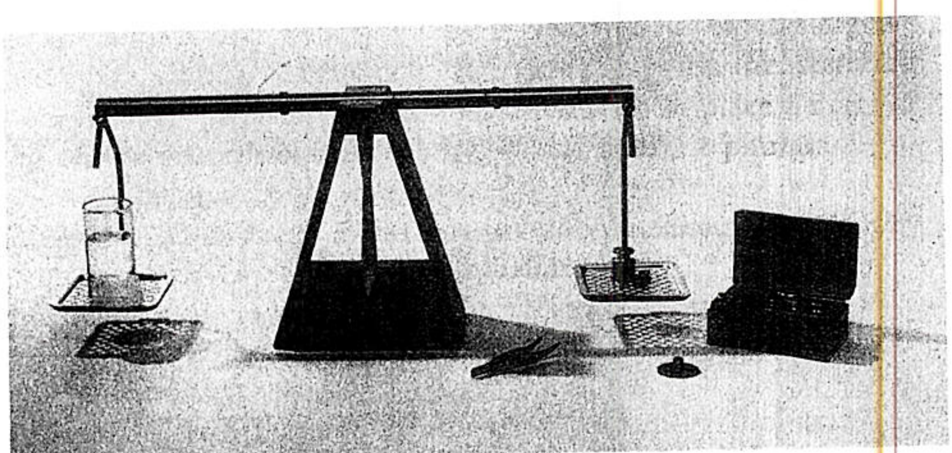

Figure 2.9
An equal-arm laboratory balance like the one you will use in your experiments. The object to be massed is placed on the pan at the left, and the standard gram masses are placed on the one at the right. The tip of the pointer hangs vertically down over the scale in the middle of the base.

Make sure that the pans swing freely and that the vertical pointer in the center does not rub against the support. The pointer of the balance should swing very nearly the same distance on each side of the center of the scale when there is nothing on either pan. In order to adjust the balance so that it swings in this manner, first make sure that the pointed metal rider on the right arm is as near to the center of the balance as possible. Then move the rider on the left arm until the long pointer on the center of the balance swings the same distance on each side of the center of the scale on the bottom of the balance.

Your balance comes with a set of masses, the smallest of which is 100 mg (1 mg, a milligram, is equal to 0.001 g. Thus 100 mg = 0.100 g). Now that your balance is adjusted, use a set of gram masses to mass several objects of between 1 and 20 grams. (We shall abbreviate "to find the mass of" to the verb "to mass.")

Exchange objects with your classmates, and compare your measurements with theirs. Do not divulge your measurements until all students have recorded their measurements.

2.7 EXPERIMENT CALIBRATING THE BALANCE

Look carefully at several pennies. Do you think they all have the same mass? Would you expect them to differ a little in mass? Now measure the masses of the pennies on your balance. Record the mass of each penny in a table in your notebook, and be careful to keep track of which penny is which.

You have massed the pennies only to the nearest 0.1 g. How can they be massed to less than 0.1 g to see if there are tiny differences in their masses, smaller than 0.1 g? By using the rider on the right arm of the balance, you can measure masses to less than 0.1 g. Move the rider until it balances a 0.1-g mass placed on the left-hand pan, and mark its position on the arm. Now make pencil marks on the arm, dividing into 10 equal spaces the distance between the 0-g and the 0.1-g position of the rider. Each mark represents an interval of 0.01 g on this rider scale.

- How can you check to see if this is true?

If your balance has already been calibrated (that is, if there already is a scale marked on it), check to see if it is accurate.

2.10 EXPERIMENT THE MASS OF DISSOLVED SALT

In section 2.3, you learned that as salt dissolves in water, the combined volume of salt plus water decreases. This leads us to ask whether the mass also decreases when salt is dissolved in water.

Pour about 2 g of salt into the cap of a small plastic bottle, and put it carefully aside. Pour water into the plastic bottle until it is about two-thirds full. Find the total mass of the bottle, water, cap, and salt when all are on the balance together but the salt and water are not mixed.

Pour the salt into the bottle, and put the cap on. What is the mass of the capped bottle of salt and water? Shake the bottle occasionally to speed up the dissolving of the salt.

- Taking into consideration the precision of the balance, what do you conclude about the mass of salt and water as the salt dissolves?

Your answer to this question sums up the result of a single experiment. To have more confidence in your conclusion, you would have to repeat the experiment a number of times to check for possible errors. Many repetitions would use up much time and would not be very exciting. So, instead of asking you to repeat this experiment, we shall bring together the results of all the experiments done by the whole class. (We shall follow the same procedure with other experiments.) To see how class results compare and what their significance is, we shall display the mass differences in a histogram. Your teacher will show you how a histogram is made.

- Considering the precision of the balance, and all the results obtained by the class, what does your class conclude about the mass of salt and water as the salt dissolves?

- Can you suggest any reasons why all the members of the class do not get the same mass difference?

19† In Experiment 2.10, how could you recover the dissolved salt? How do you think its mass would compare with the mass of dry salt you started with?

20† If the change in mass of the salt and water solution was −0.0001 g in Experiment 2.10, would you have observed this change using your balance?

2.11 EXPERIMENT THE MASS OF ICE AND WATER

Here is another process involving a volume change. When ice melts, it contracts—its volume decreases. Does its mass also change?

Mass a small container with its cover; then put in an ice cube and mass again.

- What is the mass of the ice?

After all the ice has melted (if the container is not transparent, you can tell by shaking it), mass again.

- Do you notice any condensation of water on the outside of the container?
- If so, what should you do about it?
- What do you conclude about change in mass when ice melts?

2.12 EXPERIMENT THE MASS OF MIXED SOLUTIONS

In the two experiments you have just done, a solid was either dissolved or melted. Now let us ask what happens to the mass when a solid is formed by mixing two liquids.

Your teacher will provide you with samples of two solutions. Find the total mass of the bottles of solution and their caps. Now pour one solution into the same bottle with the other, and cap both bottles. Again find the total mass of both bottles.

- Did the mass change as a result of the mixing?

2.13 EXPERIMENT THE MASS OF COPPER AND SULFUR

The changes you have examined so far were quite mild. A more drastic change in matter takes place when sulfur and copper are heated together. Does the total mass change when these substances are heated together?

Put about 2 g of granular copper and about 1 g of sulfur in a test tube. (CAUTION: Do *not* use copper powder or copper dust. Also, be sure to wear safety glasses.) Close the end with a piece of rubber sheet held in place by a rubber band. Record the total mass of the closed tube. Heat the mixture gently until it begins to glow; then remove the flame immediately. (Let the test tube cool before you touch it.)

- Has the total mass of copper and sulfur changed?

Describe the appearance of the material in the test tube.

- Do you think the substance in the bottom is sulfur, copper, or a new substance?

21† The following data were obtained in an experiment in which copper and sulfur were made to react.

	Mass (g)
Tube and cover	20.484
Tube, cover, copper, and sulfur before reaction	23.440
Tube, cover, and products after reaction	23.386

a) What is the mass of the substances before the reaction?
b) What is the apparent change in mass of the reacting substances?
c) What is the apparent percentage change in mass of the reacting substances?

22 A test tube having 4.00 g of iron and 2.40 g of sulfur was heated in a manner similar to that of the copper-and-sulfur experiment. The total mass of the tube and contents measured on the balance before the heating was 36.50 g. After the heating, its mass was measured again. The mass of the tube and contents was 36.48 g.
a) Are you inclined to think it reasonable that mass remained the same—was conserved—during this experiment?
b) What additional steps would you take to strengthen your inclination?

2.14 EXPERIMENT THE MASS OF A GAS

In this experiment, a solid and a liquid produce a gas. Is there a change in mass?

CAUTION: You have been provided with a small *thick-walled* bottle wrapped with tape. Be sure to use this bottle only, and to wear safety glasses. Fill the bottle one-third full of water, then find the mass of the bottle, its cap, and *one-eighth* of an Alka-Seltzer tablet. Place the piece of tablet in the bottle. Immediately screw the cap on very tightly and place it back on the balance.

- Does what happens inside the bottle affect the mass of the bottle and its contents?

Slowly loosen the cap.

- Can you hear gas escaping?

Again mass the cap, the bottle, and its contents.

- What do you conclude?

2.15 THE CONSERVATION OF MASS

What have the last five experiments shown? If you have worked carefully, you have found that all the changes in mass that you observed were within the experimental error of your equipment. Therefore, your results agree with the conclusion that there was no change in mass that you could measure. From these experiments alone, you cannot predict with certainty that there will be no change in mass under other circumstances. For example, if we use larger amounts of matter in our experiments and use a balance of higher accuracy, we might measure a change greater than the range of experimental error. Then we would conclude that mass really does not remain the same. Furthermore, although we checked five rather different kinds of change, there is an endless variety of other reactions we could have tried, some even more violent than the reaction of copper and sulfur.

What would happen, for example, if we set off a small explosion inside a heavy steel case, making sure no mass escapes? The experiments you have done give no direct answer to this question. But we can make the guess that the results of these five experiments can be generalized in the following way: In all changes, mass is exactly conserved, provided nothing is added (like the water that condensed on the outside of the closed container in the experiment with ice and water) or allowed to escape (like the gas in the last experiment). This generalization is known as the law of conservation of mass. It has been checked to one part in a billion* for a large variety of changes. That is, experiments have been done in which a change in mass of one billionth of the total mass would have been observed if it had occurred.

Still, all this vast amount of evidence in favor of the law of conservation of mass does not prove that it will hold forever under all conditions. Surely, if someone claimed that he or she had done an experiment in which as much as one-millionth of the mass disappeared or was created, we should treat the results with great suspicion. First of all, we should make many checks to determine whether there had been a leak of some sort in the apparatus from which, say, gas could escape. The chances are that we should find such a leak. On the other hand, if an experiment were done in which a change in mass of one part in 100 billion was reported, we might have to conclude after a thorough examination of the experiment that the law of conservation of mass has its limitations, that it holds to one part in a billion but not to one part in 100 billion (10^{11}).

We have seen in this chapter that volume is very often a convenient way of measuring the quantity of matter. But we have also found out that, when matter changes form (when ice melts, salt dissolves, and so on), there is often an easily measurable change in volume but no observable change in mass: mass is conserved. It is the conservation of mass that makes mass such a useful measure of matter.

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23 You wish to find your dog's mass, but the dog does not want to stand on the platform of the bathroom scale. You take the dog in your arms and stand on the scale; the mass indicated is 63 kg. Then you stand alone on the scale; the mass indicated is 55 kg.

a) What is the mass of your dog?

b) Give your reasoning.

24 a) Express the following numbers in powers of 10.

100 10,000 100,000,000

b) Write the following numbers without using exponents.

10^5 10^6 10^9

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*A billion is 1,000,000,000. Such a number is clumsy to write. Most of the zeros can be dispensed with by writing the number as 10^9 and reading it "ten to the ninth." The 9 is called an "exponent" and tells how many times we multiply 1 by 10 to get the number. For example, $1 \times 10 \times 10 = 10^2$, $1 \times 10 \times 10 \times 10 = 10^3$, and so on. We shall use this way of expressing numbers, called "powers-of-10 notation," whenever it is convenient. See the Appendix on pages 239–244 for further information.

c) **Express the following numbers in powers of 10.**
1,000   5,280   93,000   690,000

d) **Write the following numbers without using exponents.**
5.0×10^3 10^7 1.07×10^2 4.95×10^4

2.16 LAWS OF NATURE

The law of conservation of mass is the first of several laws of nature that we shall study in this course. It is worthwhile to pause at this point and compare the laws of nature with the laws of our society. Laws of society are legislated; that is, they are agreed upon and then enforced. If evidence is presented that you have broken such a law, you are punished. The laws of society can also be changed or repealed.

Laws of nature are quite different. These are guessed generalizations based on experiments, sometimes crude experiments. If you do an experiment that appears to violate a law of nature, you are not punished. On the contrary, if you present convincing evidence that the law is not quite true, the law is changed to take into account the new experience. Only rarely does this amount to a complete repeal of the law; in most cases the change is a recognition of the limitation of the law.

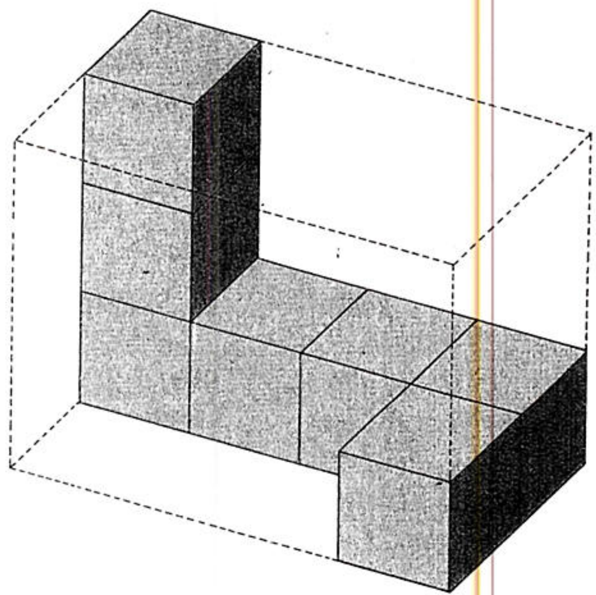
25 **There is an old saying: "What goes up, must come down." Does this express a law of nature? Why, or why not?**

For Home, Desk, and Lab

26 **How would the volume of a piece of glass as measured by displacement of water compare with its volume as measured by displacement of burner fuel?**

27 **In determining the volume of a rectangular box, five cubes were found to fit exactly along one edge, and four cubes to fit exactly along another edge. However, after six horizontal layers had been stacked in the box, a space at the top was left unfilled.**

Figure E
For problem 28



a) If the height of the space was half the length of an edge of a unit cube, what was the volume of the box?
b) If the height of the space was 0.23 of the length of an edge of a unit cube, what was the volume of the box?

28 What is the total number of cubes that will fit in the space enclosed by the dashed lines in Figure E? Is there more than one way to find an answer?

29 In an experiment in which the volume of dry sand is measured by the displacement of water, the sand was slightly wet to begin with. What effect would this have on the volume of air space that was calculated? On the percentage of the volume that was air space?

30 a) How would you measure the volume of a sponge?
b) What have you actually measured by your method?
c) Does this differ from your measurement of the volume of sand?

31 a) Completely fill two small bottles with water. Pour the water into a single larger vessel. Now refill the bottles with the same water. Are they both filled completely?
b) Now do the same thing again, but fill one bottle with water and the other with burner fuel. Compare the total volume of burner fuel and water before and after they were mixed together and poured back into the bottles. Is volume a good measure for the quantity of matter in this case?

32 Fuel oil usually is sold by the gallon, gas for cooking by the cubic

foot, and coal by the ton. What are the advantages of selling the first two by volume and the last by mass?

33 In the following list of ingredients for a recipe, which are measured by volume, which by mass, and which by other means?

1½ pounds ground chuck	pinch of pepper
1 medium-size onion	3 drops Worcestershire sauce
½ cup chopped green pepper	oregano to taste
4 slices day-old bread	3 tablespoons oil
1 teaspoon salt	1 1-pound can tomato sauce

34 a) What is the volume of an aluminum cube whose edges are 10 cm long?
b) What is the mass of the aluminum cube? (One cubic centimeter of aluminum has a mass of 2.7 g.)

35 One cubic centimeter of gold has a mass of 19 g.
a) What is the mass of a gold bar 1.0 cm × 2.0 cm × 25 cm?
b) How many of these bars could you carry?

36 Suppose that you took a balance home. When you were ready to use it, you found that you had forgotten a set of gram masses.
a) How could you make a set of uniform masses from materials likely to be found in your home?
b) How could you relate your unit of mass to a gram?

37 Figure 11.11 (p. 244) shows a sensitive equal-arm balance. Suggest reasons why it is enclosed in a case and why it is used with the sliding front cover closed.

38 You wanted to find the mass of water in a plastic bottle, and you took the following measurements using your equal-arm balance.

Mass of bottle and water	21.48 g
Mass of empty bottle	9.56 g
Mass of water	11.92 g

After you completed your measurements and calculations, you saw that you forgot to set the left-hand rider correctly; the beam was not level when the right-hand rider was on the zero mark and nothing was on the pans of the balance. Must you repeat the measurements to obtain the mass of the water?

39 a) You can compare your standard masses on the equal-arm balance after you have carefully adjusted it. How closely is the 50-g mass equal to the sum of the 20-, 10-, 10-, 5-, 2-, 2-, and 1-g masses? How closely is the 5-g mass equal to the sum of the two 2-g masses and the 1-g mass? You can make other comparisons as well.

b) When you are finding the difference in mass between an empty container and the container filled with liquid, why should you try to use as nearly as possible the same particular masses from your set for both measurements?

40 Suppose you lost the rider for your scale. Try to think of another method, not using a rider, by which you could measure hundredths of a gram.

41 Suppose you balance a piece of modeling clay on the balance. Then you reshape it. Will it still balance? If you shape it into a hollow sphere, will it still balance?

42 Suggest a reason for putting the lid on the small container that you used in studying the mass of ice and water.

43 In Experiment 2.11, would the mass of the container and its contents stay the same if you started with water and froze it? Try it.

44 Estimate in grams the mass of a wristwatch. Now find the mass of a nickel (5¢) on your balance. Estimate the mass of the watch again. Did you change your estimate? Does knowing the mass of a nickel help you to better estimate your own mass? Why?

45 Two astronauts on the moon use an equal-arm balance to find the mass of a specimen of moon rock; the specimen has a mass of 35.83 g. When the astronauts return to earth and mass the specimen once again, will they find that the mass of the rock on earth is more than, equal to, or less than the 35.83 g they measured on the moon?

Themes for Short Essays

1 Suppose you are employed as a technical writer by a company that manufactures graduated cylinders. Printed instructions are to be included in packages sent out by the company. Write instructions telling customers how to use the cylinders correctly to measure the volumes of liquids.

2 A friend wants to use your equal-arm balance during the summer. Write a complete set of instructions for her so that she will be able to do so successfully without anybody being present to help her.