3

Characteristic Properties

3.1 PROPERTIES OF SUBSTANCES AND PROPERTIES OF OBJECTS

How do we know when two substances are different? It is easy enough to distinguish between wood, iron, and rock, or between water and milk; but there are other cases in which it is not so easy. Suppose that you are given two pieces of metal. Both look equally shiny and feel equally hard in your hand. Are they the same metal? Or think of two glasses containing liquids. Both liquids are transparent and have no smell. Are they the same or different?

To answer such questions, we shall have to do things to substances that will reveal differences which are not directly apparent. Merely massing the two pieces of metal will not do. Two objects can be made of different materials and yet have the same mass; think of a 100-g steel cylinder and a 100-g brass cylinder of the kind used as masses on a balance. On the other hand, two objects can have different masses and be made of the same materials: for example, two hammers, both made of steel but one much larger and with a greater mass than the other. Mass is a property of an object; it is not a property of the substance of which the object is made.

To find out if two pieces of metal that look alike are made of the same substance, you may try to bend them. Again, one can be thick and hard to bend, and the other can be thin and easy to bend; yet they can both be made of the same substance. On the other hand, you may find that two pieces of metal of different thicknesses but made of different substances bend with equal ease. Thus, ease of bending is also a property of the object and not of the substance.

If we want to find out whether two objects are made of the same substance or of different ones, we have to look for properties that are characteristic of a substance—that is, properties that do not depend on the amount of the substance or on the shape of the sample. In this chapter we shall concentrate on such properties—those that show differences between substances. These we call "characteristic properties."

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1 State which words in the following descriptions refer to properties of the substances and which refer to properties of the objects.
a) A sharp, heavy, shiny, stainless-steel knife
b) A small chunk of black tar
c) A beautifully carved wooden chair

3.2 EXPERIMENT FREEZING AND MELTING

If you live in a part of the country where it snows in the winter, you know that a big pile of snow takes longer to melt than a small one. Does this mean that the big pile melts at a higher temperature? Let us see whether the temperature at which a sample of a substance melts or freezes is really a characteristic property of the substance. To do so, we shall measure the freezing temperatures of some substances by using samples of different mass. For convenience, we shall use substances that freeze above room temperature.

Fill a test tube one-third to one-half full with moth flakes or with moth nuggets and immerse it in a water bath. Heat the water until the solid in the test tube is completely melted. (Remember to wear safety glasses!) Insert a thermometer into the liquid. Make sure that the solid in the test tube is completely melted before removing the burner. For comparison, it may be interesting also to measure the temperature of the water with a second thermometer. (See Figure 3.1.) While the liquid cools, measure and record both temperatures every half-minute. (Stirring the water will ensure that the temperature will be the same throughout the water.)

In addition, record the temperature of the molten substance just as it begins to solidify. Continue to take readings every half-

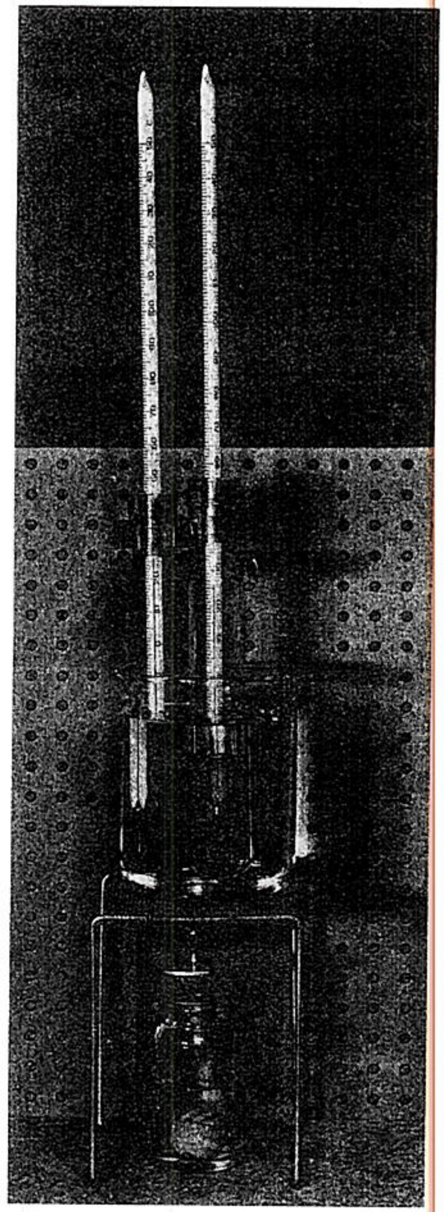


Figure 3.1
Apparatus used to obtain data for the cooling curve of a liquid as it cools and freezes. The thermometer in the test tube measures the temperature of the liquid; the one in the beaker measures that of the water bath. The thermometers are calibrated in degrees Celsius (°C).

minute until the temperature of the substance drops to about 45°C.

- In your table of temperatures and times, do you note any difference in the way the substance and the water cooled?

A better way to display your results is to plot the temperatures as a function of time on graph paper. Draw the graph of the temperatures of the substance and the water using the same axes. Compare your graphs with those of your classmates.

- Do all the graphs have a flat section?
- Does the temperature of the flat section depend on the mass of the cooling materials?
- Do you think that all the samples used in the class were of the same material?

You have now determined the freezing point of a substance by noting the plateau (flat section) in the cooling curve. For some substances the plateau is more easily recognizable than it is for others. Some cooling curves, however, may not have a flat section at

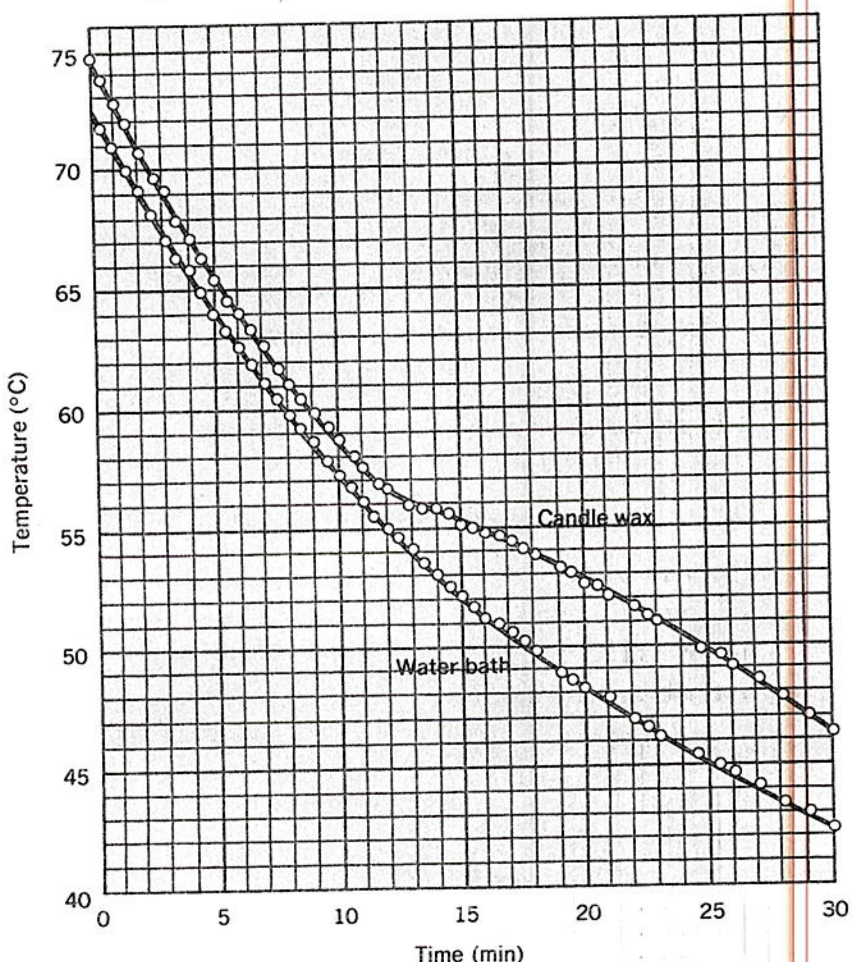


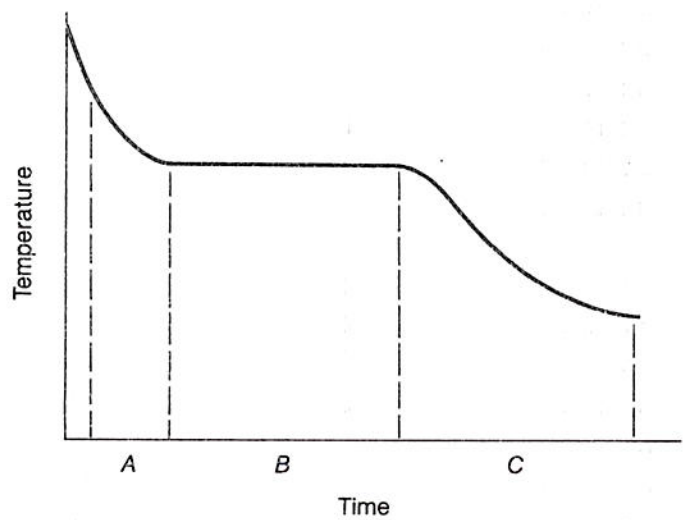
Figure 3.2
The cooling curves of candle wax and of the water bath surrounding the test tube holding the wax. The absence of a flat section in the curve for the wax means that candle wax has no freezing point.

all. For example, look at the cooling curve of candle wax shown in Figure 3.2. The data for this curve were obtained in the same way as in your experiment. The fact that no part of the curve is flat means that candle wax has no freezing point; that is, there is no temperature at which it changes from liquid to hard solid without continuing to cool down during the process. Similarly, as you warm a piece of candle wax in your hand, it becomes softer and softer, but there is no temperature at which it changes from hard solid to liquid without continuing to warm up.

It is harder to measure the melting point of a substance than to measure the freezing point; since we cannot stir a solid, it is necessary to heat it very slowly and evenly. If, however, we do very careful experiments to measure the melting point of a solid by heating it until it melts, we find that we get a curve with the flat portion at exactly the freezing temperature. A solid melts at the same temperature at which its liquid freezes.

2† The graph in Figure A represents data from an experiment on the cooling of paradichlorobenzene. During which time intervals is there (a) only liquid, (b) only solid, and (c) both liquid and solid?

Figure A
For problem 2



3 Water freezes at 0°C. Sketch a graph of temperature versus time for a container of water at 20°C, after it is placed in a freezer at −10°C. Show the temperatures +20°C, 0°C, and −10°C on the vertical axis. Continue the graph until practically no further change will take place in the temperature of the ice.

3.3 EXPERIMENT MICRO-MELTING POINT

In the preceding experiment, the quantities of moth flakes used by different students probably varied between 5 g and 10 g. This is a rather small range of mass. To give you confidence that the melting point is really a characteristic property, it is worthwhile to repeat the experiment with a *much* smaller sample—only a few tiny crystals.

To do this, you need a very small tube closed at one end to hold the crystals. Prepare this tube in the following way: Heat the center of a capillary tube in the alcohol flame. When the center melts, pull the two pieces apart, break off the glass thread, and seal the end of each piece in the flame. Crush between your fingers a small crystal of the material you used in the preceding experiment. Scoop up two or three bits of the smaller pieces in the open end of

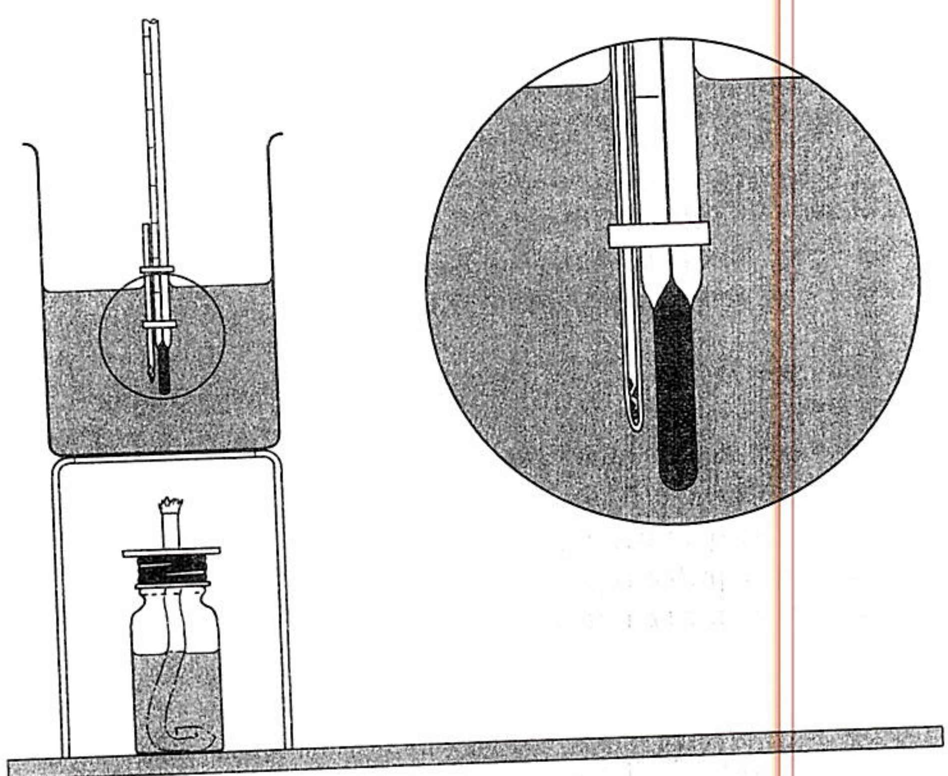


Figure 3.3
The melting point of a few tiny crystals of a substance can be measured by supporting a small capillary tube containing the crystals next to the bulb of a thermometer in a water bath.

one of the capillaries. By gently tapping the sealed end on the desk, you can make the tiny crystals fall to the bottom. Fasten the tube to the side of a thermometer with two rubber bands in such a way that the crystals are next to the thermometer bulb, as shown in Figure 3.3.

Support the thermometer in a beaker that is half-filled with water. Very slowly heat the water, while constantly observing the crystals.

- Should you stir the water during the heating? Why?

Be sure to read the thermometer the *instant* the crystals melt.

- At what temperature do the crystals melt?

You may need to use the other half of the capillary tube to make a second and more careful determination.

- How does the melting point compare with the freezing point you found when you cooled a large mass of the same substance?
- Roughly how many times larger was the large mass than one of the small crystals you melted?
- Does the melting point of a substance depend on the mass of the sample you use when you measure the melting point? Is it a characteristic property?

3.4 EXPERIMENT BOILING POINT

Everybody knows that it takes longer to get a full pan of water to boil than a half-filled one. Does this mean that the full pan gets hotter? To see what happens, heat either 10 cm^3 or 20 cm^3 of a liquid in a test tube in the apparatus shown in Figure 3.4. To prevent uneven boiling, add a few small chips of porcelain to the liquid. The glass and the rubber tubes will prevent vapors from spreading into the room. The vapors will condense in the cooled test tube.

Some of the liquids you will be using may be flammable. To guarantee gentle heating, be sure to use the burner stand as shown

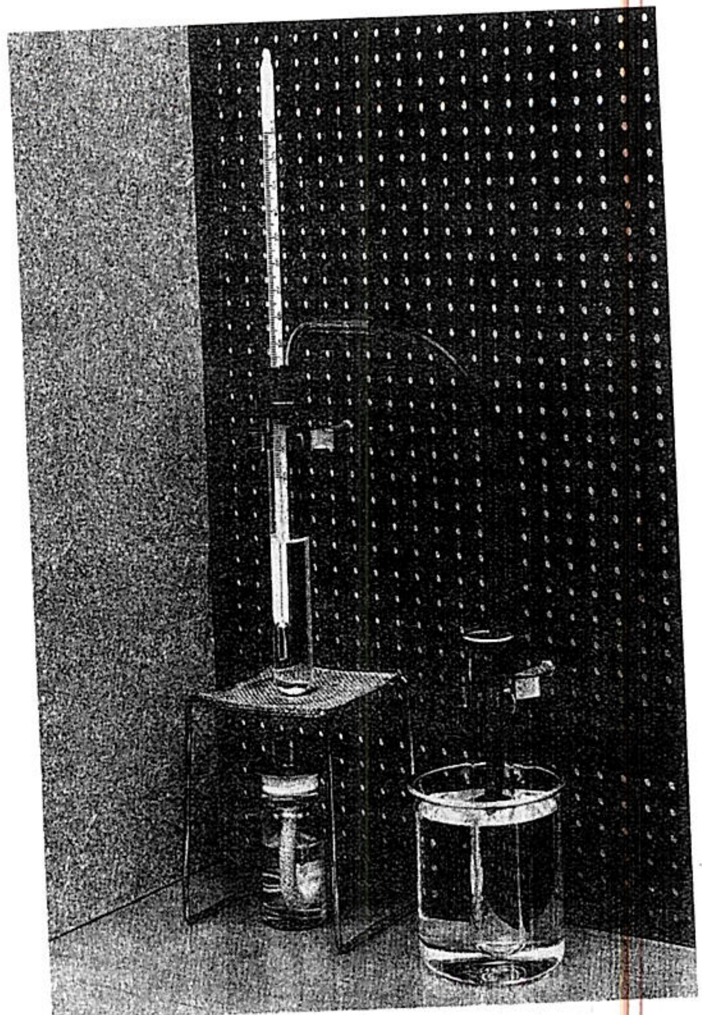


Figure 3.4
A thermometer supported by the cork in a test tube measures the temperature of the liquid as it is heated to its boiling point. To prevent uneven boiling, a few small chips of porcelain are placed in the liquid. The water in the beaker should be cold.

in Figure 3.4. Before you light the burner, remember to put on safety glasses!

Read the temperature of the liquid every half-minute until the liquid has been boiling for about five minutes. Then plot a graph of the temperature of the liquid as a function of time.

Compare your results with those of other students in your class.

- Do all the graphs look alike at the beginning?
- Do all the graphs have a flat section?
- Was the temperature the same in all test tubes once the liquid started boiling?
- What does a difference in boiling point reveal?
- Does the boiling point of a liquid depend on the amount of liquid? Is boiling point a characteristic property?

3.5 DENSITY

Suppose we cut a piece of aluminum rod into sections of equal volume—say, 1 cm^3. We find that they all have the same mass when massed on a balance, no matter from what part of the rod they come. What if we take many 1-cm^3 samples from a bottle of water? We find that each cubic centimeter of water has the same mass. However, the mass of 1 cm^3 of water is different from the mass of 1 cm^3 of aluminum rod. That is to say, the mass of a unit volume of material is the same for all samples of the same substance, but usually differs for different substances. The mass of a unit volume is, therefore, a characteristic property of a material. It can be used to distinguish one substance from another.

Rarely do we measure directly the mass of a unit volume of a sample of a substance. Usually we find that the volume of the sample is either larger or smaller than one unit volume. However, we can find the mass of a unit volume indirectly. We do this by measuring both the sample's mass and its volume. We then calculate the mass of one unit volume by dividing its mass by its volume. For example, consider a 30-g sample whose volume is 10 cm^3. The mass of 1 cm^3 of the material will be 30 g/10 = 3.0 g. Since each unit volume of a sample of a substance has the same mass, this indirect procedure will always give the same value for the mass of a unit volume as we would get by massing a sample whose volume is, in fact, one unit volume.

Because we generally find the mass of a unit volume by dividing mass by volume, we refer to it as mass *per* unit volume. (The word "per" means a division by the quantity that follows it. For example, the speed of a car is stated in miles *per* hour—that is, distance divided by time.) The mass per unit volume of a substance is called the "density" of the substance. Its units are g/cm^3 (grams per cubic centimeter). In the example mentioned (p. 53), the density of the substance is $30 \text{ g}/10 \text{ cm}^3 = 3.0 \text{ g/cm}^3$. The two statements "The mass of 1 cm^3 of the substance is 3.0 g" and "The density of the substance is 3.0 g/cm^3" contain the same information. The second statement, however, is more concise.

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4 A parking lot is filled with automobiles.

a) Does the number of wheels in the lot depend upon the number of automobiles?

b) Does the number of wheels per automobile depend upon the number of automobiles?

c) Is the number of wheels per automobile a characteristic property of automobiles that distinguishes them from other vehicles?

5 a) Draw a graph of the number of wheels in a parking lot as a function of the number of cars.

b) Draw a graph of the number of wheels per car as a function of the number of cars in the lot.

3.6 DIVIDING AND MULTIPLYING MEASURED NUMBERS

When you find the density of a substance from the measured mass and volume of a sample, your calculation uses numbers of limited accuracy. For example, consider a pebble that has a mass of 12.36 g and a volume of 4.7 cm^3. Here the mass is given to four digits and the volume to two. If you calculate the quotient $12.36 \text{ g}/4.7 \text{ cm}^3$ on a calculator, you get the number 2.62978723. (You can, of course, do the division by hand to that many digits, if you have the patience.) However, not even a calculator can produce numbers that are more accurate than the data used in the calculations.

For division and multiplication, it is good to remember a simple rule of thumb: The result should have as many digits as the measured number with the smallest number of digits. It is always advisable to calculate one additional digit, and then round off. In the example we just saw, the density is

$$\frac{12.36 \text{ g}}{4.7 \text{ cm}^3} = 2.6 \text{ g/cm}^3$$

The only significant digits are 2.6. The remaining digits in the display of the calculator are not significant and should be dropped.

If we calculate the volume of an object from its dimensions, the same rule applies. If the measured dimensions of a rectangular solid are 4.82 cm, 11.05 cm, and 1.28 cm, then the volume is correctly reported as

$$4.82 \text{ cm} \times 11.05 \text{ cm} \times 1.28 \text{ cm} = 68.2 \text{ cm}^3$$

(68.17 cm^3 is rounded off to 68.2 cm^3.) It should *not* be reported as 68.174080 cm^3.

How do we count the digits in a decimal measurement whose last digit is a zero, as in the measurement 4.20 cm? (Section 2.2 explained why the zero is written.) In these cases, the zero is counted as a significant digit. However, in such measured numbers as 0.86 cm and 0.045 g, the zeros are not counted. Their only purpose is to locate the decimal point. Both these numbers are given to two significant digits.

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6 Do the following calculations to the proper number of digits.

a) $\dfrac{125}{23.7}$

b) $\dfrac{20.5}{51.0}$

c) $\dfrac{0.065}{32.5}$

d) $\dfrac{1.23}{0.72}$

e) 4.72×0.52

f) 6.3×10.08

g) $1.55 \times 2.61 \times 5.3$

h) $3.01 \times 5.00 \times 25.62$

7 Suppose the measurement of the first dimension of the rectangular solid discussed above were 4.81 cm or 4.83 cm instead of 4.82 cm. Write all the digits in the number that would represent the volume of the solid. Which of these digits are the same as those calculated in the example above?

3.7 EXPERIMENT THE DENSITY OF SOLIDS

Pick up two cubes that look alike and that have the same volume. Can you decide by handling them whether they have the same or different masses?

Measure the masses of the cubes on your balance.

Which of the cubes has the greater density?

Now, just by handling them, compare the mass of each of the cubes with the mass of a third object which has a different volume.

- Can you decide in this way if the third object is made of a different substance?

Measure the dimensions of each of the three objects as accurately as you can. Calculate the volume and then the density of each.

- Are you now able to decide whether or not the third object is made of the same substance as either of the other two cubes?

If you have an irregularly shaped object whose volume is difficult to determine from a measurement of its dimensions, you can find its volume by the displacement of water, as described in Chapter 2. Find the density of an irregularly shaped stone. Compare the density of your stone with the results of other students who used pieces from the same rock.

- What possible reasons could you give for the different measured values of density?

8† What measurements and what calculations would you make to find the density of the wood in a rectangular block?

9 A student announced that she had made a sample of a new material that had a density of 0.85 g/cm^3. How large a sample had she made?

10† A block of magnesium whose volume is 10.0 cm^3 has a mass of 17.0 g. What is the density of magnesium?

11 Two cubes of the same size are made of iron and aluminum. How many times as heavy as the aluminum cube is the iron cube? (See Table 3.1, page 63.)

12† a) A 10.0-cm^3 block of silver has a mass of 105 g. What is the density of silver?
b) A 5.0-cm^3 block of rock salt has a mass of 10.7 g. What is the density of rock salt?
c) A sample of alcohol amounting to 0.50 cm^3 has a mass of 0.41 g. What is its density?

3.8 EXPERIMENT THE DENSITY OF LIQUIDS

Examine two samples of liquid. Smell them and shake them, but don't taste them. Can you tell whether they are the same or different? Perhaps by finding their densities you can answer the question. You can find the density of a liquid by massing it on a balance and measuring its volume with a graduated cylinder. The cylinder is too large to fit easily on the balance. You must mass the liquid in something smaller.

A small amount of liquid will stick to the inside of any container from which you pour it. Therefore, to be sure you mass the volume of the liquid you measure in the graduated cylinder, you must be careful of the order in which you make your measurements of mass and volume.

- Is it more accurate to mass the liquid in the small container before pouring it into the graduated cylinder or to determine its volume first?
- What are the densities of the two liquids?
- Are the two liquids the same or different?

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13 You are given two clear, colorless liquids. You measure the densities of these liquids to see whether they are the same substance or different ones.

a) What would you conclude if you found the densities to be 0.93 g/cm^3 and 0.79 g/cm^3?

b) What would you conclude if you found the density of each liquid to be 0.81 g/cm^3?

3.9 THE HYDROMETER

The density of a mixture of two liquids usually depends on the ratio in which they are mixed. The same is true for the density of a solution of a solid in a liquid. Thus, knowing the density of a liquid can provide useful information. For example, the density of the liquid in a car's radiator tells us whether there is enough antifreeze (in most cases, glycol) in the mixture. Similarly, the density of the liquid in a car's battery tells us whether the battery should be recharged. Service station attendants, however, must be able to find densities in

Figure 3.5
The float of a hydrometer used to check car batteries. The dark portion at the bottom contains lead shot imbedded in wax. The narrower the upper part is with respect to the lower part, the more sensitive is the hydrometer.

less time than it takes you in the laboratory. To do that they use an instrument called a "hydrometer."

You have probably noticed that though an ice cube floats in water, it is almost submerged. The same ice cube will float higher in antifreeze. In general, a solid sinks in a liquid until the mass of the liquid it displaces equals its own mass. The operation of a hydrometer is based on this law.

The main part of the hydrometer is the float (Figure 3.5). The upper part of the float is narrow; the lower part is wide and contains some lead or other

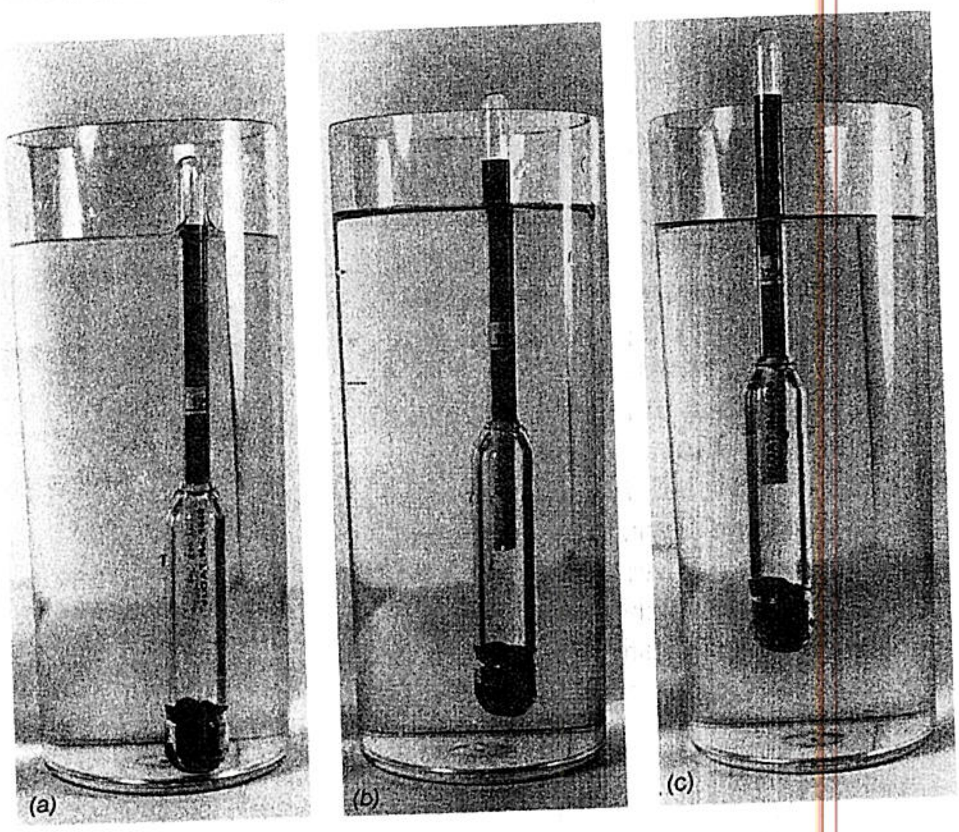

Figure 3.6
The float placed in liquids of different density.

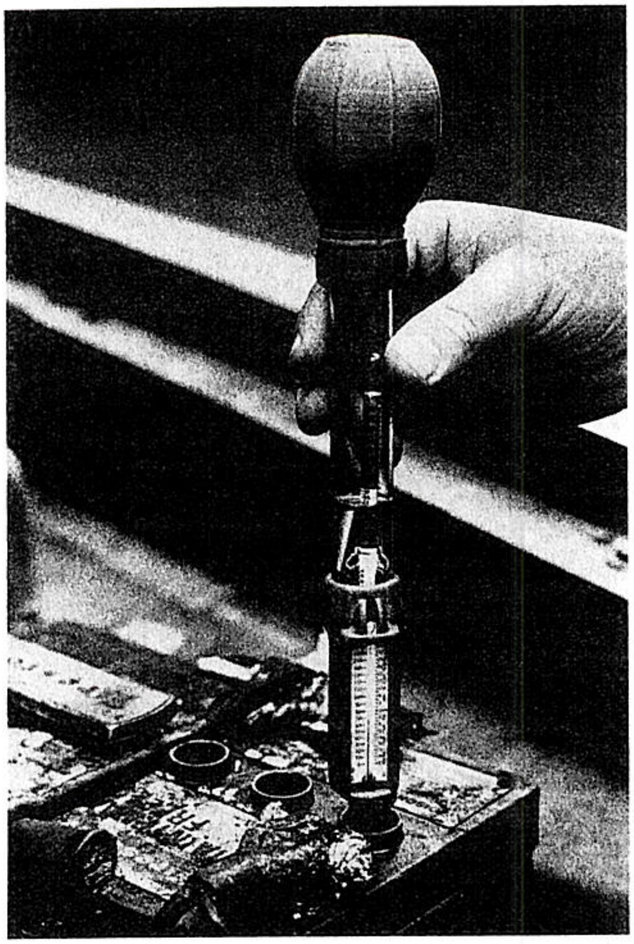

Figure 3.7
The complete hydrometer in use. The purpose of the thermometer seen on the outside will be discussed in Chapter 12.

dense solid at the bottom. The mass at the bottom and the shape of the hydrometer are determined in such a way that the scale covers the desired range of densities. The float in Figure 3.5 was made to test car batteries. In Figure 3.6, it is placed in pure water and in two solutions of different densities. Note that the float is not designed to measure the density of pure water; in water it sinks to the bottom.

It is awkward and dangerous to pour the liquid out of a car's battery. Therefore, the float is placed in an outer cylinder equipped with a suction bulb. This way the liquid can be lifted directly out of the battery and then easily returned (Figure 3.7).

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14 Which of the liquids shown in Figure 3.6 has the highest density?

3.10 EXPERIMENT THE DENSITY OF A GAS

It is more difficult to measure the density of a gas than that of a liquid or a solid. Gases are hard to handle, and most of them cannot even be seen. In fact, early chemists neglected to take into account the mass of gases produced in experiments.

When we mix Alka-Seltzer tablets and water, a large volume of gas is produced. We can find the density of this gas by massing the tablets and the water before and after they are mixed and by collecting and measuring the volume of the gas. You will recall that, in Experiment 2.14, you measured the mass of some of this same gas, but you did not measure the volume.

Place two half-tablets of Alka-Seltzer and a test tube containing about 10 cm^3 of water on the pan of your balance as shown in Figure 3.8, and find the total mass of these objects.

Arrange the apparatus as shown in Figure 3.9 so that you can collect the gas that will be evolved. Be sure the end of the rubber tube is at the top of the collecting bottle and that the whole length of the tube is clear and open. After putting on your safety glasses, drop the two half-tablets into the water, quickly insert the delivery

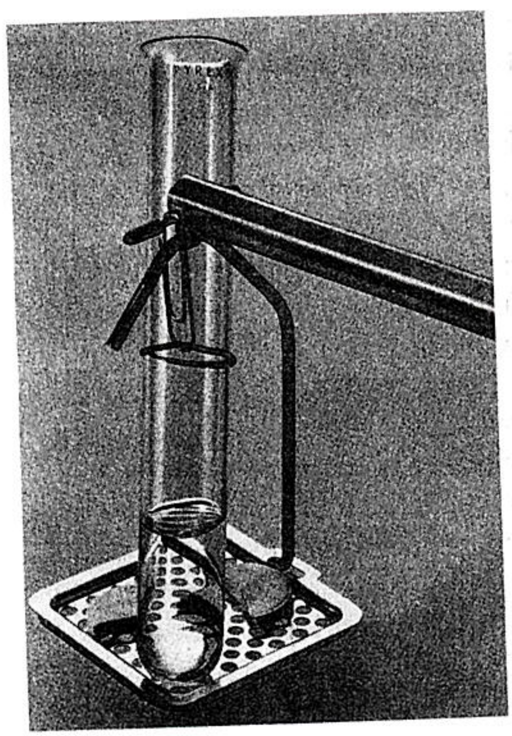

Figure 3.8
To support a test tube containing water on the balance, you can use a paper clip and a rubber band as shown. Be sure that the paper clip does not rub against the arm of the balance.

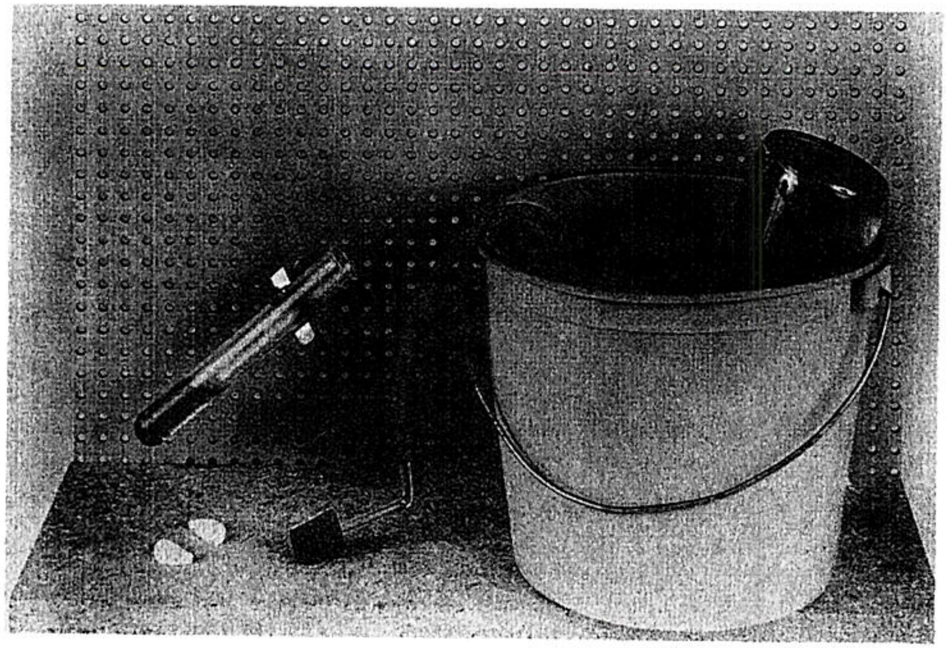

Figure 3.9
When the two half tablets are added to the test tube, the gas generated is collected by displacing water from the inverted bottle on the right.

tube and stopper into the test tube, and collect the gas produced. Practically all the gas will be produced in the first 10 minutes of the reaction. At the end of this time, remove the delivery tube from the bucket and then remove the stopper from the test tube.

- Why is it important to hold your hand across the mouth of the bottle while removing it from the bucket?

Turn the bottle upright, and find the volume of the water displaced by gas.

- How is this volume related to the volume of the gas?
- How can you find the mass of the gas?
- What is the density of the gas?
- What assumptions have you made in using this method?

15† A mixture of two white solids is placed in a test tube, and the mass of the tube and its contents is found to be 33.66 g. The tube is stoppered, and apparatus is arranged to collect any gas produced. When the tube is gently heated, a gas is given off, and its volume is found

to be 470 cm^3. After the reaction, the mass of the test tube and its contents is found to be 33.16 g.

a) What is the mass of the gas collected?

b) What is the density of the gas collected?

16 Experiment 3.10 is repeated with a sample of a different solid. Here are the data obtained:

Mass of solid, test tube, and water before action .... 35.40 g
Mass of test tube and contents after action .... 34.87 g
Volume of gas collected .... 480 cm^3

Could this gas be the same as that produced in Experiment 3.10?

17 The volume of gas generated by treating 1.0 g of magnesium carbonate with 8.8 g of sulfuric acid is 200 cm^3. The remaining acid and solid have a mass of 9.4 g. What is the density of the gas evolved?

18 If the volume of gas in the preceding problem is compressed to 50 cm^3, what will the density of the gas now be? To what volume must the gas be compressed before it will reach a density of 1.0 g/cm^3, a typical density of a liquid?

19 The gas whose density you measured in Experiment 3.10 dissolves slightly in water.

a) How does this affect the volume of the gas you collect?

b) How does this affect your determination of the density of the gas?

3.11 THE RANGE OF DENSITY

Table 3.1 lists the densities of various substances. Note that most solids and liquids have a density that is between 0.5 g/cm^3 and about 20 g/cm^3. The densities of gases are only about 1/1,000 of the densities of solids and liquids.

Is the density of a substance always the same? Most substances expand when heated, but their mass remains the same. Therefore, the density depends on the temperature, becoming less as the material expands and increases in volume. But, as we shall see in Chapter 12, the expansion is very small for solids and liquids and has little effect on the density. The situation is quite different for gases, which show a large thermal expansion. Moreover, we find it difficult to compress solids and liquids, but we can easily com-

Table 3.1 Densities of Some Solids, Liquids, and Gases (in grams per cubic centimeter)

Osmium	22.5	Oak	0.6-0.9	
Platinum	21.4	Lithium	0.53	
Gold	19.3	Liquid helium (at $-269°C$)	0.15	
Mercury	13.6			
Lead	11.3	Liquid hydrogen (at $-252°C$)	0.07	
Copper	8.9			
Iron	7.8	Carbon dioxide	1.8×10^{-3}*	At atmospheric pressure and room temperature
Iodine	4.9	Oxygen	1.3×10^{-3}	
Aluminum	2.7	Air	1.2×10^{-3}	
Carbon tetrachloride	1.60	Nitrogen	1.2×10^{-3}	
		Helium	1.7×10^{-4}	
Water	1.00	Hydrogen	8.4×10^{-5}	
Ice	0.92	Air at 20 km altitude	9×10^{-5}	
Methyl alcohol	0.79			

* Small numbers less than 1 can, like large numbers, be expressed in powers of 10. For example, we write 0.1 as 10^{-1}, 0.01 as 10^{-2}, 0.001 as 10^{-3}, and so on, using negative numbers as exponents.

If we have decimals like 0.002, we can write this first as 2×0.001 and then, in powers-of-10 notation, as 2×10^{-3}. Another example: $0.00009 = 9 \times 0.00001 = 9 \times 10^{-5}$. The negative exponent of the 10 tells how many places the decimal point must be moved to the left to give the correct value in regular notation. For further information, see the Appendix (pages 287–292).

press gases, as you know from pumping up a bicycle tire. Therefore, when measuring the density of a gas, we have to state the temperature and the pressure at which it was measured.

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20 Write the following numbers in powers-of-10 notation.
a) 0.001 0.1 0.0000001
b) 1/100 1/10,000

21 Write each of the following numbers as a number between 1 and 10 times the appropriate power of 10.
a) 0.006 0.000032 0.00000104
b) 6,000,000 63,700

22 Change the following numbers to ordinary notation.
a) 10^{-2} 10^{-5} 3.7×10^{-4}
b) 1.05×10^{-5} 3.71×10^{3}

23† A small beaker contains 50 cm^3 of liquid.
a) If the liquid were methyl alcohol, what would be its mass?
b) If the liquid were water, what would be its mass?

24† The densities in grams per cubic centimeter of various substances are listed below. Indicate which of the substances might be gas, liquid, or solid. (Refer to Table 3.1.)
(a) 0.0015 (b) 10.0 (c) 0.7 (d) 1.1 (e) 10^{-4}

25 Estimate the mass of air in an otherwise empty room that is the size of your classroom.

3.12 IDENTIFYING SUBSTANCES

We have looked for properties that can help us to distinguish between substances that appear to be the same. So far we have found three properties that do not depend on how much of a substance we have or on its shape. These properties are melting point, boiling point, and density.

Suppose we measured the melting points of two samples of matter and found them to be the same. If we then measured their boiling points and found that these were also the same, we might suspect that we had two samples of the same substance. We would not expect them to differ in their density or in any other properties. But, as Table 3.2 shows, we cannot depend on two properties alone to distinguish between substances. This is particularly true if the measurements are not highly accurate.

In Group 1 of the table, we have substances with the same boiling points and nearly the same melting points. It would be hard to measure these two properties carefully enough to see that they are different substances, but a measurement of their densities would prove without question that they are different.

The substances in Group 2 have the same density and nearly the same boiling point, but can be told apart by their different melting points.

If you compared only their densities, you might conclude that the three substances in Group 3 are the same. If you also measured their melting points, you would probably decide that the second and third substances in this group are the same. If you compared their densities and boiling points but not their melting points, which would you conclude are the same? In fact, all three substances in Group 3 are different. That is why they were given different names when first discovered.

Table 3.2 Some Substances with Similar Properties

	Density (g/cm^3)	Melting point (°C)	Boiling point (°C)
Group 1			
Methyl acetate	0.93	−98	57
Acetone	0.79	−95	57
Group 2			
Isopropanol	0.79	−89	82
t-Butanol	0.79	26	83
Group 3			
Cycloheptane	0.81	−12	118
n-Butanol	0.81	−90	118
s-Butanol	0.81	−89	100

The names of the substances in this table are not important to us now, and you do not need to remember them. They are good examples of substances that we cannot tell apart unless we measure all three properties: density, melting point, and boiling point.

There are not very many examples of substances that are nearly the same in two of these three properties and yet differ in the third. We would have to search even harder to find two samples of matter that have the same density, melting point, and boiling point but that differ in some other property and are, in fact, samples of different substances. If we can determine density, melting point, and boiling point, we can distinguish between almost all substances.

In many cases, the melting point and the boiling point of a sample of matter can be measured easily in the laboratory. However, some substances have boiling points so high that it is difficult to get them hot enough to boil. For example, table salt boils at 1413°C. Others have boiling points so low that it is difficult even to get them cold enough to become liquid. The same experimental difficulties come up when we try to determine the melting points of some substances. Grain alcohol melts at −117°C.

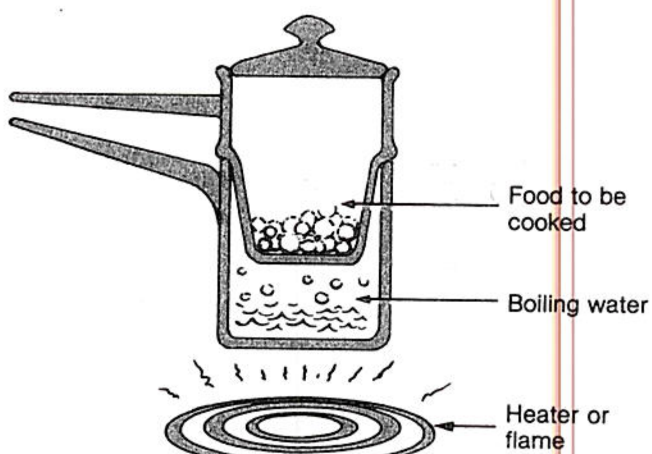
Suppose we have a sample of a newly made substance. We wish to find out whether it is truly a new substance, different from all others, or a substance already known but made in a new way. If its boiling and melting points are too high or too low to measure easily, we must look for other characteristic properties that might help to distinguish it from similar substances.

26 Which of the substances listed in Table 3.2 are solids, which are liquids, and which are gases at (a) room temperature (20°C), (b) 50°C, (c) 100°C?

For Home, Desk, and Lab

27 Figure B shows a diagram of a double boiler. Why is the double boiler used to cook food that is easily scorched?

Figure B
For problem 27



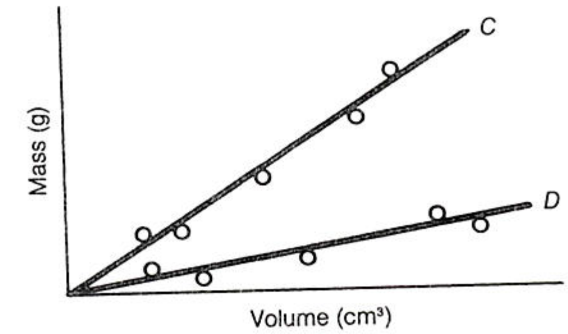
28 Object A has a mass of 500 g and a density of 5.0 g/cm^3; object B has a mass of 650 g and a density of 6.5 g/cm^3.
a) Which object would displace the most liquid?
b) Could object A and object B be made of the same substance?

29 A student measures the volume of a small aluminum ball by water displacement and then finds its mass on a balance. He finds that the sphere displaces 4.5 cm^3 of water. He determines that the mass of the sphere is 6.5 g.
a) What value does the student obtain for the density of aluminum?

b) How might you account for the difference between this value for the density of aluminum and the one given in Table 3.1?

30 A student has several different-size specimens of substances C and D. She measures the masses and volumes of these specimens and plots the graphs shown in Figure C. Which substance has the greater density? How do you know?

Figure C
For problem 30



31 How would you determine the density of ice? Could you get the volume by melting the ice and measuring the volume of the resulting water?

32 How would you distinguish between unlabeled pint cartons of milk and of cream without breaking the seals?

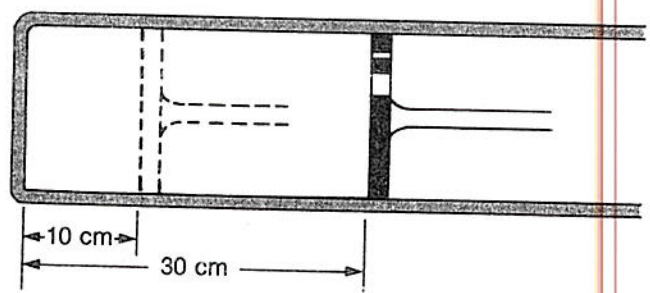
33 a) Suppose you made your own hydrometer. Its mass is 11.5 g. What volume will the hydrometer displace in a liquid with a density of 1.20 g/cm^3?
b) Suppose the lower part of your hydrometer has a volume of 7.0 cm^3, and the upper part is 5.0 cm long and has a cross-sectional area of 0.62 cm^2. What length of the upper part of the hydrometer will be submerged?

34 In Table 3.1, why are the pressure and temperature stated for the densities of gases and not stated for the densities of solids and liquids?

35 The students in an *IPS* class in one of the coastal cities of the United States measured the boiling point of water and found that it was 100°C. On the same day the students in an *IPS* class in one of the mountain cities in the United States also measured the boiling point of water and found that it was 95°C. What can be inferred about the boiling point of water from these reports?

36 A cylinder is closed with a tight-fitting piston 30 cm from the end wall (Figure D); it contains a gas with a density of 1.2×10^{-3} g/cm^3. The piston is pushed in until it is 10 cm from the end wall; no gas escapes. What is the density of the compressed gas? What is your reasoning?

Figure D
For problem 36



37 Does the density of air change when it is heated:
a) in an open bottle?
b) in a tightly stoppered bottle?

Themes for Short Essays

1 Ice floats on water. Suppose it did not. What would happen to life in lakes and rivers? Write a short science-fiction story on this subject.

2 Write a short mystery story in which a crook tries to pass off a small statue of gold-plated lead as solid gold. Have the detective uncover the plot without damaging the statue.