Introductory Physical Science

9th Edition

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Ninth Edition

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Preface to the Ninth Edition

The objective of the *IPS* program is to guide all students to knowledge of physical science and the way scientific knowledge is acquired. Rather than surveying the entire field of physical science, *IPS* defines a path toward this objective, with options for achieving it. The result is a course that avoids being dogmatic and "a mile wide and an inch deep." These attributes and extensive reliance on experimental results to guide student learning make *IPS* a unique physical science course.

Inquiry and guided reasoning based on the results of student experiments are used to achieve these outcomes. Students acquire laboratory skills, reasoning skills, and the ability to communicate by participating in a cooperative learning process. *IPS* students learn from nature, the text, their teacher, and each other.

This edition combines instructional material from previous editions of *IPS* with that from *Force Motion and Energy (FM&E)*, another course by the same team of authors. This combination provides the breadth of material needed to meet the local, state, and national physical science standards.

Part One, the first six chapters, provides an overview of macroscopic properties of matter and is the foundation for the next two parts. Part Two, Chapters 7–11, presents atomicity and the classification of elements. Part Three, Chapters 12–16, guides the study of energy, forces, and Newton's laws.

This edition continues the use of formative assessment questions, designated by a light yellow background at the end of each section. Additional formative assessment questions are included in the *Teacher's Guide and Resource Book*. Comprehension Guide Questions™ (CGQs) are new to this edition. They are placed in the margin for students to use in assessing their own comprehension as they read the text.

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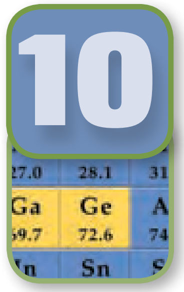

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To The Student

You will have a different experience in this course than you have had in other science courses. You and your classmates will work together to do experiments, evaluate data, draw graphs, write, read, develop arguments, defend conclusions, and solve problems. Although you may find that it takes time to adjust to learning this way, you will find it a satisfying and productive way to gain knowledge.

To arrive at meaningful conclusions, you need large amounts of data. Rather than depending only on the data that your team collects, you will share your team's data with the entire class and reach conclusions based on this larger pool of data. Your classmates will be depending on your data, just as you will be depending on theirs. A well-kept notebook will be of great help in organizing your data and helping you learn from your experiments.

This course will also help you learn science through the written word, a valuable skill that you will need throughout your life. Comprehension Guide Questions™ (CGQs) located in blue boxes in the margins will allow you to check your understanding of the material you have just read.

What you learn from your experiments and reading becomes truly useful when you can apply it successfully to new situations. The many problems at the ends of sections and chapters will help you sharpen your problem-solving skills and build a solid foundation of science content and skills for future learning.

The Authors

1

VOLUME AND MASS

There are many ways to begin the study of physical science. We will begin with a simple experiment that produces some surprising results. The experiment may raise some questions in your mind. At the same time, you will learn very useful laboratory skills.

1.1 Heating Baking Soda

What do you think will happen if you heat some baking soda in a test tube? Will the baking soda change color? Will anything come out of the test tube? Before you read on, try to predict what will happen and be prepared to explain what you based your prediction on.

Put some baking soda into a dry test tube to a height of about 0.5 cm. In case a gas is produced, it will be useful to be able to collect it. You can do that with the apparatus shown in Figure 1.1. The bent glass tube may already have been inserted into the rubber stopper. If you have to insert the tube yourself, look closely at Figure 1.2 and its caption for useful advice on how to do it safely.

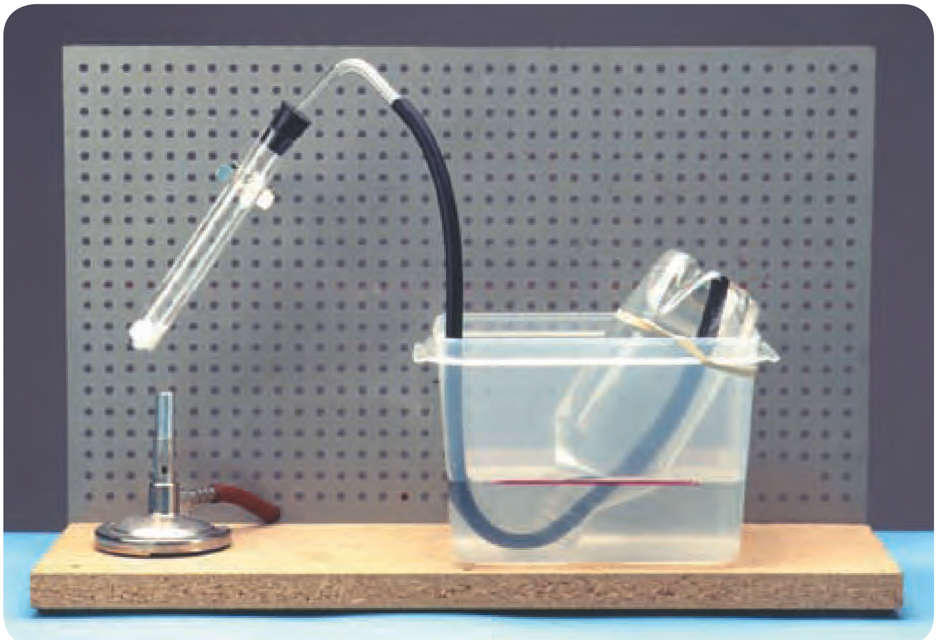


Figure 1.1

The apparatus used in heating baking soda. To be sure that no water will spill during the experiment, fill the large plastic container only up to the marker. Fill the bottle with water and hold your hand over the mouth of the bottle as you invert it, and place it in the container. Use a rubber band to hold the bottle in place. Finally, insert the rubber tube all the way up to the bottom of the inverted bottle.

After your teacher has checked your setup, you may begin heating the baking soda over either a microburner or an alcohol burner. Look at Figure 1.3 to see how the flame on the burner you are using should appear.

CAUTION: Always wear safety glasses when you use a burner or work with gases.

Figure 1.2

Lubricate the glass tube with glycerin or water before pushing it into the stopper. Hold the tube with a towel as close to the stopper as possible while pushing it in. This will prevent the tube from hurting you in case it breaks.

Figure 1.3

The proper size and color of the flame for a microburner (left) and for an alcohol burner.

Watch the test tube and collecting bottle as you heat the baking soda.

- What do you observe at the bottom of the test tube?*
- What do you observe near the top of the test tube?
- What do you observe in the inverted bottle?

When it appears that no further changes are taking place, pull the rubber tube completely out of the water while the flame is still on. Only then turn off the flame. (Why is the order of these steps important?)

CAUTION: Do not blow out the flame of a microburner; turn off the gas supply valve.

Even without measuring, you can see that there is more gas in the bottle than there was air in the test tube. To make sure of this, we heated an empty test tube connected to the same collecting bottle shown in Figure 1.1. All the air that was driven out of the heated test tube shows up as the small bubble in the bottle in Figure 1.4.

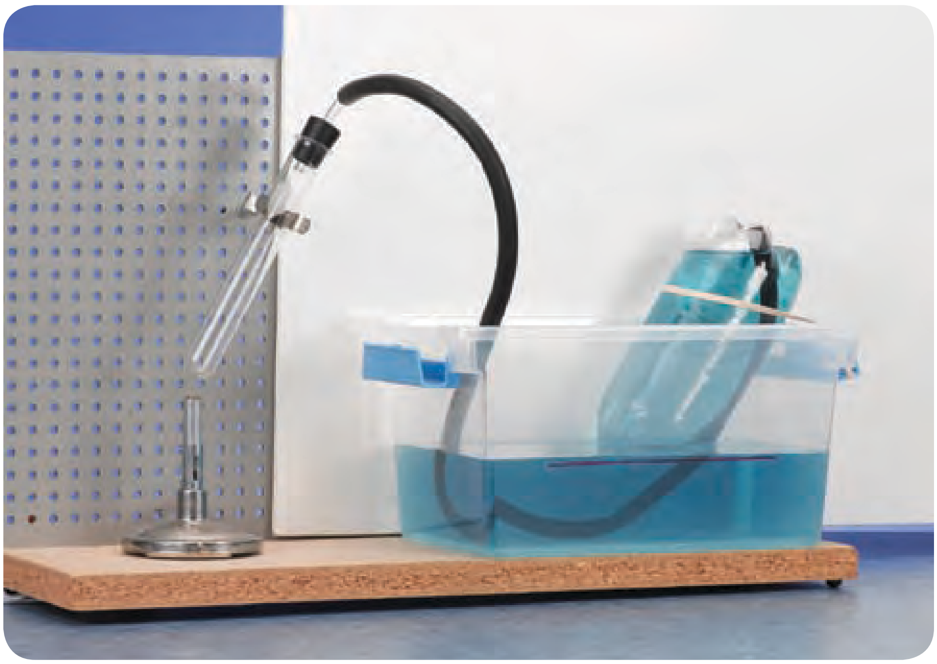


Figure 1.4

The result of heating an empty test tube for a few minutes. Blue food coloring has been added to the water to make the bubble at the top of the inverted bottle more visible. Clearly, the gas in your experiment was not just air from the test tube.

*Answer all bulleted questions in complete sentences. Restate enough of the information in the question so that it is clear which question is being answered.

- Where do you think the gas came from?
- Where did the droplets on the test tube come from?

As far as you can tell by looking, the baking soda in the test tube remained unchanged. But did it really? You can answer this question with the following test.

First let the test tube in which you heated the baking soda cool down. Then put about an equal amount of baking soda in a second test tube. Pour some tea into each of the two test tubes (about a quarter tube will do). Gently shake both test tubes or use a stirring rod to dissolve the powders. You have now treated the contents of the two test tubes equally.

- Describe the color of the liquid in each test tube.
- Are the two white powders the same substance? What is your evidence?

Do you think you can you get the baking soda back by mixing all the substances that you collected? Were these substances there all the time, or were they formed by heating? How can you compare the amounts of solid, liquid, and gas that you got from heating baking soda?

To answer these questions, you will do experiments. These experiments, in turn, will raise new questions. In the next section we will start with the last question: How can we compare amounts of solids, liquids, and gases?

1. Why do you think baking soda is used in baking?

2. List some tools that you have used

  a. to extend your vision to see distant objects.

  b. to extend your vision to see very small objects.

  c. to tell how hot something is.

1.2 Volume

Suppose that you have several stacks of pennies of different heights. How can you find the number of pennies in each stack? The obvious answer is to count them. But if you had to count the pennies in many stacks, it would take you quite awhile. You could speed up the counting by making a scale like that shown in Figure 1.5 (on the next page), marking it off in spaces equal to the thickness of one penny. You can then place this scale alongside each stack and read off the number of pennies.

Figure 1.5

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

Suppose that each penny is pure copper. If you want to measure the amount of copper in each stack of pennies, you must first decide on a unit to use in your measurement. If you choose as a unit the amount of copper in one penny, you simply count the number of pennies.

Could you use the same unit to find out how much copper there is in a solid rectangular bar of copper? You might think of making a box that is 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, though, because when you place pennies next to one another in a rectangular box, there will always be empty space between them.

A better way to find out how much copper there is in a solid rectangular bar of copper is to choose a new unit of measure, the volume of a small cube. We will call it a unit cube (Figure 1.6). Cubes have the advantage that you can place them next to one another without air spaces.

Suppose you had a box the same size and shape as the copper bar, and you could fill it with unit cubes. You could simply count the number of cubes to find the amount of copper in the bar. Of course, you 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 1.6.) This is the amount of copper in the solid bar, expressed in unit cubes. This amount is also the *volume* of the bar, expressed as the number of the unit cubes.

How do you calculate the volume of a rectangular box or bar?

What we choose for 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 length in the metric system. In this case, as in much of this course, we shall use the centimeter (cm). A centimeter is 0.01 m. The volume of our unit cube would then become 1.0 cm × 1.0 cm × 1.0 cm or one *cubic centimeter* (cm^3), a small cube 1 cm on an edge.

How many centimeters are there in one meter?

To summarize, we can compare different amounts of the same substance by comparing their volumes—that is, the amounts of space they occupy. For a rectangular solid, we find that volume by measuring the length of its three edges and calculating the product of these numbers.

Using volume to compare amounts of substances is easier with liquids, because liquids take the shape of their containers. Suppose you wish to compare the amounts of water in two bottles that have very different shapes. You simply pour the contents of each bottle separately into a graduated cylinder that has already been marked with the desired

Why is the volume of a liquid often easier to measure than the volume of a solid?

units, and read the volumes (Figure 1.7). This way of measuring volume is very much like counting pennies in a stack.

You can use the property of a liquid to take the shape of its container when you 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 the volume of the water, you can put the stone in the water. The stone will sink to the bottom, and the water level will rise. You can then read the combined volume of the water and the stone. The difference between the two readings is the volume of the stone.

To find the volume of an irregular solid, what two measurements must be subtracted from each other?

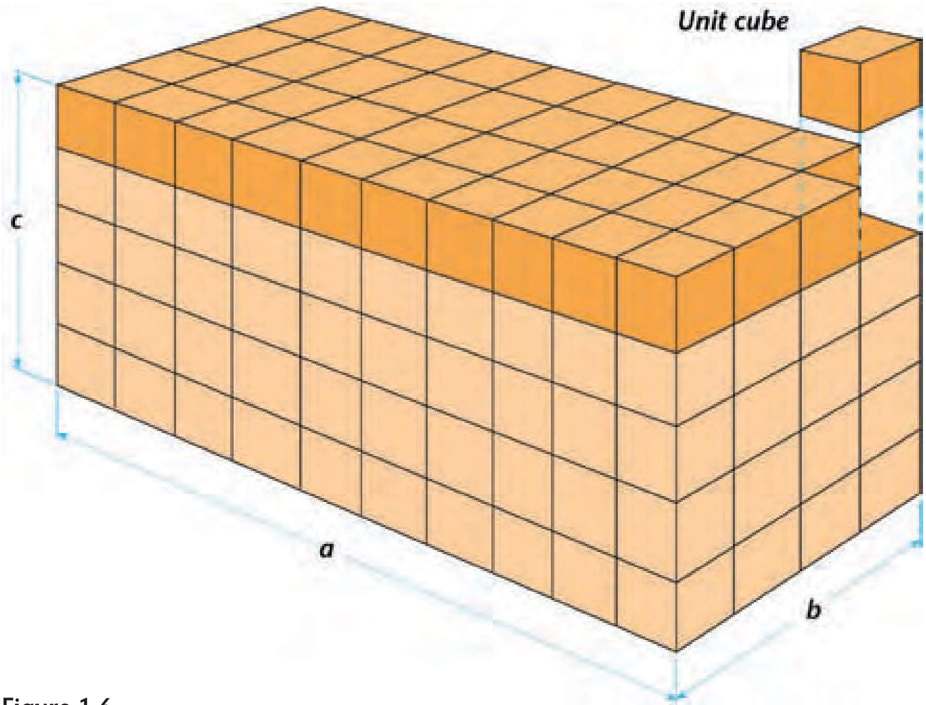


Figure 1.6

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. There are 5 layers in the bar. Each layer contains 10 × 4 cubes. Therefore, the number of unit cubes in the bar is 10 × 4 × 5 = 200. 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, $a \times b \times c$.

Figure 1.7

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 container full of the liquid is poured in. Many graduated cylinders are marked off in *milliliters* (mL). A milliliter is the same volume as a cubic centimeter. (1 mL = 1 cm^3.)

3. How many cubic centimeters of water are required to fill a graduated cylinder to the 50.0-mL mark?
4. Rectangular box A has a greater volume than rectangular box B but the length of box A is less than the length of Box B. How is this possible?
5. Adding a stone to a graduated cylinder containing 25.0 cm^3 of water raises the water level in the cylinder to the 32.0-cm^3 mark. What is the volume of the stone?
6. A student has a large number of cubes that measure 1 cm along each 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 measures 2 cm along each edge?
   b. How many cubes will be needed to build a cube that measures 3 cm along each edge?
   c. What is the volume, in cubic centimeters, of each of the cubes in (a) and (b)?
7. 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?
8. 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 8

1.3 Reading Scales

To measure length with a ruler, volume with a graduated cylinder, or temperature with a thermometer, you must be able to read a scale. Begin by reading a metric ruler (Figure 1.8). The smallest divisions on such a ruler are 0.1 cm, or one *millimeter* (mm), apart.

> Why is it not useful to have divisions 0.01 cm (or 0.1 mm) apart on a ruler?

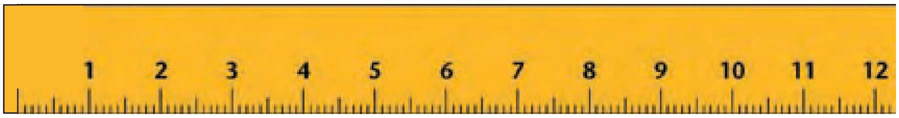


Figure 1.8

A metric ruler. The numbered divisions are centimeters. The small divisions are 0.1 cm, or millimeters.

When the object you wish to measure has sharp edges, you can clearly see where the edge lines up with the ruler. Most often the edge of the object falls between two lines. To record the length, you can estimate the position of the edge. In Figure 1.9, it is clear that the length of the object is between 4.8 cm and 4.9 cm. In fact, you cannot tell whether the edge is closer to one line or the other, so it is best to report it as halfway between the two lines. In this case, the length is reported as 4.85 cm.

> Suppose you measure the length of an object, and it appears to be halfway between 2.6 cm and 2.7 cm. How should you report the length?

In Figure 1.10 the edge falls closer to the line on the left than to the line on right. So you know that your estimate should be more than 4.80 cm and less than 4.85 cm. In other words, the possible values range from 4.81 cm to 4.84 cm. The best estimate here is a value near the center of this range. Report the length as 4.82 cm or 4.83 cm. (Remember that it is not possible to read thousandths of a centimeter with a ruler, so do not report the length as "4.825 cm.")

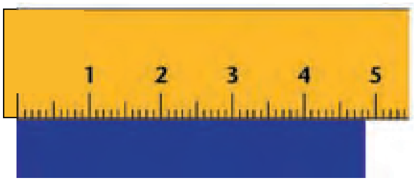


Figure 1.9

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

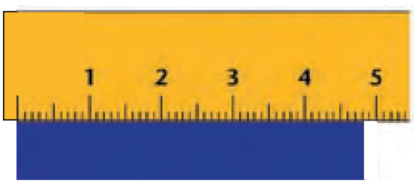


Figure 1.10

Here the edge is closer to the line on the left.

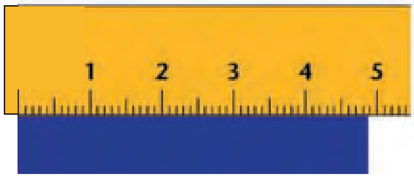


Figure 1.11
Here the edge is closer to the line on the right.

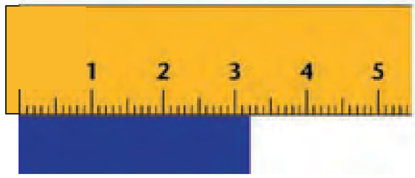


Figure 1.12
Here the edge falls on one of the millimeter marks.

Why is it important to estimate the position of the edge of an object if it falls between two marks on the ruler?

Figure 1.11 shows a different situation. Here the edge of the object falls closer to the line on the right than to the line on the left. Its length must be more than 4.85 cm and less than 4.90 cm. It is best to report this measurement as 4.87 cm or 4.88 cm.

In Figure 1.12 the edge falls on a line. In this case, you should report the reading as 3.20 cm, rather than just 3.2 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 have been lost if you had written only "3.2 cm." Notice, however, that you should not report the length as "3.200 cm." The additional zero would suggest that you can tell the difference between 3.200 cm and either 3.199 cm or 3.201 cm. This is not possible with this ruler.

Your reading of the last digit on a ruler is an estimate. Others might measure the same object and estimate slightly different values. How far apart might those estimates be? To find out, consider the object shown in Figure 1.10. You know that the possible values for its length range from 4.81 cm to 4.84 cm. That means that if you estimate the length to be 4.82 cm, your estimate might be as much as 0.02 cm too low (4.84 cm – 4.82 cm = 0.02 cm).

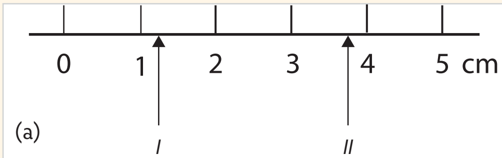
If you estimate the length of the object to be 4.83 cm, you might still be off by as much as 0.02 cm. In this case, your estimate might be 0.02 cm too high (4.83 cm – 4.81 cm = 0.02 cm).

With either estimate, you will not be more than 0.02 cm too high or too low. We write this as ±0.02 cm. (The symbol ± is read "plus or minus.") This value is called the *uncertainty* of your scale reading.

How do you read the volume of a liquid in a graduated cylinder?

Reading the level of a liquid in a graduated cylinder poses a special problem because the top of the liquid is curved. The curved surface is called a *meniscus*. Generally, we read the volume of the liquid by looking at the meniscus at eye level and reading the position of its lowest part. Measurements of volume can be reported to the nearest half of a division. For the same reasons as discussed for the ruler, reading the scale on the graduated cylinder also introduces uncertainty in the reported value.

9. The scale in Figure B is in centimeters.



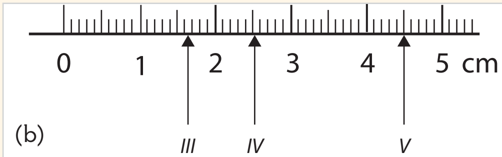


Figure B
For Problem 9

a. Estimate the positions of arrows *I* and *II* in Figure B(a) to the nearest 0.1 cm. Can you estimate their positions to 0.01 cm?

b. Estimate the positions of arrows *III*, *IV*, and *V* in Figure B(b) to the nearest 0.01 cm. Can you estimate their positions to 0.001 cm?

c. Why should you report the positions of the arrows in part (b) to the nearest 0.01 cm and not to the nearest 0.1 cm?

10. What part of a cubic centimeter do the smallest divisions on each of the graduated cylinders in Figure C represent? Express your answer as a decimal.

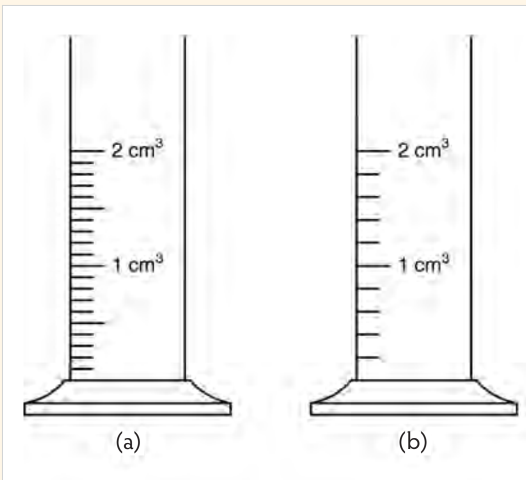


Figure C
For Problem 10

11. What is the level of the liquid in Figure D(a) to the nearest half division? What is the level in Figure D(b) to the nearest half division?

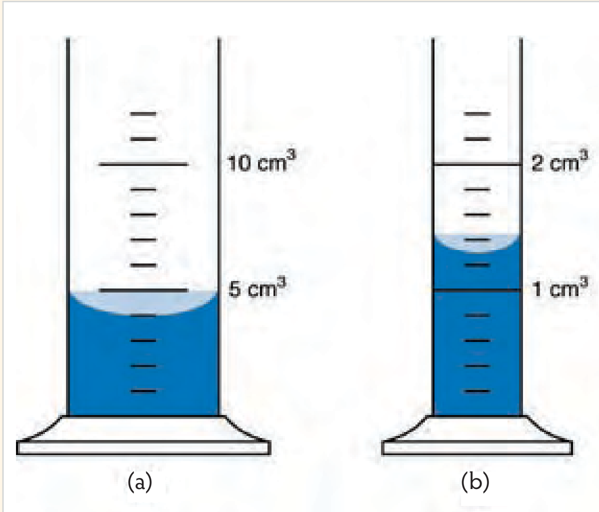


Figure D
For Problem 11

12. 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?

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

EXPERIMENT E

1.4 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 in the last section. Suppose you have some sand in a cup. To find the volume of the sand, you could simply pour the sand into a graduated cylinder. But does the level of the sand in the graduated cylinder really show the volume of the sand alone? What about the air spaces between the loosely packed grains? The graduated cylinder measures the combined volume of the sand plus the air spaces. However, you 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.

- What is the volume of the water?

Add the sand to the water. What is the volume of the sand plus the water?

- What is the volume of the sand alone?
- What is the volume of the air space(s) in the sand?
- What fraction of the dry sand is just air space? Express your answer as a decimal.

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 you have a bag of dry sand and want to know how many quart bottles it will fill, you need to know its volume dry. You need to know the volume of both the sand and the air spaces. But if you want to know the volume of sand alone, then you must use a procedure like that in the experiment you have just done. This is similar to measuring the volume of an irregular solid. You measure the volume of the sand alone by the volume of the liquid that is displaced.

14. The volume of a marble is 1.0 cm^3. Of the following choices, which tells how many identical marbles are needed to fill an empty graduated cylinder to the 100-cm^3 mark?

A. 100 B. More than 100 C. Less than 100

15. 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? Express your answer as a decimal.

16. How would you measure the volume of granulated sugar?
17. How would you measure the volume of a cork stopper?

1.5 Limitations of Volume as a Measure of Matter

Whenever we measure the volume of a solid by displacement of water, we make an assumption. We assume that the volumes of the solid alone and of the water alone add up to the volume of the solid and water together after they are mixed. This assumption may or may not be correct, depending on the kind of solid we have. For example, suppose you measure the volume of a few chunks of rock salt by the displacement of water. You will see in Figure 1.13 that the total volume of rock salt and water decreases as the salt dissolves.

Why is the test tube containing only water included in the photos in Figure 1.13?

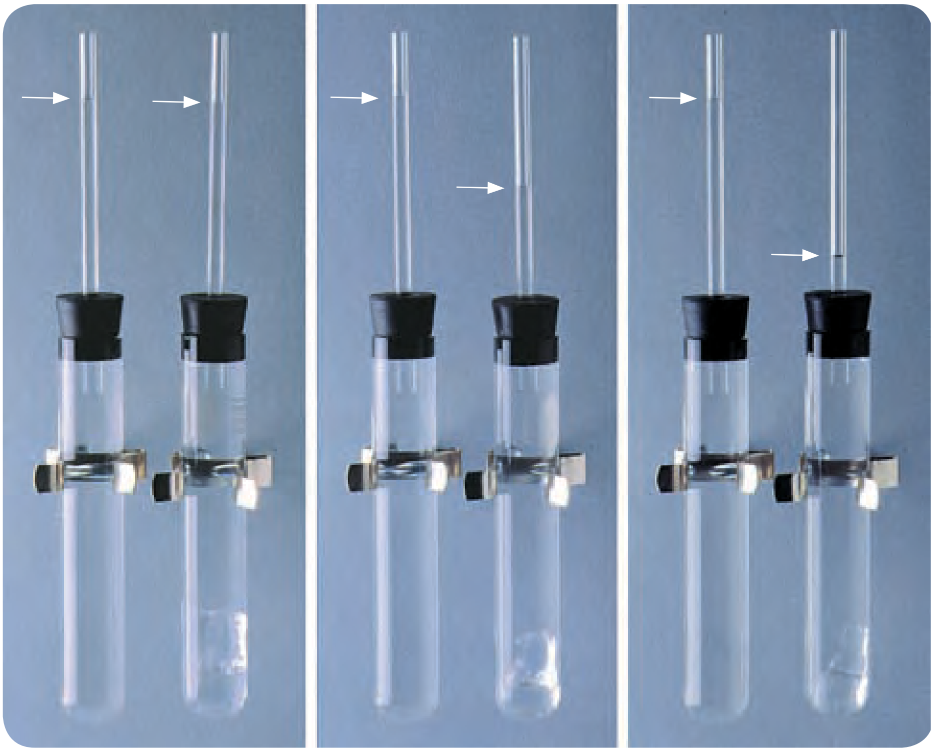


Figure 1.13

(a) Two test tubes. The one on the left contains only water. The one on the right contains water and two pieces of rock salt that have just been added. Notice that the total volume is the same for both, as shown by the water levels in the narrow tubes that extend above each test tube. (b) The same test tubes are shown 15 minutes later, after the salt has begun to dissolve. (c) The same test tubes 30 minutes after the rock salt was added. 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 results of the experiment shown in Figure 1.13 strongly suggest that volume is not always a good measure of the amount of a substance. Here are some other difficulties with the use of volume to measure the amount of a substance. If you have ever pumped up a bicycle tire, you know that a gas is very compressible. As you pump more and more air into the tire, the volume of the tire 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 heating baking soda by forcing it into a container of smaller volume, would there be less of the gas?

Finally, can we really use volume to compare the amounts of different substances, some of which are solids, some liquids, and others gases? Consider the heating of baking soda. Does measuring the volume of the baking soda, the liquid condensed near the top of the test tube, and the gas collected in the bottle really tell us how much of each of these substances we have?

1.6 Mass: The Equal-Arm Balance

The limitations of volume as a measure of the amount of matter must have been known to people many centuries ago. They developed a method for measuring the amounts of different substances without measuring their volumes. Archaeologists have recovered from an Egyptian tomb several thousand years old a little balance beam made of carved stone (Figure 1.14), along with carefully made stone masses. The balance was

(a)

(b)

Figure 1.14

(a) This balance, the earliest 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 8.5 cm long. The balance is shown at its true size.
(b) The standard masses shown are in units of beqa (BEK-ah). The letters and numbers on these four masses were placed there by archaeologists. *(Courtesy of Science Museum, London)*

probably used 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 had.

The balance was hung by the upper loop so that the horizontal beam was divided exactly into two arms of equal length. With no objects suspended from either arm, the balance bar would hang horizontally. An object hung from the loop on the end of one arm could be balanced by hanging masses shown in Figure 1.14(b) from the end of the other arm.

People soon learned that the bar would remain horizontal even if there were drastic changes in the shapes of the objects being balanced. Cutting up a chunk of iron into several 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 an object. It responds to what 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 the masses of objects of any kind, regardless of volume, shape, color, or the substance they are made of.

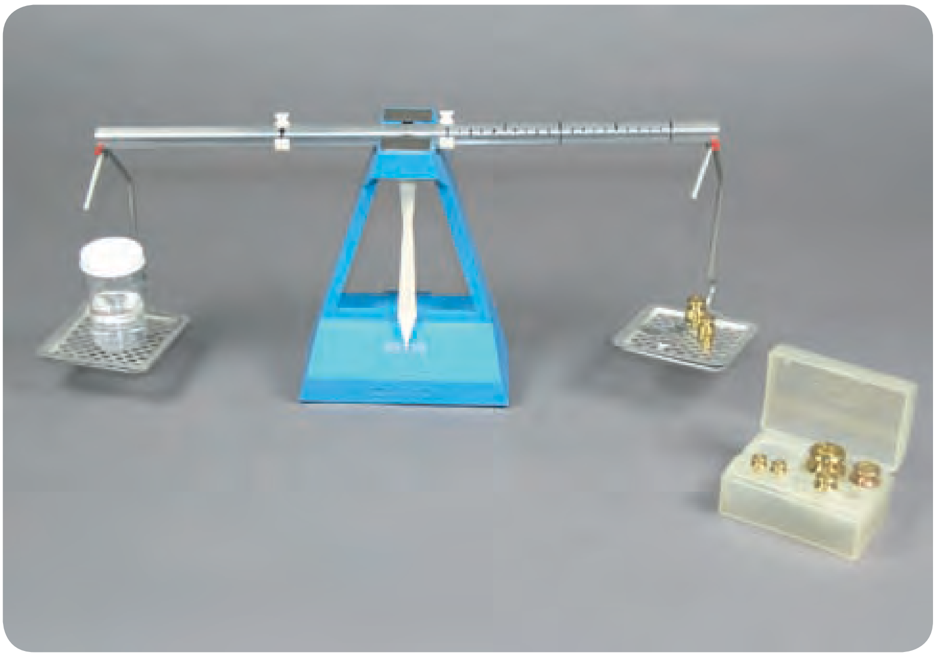


Figure 1.15

An equal-arm laboratory balance. The object to be massed is placed on the pan at the left. The standard gram masses are placed on the pan at the right. The tip of the pointer is at the middle of the scale on the base.

To use the balance, people used standard units of mass, something like those in Figure 1.14(b). They compared their gold or other objects to these standard masses.

A modern equal-arm balance is shown in Figure 1.15. The standard unit of mass being used with this balance is the *gram* (g), a 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, France, near Paris. This cylinder has a mass of 1 *kilogram* (kg), or 1,000 g. All other kilogram masses are compared, directly or indirectly, with the standard. If you were to place an object with a mass of 1 kilogram on a supermarket scale in the United States, the scale would read 2.2 pounds.

18. Suppose two objects with different shapes were hung from opposite ends of an equal-arm balance. The bar remained horizontal. Which of the following statements about the properties of the objects are true?

A. The volumes of the objects are the same.

B. The masses of the objects are the same.

C. The objects are made up of the same substance.

D. The colors of the objects are the same.

19. For each of the following objects, tell whether you would you use a count, a volume measurement, or a mass measurement to describe how much the object could hold. Explain.

a. Elevator

b. Stadium

c. Bridge

d. Bus

e. Water tank

f. Train car

g. Theater

h. Saucepan

20. Are items you buy at a grocery store measured more often by volume or by mass? Give some examples.

21. What is your mass in kilograms?

1.7 Single-Pan and Electronic Balances

An alternative to an equal-arm balance with a set of standard masses is a balance with a pan on one side of the support and beams with sliding masses, called *riders*, on the other side (Figure 1.16). Such a balance is known as a *single-pan balance*. These balances are very common. You have probably seen one in your physician's office or in your school's health clinic (Figure 1.17).

Both the equal-arm and the single-pan balances compare the mass of the object on the pan with standard masses. The standard masses are placed either on the second pan of an equal-arm balance or as riders on the beams of the single-pan balance. An electronic balance (Figure 1.18) does not look at all like a balance. It has neither a second pan nor beams carrying riders.

What does the tare button on an electronic balance do?

Electronic balances have two advantages. First, it takes only seconds to mass an object. Thus, many teams in the laboratory can share one balance. Second, in many experiments you will need to find the mass of a liquid or powder in a container. An electronic balance can subtract the mass of the container and give you the mass of the contents alone. To use this feature, you press the *tare* button with the empty container on the pan. Then you mass the container and its contents.

Electronic balances are delicate instruments and must be handled with care. Use them only within the range they were designed to handle. Your balance should probably not be loaded with more than 200 g.

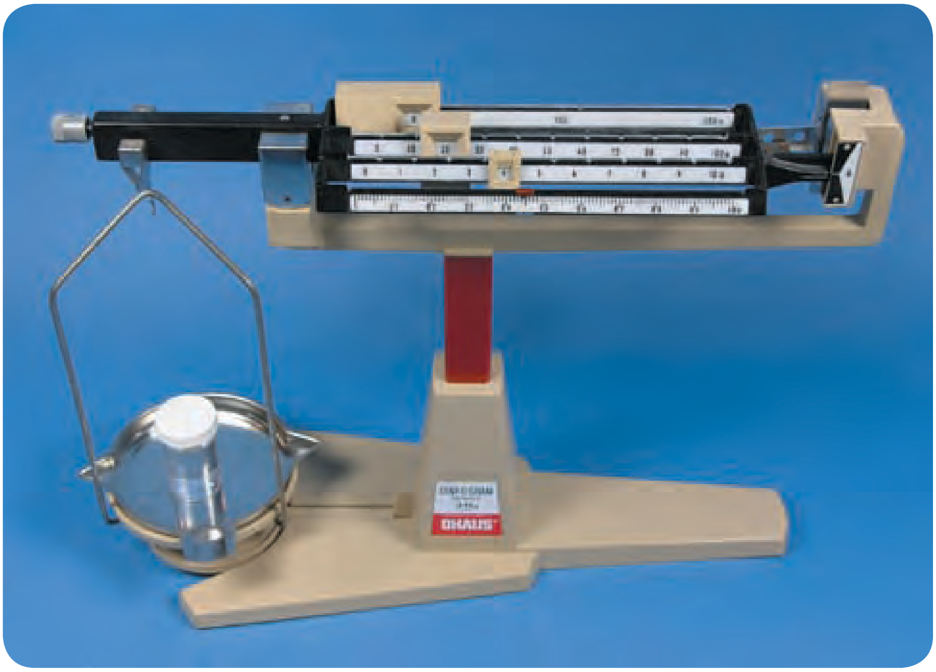


Figure 1.16

A single-pan balance with four beams and four riders.

Figure 1.17

The top of a common balance in a physician's office. The scale is shown in both kilograms and pounds. *(Courtesy of Detecto, a Division of Cardinal Scale Mfg. Co.)*

Figure 1.18

An electronic balance with the 100-g calibration mass on the pan.

22. What is the advantage of using a single-pan balance rather than an equal-arm balance when massing a person?

1.8 The Sensitivity of a Balance

If you mass the same object several times on the same balance, will you find the same mass each time? And a related question: How much must the masses of two objects differ before your balance is able to tell the difference between them? The purpose of this experiment is to answer these questions.

To answer these questions you must zero the balance before each use. This means that the balance must be adjusted so that it correctly displays a reading of “zero” when there is zero mass on its pan. Your teacher will tell you how to zero the balance you are using.

Let us return to the first question: If you mass the same object several times, will you find the same mass each time? Mass two objects, such as a penny and a rubber stopper. Place the objects on the balance one at a time and have your lab partner read and record each result. Now switch roles with your lab partner, mass the two objects again, and record these results. Repeat this procedure as many times as specified by your teacher. Compare the results for each object obtained by you and your lab partner.

- Does your balance give the same results to the nearest 0.01 g? the nearest 0.001 g? or something in between?

Now for the second question: How much must the masses of two objects differ before your balance is able to tell the difference between them? To answer this question you can add small, known masses to an object already massed on your balance. A set of such small masses can be obtained using the squares from a piece of graph paper.

To obtain small, known masses, cut a group of smaller squares from a large square of graph paper that you have massed. Begin by neatly cutting a large square of graph paper that has 20 squares along each edge. This large square is made up of 400 small squares.

Estimate the mass of the large square to the nearest 0.1 g. You can write your estimate on the square and compare it with the estimates made by your classmates. Now mass the large square.

- What is the mass of your large square of graph paper?
- What is your calculated mass of a single small square?

For the purpose of this experiment, it will be convenient to have rectangular pieces of graph paper made up of small squares with a total mass between 0.003 and 0.007 g.

- How many of the small squares are in a group that has a mass between 0.003 and 0.007 g?
- What is the mass of this group of small squares?

These groups of squares are the known mass that you will add to an object massed on your balance.

Prepare ten of these groups of small squares. With a penny or rubber stopper already balanced, add the groups of small squares one by one and observe the effect on the balance.

- How many groups of squares did you have to add before the balance gave you an observable response?

The smallest change in mass that a balance can detect in a reproducible way is called the *sensitivity* of the balance.

- What is the sensitivity of your balance?
- How does this value for the sensitivity of the balance compare with your answer to the first bulleted question in this experiment?

23. A rectangle made from two squares of graph paper has a mass of 0.0045 g. The results of adding 10 such rectangles, one at a time, to an electronic balance are given below along with the mass readings on the scale.

Initial mass on the balance = 2.64 g

Number of rectangles	Was there a change from the previous reading?	Mass reading (g)
1	No	2.64
2	No	2.64
3	Yes	2.65
4	No	2.65
5	Yes	2.66
6	No	2.66
7	No	2.66
8	Yes	2.67
9	No	2.67
10	Yes	2.68

Based on these results, what should you report for the sensitivity of the balance?

24. Karen massed an object three times, using the same equal-arm balance and gram masses. Her results were 18.324 g, 18.308 g, and 18.342 g. How could she best report the mass of the object?

25. Five students in turn used the same equal-arm balance to measure the mass of a small dish. None knew what results the others obtained. The masses they found are given in the table below.

Student	Mass (g)
1	3.752
2	3.755
3	3.752
4	3.756
5	3.760

a. Can you tell whether any student made an incorrect measurement?

b. Do you think there is anything wrong with the balance?

c. What do you think is the best way to report the mass of the dish?

26. Susan massed an object three times, using the same single-pan balance. Her results were 21.420 g, 21.425 g, and 21.410 g. How could she best report the mass of the object?

27. Five students in turn used the same single-pan balance to measure the mass of a small dish. None knew the results the others obtained. The masses they found are given in the table below.

Student	Mass (g)
1	4.360
2	4.370
3	4.365
4	4.360
5	4.355

a. Can you tell whether any student made an incorrect measurement?

b. Do you think there is anything wrong with the balance?

c. What do you think is the best way to report the mass of the dish?

28. Five students in turn used the same electronic balance to measure the mass of a small dish. None knew the results of the others. The masses are given in the table below.

Student	Mass (g)
1	4.36
2	4.37
3	4.36
4	4.37
5	4.36

a. Can you tell whether any student made an incorrect measurement?

b. Do you think there is anything wrong with the balance?

c. What do you think is the best way to report the mass of the dish?

For Review, Applications, and Extensions

29. Suppose the volume of a piece of glass is measured by displacement of water and by displacement of burner fuel. How would the two measurements compare?

30. 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.

    a. If the height of the space was half the length of an edge of a 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 cube, what was the volume of the box?

31. 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?

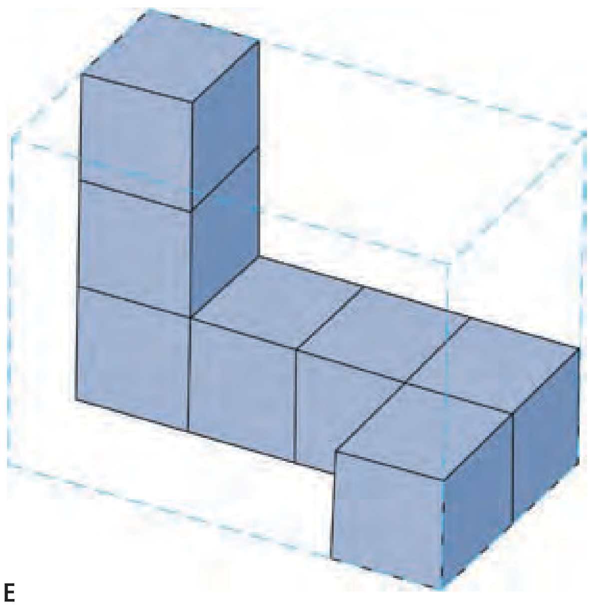


Figure E
For Problem 31

32. In an experiment in which the volume of 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?

33. 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?

34. 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?

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

1 ½ pounds ground chuck	pinch of pepper
1 medium-size onion	3 drops steak 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

36. a. What is the volume of an aluminum cube with edges that 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.)

37. 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?

38. Suppose that you took home an equal-arm balance. 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?

39. 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?

40. Estimate in grams the mass of a watch. 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?

41. How could a person easily tell which envelopes contained four sheets of paper and which contained five sheets without opening the envelopes? What assumption did you make in arriving at your answer?

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 balance during the summer. Write a complete set of instructions for her so that she will be able to do so successfully on her own without anybody being present to help her.