1.3 MEASUREMENT

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NOTE: THIS IS ONLY A PORTION OF ONE CHAPTER.

Measurement is the process of gaining quantitative information about the physical world. The science of measurement is closely linked to the development of technology because more advanced technologies demand better systems of measurement. For example, while a farmer may be satisfied knowing the length of a furrow to within one meter, an electronic engineer may require a tolerance of one nanometer (billionth of a meter) when designing an integrated circuit on an advanced computer microprocessor. The demand for improved systems of measurement is found in nearly all technological fields and has been accentuated by major scientific endeavors such as the American space program.

Between 1966 and 1968, Americans landed a series of 7 probes on the Moon to photograph and study the lunar surface in preparation for the first manned expedition. In 1967, Surveyor 3 landed in an ancient crater known as the Sea of Tranquillity and sent back data indicating that it would be a suitable landing site for a manned mission. On July 16, 1969, Neil Armstrong and Edwin Aldrin became the first humans to set foot on the surface of the Moon. They traveled over 400,000 kilometers through space and landed within walking distance of the Voyager 3 craft with only 10 seconds of fuel remaining. Imagine what would have happened if NASA scientists had inaccurately measured the thrust of the Saturn V rockets, the mass of the payload, the distance to the Moon, the location of Voyager 3 craft, the gravitational field of the Moon, the rate of fuel consumption, the speed of the Apollo 11 craft, the orbit of the Moon around the Earth, the astronauts' rate of oxygen consumption, or the radio frequency of the communication gear! Had scientists inaccurately measured any of these or thousands of other variables, the most dramatic human exploration in history would have ended in sheer disaster.

All measurements are merely comparisons to a standard measure. The most universal system of measuring length in the ancient world was the cubit (approximately the length from the elbow to the extended middle finger), and "cubit" sticks were often checked for accuracy against the royal granite cubit block in Egypt. Today, we no longer standardize measures against cubit blocks, or meter steel sticks, but rather against physical phenomenon that we believe change even less than granite or steel. The meter, for example, is currently defined as the length of the path traveled by light in a vacuum during a time interval of 1/299,792,458 of a second, where a second is defined as exactly 9,192,631,770 periods of radio radiation emitted as a result of gyroscopic precession of the outermost electron in undisturbed cesium atoms! Although these definitions do not help us gain an intuitive understanding of their magnitude, they are invariant and thus serve as excellent standards for measurement.

All measurements are approximations. Suppose we use the two metric rulers shown in Figure A to measure the length of a metal rod. The bottom ruler is graduated (marked) in centimeters while the top is graduated in millimeters. Using the cm-ruler we can see that the length of the rod is between 2 and 3 centimeters and the best we can do is estimate that the length of the rod is about 50% of the distance from the 2 centimeter mark to the 3 centimeter mark. Our best guess at the length is 2.5 centimeters. The first digit of our answer is certain (it is clearly more than 2 and less than 3), but the second digit, an estimate, is uncertain. Using the centimeter ruler we measure the length of the rod to two significant digits (one measured, plus one estimated).

Using the millimeter-ruler we can see that the end of the rod is about 60% of the distance between the 2.5 and 2.6 marks. Using this ruler we estimate the length of the rod to be 2.56 centimeters. The first two digits of the answer are certain (it is clearly more than 2.5 and less than 2.6) but the last digit is an estimate and is uncertain. Using the millimeter ruler we measure the length of the rod to three significant figures (two measured, plus one estimated). Whenever you make measurements, make sure that you include only significant digits: all measurable digits, plus one estimated.

1.3.1 LENGTH: ESTIMATING AND MEASURING

Concepts to Investigate: Length, units, approximations, direct measurement, indirect measurement, estimating, optical illusions, significant digits.
Materials: Meter stick, mm ruler.
Principles and Procedures: Linguists say that people are fluent in a language when they start thinking in that language. For example, an English-speaking person is considered fluent in Swahili (the language of Eastern Africa) when he or she actually thinks in that language. Linguists suggest that the best way to become fluent in a new language is to immerse yourself in a culture where you must use that language to communicate. Thus, although it may be helpful to learn Swahili by listening to tapes, reading books, and taking classes, the best way to become fluent is to live in Kenya, Tanzania, or Mozambique where you must speak Swahili to be understood.

Many Americans learn the English system of measurement from childhood, but never become fluent in the metric system because they have never had to use it to communicate. When they report their height, they report it in inches, and when they report their weight, they do so in pounds. If asked their height or weight in metric terms, they generally do some calculations in their heads to convert English units to metric units. In this activity you will be asked to think purely in metric terms, without first thinking in English terms and then converting to metric. By developing some common benchmark measures of length in metric units, it will be easier to become fluent.

<u>Part 1: Estimating length</u>: To think in metric units it is helpful to have some easy-to-remember "benchmark" measures with which to compare. Use a meter stick and a ruler with millimeter divisions to find common objects that are approximately 1 millimeter, 1 centimeter and 1 meter in length. For example, the tip of a sharpened pencil may be approximately 1 mm in diameter, or the width of one of your fingernails may be approximately 1 cm. Identify the items you have chosen in the spaces provided in the Table 1.

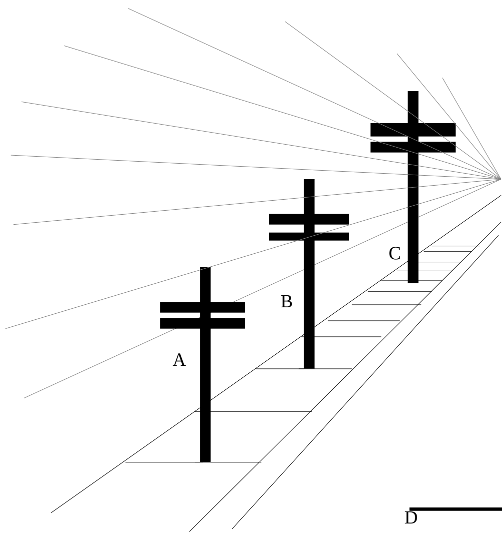
Table 1 "Benchmarks" for length	
Metric unit	*approximately the same length as this common item:*
millimeter	
centimeter	
meter	

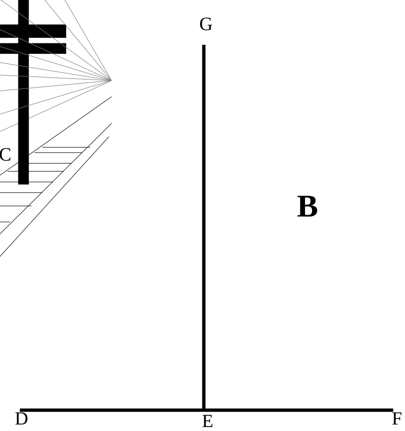
Using these "benchmarks", estimate some the following distances in the appropriate metric units. After you have written your estimates, measure the distances and calculate the percentage error for each: [(estimate - measured)/(measured)]x 100%. Enter your answer in Table 2.

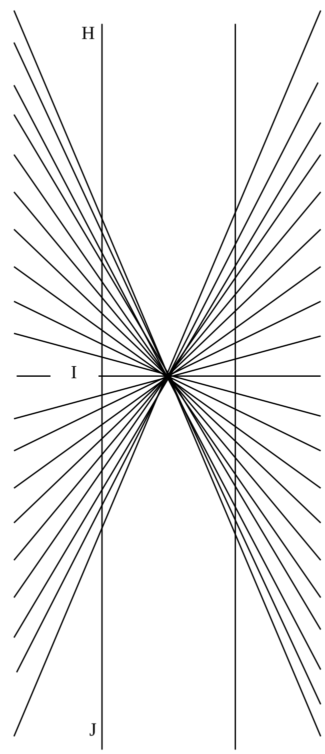
Table 2 Estimates of Length			
	Your estimate	*Your measurement*	*Percent error*
length of room	(m)	(m)	(m)
width of room	(m)	(m)	(m)
your height	(cm)	(cm)	(cm)
height of door	(cm)	(cm)	(cm)
length of pencil or pen	(mm)	(mm)	(mm)
thickness of 50 sheets of paper	(mm)	(mm)	(mm)

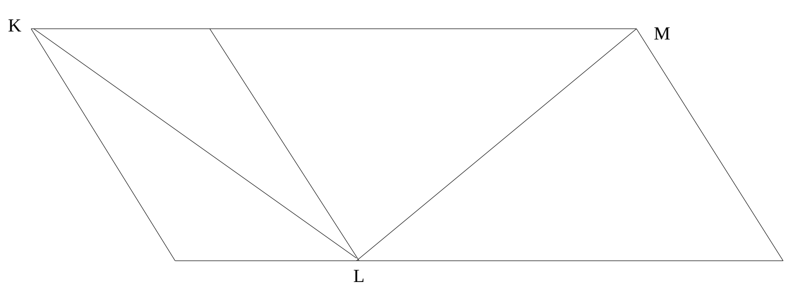
Part 2: Measuring distance: Look at the illustrations in Figure B and then answer the questions in the first column of Table 3. Now measure each length as accurately as possible and record your measurements in the appropriate boxes in the middle of the chart. Draw conclusions based upon your measurements and put the answers in the final column. Were your original assumptions correct? Why or why not?

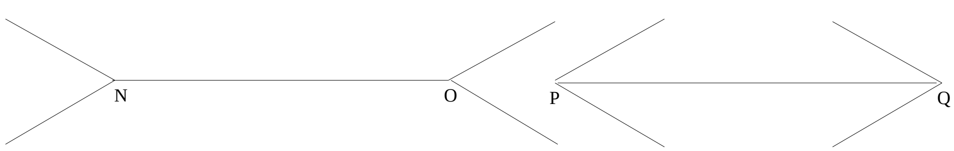
Table 3 Estimating and Measuring Distance				
Assumption based on observation.	*Measurement to the nearest tenth of a millimeter.*			*Conclusion based upon measurement.*
Which appears the tallest? A B C	Pole A	Pole B	Pole C	Which pole is the tallest? A B C
Which line appears longer? DF GE	DF	GE		Which line is longer? DF GE
Do the tracks appear parallel? yes no	width at H	width at I	width at J	Are the tracks parallel? yes no
Which line appears longer? KL LM	KL	LM		Which line is longer? KL LM
Which line appears longer? NO PQ	NO	PQ		Which line is longer? NO PQ











Part 3: Indirect measurement of distance**:** Suppose we wish to measure the thickness of one page of a book. It is impossible to measure the thickness of a page directly with your ruler because the thickness is much less than the distance between the mm markings . However, we can obtain an indirect measurement. Use a ruler to measure the thickness of all the pages together (not counting the back and front covers). Divide the result by the total number of sheets. For example, if a book of 800 pages length (400 sheets) has a width of 40 mm, then the thickness of one sheet is 0.10 mm (40 mm/400 sheets). Compute the thickness of sheets in this book and compare them with those from another book of your choice. Chemists must often use indirect measurement to determine such things as the mass of a molecule or the length of a chemical bond.

Questions:

(1) A chemistry student measures the width of a platinum electrode with a millimeter ruler and reports that it is 9.0000 mm. The teacher says the student's measurement is impossible. Why?

(2) Did your conclusions based upon direct measurement in part 2 agree with your predictions based solely on observation? Why is it important to make direct measurements in science whenever possible.

(3) Polyethylene is a polymer (a long chain of smaller molecules known as monomers) used in the manufacture of many plastic containers. If you see a recycle symbol (Figure C) with the number 2 or the letters HDPE, then the container is made of high density polyethylene. Suppose a chemist has determined that a single polymer strand of polyethylene measuring 0.07 millimeters in length is composed of 100,000 monomers. Using the principal of indirect measurement, how long would you estimate each monomer to be?

1.3.2 AREA: ESTIMATING AND MEASURING

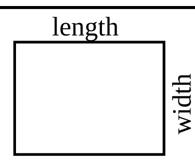
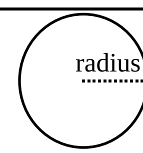
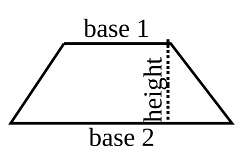
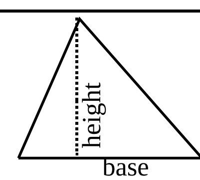
Concepts to Investigate: Area, measuring area of regular and irregular surfaces, indirect measurement, optical illusions.

Materials: Metric graph paper, centigram balance, scissors.

Principles and Procedures: Chemists are very interested in surface area because it is one of the key factors that determines the rate at which a chemical or physical reaction proceeds. The larger the surface area of contact between two reactants, the faster the resulting reaction. For example, when making hot cocoa, you stir the cocoa powder into the water or milk to separate the cocoa particles from each other and place them in contact with the water or milk so they can dissolve. Stirring increases the surface area of contact between the cocoa and the milk. In a similar manner, a snow-making machine at a ski slope sprays out an aerosol of water rather than a stream of water so the tiny water droplets will be in direct contact with the cold air and freeze more rapidly.

Part 1: Surface area of regular objects: The surface area of regular planar surfaces can be calculated using standard formulas such as those shown in Table 4. Verify these formulas by drawing these shapes on millimeter graph paper and then counting the number of millimeter squares in which the majority of the square is inside the figure as shown in Figure D. If the formulas are correct, the number of square millimeters counted inside the boundary of the object should be nearly equivalent to the value obtained by formula.

Table 4 Formulas for surface area of regular shapes

Rectangle A = length x width		*Circle* A = π x radius^2	
Trapezoid A = height x 1/2 x (base 1+ base 2)		*Triangle* A = 1/2 x base x height	

Part 2: Indirect measurement of irregular surface area: The surface area of an irregular shaped two dimensional object can be estimated by counting the number of squares within its boundary as illustrated in Figures D and E. This technique provides an estimate, but it is rather tedious and time consuming. In this activity you will perform a less tedious and more accurate indirect measurement of surface area (Figures F). Measure the dimensions

of a plain sheet (without holes) of photocopy or drawing paper. Measure the length and width of the paper and calculate its area. Weigh the paper on the most sensitive balance available (sensitivity of .01 grams or better) and calculate the area to mass ratio. Now trace the irregular shape to be measured (a leaf, the palm of your hand, etc.) onto the paper and cut out and weigh the trace. Multiply the mass of the cutout by the area/mass ratio for the paper to indirectly measure the area of the object. If you do not have a sensitive balance, you may wish to carryout the process using heavy cardboard.

Table 5 Indirect Measurement of Surface Area

object	*estimated area (number of boxes enclosed)*	*indirectly measured area.*
leaf	mm^2	mm^2
hand	mm^2	mm^2
your figure	mm^2	mm^2

Questions:

(1) For regular planar objects, is the value determined by counting squares more or less accurate than the value obtained by calculation? Explain.
(2) Why is it advantageous to use heavy poster-board or cardboard instead of paper when determining the area of an irregular object if you do not have a sensitive scale?
(3) For irregular planar objects do you think the weight is more accurately measured by counting the squares or by indirectly measuring the area by massing the cut-out and multiplying this value by the area/mass ratio for the paper?

1.3.3 VOLUME: ESTIMATING AND MEASURING

Concepts to Investigate: Volume of regular objects, volume of irregular objects, volume formulas, displacement method for measuring volume, incompressibility of liquids.

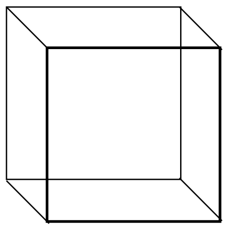
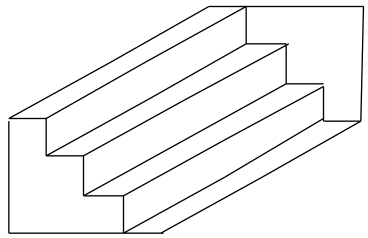
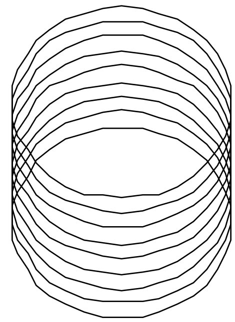
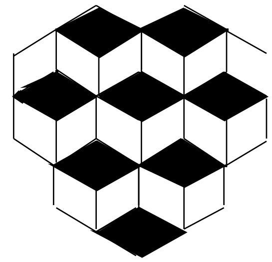
Materials: Centimeter graph paper, paper clips, pennies, cardboard, plastic wrap or aluminum foil, 1 liter plastic soda bottle, two 50 mL burets, isopropyl alcohol.

Safety: Isopropyl alcohol is flammable and must be kept away from flames. Like all organic solvents, it should be used only in a well ventilated area.

Principles and Procedures: Part 1: Units of volume: The volume of a solid, liquid, or gas is the amount of space it occupies. A variety of SI units are used to indicate volume depending upon the size of the object measured. The volume of a house may be measured in cubic meters (m^3), while the volume of an automobile fuel tank is measured in liters (L) and a soda can in milliliters (1 milliliter = 1 cubic centimeter (cm^3)).

This activity will help you discover some important relationships among the various metric units of volume. Cut three 10 cm x 10 cm squares from centimeter graph paper and paste them onto stiff cardboard cut as shown in Figure G. Fold the cardboard on the dotted lines and securely tape the edges to form a cube (no top) with inside dimensions 10 cm by 10 cm by 10 cm. Line the inside of the box with a clear plastic bag so it will hold water. The volume of a regularly shaped container such as your box is easy to compute. Simply multiply the length by the width by the height: 10 cm x 10 cm x 10 cm = 1000 cm^3 (1000 cubic centimeters). A volume of 1000 cm^3 is also called one cubic decimeter (1 dm^3). Note that the term *cubic centimeter* (cm^3) is derived from the fact that it is the volume of a cube with sides of length 1 cm (1 cm x 1 cm x 1 cm= 1 cm^3= 1 mL)

Obtain a one liter plastic bottle such as those used to hold drinking water and other beverages. You have seen one liter bottles of soda in the supermarket and have probably noticed that the liquid level in the bottle is generally about 5 millimeters below the top because this is the actual 1 liter line. Fill the bottle with water to this point, and then carefully pour the water into the plastic-lined box. What is the approximate volume of the box in liters?

<u>Part Two: Calculating volume</u>. Figures H-K illustrate optical illusions, pictures that play tricks on our perception. Examine the cube (Figure H). Is the area within the darker lines the outside or inside of the cube? It depends on the orientation of the cube seen by your mind. Keep looking and you will see the cube flip back and forth between these two orientations. Inspect the stairs and hollow tube shown in Figures I and J. In which direction does the staircase run? (right side up, or upside down?) In which direction does the tube in Figure J run; up or down? Keep looking at each figure and you will see each reverse! Try blinking if you can't see both ways. How many stacked boxes do you see in Figure K? Are the black squares the tops or bottoms of the boxes. Are there six or seven boxes?

It is not possible for you to make direct computations of the volumes of these figures because they are displayed in only two dimensions and presented at oblique angles. We will therefore provide linear dimensions and ask you to calculate volumes.

(a) Find the volume of the cube (Figure H) assuming the dimensions of its sides are 23.0 cm. (b) Find the volume of the staircase (Figure I) assuming that each step is 14.4 cm high, 160.5 cm wide and 29.2 cm deep. (c) If the radius of each of the circles at the end of the tube (Figure J) is 4.00 cm and the length of the tube is 5.10 cm, what is the volume? Since the tube is in the shape of a cylinder its volume is computed by multiplying the area of one end (the base; $A = \pi r^2$) by the length. (d) What is the total volume of all the boxes in Figure K (six or seven as you see it !) given that the length of an edge is 12.5 mm? Record these values in Table 6 .

Table 6 Apparent volumes of illusions	*Volume (cm^3)*	*Volume (mL)*	*Volume (L)*
(a) Cube	cm^3	mL	L
(b) Stairs	cm^3	mL	L
(c) Cylinder	cm^3	mL	L
(d) Blocks (6)	cm^3	mL	L
(d) Blocks (7)	cm^3	mL	L

Part 3: Measurement of volume by displacement: Chemists must often determine the volume of small or irregular objects. For example, a forensic chemist (one who works with law enforcement officials to help solve crimes) might be asked to determine the manufacturer of a bullet recovered from a crime scene. Knowing that different manufacturers use different alloys with different densities, the chemist may first determine the volume of the bullet so that he or she may then mass it and ascertain the density (density = mass/volume). How would you determine the volume of an irregular object such as a bullet?

In this activity you will be asked to measure the volume of some small irregular objects such as a penny, a paper clip, and a tack using indirect measurement and water displacement. Fill a graduated cylinder partially with water and carefully record the volume to the nearest 0.1 mL. When reading volumes, always report the value at the bottom of the meniscus (the curved surface at the air/fluid interface) as shown in Figure L. Place 50 or more paper clips in the cylinder and lightly tap the glass until no air bubbles remain attached to the paper clips. Record the final volume. The difference between the two volume measurements is the volume of 50 paper clips (Figure M). Therefore, you can determine the volume of one paper clip simply by dividing this volume by 50. Repeat with tacks and pennies and enter your findings in Table 7.

Table 7 Measuring Volume by Displacement

	original volume (V_1)	*final volume (V_2)*	*displacement volume ($V=V_2-V_1$)*	*quantity of object (n)*	*volume of single object (v)*
paper clips					
thumbtacks					
penny					

Part 4: The case of the vanishing volume; or 2+2=3. A liquid is defined as a form of matter that flows, has constant (fixed) volume and takes the shape of its container. The object

was placed in a cylinder containing water, and the water flowed around it. Since water is relatively incompressible (maintains a fixed volume), the change in volume in the cylinder was equivalent to the volume of the submerged object.

When you apply pressure to a liquid its shape may change, but not its volume. This principle is used in automobile brakes. When the driver presses on the pedal, brake fluid flows through the brake line, transmitting pressure to the brake shoes. If the brake fluid were compressible, the fluid would compress and less force would be transmitted to the brake shoes, rendering the design useless.

(a) Fill two 50 mL burets to the 25.0 mL mark with water. Slowly drain 25.0 mL of water from one buret into the other and read the final volume to the nearest tenth of a milliliter (Figure N). Record the final volume to the nearest tenth of a milliliter in Table 8. (b) Repeat procedure "a" using isopropyl alcohol in both burets. (c) Finally, fill one 50 mL buret to the 25.0 mL mark with water and another 50 mL buret to the 25.0 mL mark with isopropyl alcohol. Slowly pour 25.0 mL of water from the water buret into the alcohol buret and carefully read the final volume to the nearest tenth of a millimeter.

Do all of the mixtures add up to 50.0 mL? Did the volume of any of the mixtures decrease or increase significantly (by more than 1%)?

Table 8 Vanishing Volume?

(a) 25.0 mL water + 25.0 mL water	*(b) 25.0 mL alcohol + 25.0 mL alcohol*	*(c) 25.0 mL water + 25.0 mL alcohol*
mL	mL	mL

Questions:

(1) Complete the following:

(a) 1 dm^3 = ? cm^3

(b) 1 mL = ? cm^3

(c) 100,000 mL = ?L

(d) 1 m^3 = ? cm^3

(e) 2 km^2 = ? mm^3

(2) Explain how indirect measurement can be used to find the volume of a drop of liquid too small to be measured directly.

(3) Given the following formulas, determine the volumes of the objects illustrated in figures (O-R).

Rectangular Prism (Box) $V = L \times W \times H$

Cylinder $V = \pi \times R^2 \times H$

Cone	$V = 1/3 \times \pi \times R^2 \times H$
Sphere	$V = 4/3 \times \pi \times R^3$

(4) A liquid is defined as a form of matter that flows, has constant (fixed) volume and takes the shape of its container. Which of these characteristics seems not to hold true upon mixing of alcohol and water? Explain.