

Laboratory Manual

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CONCEPTUAL PHYSICS

The High School Physics Program

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Paul Robinson

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Laboratory Manual

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Paul Robinson

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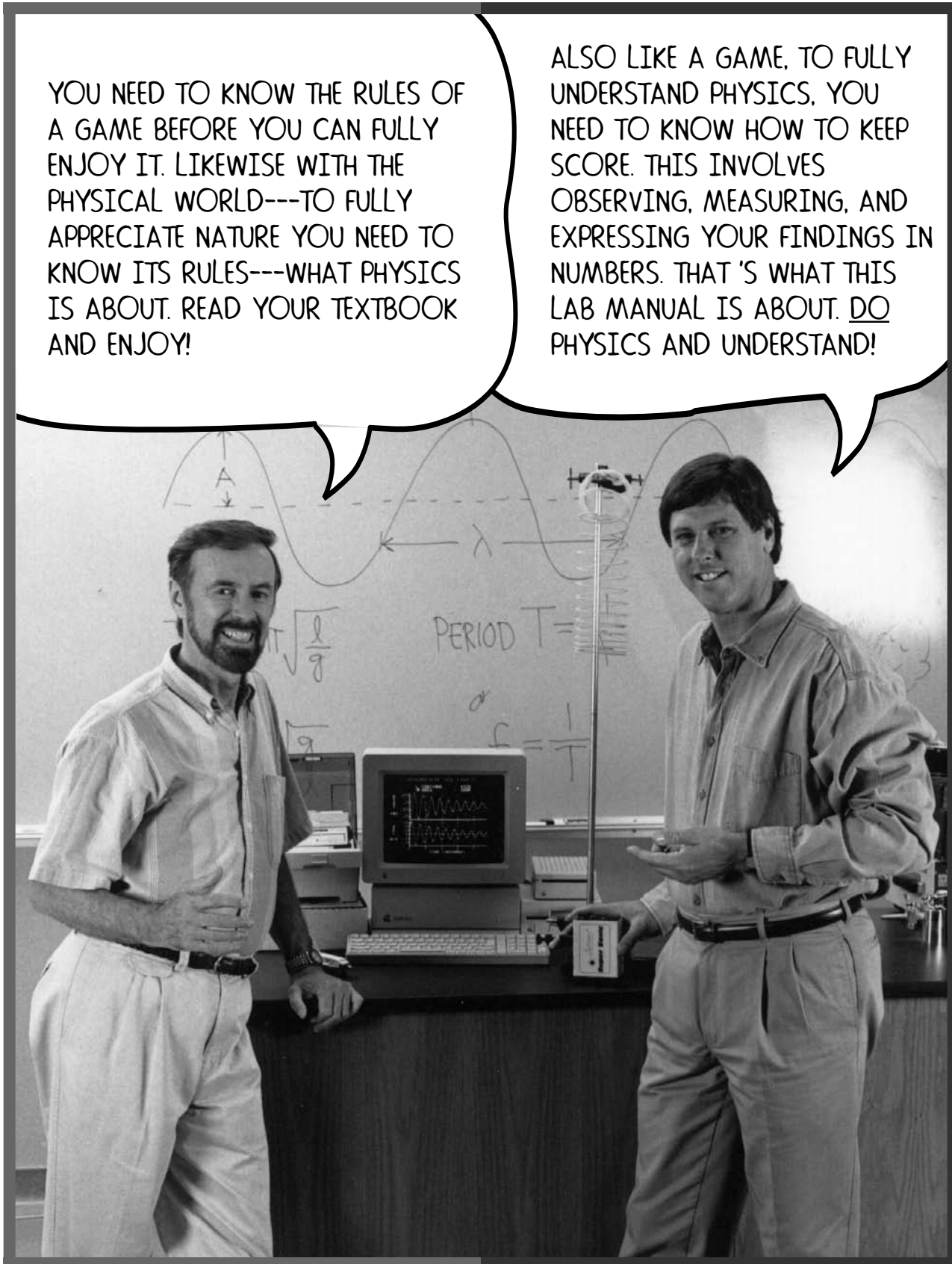
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To the Student

YOU NEED TO KNOW THE RULES OF A GAME BEFORE YOU CAN FULLY ENJOY IT. LIKewise WITH THE PHYSICAL WORLD---TO FULLY APPRECIATE NATURE YOU NEED TO KNOW ITS RULES---WHAT PHYSICS IS ABOUT. READ YOUR TEXTBOOK AND ENJOY!

ALSO LIKE A GAME, TO FULLY UNDERSTAND PHYSICS, YOU NEED TO KNOW HOW TO KEEP SCORE. THIS INVOLVES OBSERVING, MEASURING, AND EXPRESSING YOUR FINDINGS IN NUMBERS. THAT 'S WHAT THIS LAB MANUAL IS ABOUT. DO PHYSICS AND UNDERSTAND!



Goals

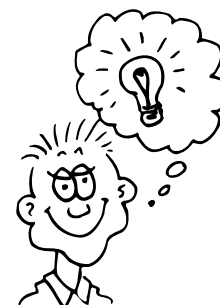
The laboratory part of the *Conceptual Physics* program should

- 1) Provide you with hands-on experience that relates to physics concepts.
- 2) Provide training in making measurements, recording, organizing, and analyzing data.
- 3) Provide you with the experiences in elementary problem solving.
- 4) Show you that all this can be interesting and worthwhile—*doing* physics can be quite enjoyable!

This lab manual contains 61 activities and 38 experiments. Most activities are designed to provide you with hands-on experience that relates to a specific concept. Experiments are usually designed to give you practice using a particular piece of apparatus. The goals for activities and experiments, while similar, are in some ways different.

The chief goal of activities is to acquaint you with a particular physical phenomenon which you may or may not already know something about. The emphasis during an activity is for you to observe relationships, identify variables, and develop tentative explanations of phenomena in a qualitative fashion. In some cases, you will be asked to design experiments or formulate models that lead to a deeper understanding.

Experiments are more quantitative in nature and generally involve acquiring data in a prescribed manner. Here, a greater emphasis is placed on learning how to use a particular piece of equipment, making measurements, identifying and estimating errors, organizing your data, and interpreting your data.



Graphing

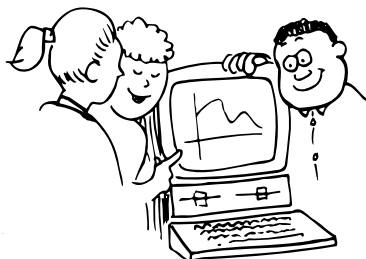
When you look at two columns of numbers that are related some way, they probably have little meaning to you. A *graph* is a visual way to see how two quantities are related. You can tell at an instant what the stock market has been doing by glancing at a plot of the Dow Jones Industrial Average plotted as a function of time.

Often you will take data by changing one quantity, called the *independent variable*, in order to see how another quantity, called the *dependent variable*, changes. A graph is made by plotting the values of the independent variable on the *horizontal axis*, or *x-axis* with values of the dependent variable on the *vertical axis*, or *y-axis*. When you make a graph, it is always important to label each of the axes with the quantity and units used to express it. The graph is completed by sketching the best smooth curve or straight line that fits all the points.

To eliminate confusion and increase learning efficiency, your teacher will guide you before each experiment as to how to label the axes and choose a convenient scale. Often you will work in groups and graph your data *as you perform the experiment*. This has the chief advantage of providing immediate feedback if an erroneous data point is made. This gives you time to adjust the apparatus and make the necessary adjustments so that your data are more meaningful. Everyone in the class can be easily compared by simply overlapping the graphs on an overhead projector. This method also has the added benefit of eliminating graphing as a homework assignment!



Use of the Computer



The computer provides a powerful tool in collecting and analyzing your data and displaying it graphically. Data plotting software enables you to input data easily and to plot the corresponding graph in minutes. With the addition of a printer, your graphs can be transferred to paper and included with your lab report.

Because of the computer's ability to calculate rapidly and accurately, it can help you analyze your data quickly and efficiently. The interrelationships between variables become more apparent than if you had to plot the data by hand.

In this course you will be encouraged to use the computer (if it is available in your lab room) as a laboratory instrument that can measure time and temperature and sense light. You can convert the computer into a timer, a light sensor, and a thermometer by connecting to it one or more variable resistance probes. Though not required for any of the labs, the use of probeware greatly facilitates data collection and processing.

Lab Reports

Your teacher may ask that you write up a lab report. Be sure to follow your teacher's specific instructions on how to write a lab report. The general guideline for writing a lab report is: Could another student taking physics at some other school read your report and understand what you did well enough to replicate your work?

Suggested Guidelines for Lab Reports

Lab number and title Write your name, date, and period in the upper right-hand corner of your report. Include the names of your partners underneath.

Purpose Write a brief statement of what you were exploring, verifying, measuring, investigating, etc.

Method Make a rough sketch of the apparatus you used and a brief description of how you planned to accomplish your lab.

Data Show a record of your observations and measurements, including all data tables.

Analysis Show calculations performed, any required graphs, and answers to questions. Summarize what you accomplished in the lab.



Safety in the Physics Laboratory

By following certain common sense in the physics lab, you can make the lab safe not only for yourself but for all those around you.

1. Never work in the lab unless a teacher is present and aware of what you are doing.
2. Prepare for the lab activity or experiment by reading it over first. Ask questions about anything that is unclear to you. Note any cautions that are stated.
3. Dress appropriately for a laboratory. Avoid wearing bulky or loose-fitting clothes or dangling jewelry. Pin or tie back long hair, and roll up loose sleeves.
4. Keep the work area free of any books and materials not needed for what you are working on.
5. Wear safety goggles when working with flames, heated liquids, or glassware.
6. Never throw anything in the laboratory.
7. Use the apparatus only as instructed in the manual or by your teacher. If you wish to try an alternate procedure, obtain your teacher's approval first.
8. If a thermometer breaks, inform your teacher immediately. Do not touch either the mercury or the glass with your bare skin.
9. Do not force glass tubing or thermometer into dry rubber stopper. The hole and the glass should both be lubricated with glycerin (glycerol) or soapy water, and the glass should be gripped through a paper towel to protect the hands.
10. Do not touch anything that may be hot, including burners, hot plates, rings, beakers, electric immersion heaters, and electric bulbs. If you must pick up something that is hot, use a damp paper towel, a pot holder, or some other appropriate holder.
11. When working with electric circuits, be sure that the current is turned off before making adjustments in the circuit.
12. If you are connecting a voltmeter or ammeter to a circuit, have your teacher approve the connections before you turn the current on.
13. Do not connect the terminals of a dry cell or battery to each other with a wire. Such a wire can become dangerously hot.
14. Report any injuries, accidents, or breakages to your teacher immediately. Also report anything that you suspect may be malfunctioning.
15. Work quietly so that you can hear any announcements concerning cautions and safety.
16. Know the locations of fire extinguishers, fire blankets, and the nearest exit.
17. When you have finished your work, check that the water and gas are turned off and that electric circuits are disconnected. Return all materials and apparatus to the places designated by your teacher. Follow your teacher's directions for disposal of any waste materials. Clean the work area.

** See page xiv for descriptions of the safety symbols you will see throughout this laboratory manual.*

Safety Symbols

These symbols alert you to possible dangers in the laboratory and remind you to work carefully.



Safety Goggles



Corrosive Chemical



Lab Apron



Poison



Breakage



Physical Safety



Heat-Resistant Gloves



Flames



Heating



No Flames



Sharp Object



Fumes



Electric Shock



General Safety Awareness

Emergency Procedures

Report all injuries and accidents to your teacher immediately. Know the locations of fire blankets, fire extinguishers, the nearest exit, first aid equipment, and the school's office nurse.

Situation	Safe Response
Burns	Flush with cold water until the burning sensation subsides.
Cuts	If bleeding is severe, apply pressure or a compress directly to the cut and get medical attention. If cut is minor, allow to bleed briefly and wash with soap and water.
Electric Shock	Provide fresh air. Adjust the person's position so that the head is lower than the rest of the body. If breathing stops, use artificial resuscitation.
Eye Injury	Flush eye immediately with running water. Remove contact lenses. Do not allow the eye to be rubbed.
Fainting	See Electric Shock.
Fire	Turn off all gas outlets and disconnect all electric circuits. Use a fire blanket or fire extinguisher to smother the fire. Caution: Do not cut off a person's air supply. Never aim fire extinguisher at a person's face.

1

Making Hypotheses

Purpose

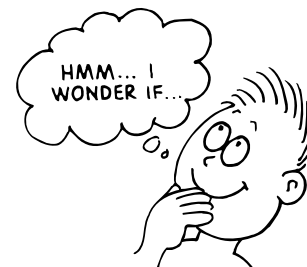
To practice using observations to make hypotheses.

Required Equipment/Supplies

2 1-gallon metal cans
2 2-hole #5 stoppers
glass funnel or thistle tube
glass tubing
rubber tubing
500-mL beaker

Discussion

Science involves asking questions, probing for answers, and inventing simple sets of rules to relate a wide range of observations. Intuition and inspiration come into science, but they are, in the end, part of a systematic process. Science rests on observations. These lead to educated guesses, or *hypotheses*. A hypothesis leads to predictions, which can then be tested. The final step is the formulation of a theory that ties together hypotheses, predictions, and test results. The theory, if it is a good one, will suggest new questions. Then the cycle begins again. Sometimes this process is brief, and a successful theory that explains existing data and makes useful predictions is developed quickly. More often, success takes months or years to achieve. Scientists must be patient people!

**Activity**

Procedure

Step 1: Observe the operation of the mystery apparatus (shown in Figure A) set up by your teacher.

Observe apparatus.

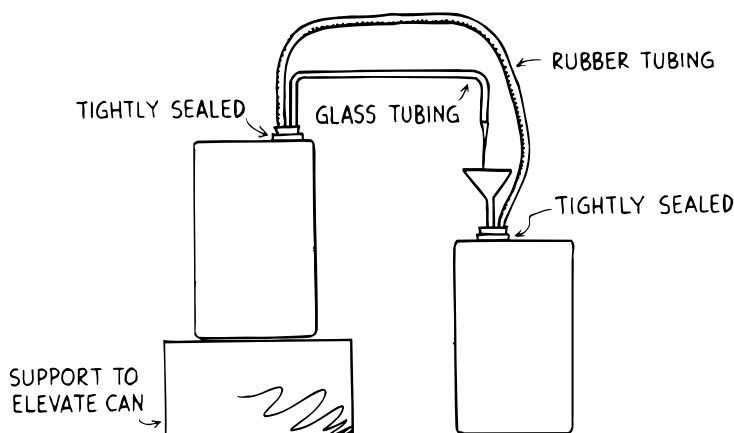


Fig. A

Propose explanations.

Step 2: Attempt to explain what is happening in the mystery apparatus and how it works. Write a description of how you think it works.

Step 3: Report your findings to the rest of the class. The class should reach a consensus about how it works. Record the consensus here.

2

The Physics 500

Purpose

To compute the average speed of at least three different races and to participate in at least one race.

Required Equipment/Supplies

meterstick
stopwatch
string
equipment brought by students for their races

Discussion

In this activity, you will need to think about what measurements are necessary to make in order to compute the average speed of an object. How does the average speed you compute compare with the maximum speed? How could you find the maximum speed of a runner or a car between stoplights?

Procedure

Step 1: Work in groups of about three students. Select instruments to measure distance and time. Develop a plan that will enable you to determine speed. Two students race each other in races such as hopping on one foot, rolling on the lawn, or walking backward. The third student collects and organizes data to determine the average speed of each racer. Repeat this process until each member of your group has a chance to be the timer. For the race in which you are the timer, record your plan and the type of race.

When measurements are to be made in an experiment, a good experimenter organizes a table showing *all* data, not just the data that “seem to be right.” Record your data in Data Table A. Show the units you used as well as the quantities. For each measurement, record as many digits as you can read directly from the measuring instrument, plus one estimated digit. Then calculate the average speed for each student.

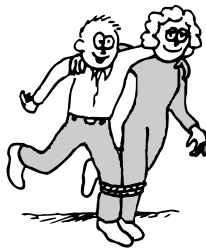
Measure average speed.



ACTIVITY	DISTANCE	TIME	SPEED

Data Table A

Compute unknown distance.



Step 2: Upon completing Step 1, report to your teacher. Your teacher will then ask you to perform one of your events over an unknown distance. Then, compute the distance covered (such as the distance across the amphitheater or the length of a corridor), using the average speed from Step 1.

event: _____

average speed = _____

distance = _____

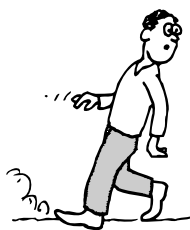
Analysis

- How does average speed relate to the distance covered and the time taken for travel?

- Should the recorded average speed represent the maximum speed for each event? Explain.

- Which event had the greatest average speed in the class in miles per hour ($1.00 \text{ m/s} = 2.24 \text{ mi/h}$)?

- Does your measurement technique for speed enable you to measure the fastest speed attained during an event?



Chapter 2: Linear Motion**Maximizing Average Speed****3****The Domino Effect****Purpose**

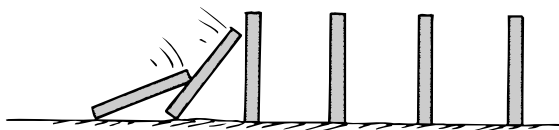
To investigate the ways in which distance, time, and average speed are interrelated by maximizing the speed of falling dominoes. To become familiar with elementary graphing techniques.

Required Equipment/Supplies

approximately 50 dominoes
stopwatch
meterstick

Discussion

A central property of motion is *speed*—the rate at which distance is covered. By rate, we mean how much or how many of something per unit of time: how many kilometers traveled in an hour, how many feet moved in a second, how many raindrops hitting a roof in a minute, how much interest earned on a bank account in a year. When we measure the speed of an automobile, we measure the rate at which this easily seen physical thing moves over the ground—for instance, how many kilometers per hour. But when we measure the speed of sound or the speed of light, we measure the rate at which energy moves. We cannot see this energy. We can, however, see and measure the speed of the energy pulse that makes a row of dominoes fall.

**Procedure**

Step 1: Set up 50 dominoes in a straight row, with equal spacing between them. The dominoes must be spaced at *least* the thickness of one domino apart. Your goal is to maximize the speed at which a row of dominoes falls down. Set the dominoes in a way you think will give the greatest speed.

Set up string of dominoes.

Step 2: Measure the total length of your row of dominoes.

length = _____

Step 3: Compute the average spacing distance between dominoes by measuring the length from the middle of the first domino to the middle of the last one, and divide this by the number of domino spacings.

average distance between dominoes = _____

Step 4: Measure the length of a domino.

length of domino = _____

spacing distance = _____ domino lengths

Step 5: Measure the time it takes for your row of dominoes to fall down.

time = _____

Compute average toppling speed.

Step 6: Compute the average toppling speed for your row of dominoes.

average speed = _____

Repeat for different spacings.

Step 7: Repeat Steps 5 and 6 for at least three more spacings. Include a spacing that is about as small as you can make it and still produce toppling and a spacing that is about as large as you can make it and still produce toppling. Record your data (including data for the first trial) in Data Table A.

Graph data.

Step 8: Using a separate piece of graph paper, make a graph of your data by sketching a smooth curve through your data points. Identify the point on the curve where the speed is maximum or minimum (this need not be exactly at one of your measured points).

Data Table A

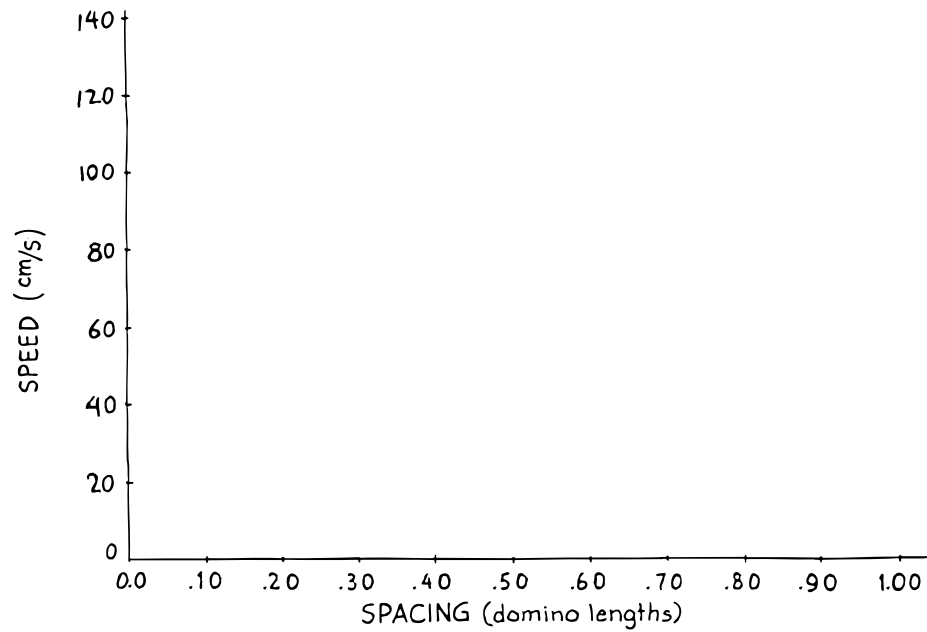


Fig. A

Analysis

1. What is a definition of average speed?

2. What are the factors that affect the speed of falling dominoes?

3. Why do we use *average speed* for the pulse running down the dominoes rather than *instantaneous speed*?

4. From your graph, what is the maximum or minimum toppling speed?

5. What spacing between dominoes do you predict would give the maximum or minimum speed? What is the ratio of this spacing to the length of a domino?

6. At the maximum or minimum toppling speed of the row of dominoes, how long a row of dominoes would be required to make a string that takes one minute to fall?

Chapter 2: Linear Motion**Acceleration Down an Incline****4****Merrily We Roll Along!****Purpose**

To investigate the relationship between distance and time for a ball rolling down an incline.

Required Equipment/Supplies

2-meter ramp
 steel ball bearing or marble
 wood block
 stopwatch
 tape
 meterstick
 protractor
 overhead transparencies

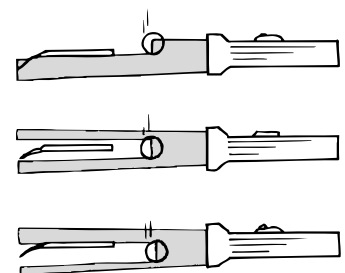
Optional Equipment/Supplies

computer
 3 light probes with interface
 3 flashlights or other light sources
 6 ring stands with clamps

Discussion

Measurement of the motion of a freely falling object is difficult because the speed increases rapidly. In fact, it increases by nearly 10 m/s every second. The distance that the object falls becomes very large, very quickly. Galileo slowed down the motion by using inclined planes. The component of gravity acting along the direction of the inclined plane is less than the full force of gravity that acts straight down—so the change of speed happens more slowly and is easier to measure. The less steep the incline, the smaller the acceleration. The physics of free fall can be understood by first considering the motion of a ball on an inclined plane.

This experiment will require you to make many timing measurements using a stopwatch or, if available, a computer. If you use a stopwatch, develop good timing techniques so as to minimize errors due to reaction time. The computer-photogate system is a powerful stopwatch because it not only eliminates reaction time, but can be used in a variety of timing modes. Since the diameter of the ball can be measured directly, its *speed* can be found by dividing the diameter by the amount of time it



takes to pass through the beam striking the light probe. Strictly speaking, since the ball's speed is increasing as it rolls through the light beam, it exits the beam *slightly* faster than it enters the beam. The width of the ball divided by the time the ball eclipses the light beam gives the *average* speed of the ball through the light beam, not the *instantaneous* speed. But once the ball has picked up speed partway down the incline, its percentage change in speed is small during the short time that it eclipses the light. Then its measured average speed is practically the same as its instantaneous speed.

Procedure

Set up ramp.

Step 1: Set up a ramp with the angle of the incline at about 10° to the horizontal, as shown in Figure A.

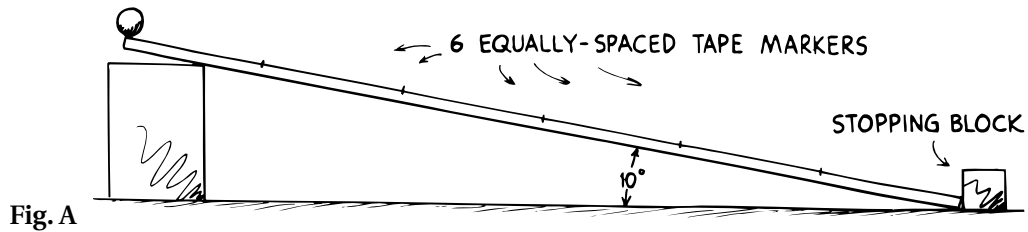


Fig. A

Divide ramp into equal parts.

Step 2: Divide the ramp's length into six equal parts and mark the six positions on the board with pieces of tape. These positions will be your release points. Suppose your ramp is 200 cm long. Divide 200 cm by 6 to get 33.33 cm per section. Mark your release points every 33.33 cm from the bottom. Place a stopping block at the bottom of the ramp to allow you to hear when the ball reaches the bottom.

DISTANCE (cm)	TIME (s)			
	TRIAL 1	TRIAL 2	TRIAL 3	AVERAGE

Data Table A

Time the ball down the incline.

Step 3: Use either a stopwatch or a computer to measure the time it takes the ball to roll down the ramp from each of the six points. (If you use the computer, position one light probe at the release point and the other at the bottom of the ramp.) Use a ruler or a pencil to hold the ball at its starting position, then pull it away quickly parallel to incline to release the ball uniformly. Do several practice runs with the help of your partners to minimize error. Make at least three timings from each position, and record each time and the average of the three times in Data Table A.

Graph data.

Step 4: Graph your data, plotting distance (vertical axis) vs. average time (horizontal axis) on an overhead transparency. Use the same scales

on the coordinate axes as the other groups in your class so that you can compare results.

Step 5: Repeat Steps 2–4 with the incline set at an angle 5° steeper. Record your data in Data Table B. Graph your data as in Step 4.

Change the tilt of the ramp and repeat.

DISTANCE (cm)	TIME (s)			
	TRIAL 1	TRIAL 2	TRIAL 3	AVERAGE

Data Table B

1. What is acceleration?

2. Does the ball accelerate down the ramp? Cite evidence to defend your answer.

3. What happens to the acceleration if the angle of the ramp is increased?

Step 6: Remove the tape marks and place them at 10 cm, 40 cm, 90 cm, and 160 cm from the stopping block, as in Figure B. Set the incline of the ramp to be about 10° .

Reposition the tape markers on ramp.

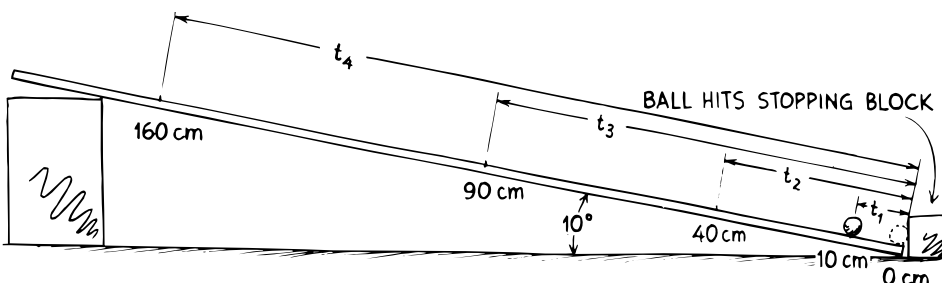


Fig. B

Time the ball down the ramp.

Step 7: Measure the time it takes for the ball to roll down the ramp from each of the four release positions. Make at least three timings from each of the four positions and record each average of the three times in Column 2 of Data Table C.

COLUMN 1	COLUMN 2				COLUMN 3	COLUMN 4
DISTANCE TRAVELED (cm)	ROLLING TIME (s)				TIME DIFFERENCES BETWEEN SUCCESSIVE INTERVALS (s)	TIME IN "NATURAL UNITS"
	TRIAL 1	TRIAL 2	TRIAL 3	AVERAGE		
10				$t_1 =$		1
40				$t_2 =$	$t_2 - t_1 =$	
90				$t_3 =$	$t_3 - t_2 =$	
160				$t_4 =$	$t_4 - t_3 =$	

Data Table C

Graph data.

Step 8: Graph your data, plotting distance (vertical axis) vs. time (horizontal axis) on an overhead transparency. Use the same coordinate axes as the other groups in your class so that you can compare results.

Study your data.

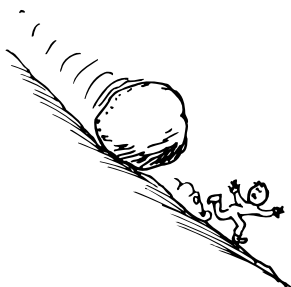
Step 9: Look at the data in Column 2 a little more closely. Notice that the *difference* between t_2 and t_1 is approximately the same as t_1 itself. The difference between t_3 and t_2 is also nearly the same as t_1 . What about the difference between t_4 and t_3 ? Record these three time intervals in Column 3 of Data Table C.

Step 10: If your values in Column 3 are slightly different from one another, find their average by adding the four values and dividing by 4. Do as Galileo did in his famous experiments with inclined planes and call this average time interval one "natural" unit of time. Note that t_1 is already listed as one "natural" unit in Column 4 of Table C. Do you see that t_2 will equal—more or less—two units in Column 4? Record this, and also t_3 and t_4 in "natural" units, rounded off to the nearest integer. Column 4 now contains the rolling times as multiples of the "natural" unit of time.

4. What happens to the *speed* of the ball as it rolls down the ramp? Does it increase, decrease, or remain constant? What evidence can you cite to support your answer?

Step 11: Overlay your transparency graph with other groups in your class and compare them.

5. Do balls of different mass have different accelerations?



Step 12: Investigate more carefully the distances traveled by the rolling ball in Table D. Fill in the blanks of Columns 2 and 3 to see the pattern.

COLUMN 1	COLUMN 2	COLUMN 3
DISTANCE TRAVELED (cm)	FIRST FOUR INTEGERS	SQUARES OF FIRST FOUR INTEGERS
10	1	1
40	2	4
90	3	9
160		

Table D

6. What is the relation between the distances traveled and the squares of the first four integers?

Step 13: You are now about to make a very big discovery—so big, in fact, that Galileo is still famous for making it first! Compare the distances with the times in the fourth column of Data Table C. For example, t_2 is two “natural” time units and the distance rolled in time t_2 is 2^2 , or 4, times as great as the distance rolled in time t_1 .

7. Is the distance the ball rolls proportional to the square of the “natural” unit of time?

The sizes of your experimental errors may help you appreciate Galileo’s genius as an experimenter. Remember, there were no stopwatches 400 years ago! He used a “water clock,” in which the amount of water that drips through a small opening serves to measure the time. Galileo concluded that the distance d is proportional to the square of the time t .

$$d \sim t^2$$

Step 14: Repeat Steps 6–10 with the incline set at an angle 5° steeper. Record your data in Data Table E.

Increase tilt of ramp.

8. What happens to the acceleration of the ball as the angle of the ramp is increased?

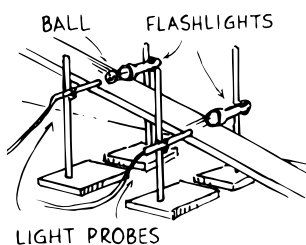
COLUMN 1	COLUMN 2				COLUMN 3	COLUMN 4
DISTANCE TRAVELED (cm)	ROLLING TIME (s)				TIME DIFFERENCES BETWEEN SUCCESSIVE INTERVALS (s)	TIME IN "NATURAL UNITS"
	TRIAL 1	TRIAL 2	TRIAL 3	AVERAGE		
10				$t_1 =$		1
40				$t_2 =$	$t_2 - t_1 =$	
90				$t_3 =$	$t_3 - t_2 =$	
160				$t_4 =$	$t_4 - t_3 =$	

Data Table E

9. Instead of releasing the ball along the ramp, suppose you simply dropped it. It would fall about 5 meters during the first second. How far would it freely fall in 2 seconds? 5 seconds? 10 seconds?

Going Further: Investigating the Speed of the Ball Down the Ramp

Set up computer with light probes.



You can use the computer to investigate the speed the ball acquires rolling down the ramp. This can be accomplished several different ways using light probes. One way is to position three light probes 10 cm, 40 cm, and 90 cm from the release point on the ramp. The speed of the ball as it passes a probe can be determined by measuring the time interval between when the front of the ball enters the light beam and the back of the ball leaves it. The distance traveled during this time interval is just the diameter of the ball. Measure the diameter of the ball.

diameter of ball = _____

With the incline set at an angle of about 10° , measure the respective eclipse times for each probe, and record your timings in Data Table F. To approximate the instantaneous speed of the ball at the three positions, divide the diameter of the ball by the eclipse time. Record the speeds in the table. Also record the average rolling time it took for the ball to travel each distance from the release point, from the information recorded in Data Table C.

Make a plot of instantaneous speed (vertical axis) vs. rolling time (horizontal axis).

Repeat with the ramp at an angle 5° steeper. Use the rolling times recorded in Data Table E.

	TOTAL DISTANCE TRAVELED (cm)	ECLIPSE TIME (s)	INSTANTANEOUS SPEED (cm/s)	AVERAGE ROLLING TIME (s)
FIRST ANGLE	10			
	40			
	90			
SECOND ANGLE	10			
	40			
	90			

Data Table F

10. How do the slopes of the lines in your graphs of speed vs. time relate to the acceleration of the ball down the ramp?

11. When you determined the speed of the ball with the light probes, were you really determining instantaneous speed? Explain.

12. As the angle of the ramp increased, the acceleration of the ball increased. Do you think there is an upper limit to the acceleration of the ball down the ramp? What is it?

Chapter 2: Linear Motion**Graphical Analysis of Motion****5****Conceptual Graphing****Purpose**

To make qualitative interpretations of motions from graphs.

Required Equipment/Supplies

sonic ranger
computer
masking tape
marking pen
ring stand
large steel ball
soup can
board
pendulum clamp

Discussion

Have you ever wondered how bats can fly around in the dark without bumping into things? A bat makes squeaks that reflect off walls and objects, return to the bat's head, and are processed by its brain to give clues as to the location of nearby objects. The automatic focus on some cameras works on very much the same principle. The sonic ranger is a device that measures the time that ultra-high-frequency sound waves take to go to, and return from, a target object. The data are fed to a computer, where they are graphically displayed on the monitor. Data plotting software can display the data in three ways: distance vs. time, velocity vs. time, and acceleration vs. time.

Procedure

Step 1: Your teacher will set up the sonic ranger and the computer for you. Check to see that the sonic ranger appears to be functioning properly.

Step 2: Place the sonic ranger on a desk or table so that its beam is chest high. A floor stand is very useful for this purpose, if available. Affix 5 meters of masking tape to the floor in a straight line from the sonic ranger, as shown in Figure A.



Check sonic ranger.

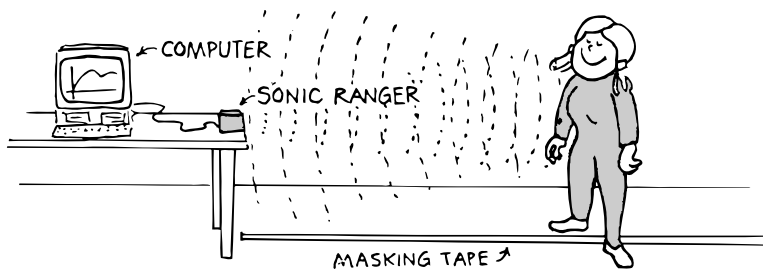


Fig. A

Calibrate the floor.

Step 3: Adjust the sonic ranger software so that it displays a distance vs. time plot. Point the sonic ranger at a student standing at the 5-meter mark of the tape. Calibrate the tape by marking where the computer registers 1 m, 2 m, and so on.

Observe graphs on computer monitor.

Step 4: Stand on the 1-meter mark. Always face the sonic ranger and watch the monitor. Back away from the sonic ranger slowly and observe the graph made. Repeat, backing away from the sonic ranger faster, and observe the graph made.

1. How do the graphs compare?

Step 5: Stand at the far end of the tape. Slowly approach the sonic ranger and observe the graph plotted. Repeat, walking faster, and observe the graph plotted.

2. How do the graphs compare?

Step 6: Back away from the sonic ranger slowly; stop; then approach quickly.

3. Sketch the shape of the resulting graph.

4. Describe what walking motions result in the graphs shown in Figures B, C, D, and E.

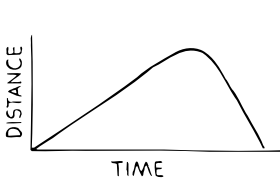


Fig. B

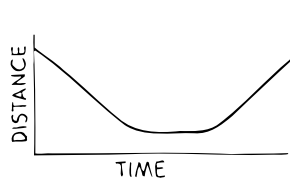


Fig. C

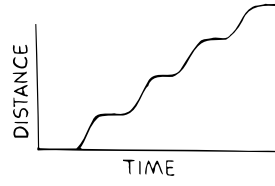


Fig. D

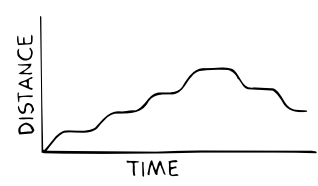


Fig. E

Step 7: Repeat Step 4, but use a velocity vs. time plotter.

5. How do the graphs of velocity vs. time compare?

Step 8: Repeat Step 5, using the velocity vs. time plotter.

6. How do the two new graphs compare?

Step 9: Repeat Step 6, using the velocity vs. time plotter.

7. Sketch the shape of the resulting graph.

Analyze motion on an incline.

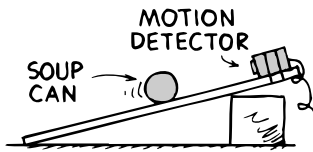


Fig. F

Going Further

Step 10: Set up the sonic ranger as shown in Figure F to analyze the motion of a can or a large steel ball rolled up an incline. Initially position the can at least 40 cm (the minimum range) from the sonic ranger. Predict what the shapes of the distance vs. time and velocity vs. time graphs will look like for the can or ball rolled up and down the incline.

8. Sketch your predicted shapes in the following space.

Now observe the two graphs, distance vs. time and velocity vs. time.

9. Sketch the shape of the distance vs. time graph.

10. Sketch the shape of the velocity vs. time graph.

Step 11: Devise an experimental setup that uses the sonic ranger to analyze the motion of a pendulum based on Figure G. Perform your experiment and answer the following questions.

Analyze motion of a pendulum.

11. Sketch the shape of the distance vs. time graph.

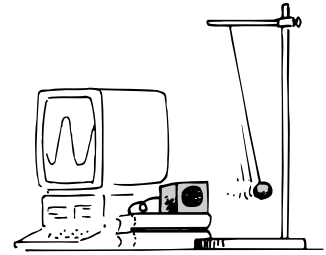


Fig. G

12. Sketch the shape of the velocity vs. time graph.

13. Where is the speed greatest for a swinging pendulum bob?

14. Where is the speed least for a swinging pendulum bob?

6

Race Track

Purpose

To introduce the concept of constantly changing speed.

Required Equipment/Supplies

race grid in Figure A
colored pencil or pen
graph paper (optional)

Discussion

A car can accelerate to higher speed at no more than a maximum rate determined by the power of the engine. It can decelerate to lower speed at no more than a maximum rate determined by the brakes, the tires, and the road surface. This simple but fun game will quickly teach you the meaning of fixed acceleration.

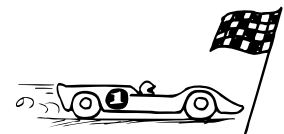
Race Track is a truly remarkable simulation of automobile racing. Its inventor is not known. It is described in the column “Mathematical Games” in the journal *Scientific American*, January 1973, p. 108.

Procedure

Step 1: Each contestant should have a pencil or pen of a different color. Use the race grid in Figure A. Each player draws a tiny box just below a grid point on the starting line. The players then move in order.

Step 2: Contestants must obey the following rules.

- (1) The first move must be one square forward: horizontally, vertically, or both (diagonally).
- (2) On each succeeding move a car can maintain its latest velocity *or* increase or decrease its speed by *one* square per move in the horizontal or vertical direction or *both*. For example, a car going 2 squares per move vertically can change to 2 squares per move vertically *and* 1 square to the left or right; 1 or 3 squares per move vertically; or 1 or 3 squares per move vertically *and* 1 square to the left or right.
- (3) The new grid point and the straight-line segment joining it to the preceding grid point must lie entirely within the track.
- (4) No two cars may simultaneously occupy the same grid point. That is, no collisions are allowed!



Getting started.

Rules of the road.

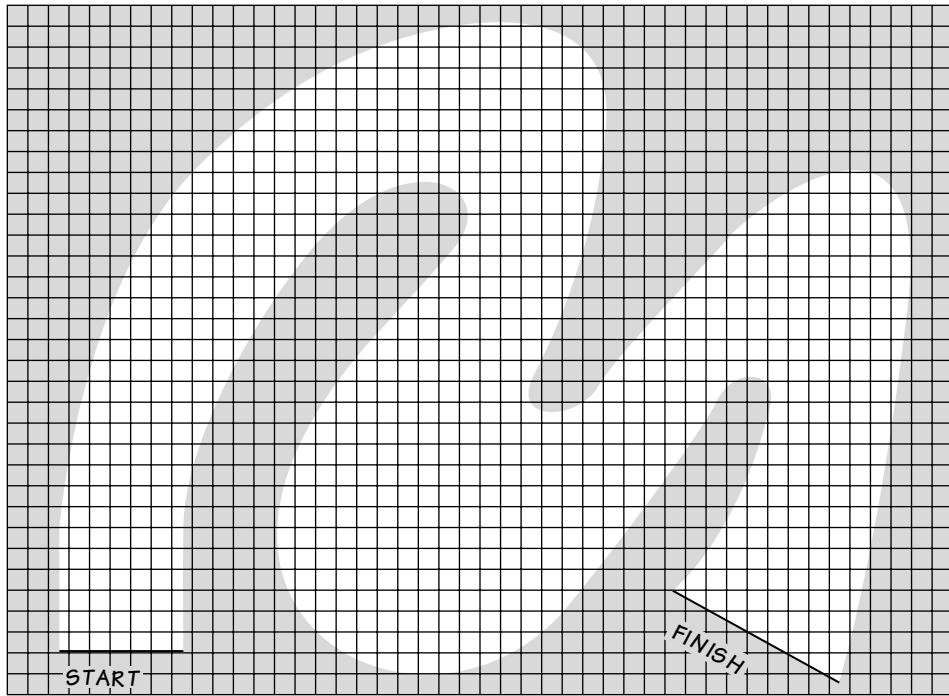


Fig. A

(5) The first player to cross the finish line wins!

To summarize, the speed in either the x or y direction can change by no more than one each turn.

Lay out new course.

Step 3: If you want to play the game again, you can draw a new race grid on a piece of graph paper. The width of the track can vary but should be at least 3 squares wider than the number of cars. To make the game interesting, the track should be strongly curved. Draw a start/finish line at a straight portion of the track.

Analysis

1. What was the fastest any player ever went during the course of the race?

2. Did that player win the race?

3. Did anybody crash? If so, why do you think they did?

7**Bull's Eye****Purpose**

To investigate the independence of horizontal and vertical components of motion. To predict the landing point of a projectile.

Required Equipment/Supplies

ramp or Hot Wheels® track
 1/2-inch (or larger) steel ball
 empty soup can
 meterstick
 plumb line
 stopwatch, ticker-tape timer, or
 computer
 light probes with interface
 light sources

Discussion

Imagine a universe without gravity. In this universe, if you tossed a rock where there was no air, it would just keep going—forever. Because the rock would be going at a constant speed, it would cover the same amount of distance in each second (Figure A). The equation for distance traveled when motion is uniform is

$$x = vt$$

The speed is

$$v = \frac{x}{t}$$

Coming back to earth, what happens when you drop a rock? It falls to the ground and the distance it covers in each second increases (Figure B). Gravity is constantly increasing its speed. The equation of the vertical distance y fallen after any time t is

$$y = \frac{1}{2}gt^2$$

where g is the acceleration of gravity. The falling speed v after time t is

$$v = gt$$

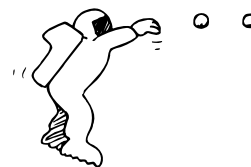


Fig. A



Fig. B

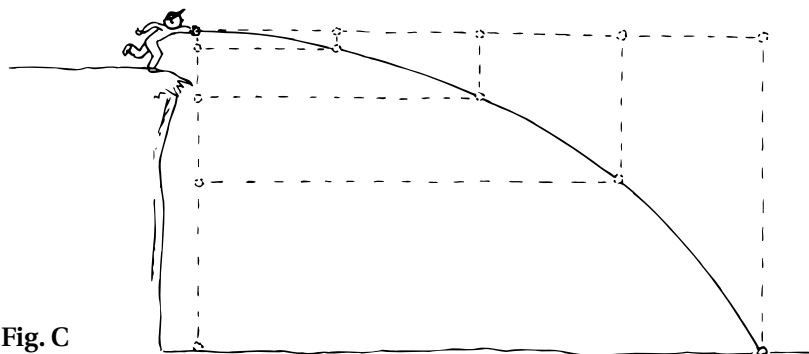


Fig. C

What happens when you toss the rock sideways (Figure C)? The curved motion that results can be described as the combination of two straight-line motions: one vertical and the other horizontal. The vertical motion undergoes the acceleration due to gravity, while the horizontal motion does not. The secret to analyzing projectile motion is to keep two separate sets of “books”: one that treats the horizontal motion according to

$$x = vt$$

and the other that treats the vertical motion according to

$$y = \frac{1}{2}gt^2$$

Horizontal motion

- When thinking about how *far*, think about $x = vt$.
- When thinking about how *fast*, think about $v = x/t$.

Vertical motion

- When thinking about how *far*, think about $y = (1/2)gt^2$
- When thinking about how *fast*, think about $v = gt$.

Your goal in this experiment is to predict where a steel ball will land when released from a certain height on an incline. The final test of your measurements and computations will be to position an empty soup can so that the ball lands in the can the *first* time!

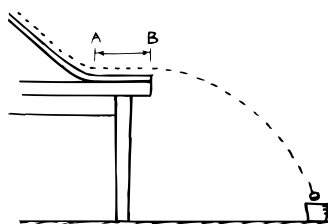


Fig. D

Compute the horizontal speed.

Procedure

Step 1: Assemble your ramp. Make it as sturdy as possible so the steel balls roll smoothly and reproducibly, as shown in Figure D. The ramp should not sway or bend. The ball must leave the table *horizontally*. Make the horizontal part of the ramp at least 20 cm long. The vertical height of the ramp should be at least 30 cm.

Step 2: Use a stopwatch or light probe to measure the time it takes the ball to travel, from the first moment it reaches the level of the tabletop (point A in Figure D) to the time it leaves the tabletop (point B in Figure D). Divide this time interval into the horizontal distance on the ramp (from point A to point B) to find the horizontal speed. Release the ball from the same point (marked with tape) on the ramp for each of three runs.

Do *not* permit the ball to strike the floor! Record the average horizontal speed of the three runs.

horizontal speed = _____

Step 3: Using a plumb line and a string, measure the vertical distance h the ball must drop from the bottom end of the ramp in order to land in an empty soup can on the floor.

Measure the vertical distance.

1. Should the height of the can be taken into account when measuring the vertical distance h ? If so, make your measurements accordingly.

$$h = \underline{\hspace{2cm}}$$

Step 4: Using the appropriate equation from the discussion, find the time t it takes the ball to fall from the bottom end of the ramp and land in the can. Write the equation that relates h and t .

$$\text{equation for vertical distance: } \underline{\hspace{2cm}}$$

Show your work in the following space.

$$t = \underline{\hspace{2cm}}$$

Step 5: The range is the horizontal distance of travel for a projectile. Predict the range of the ball. Write the equation you used and your predicted range.

Predict the range.

$$\text{equation for range: } \underline{\hspace{2cm}}$$

$$\text{predicted range } R = \underline{\hspace{2cm}}$$

Place the can on the floor where you predict it will catch the ball.

Analysis

2. Compare the actual range of the ball with your predicted range. Compute the percentage error. (See Appendix 1 on how to compute percentage error.)

3. What may cause the ball to miss the target?

4. You probably noticed that the range of the ball increased in direct proportion to the speed at which it left the ramp. The speed depends on the release point of the ball on the ramp. What role do you think air resistance had in this experiment?

Going Further

Horizontally launch ball.

Suppose you don't know the firing speed of the steel ball. If you go ahead and fire it, and then measure its range rather than predicting it, you can work backward and calculate the ball's initial speed. This is a good way to calculate speeds in general! Do this for one or two fired balls whose initial speeds you don't know.

8**Going Nuts****Purpose**

To explore the concept of inertia.

Required Equipment/Supplies

12-inch wooden embroidery hoop
 narrow-mouth bottle
 12 1/4-inch nuts

Discussion

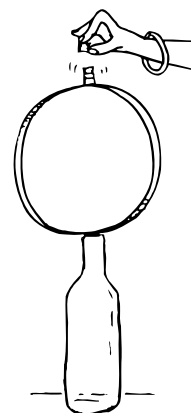
Have you ever seen magicians on TV whip a tablecloth out from underneath an entire place setting? Can that really be done, or is there some trick to it?

Procedure 

The game is simple. Carefully balance an embroidery hoop vertically on the mouth of a narrow-mouth bottle. Stack the nuts on the top of the hoop. The idea is to get as many nuts as possible into the bottle by touching the hoop with only one hand.

Analysis

1. Describe the winner's technique.



2. Explain why the winner's technique was successful.

Chapter 4: Newton's First Law of Motion—Inertia**Inertia****9****Buckle Up!****Purpose**

To demonstrate how Newton's first law of motion is involved in collisions.

Required Equipment/Supplies

4 m of string
2 dynamics carts
2 200-g hook masses
rubber band
2 small dolls
2 pulleys
2 wood blocks

Discussion

Newton's first law of motion states that an object in motion keeps moving with constant velocity until a force is applied to that object. Seat belts in automobiles and other vehicles are a practical response to Newton's first law of motion. This activity demonstrates in miniature what happens when that important law is ignored.

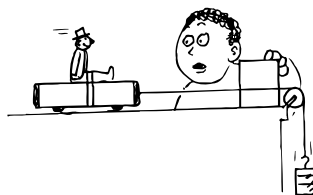
Procedure

Step 1: Attach 2 m of string to each of two small dynamics carts. Attach a 200-g mass to the other end of each of the strings. Attach the pulleys to the table edge and hang the masses over them with the masses on the floor and the carts on the table. Place a wood block on the table in front of each pulley.

Step 2: Place one doll on each cart. Use a rubber band to serve as a seat belt for one of them.

Step 3: Pull the carts back side by side and release them so they accelerate toward the table's edge.

Crash doll on cart with and without "seat belts."



Analysis

1. What stopped the motion of the doll without a seat belt when the cart crashed to a stop?

2. Was there any difference for the doll with a seat belt?

10

24-Hour Towing Service

Purpose

To find a technique to move a car when its wheels are locked.

Required Equipment/Supplies

7 m to 10 m of chain or strong rope
tree or other strong vertical support
automobile or other large movable mass

Discussion

You can exert a force on a parked automobile if you push or pull on it with your bare hands. You can do the same with a rope, but with more possibilities. Even without using pulleys, you can multiply the forces you exert. In this activity, you will try to show that you can exert a far greater force with brains than with brawn.

Procedure

Step 1: Park a car on a level surface with a tree in front of it, the brakes locked, and the gear selector set on “park” or in first gear.

Devise technique to move parked car.

Step 2: Your goal is to move the car closer to the tree. You will do this by exerting force on a rope, chain, or cable tied to the car's front end. How and where the force is exerted is up to your imagination. Your own body is the only energy source you can use. Make a sketch of your method. Show the applied force and the other forces with arrows.



Analysis

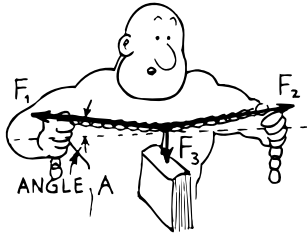


Fig. A

1. Look at Figure A. Suppose a force F_3 is applied to a chain at right angles to the horizontal. Tension in the chain can then be shown as vectors F_1 and F_2 . Since the system is not accelerating, all forces must add up to zero. The force F_1 is the tension in the chain and the force on whatever it is attached to, in this case, the right hand of the strongman. The same is true for F_2 . The force F_3 , in this case the weight of the book, is small, while F_1 and F_2 are large. As the angle A becomes smaller, the forces F_1 and F_2 become larger. This idea is explained further in Chapter 4 of your text. Use a vector diagram to explain how a small sideways force can result in a large pull on the car.

2. List other situations that could use this technique for “force multiplication.”

3. This method for making a large force is used to fell trees, pull stumps, straighten dents in car fenders, and pull loose teeth! Explain how this might be possible.

**Chapter 5: Newton's Second Law of Motion—
Force and Acceleration****Variables Affecting
Acceleration****11****Getting Pushy****Purpose**

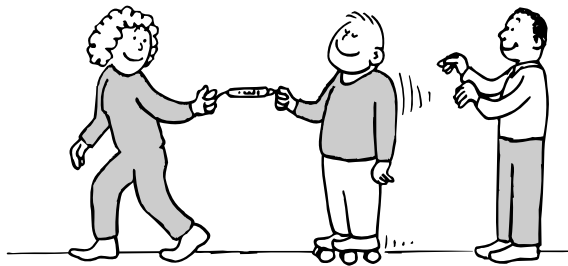
To investigate the relationship between mass, force, and acceleration.

Required Equipment/Supplies

roller skates or skateboard
spring balance
stopwatch
meterstick
tape

Discussion

Most of us have felt the acceleration of a car as it leaves a stop sign or the negative acceleration when it comes to a stop. We hear sportscasters describe a running back as accelerating through the defensive line. In this activity, you will investigate some variables that influence acceleration.

**Procedure** 

Step 1: With pieces of tape, mark positions on the floor at intervals of 0 m, 5 m, 10 m, and 15 m. The path along the floor should be smooth, straight, and level. Gym areas or hallways work well.

Mark off distances.

Step 2: A student must put on the skates and stand on the 0-m mark. Another student must stand behind the 0-m mark and hold the skater. The skater holds a spring balance by its hook.

Step 3: A third student must grasp the other end of the spring balance and exert a constant pulling force on the skater when the skater is released.

Pull on skater. . . catch skater.

The puller must maintain a constant force throughout the distance the skater is pulled. Do not pull harder to “get going.” Time how long it takes to get to the 5-m, 10-m, and 15-m marks, and record this data in Data Table A along with the readings on the spring balance.

TRIAL	DISTANCE (m)	FORCE (N)	TIME (s)
1	5		
	10		
	15		
2	5		
	10		
	15		
3	5		
	10		
	15		

Data Table A

Step 4: Repeat the experiment twice, using different skaters to vary the mass, but keeping the force the same. If the results are inconsistent, the skater may not be holding the skates parallel or may be trying to change directions slightly during the trial.

Step 5: Repeat with the puller maintaining a *different* constant force throughout the distance the skater is pulled, but using the same three skaters as before. Record your results in Data Table B.

TRIAL	DISTANCE (m)	FORCE (N)	TIME (s)
1	5		
	10		
	15		
2	5		
	10		
	15		
3	5		
	10		
	15		

Data Table B

Analysis

1. Until the time of Galileo, people believed that a constant force is required to produce a constant speed. Do your observations confirm or reject this notion?

2. What happens to the speed as you proceed farther and farther along the measured distances?

3. What happens to the rate of increase in speed—the acceleration—as you proceed farther and farther along the measured distances?

4. When the force is the same, how does the acceleration depend upon the mass?

5. When the mass of the skater is the same, how does the acceleration depend upon the force?

6. Suppose a 3-N force is applied to the skater and no movement results. How can this be explained?

**Chapter 5: Newton's Second Law of Motion—
Force and Acceleration****Mass and Acceleration****12****Constant Force and
Changing Mass****Purpose**

To investigate the effect of increases in mass on an accelerating system.

Required Equipment/Supplies

meterstick
 2 Pasco dynamics carts and track
 4 500-g masses (2 masses come with Pasco carts)
 1 50-g hook mass
 pulley with table clamp
 triple-beam balance
 string
 paper clips or small weights
 masking tape
 graph paper or overhead transparencies
 stopwatch, ticker-tape timer, or
 computer
 light probes with interface
 light sources

Discussion

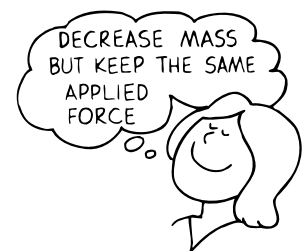
Airplanes accelerate from rest on the runway until they reach their take-off speed. Cars accelerate from a stop sign until they reach cruising speed. And when they come to a stop, they decelerate. How does mass affect these accelerations?

In Activity 11, “Getting Pushy,” you discovered that less massive people undergo greater acceleration than more massive people when the same force is applied to each. In this experiment you will accelerate a dynamics cart. You will apply the same force to carts of different mass. You will apply the force by suspending a weight over a pulley. The cart and the hanging weight comprise a *system* and accelerate together. A relationship between mass and acceleration should become evident.

Procedure

Step 1: Fasten a pulley over the edge of the table. The pulley will change the direction of the force from a downward pull on the mass into a sideways pull on the cart.

Step 2: Mark off a distance on the tabletop slightly shorter than the distance the mass can fall from the table to the floor.



Set up pulley-and-cart system.

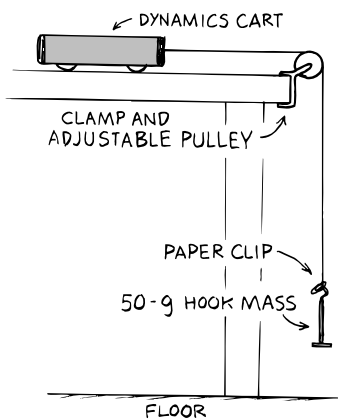


Fig. A

Set up timing system.

Step 3: Use a triple-beam balance to determine the mass of the carts. Record the total mass of the cart(s) and the four additional masses in Data Table A. Do not include the 50-g hanging mass or the mass of the paper clip counterweight.

Step 4: Nest the two dynamics carts on top of one another, and stack the 500-g masses on the top cart. It may be necessary to secure the masses and carts with masking tape. Tie one end of the string to the cart and thread it over the pulley, as shown in Figure A. To offset frictional effects, add enough paper clips or small weights to the other end of the string so that when the cart is pushed slightly it moves at a *constant speed*. (Give your teacher a break! Stop the cart before it crashes into the pulley during the experiment by adjusting the stop bar on the dynamics track.)

Step 5: Practice accelerating the cart a few times to ensure proper alignment. Add a 50-g hook mass to the paper clip counterweight. Keep this falling weight the same at all times during the experiment.

Step 6: There are a variety of ways to time the motion of the cart and the falling weight. You could use a stopwatch, a ticker-tape timer (ask your teacher how to operate this device), or a computer with light probes. The distance is the distance between two light probes. Position the cart so that as it is released, it eclipses the first light probe and starts the timer. The timer stops when the second light probe is eclipsed.

Repeat three times, recording the times in Data Table A. Compute and record the average time.

TIME TO COVER SAME DISTANCE				ACCELERATION (m/s^2)
TRIAL 1	TRIAL 2	TRIAL 3	AVG	

Data Table A

Remove masses from the cart and repeat.

Step 7: Repeat Step 5 five times, removing a 500-g mass from the cart each time (the last time removing the top cart). Record the times in Data Table A, along with the average time for each mass.

Compute the acceleration.

Step 8: Use the average times for each mass from Steps 5 and 6 to compute the accelerations of the system. To do this, use the equation for an accelerating system that relates distance d , acceleration a , and time t .

$$d = \frac{1}{2}at^2$$

Rearrange this equation to obtain the acceleration.

$$a = \frac{2d}{t^2}$$

The cart always accelerates through the same distance d . Calculate the acceleration, a . Provided you express your mass units in kilograms and your distance in meters, your units of acceleration will be m/s^2 .

Record your accelerations in Data Table A.

Graph your data.

Step 9: Using an overhead transparency or graph paper, make a graph of acceleration (vertical axis) vs. mass (horizontal axis).

Analysis

1. Describe your graph of acceleration vs. mass. Is it a straight-line graph or a curve?

2. Share your results with other class members. For a constant applied force, how does increasing the mass of an object affect its acceleration?

Chapter 5: Newton's Second Law of Motion— Force and Acceleration

Force and Acceleration

13 Constant Mass and Changing Force

Purpose

To investigate how increasing the applied force affects the acceleration of a system.

Required Equipment/Supplies

Pasco dynamics cart and track
masking tape
pulley with table clamp
6 20-g hook masses
string
paper clips
graph paper or overhead transparency
stopwatch, ticker-tape timer, or
computer
light probes with interface
light sources

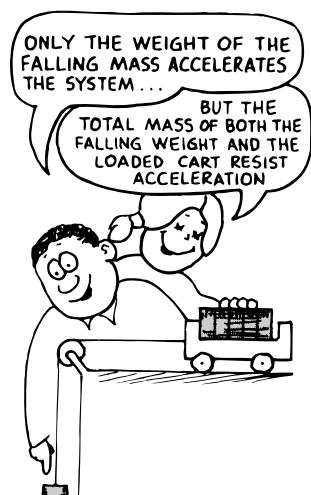
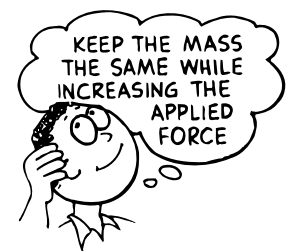
Discussion

Have you ever noticed when an elevator cage at a construction site goes *up* that a large counterweight (usually made of concrete) comes *down*? The elevator and the counterweight are connected by a strong cable. Thus, the elevator doesn't move without the counterweight moving the same amount. Since the electric motor can't move one without moving the other, the two so connected together form a *system*.

In Experiment 12, "Constant Force and Changing Mass," you learned how the acceleration of a dynamics cart was affected by increasing the mass of the cart. But the cart is really part of a *system* consisting of the *cart and the falling weight*—just as the elevator and the counterweight together form a system. The cart doesn't move without the falling weight moving exactly the same amount. By adding mass to the cart, you were actually adding mass to the *cart-and-falling-weight system*.

Adding mass to the cart rather than to the falling weight was *not* accidental, however. In doing so, you changed only one variable—mass—to see how it affects the acceleration of the entire system.

In this experiment, you will investigate how increasing the applied force on a cart-and-falling-weight system affects its acceleration while keeping the mass of the system constant. The applied force is increased without changing the mass *by removing mass from the cart and placing it on the hanging weight*.



The same general procedure used in Experiment 12 will be used here. In Experiment 12, you measured the total time the cart accelerated to compute the acceleration using the formula:

$$a = \frac{2d}{t^2}$$

Procedure

Set up cart-and-hanging-weight system.

Step 1: Set up your apparatus much the same as you did in Experiment 12, except that you should load the dynamics cart with six 20-g masses. Masking tape may be required to hold the masses in position.

Step 2: Attach one end of the string to the cart, pass the other over the pulley, and tie a large paper clip to the end of the string. To offset frictional effects, place just enough paper clips or other small weights on the end of the string so that when the cart is moved by a small tap, it rolls on the track or table with constant speed. Do not remove this counterweight at any time during the experiment.

Set up timing system.

Step 3: You can time the system in a variety of ways. You could use a stopwatch, a ticker-tape timer (your teacher will show you how this device works), or a computer with light probes. The distance is the distance between two light probes. Position the cart so that as it is released, it eclipses the first light probe and starts the timer. The timer stops when the second light probe is eclipsed.

Step 4: For the first trial, remove one of the hooked 20-g masses from the cart and hang it on the end of the string.

Measure the acceleration time.

Step 5: With your timing system all set, release the cart and measure the time it takes to accelerate your cart toward the pulley. Catch the cart *before* it crashes into the pulley and spews your masses all over the floor and damages the pulley! Repeat each trial at least twice. Record your data and compute the average of your three trials in Data Table A.

Data Table A

Increase the applied force.

Step 6: Remove another 20-g mass from the cart and place it on the end of the string with the other 20-g mass. Make several runs and record your data in Data Table A.

Step 7: Repeat Step 5 five times, increasing the mass of the falling weight by 20 grams each time. Make several runs and record your data in Data Table A.

Step 8: With the help of your teacher, calculate the accelerations and use an overhead transparency to make a graph of acceleration (vertical axis) vs. force (horizontal axis). Since the cart always accelerates through the same distance d , the acceleration equals $2d/t^2$. Express your distance in meters and your acceleration will have units of m/s^2 . Call the force caused by the single 20-g mass “F,” the force caused by two 20-g masses “2F,” and so on.

Graph your data.

Analysis

1. Describe your graph of acceleration vs. force. Do your data points produce a straight-line graph or a curved graph?

2. Does the acceleration of the cart increase or decrease as the force increases?

3. Was the mass of the accelerating system (cart + falling weight) the same in each case?

4. In Experiment 12, you learned (or should have!) that when a constant force is applied, the acceleration of the system *decreases* as its mass increases. The acceleration is *inversely proportional* to the mass of the system. Here in Experiment 13, the acceleration of the system increases as the force applied to it (the weights of the falling masses) increases. That is, the acceleration is *directly proportional* to the applied force. Combine the results of Experiments 12 and 13 to come up with a general relationship between force, mass, and acceleration.

Chapter 5: Newton's Second Law of Motion— Force and Acceleration

Effect of Air Friction on Falling Bodies

14 Impact Speed

Purpose

To estimate the speed of a falling object as it strikes the ground.

Required Equipment/Supplies

stopwatch
string with a rock tied to one end
object with a large drag coefficient, such as a leaf or feather
Styrofoam[®] plastic foam ball or Ping-Pong[®] table-tennis ball

Discussion

The area of a rectangle is its height multiplied by its base. The area of a triangle is its height multiplied by half its base. If the height and base are measured in meters, the area is measured in square meters. Consider the area under a graph of speed vs. time. The height represents the speed measured in meters per second, m/s, and the base represents time measured in seconds, s. The area of this patch is the speed times the time, expressed in units of m/s times s, which equals m. The speed times the time is the distance traveled. *The area under a graph of speed vs. time represents the distance traveled.* This very powerful idea underlies the advanced mathematics called integral calculus. You will investigate the idea that the area under a graph of speed vs. time can be used to predict the behavior of objects falling in the presence of air resistance.

If there were no air friction, a falling tennis ball or Styrofoam ball would fall at constant acceleration g so its change of speed is

$$v_f - v_i = gt$$

where v_f = final speed

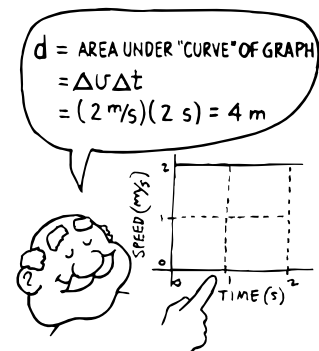
v_i = initial speed

g = acceleration of gravity

t = time of fall

A graph of speed vs. time of fall is shown in Figure A, where $v_i = 0$. The y -axis represents the speed v_f of the freely falling object at the end of any time t . The area under the graph line is a triangle of base t and height v_f , so the area equals $\frac{1}{2}v_f t$.

To check that this does equal the distance traveled, note the following. The *average* speed \bar{v} is half of v_f . The distance d traveled by a con-



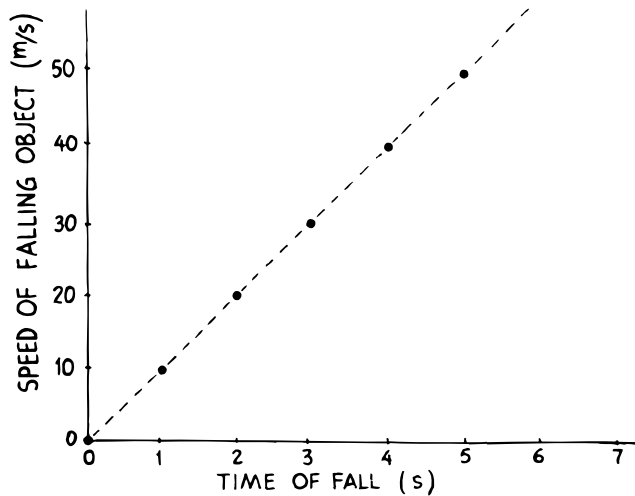


Fig. A

stantly accelerating body is its average speed \bar{v} multiplied by the duration t of travel.

$$d = \bar{v}t \quad \text{or} \quad d = \frac{1}{2}v_f t$$

If you time a tennis ball falling from rest a distance of 43.0 m in air (say from the twelfth floor of a building), the fall takes 3.5 s, *longer* than the theoretical time of 2.96 s. Air friction is *not negligible* for most objects, including tennis balls. A graph of the actual speed vs. the time of fall looks like the curve in Figure B.

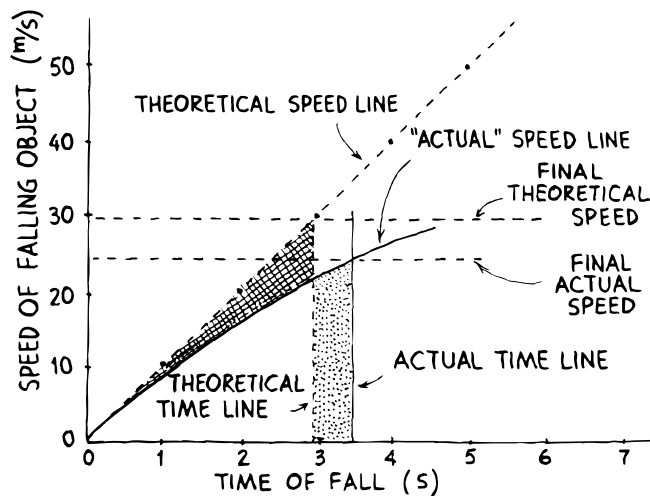
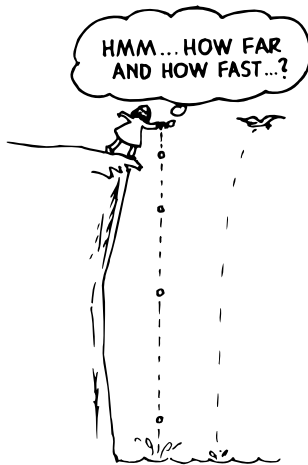


Fig. B

Since air resistance reduces the acceleration to below the theoretical value of 9.8 m/s^2 , the falling speed is less than the theoretical speed. The difference is small at first, but grows as air resistance becomes greater and greater with the increasing speed. The graph of actual speed vs. time curves away from the theoretical straight line.

Is there a way to sketch the actual speed vs. time curve from only the distance fallen and the time of fall? Calculate the theoretical time of fall for no air resistance. The *height* from which the object is dropped is the same with or without air resistance. *The area under the actual speed vs. time curve must be the same as the area under the theoretical speed vs. time line.* It is the distance fallen. On a graph of theoretical speed vs. time, draw a vertical line from the theoretical time of fall on the horizontal axis up to the theoretical speed vs. time line. (In Figure B, this line is

labeled “theoretical time line.”) Draw another vertical line upward from the *actual* time of fall on the horizontal axis. (This line is labeled “actual time line” in Figure B.) Sketch a curve of actual speed vs. time that crosses the second vertical line below the theoretical speed vs. time line. Sketch this curve so that the area added below it due to increased time of fall (stippled area) equals the area subtracted from below the theoretical speed vs. time line due to decreased speed (cross-hatched area). *The areas under the two graphs are then equal.* This is a fair approximation to the actual speed vs. time curve. The point where this curve crosses the vertical line of the actual time gives the probable impact speed of the tennis ball.

Procedure

Step 1: Your group should choose a strategy to drop a Ping-Pong ball or Styrofoam ball and clock its time of fall within 0.1 s or better. Consider a long-fall drop site, various releasing techniques, and reaction times associated with the timer you use.

Devise dropping strategy.

Step 2: Devise a method that eliminates as much error as possible to measure the distance the object falls.

Measure falling height.

Step 3: Submit your plan to your teacher for approval.

Submit proposal to teacher.

Step 4: Measure the height and the falling times for your object using the approved methods of Steps 1 and 2.

Measure height and falling times.

height = _____
actual time of fall = _____

Step 5: Using your measured value for the height, calculate the theoretical time of fall for your ball. Remember, this is the time it would take the ball to reach the ground if there were no air resistance.

Compute theoretical falling time.

theoretical time = _____

Step 6: Using an overhead transparency or graph paper, trace Figure B, leaving out the actual speed vs. time curve. Draw one vertical line from the *theoretical* time of fall for your height up to the theoretical speed vs. time line. Draw the other vertical line from the *actual* time of fall up to the theoretical speed vs. time line.

Draw theoretical and actual speed lines.

Step 7: Starting from the origin, sketch your approximation for the actual speed vs. time curve, out to the point where it crosses the actual time line, using the example mentioned in the discussion. The area of your stippled region should be the same as that of the cross-hatched region.

Sketch curve on graph.

One possible way to do this is to tape a piece of cardboard to the wall and project your transparency onto it. Trace your two regions onto the cardboard and cut them out. Then measure the mass of the two regions. If their masses are not the same, adjust your actual speed curve and try again. Your approximation is done when the two regions have the same mass.

Step 8: Draw a horizontal line from the upper right corner of your stippled region over to the speed axis. Where it intersects the speed axis is the object's probable impact speed.

Predict probable impact speed.

Analysis

1. Have your teacher overlap your graph with those of others. How does your actual speed vs. time curve compare with theirs?

2. What can you say about objects whose speed vs. time curves are close to the theoretical speed vs. time line?

3. What does the area under your speed vs. time graph represent?

4. The equation for distance traveled is $d = \bar{v}t$. In this lab, the distance fallen is the same with or without air friction. How do the average speeds and times compare with and without air friction? Try to use different-sized symbols such as those used on page 66 of your text.

5. If you dropped a large leaf from the Empire State Building, what would its speed vs. time graph look like? How might it differ from that of a baseball?

6. The *terminal* speed of a falling object is the speed at which it stops accelerating. How could you tell whether an object had reached its terminal speed by glancing at an actual speed vs. time graph?

Chapter 5: Newton's Second Law of Motion— Force and Acceleration

Components of Force

15 Riding with the Wind

Purpose

To investigate the relationship between the components of the force that propels a sailboat.

Required Equipment/Supplies

dynamics cart fitted with an aluminum or cardboard sail
protractor
electric fan
ruler pulley
mass hangers
set of slotted masses
string

Discussion

In this experiment, you will use a small model sailboat and an electric fan. The physics of sailing involves vectors—quantities that have both magnitude and direction. Such directed quantities include force, velocity, acceleration, and momentum. In this lab, you will be concerned with force vectors.

In Figure A, a crate is being pulled across a floor. The vector F represents the applied force. This force causes motion in the horizontal direction, and it also tends to lift the crate from the floor. The vector can be “resolved” into two vectors—one horizontal and the other vertical. The horizontal and vertical vectors are *components* of the original vector. The components form two sides of a rectangle. The vector F is the diagonal of this rectangle. When a vector is represented as the diagonal of a rectangle, its components are the two sides of the rectangle.

Whatever the direction of wind impact on a sail, the direction of the resulting force is always perpendicular to the sail surface. The magnitude of the force is smallest when the wind blows parallel to the sail—when it goes right on by without making any impact. The force is largest when the sail is perpendicular to the wind—when the wind makes full impact. Even if the wind hits the sail at another angle, the resulting force is always directed *perpendicular* to the sail.

The keel of a sailboat is a sort of fin on the bottom of the boat. It helps prevent the boat from moving sideways in the water. The wind force on the sail can be resolved into two components. One component, K (for *keel*), is parallel to the keel. The other component, T (for *tip*), is perpendicular to the keel, as shown in Figure B. Only the component K contributes to the motion of the boat. The component T tends to move the boat sideways and tip it over.

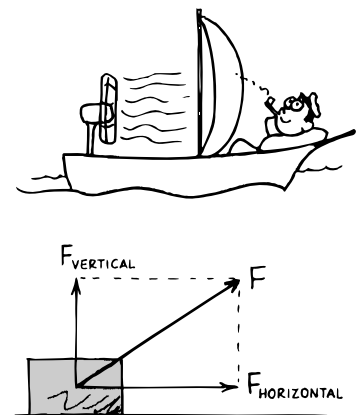


Fig. A

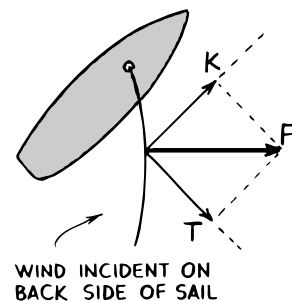


Fig. B

Any boat with a sail can sail downwind, that is, in the same direction as the wind. As the boat goes faster, the wind force on the sail decreases. If the boat is going as fast as the wind, then the sail simply sags. The wind force becomes zero. The fastest speed downwind is the speed of the wind.

A boat pointed directly into the wind with its sail at right angles to the keel is blown straight backward. No boat can sail *directly* into the wind. But a boat can *angle* into the wind so that a component of force K points in the forward direction. The procedure of going upwind is called *tacking*.

CAUTION: In the following procedure, you will be working with an electric fan. *Do not let hair or fingers get in the blades of the fan.*

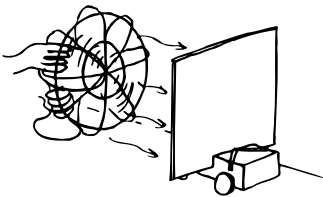
Procedure

Try to sail the boat directly upwind.

Step 1: Position the cart with its wheels (the keel) parallel to the wind from the fan. Position the sail perpendicular to the wheels. Start the fan blowing on the *front* of the cart with the wind parallel to the wheels.

1. What happens to the cart?

Sail the boat directly downwind.



Step 2: Direct the wind from *behind* the cart and parallel to the wheels, keeping the sail perpendicular to the wheels, as shown in Figure C.

2. How does the cart move?

Fig. C

Sail the boat at an angle.

Step 3: Reposition the sail at a 45° angle to the wheels. Direct the wind behind, parallel to the wheels.

3. What happens to the cart?

Step 4: Use a ruler to draw a vector that represents the wind force perpendicular to the sail. Remember that the *length* of the vector you draw

represents the size of the force. Split the vector into its T and K components. Label the forces and each component on the diagram.

Change the wind direction.

Step 5: Repeat Step 3 with the fan perpendicular to the wheels. Make a vector diagram for this case.

Change the wind direction.

Step 6: Repeat Step 3 but direct the wind at a 60° angle to the wheels from the front, as shown in Figure D.

4. Does the cart sail against or with the wind?

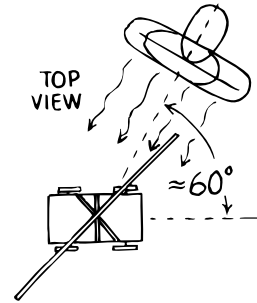


Fig. D

Draw a vector representing the wind force, and split it into its T and K components.

Step 7: Set up a pulley on the edge of the table, as shown in Figure E. Attach one end of a piece of lightweight string to the cart and thread the other end over the pulley. Attach a mass hanger to the string. Set the sail perpendicular to the direction of the cart. Place the fan directly between the pulley and the cart so that the full force of the wind strikes the sail at 90° . Holding the cart, turn the fan on its highest speed setting. The wind force depends on how close the fan is to the sail. Place the fan close to the sail. *Slowly* add very small masses to the mass hanger. Continue adding them until the weight of the masses (including the mass hanger) just balances the wind force on the cart. The wind force is balanced when adding the smallest mass you have causes the cart to move toward the pulley and removing the smallest mass causes the cart to move away from the pulley. Record the mass required to balance the cart.

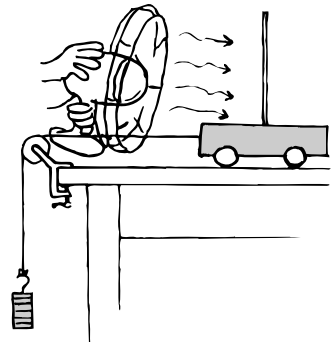


Fig. E

mass = _____

Calculate the weight of this mass, using the approximation that a mass of 1 kg has a weight of 10 N.

weight = _____

5. What is the amount of wind force acting on the sail in this configuration?

Step 8: Repeat Step 7, but this time orient the sail at a 45° angle to the wind. Record the mass and calculate the weight required to balance the cart.

mass = _____

weight = _____

6. What is the amount of wind force acting on the sail in this configuration?

Analysis

7. Which orientation of the sail with respect to the wind provided the greatest wind force?

8. When the sail is oriented at 45° to the wind, is the wind force less than half, equal to half, or greater than half the wind force at 90° ? Justify your answer with a vector diagram.

**Chapter 6: Newton's Third Law of Motion—
Action and Reaction****Action and Reaction****16****Balloon Rockets****Purpose**

To investigate action-reaction relationships.

Required Equipment/Supplies

balloons
paper clips
guide wire or string
tape
straws

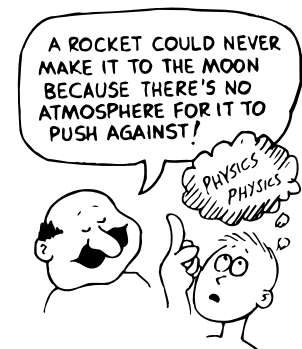
Discussion

Early in this century, the physicist Robert Goddard proposed that rockets would someday be sent to the moon. He met strong opposition from people who thought that such a feat was impossible. They thought that a rocket could not work unless it had air to push against (although physics types knew better!). Your mission is a less ambitious one—to construct a balloon rocket system that will travel across the room!

Scientists look for the causes of observed effects. As you construct your balloon rockets and improve upon the design, think about how you would explain to a friend how and why your design works.

Procedure 

Step 1: String the guide wire or string across the room. Make a rocket system that will propel itself across the classroom on the wire or string. Use a balloon for the rocket power, and the straw, paper clips, and tape to make a guidance system. Draw a sketch or write a description of your design.



Devise a rocket system.

Modify system design.



Step 2: Getting there is only half the problem! Make a rocket system that will get across the room and then come *back* again. Draw a sketch or write a description of your design.

Analysis

1. Explain why an inflated balloon moves when the air escapes.

2. Would the rocket action still occur if there were no surrounding air?

**Chapter 6: Newton's Third Law of Motion—
Action and Reaction****Action and Reaction****17 Tension****Purpose**

To introduce the concept of tension in a string.

Required Equipment/Supplies

3 large paper clips
3 large identical rubber bands
1 m of strong string
500-g hook mass
ring stand
spring scale
ruler
marking pen

Discussion

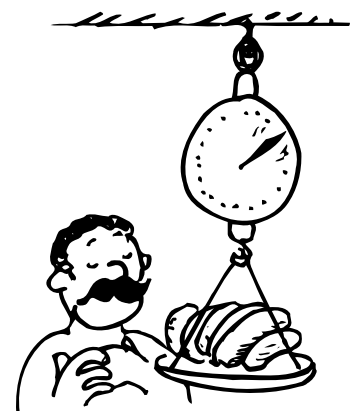
When you put bananas on a hanging scale at the supermarket, a spring is stretched. The greater the weight of the bananas (the force that is exerted), the more the spring is stretched. Rubber bands act in a similar way when stretched. For stretches that are not too great, the amount of the stretch is directly proportional to the force.

If you hang a load from a string, you will produce a tension in the string and stretch it a small amount. The amount of tension can be measured by attaching the top end of the string to the hook of a spring scale hanging from a support. The scale will register the tension as the sum of the weights of the load and the string. The weight of the string is usually small enough to be neglected, and the tension is simply the weight of the load.

Is this tension the same all along the string? To find the tension at the lower end of the string you could place a second scale there, but the weight of the added scale would increase the tension in the top scale. You need a scale with a tiny mass. Since a rubber band stretches proportionally with the force, you could use it to measure the tension at the lower end of the string. Its tiny weight will not noticeably affect the reading in the top scale. In this activity, you will use rubber bands to investigate the tensions at different places along short and long strings supporting the same load.

Procedure

Step 1: Without stretching them, place three identical large rubber bands flat on a table. Carefully mark two ink dots 1 cm apart on each of the rubber bands.



Mark rubber bands.

Cut string.

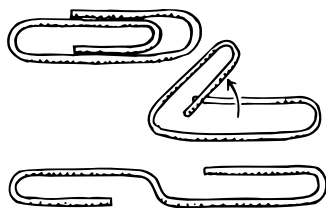


Fig. A

Step 2: Cut a 1-meter string into 2 lengths of 25 cm each, and 1 length of 50 cm. Tie each end of each string into a loop.

Step 3: Bend the paper clips into double hooks, as shown in Figure A.

Step 4: Suspend the spring scale from the top of a ring stand such that it extends over the edge of the table. Place one end of a rubber band over the scale hook. Suspend the 500-g load from the lower end of the rubber band as shown in Figure B. Note that the weight of the load stretches both the rubber band and the spring inside the spring scale.

While the load is suspended, measure and record the distance between the ink marks on the rubber band. Also record the reading on the spring scale.

distance between marks = _____

tension (scale reading) = _____

3-rubber-band stretch.

Step 5: With the use of paper-clip hooks, repeat the previous step using three rubber bands connected as shown in Figure C. Measure the stretch of the three bands. Record your results.

distance between marks of top band = _____

distance between marks of middle band = _____

distance between marks of bottom band = _____

tension (spring-scale reading) = _____

Hang load from one band and string.

Step 6: Disconnect the load and two of the rubber bands. Using a paper-clip hook, connect one end of a 25-cm length of string to the remaining rubber band. Suspend the load on the other end of the string, as shown in Figure D. Record the spring-scale reading and the distance between the marks of the rubber band.

tension (spring-scale reading) = _____

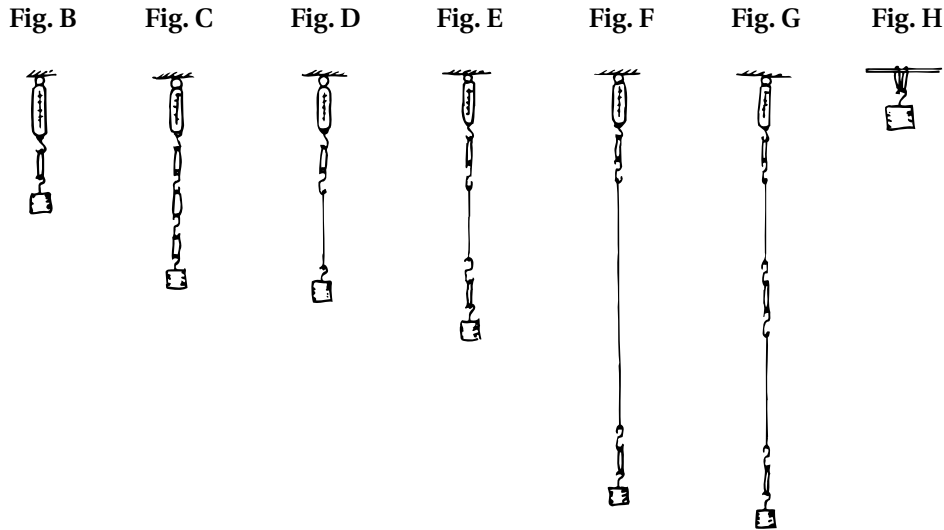
distance between marks of band = _____

Hang load from string and two bands.

Step 7: Using a paper-clip hook, insert a rubber band between the lower end of the string and the load, as shown in Figure E. While you are attaching the bottom rubber band, mentally predict the amount of stretch of the added band. Compare the tensions at the top and the bottom of the string by measuring the stretches of the two rubber bands. Record your findings.

distance between marks of top band = _____

distance between marks of bottom band = _____



Step 8: Repeat Step 7 using the 50-cm piece of string, as shown in Figure F, to see whether the tension in the string depends on the length of the string. Make a mental prediction before you measure and record your findings.

Repeat using longer string.

distance between marks of top band = _____

distance between marks of bottom band = _____

Step 9: Repeat the previous step, substituting two 25-cm pieces of string joined by paper-clip hooks with a rubber band in the middle (as shown in Figure G) for the 50-cm string. This arrangement is to compare the tension at the middle of a string with the tension at its ends. While you are substituting, mentally predict how far apart the ink marks will be. After your prediction, measure and record your findings.

Add rubber band between two strings.

distance between marks of top band = _____

distance between marks of middle band = _____

distance between marks of bottom band = _____

Analysis

- Does the length of the string have any effect on the reading of the spring scale? What evidence can you cite?

2. Does the tension in the string depend on the length of the string? What evidence can you cite?

3. How does the tension at different distances along a stretched string compare? What evidence can you cite?

4. How much would each rubber band stretch if the 500-g load were suspended by two side-by-side bands as shown in Figure H? Make your prediction, then set up the experiment. Explain your result.

predicted stretch = _____

actual stretch = _____

Chapter 6: Newton's Third Law of Motion— Action and Reaction

Action and Reaction

18 Tug-of-War

Purpose

To investigate the tension in a string, the function of a simple pulley, and a simple “tug-of-war.”

Required Equipment/Supplies

5 large paper clips	2 low-friction pulleys
2 large identical rubber bands	2 ring stands
2 m of strong string	spring scale
2 500-g hook masses	measuring rule

Discussion

Suppose you push on the back of a stalled car. You are certainly aware that you are exerting a force on the car. Are you equally aware that the car is exerting a force on you? And that the magnitudes of the car's force on you and your force on the car are the same? A force cannot exist alone. Forces are always the result of interactions between two things, and they come in balanced pairs.

Now suppose you get a friend to tie a rope to the front of the car and pull on it. The rope will be pulling back on your friend with exactly the same magnitude of force that she is exerting on the rope. The other end of the rope will be pulling on the car and the car will be pulling equally back on it. There are two interaction pairs, one where your friend grasps the rope and one where the rope is attached to the car.

A rope or string is a transmitter of force. If it is not moving or it is moving but has a negligible mass, the forces at its two ends will also be equal. In this activity, you will learn about balanced pairs of interaction forces and about the way a string transmits forces.

Procedure

Step 1: Suspend a 500-g load from a string that is held by a spring scale as shown in Figure A.

1. What does the scale reading tell you about the tension in the string?

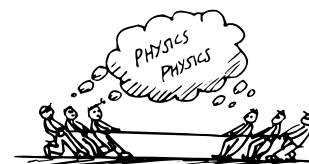


Fig. A

Put tension on a string.

Hang weight over pulley.

Step 2: Drape the string over a pulley such that both ends of the string hang vertically, as shown in Figure B. Hold the scale steady so that it supports the hanging load.

2. What does the scale read, and how does this force compare with the weight of the load?

3. How does it compare with the tension in the string?

Move spring scale to different positions along vertical.

Step 3: Move the spring scale first to a higher, then to a lower position, keeping the strings on each side of the pulley vertical.

4. Does the reading at the higher position change?

5. Move the scale to a lower position. Does the reading at the lower position change? Briefly explain these results.

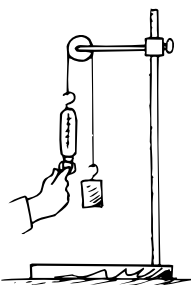


Fig. B

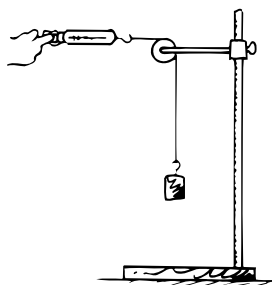


Fig. C

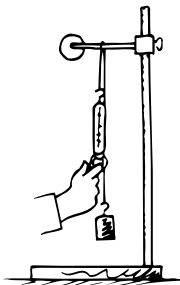


Fig. D

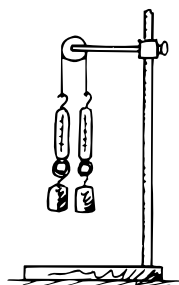


Fig. E

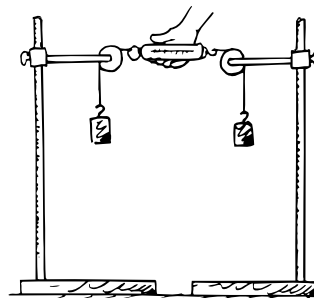


Fig. F

Step 4: Move the spring scale to various angles to the vertical, until the scale is horizontal, as shown in Figure C.

Move spring scale to different positions away from vertical.

6. Does the reading on the scale ever deviate from what you measured in the previous steps? Briefly explain your result.

Step 5: Remove the string from the pulley and drape it over a horizontal rod. Repeat Step 4, as shown in Figure D.

Hang weight over rod.

7. Do you find a difference between the results of Steps 4 and 5? Explain.

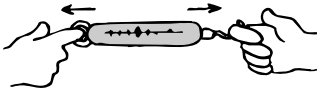
Step 6: Attach a spring scale to each end of the string. Drape the string over the pulley and attach equal masses to each end, as shown in Figure E.

Pull on both ends of string over pulley.

8. What do the scales read?

9. What role does friction play in the function of a pulley?

Have mini tug-of-war with two spring scales.



Step 7: Have your partner hold one end of a spring scale stationary while you pull horizontally on the other end. Pull until the scale reads the same force as it did when suspending the mass. Record the following observations.

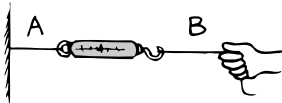
force you exert on the scale = _____

force the scale exerts on you = _____

force your partner exerts on the scale = _____

force the scale exerts on your partner = _____

Attach string to wall and tug.



Step 8: Attach strings on both ends of the spring scale. Fasten one end to the wall or a steady support. Call this String A. Pull horizontally on the other string, String B, until the scale reads the same as in the previous step. Record the following observations.

force you exert on String A = _____

force String A exerts on scale = _____

force the scale exerts on String B = _____

force String B exerts on the wall = _____

force the wall exerts on String B = _____

10. What is the essential difference between the situations in Step 7 and Step 8?

Think and Explain

11. From a microscopic point of view, how does the spring or string transmit the force you are exerting on your partner or the wall?

Step 9: Study Figure F and predict the reading on the scale when two 500-g loads are supported at each end of the strings. Then assemble the apparatus and check your prediction.

predicted scale reading = _____

actual scale reading = _____

Chapter 7: Momentum**Two-Body Collisions**

19 Go Cart

Purpose

To investigate the momentum imparted during elastic and inelastic collisions.

Required Equipment/Supplies

“bouncing dart” from Arbor Scientific
 ring stand with ring
 dynamics cart (with a mass of 1 kg or more)
 string
 pendulum clamp
 C clamp
 meterstick
 brick or heavy weight

Discussion

If you fell from a tree limb onto a trampoline, you’d bounce. If you fell into a large pile of leaves, you’d come to rest without bouncing. In which case, if either, is the change in your momentum greater? This activity will help you answer that question. You’ll compare the changes in momentum in the collision of a “bouncing dart” where bouncing does take place and where it doesn’t.

The dart consists of a thick wooden dowel with a rubber tip on *each* end. Although the tips look and feel the same, the tips are made of different kinds of rubber. One end acts somewhat like a very bouncy ball. The other end acts somewhat like a lump of clay. They have different *elasticities*. Bounce each end of the dart on the table and you’ll easily see which end is more elastic. In the activity, you’ll do the same against the dynamics cart using the dart as a pendulum.

Procedure

Step 1: Attach the dart to the ring stand as a pendulum, using a heavy weight to secure the base of the ring stand. To prevent the dart from swinging into the weight, position the ring on the stand so that it faces the opposite direction. Adjust the string so that the dart strikes the middle of one end of the cart when the dart is at the lowest point of its swing.

Step 2: Elevate the dart so that when impact is made, the cart will roll forward a foot or so on a level table or floor when struck by the inelastic end of the dart. Use a meterstick to measure the vertical distance

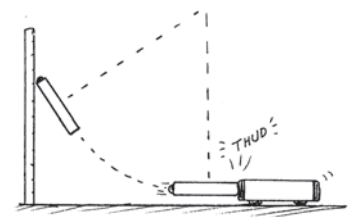
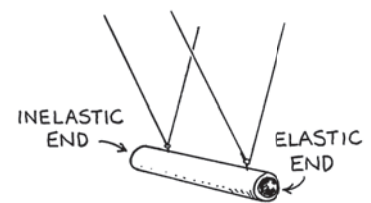


Fig. A



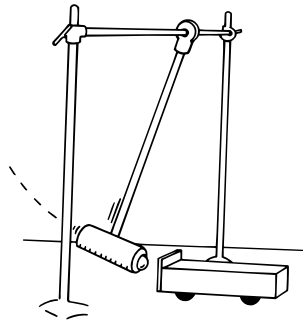
Observe collision without bouncing.

between the release point of the dart and the bottom of its swing. Repeat several times. Record the average stopping distance of the cart.

vertical distance = _____

stopping distance (no bouncing) = _____

Observe collision with bouncing.



Alternate setup

Step 3: Repeat using the elastic end of the dart. Be sure to release the dart from the *same position* as in Step 2. Note what happens to the dart after it hits the cart. Make sure to release the dart from the same height each time. Repeat several more times to see whether your results are consistent. Record the average stopping distance of the cart.

stopping distance (with bouncing) = _____

Write down your observations.

Analysis

1. Define the momentum of the swinging dart before it hits the cart to be positive, so that momentum in the opposite direction is negative. After the dart bounces off the cart, is its momentum negative or positive?

2. When does the dart acquire the greater momentum—when it bounces off the cart or when it doesn't? Explain.

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3. When does the *cart* undergo the greater change in momentum—when struck by the end of the dart that bounces or by the end of the dart that doesn't bounce? Explain.

4. How do the stopping distances of the cart compare?

5. How would you account for the difference in stopping distances?

Chapter 7: Momentum**Momentum Conservation**

20 Tailgated by a Dart

Purpose

To estimate the speed of an object by applying conservation of momentum to an inelastic collision.

Required Equipment/Supplies

opposite types of Velcro[®] hook and loop fastener tape
 toy car
 toy dart gun using rubber darts
 stopwatch
 meterstick
 balance

Optional: photogate timer or computer, light probe with interface, and light source.

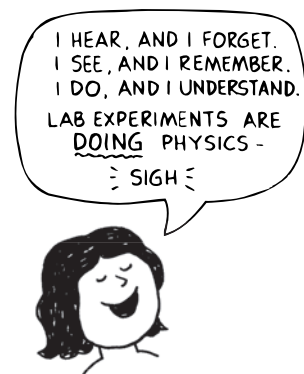
Discussion

If you catch a heavy ball while standing motionless on a skateboard, the momentum of the ball is transferred to you and sets you in motion. If you measure your speed and the masses of the ball, the skateboard, and yourself, then you know the momentum of everything after the ball is caught. But this is equal to the momentum of the ball just before you caught it, from the law of conservation of momentum. To find the speed of the ball just before you caught it, divide the momentum by the mass of the ball. In this experiment, you will find the speeds of a toy dart before and after it collides with a toy car.

Procedure

Step 1: Fasten one type of Velcro tape to the back end of a toy car of small mass and low wheel friction. Fasten the opposite type of Velcro to the suction-cup end of a rubber dart. When the toy car is hit, it must be free to coast in a straight line on a level table or the floor until it comes to a stop.

Practice shooting the dart onto the back end of the car. The dart should stick to the car and cause it to coast.



Tailgate car with dart.

1. What is the relationship between the momentum of the dart before the impact and the combined momentum of the dart *and* car just immediately after the impact?

Step 2: Measure the distance and time that the car coasts after it is hit by the dart, until it comes to a stop. Record your data in Data Table A. Repeat for two more trials.

Step 3: Calculate the average speed of the car after impact for the three trials, and record in Data Table A.

TRIAL	COASTING DISTANCE	COASTING TIME	AVERAGE SPEED OF CAR AFTER IMPACT	SPEED OF CAR UPON IMPACT	INITIAL SPEED OF DART
1					
2					
3					

Data Table A

2. Was the speed of the car constant as it coasted? Explain.

Determine speed upon impact.

3. If the retarding force on the car is assumed to be nearly constant, how does the speed of the car immediately after impact compare with the average speed?

Enter values for the speed of the car upon impact in Data Table A.

Step 4: Find the masses needed to compute the momenta.

mass of car = _____

mass of dart = _____

Step 5: Write an equation showing the momenta before and after the collision.

Compute the initial speed of the dart before impact for each of the three trials. Record your values for the initial speed of the dart in Data Table A.

Step 6: Use a photogate timer or a computer with a light probe to measure the speed of the toy car just after it collides with the dart. Calculate the initial speed of the dart before impact from this measurement.

speed of car upon impact = _____

initial speed of dart before impact = _____

4. How does the speed of the car upon impact, as measured by the light probe or photogate timer, compare with the value you obtained in Step 3?

Analysis

5. Is the momentum of the tailgated car constant the whole time it is moving? Explain.

21**Making the Grade****Purpose**

To investigate the force and the distance involved in moving an object up an incline.

Required Equipment/Supplies

board for inclined plane
 spring scale
 meterstick
 ring stand
 clamp
 cart

Discussion

One of the simplest machines that makes doing work easier is the inclined plane, or ramp. It is much easier to push a heavy load up a ramp than it is to lift it vertically to the same height. When it is lifted vertically, a greater lifting force is required but the distance moved is less. When it is pushed up a ramp, the distance moved is greater but the force required is less. This fact illustrates one of the most powerful laws of physics, the law of energy conservation.

1. A hill has three paths up its sides to a flat summit area, D, as shown in Figure A. The three path lengths AD, BD, and CD are all different, but the vertical height is the same. Not including the energy used to overcome the internal friction of a car, which path requires the most energy (gasoline) for a car driving up it? Explain your answer.

Fig. A

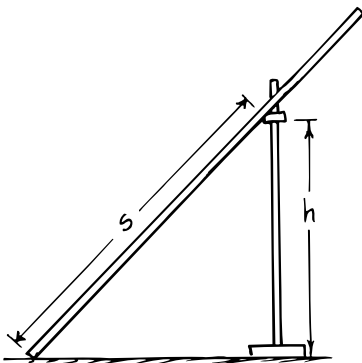


Fig. B
Raise the cart.

Procedure

Step 1: Place a clamp on a ring stand. Clamp the board in place at an angle of 45° , as shown in Figure B. Pull the cart up the inclined plane with a spring scale kept parallel to the plane, to measure the force. Measure the distance s from the bottom of the incline to the ring stand clamp. Record the force and distance in Data Table A.

	10°	30°	45°	60°
FORCE (N)				
DISTANCE (cm)				

Data Table A

Change the angle of the incline.

Step 2: Vary the angle while keeping the height h the same by sliding the board up or down inside the clamp to make angles of 10° , 30° , and 60° . For each of the different angles (and distances), pull the cart parallel to the board. Record your force and distance data in Data Table A.

Analysis

2. What pattern or relationship do you find between the forces and the distances?

Chapter 8: Energy**Power****22****Muscle Up!****Purpose**

To determine the power that can be produced by various muscles of the human body.

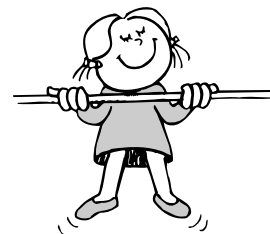
Required Equipment/Supplies

bleachers and/or stairs
stopwatch
meterstick
weights
rope

Discussion

Power is usually associated with mechanical engines or electric motors. Many other devices also consume power to make light or heat. A lighted incandescent bulb may dissipate 100 watts of power. The human body also dissipates power as it converts the energy of food to heat and work. The human body is subject to the same laws of physics that govern mechanical and electrical devices.

The different muscle groups of the body are capable of producing forces that can act through distances. Work is the product of the force and the distance, provided they both act in the same direction. When a person runs up stairs, the force lifted is the person's weight, and the distance is the vertical distance moved—not the distance along the stairs. If the time it takes to do work is measured, the power output of the body, which is the work divided by the time, can be determined in watts.

**Activity****Procedure** 

Step 1: Select five different activities from the following list:

Possible Activities

Lift a mass with your wrist only, forearm only, arm only, foot only, or leg only.
Do push-ups, sit-ups, or some other exercise.
Run up stairs or bleachers.
Pull a weight with a rope.
Jump with or without weights attached.

Perform these activities, and record in Data Table A the *force* in newtons that acted, the *distance* in meters moved against the force, the number of repetitions (or “reps”), and the *time* in seconds required. Then calculate the *power* in watts. (One hundred seconds is a convenient time interval.)

Measure force and distance.

Count the number of reps and measure the time.

	1	2	3	4	5	6	7	8	9	10
FORCE										
DISTANCE										
# REPS										
WORK										
TIME										
POWER										

Data Table A

Step 2: Complete the table by recording the results of four other activities performed by other class members.

Analysis

1. What name is given to the rate at which work is done? What are the units of this rate?

2. In which activity done by your class was the largest power produced? Which muscle groups were used in this activity?

3. Did the activity that used the largest force result in the largest power produced? Explain how a large force can result in a relatively small power.

4. Can a pulley, winch, or lever increase the rate at which a person can do work? Pay careful attention to the wording of this question, and explain your answer.

Chapter 8: Energy**Conservation of Energy****23****Cut Short****Purpose**

To illustrate the principle of conservation of energy with a pendulum.

Required Equipment/Supplies

3 ring stands
pendulum clamp
string
steel ball
rod
clamp

Discussion

A pendulum swinging to and fro illustrates the conservation of energy. Raise the pendulum bob to give it potential energy. Release it and the potential energy is converted to kinetic energy as the bob approaches its lowest point. Then, as the bob swings up on the other side, kinetic energy is converted to potential energy. Back and forth, the forms of energy change while their sum is constant. Energy is conserved. What happens if the length of the pendulum is suddenly changed? How does the resulting motion illustrate energy conservation?

Procedure

Step 1: Attach a pendulum clamp to the top of a ring stand set between two other ring stands, as shown in Figure A. Attach a steel ball to a piece of string that is nearly as long as the ring stand is tall.

Make pendulum.

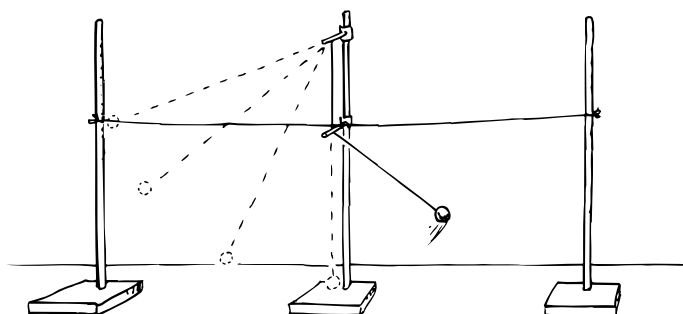


Fig. A

Step 2: Tie a string horizontally from one empty ring stand to the other, as shown in Figure A. The string should be about two-thirds as high as the pendulum clamp. *Set up level string.*

Attach crossbar.

Step 3: Attach a rod to the central ring stand at the same height as the horizontal string (Figure A). The rod should touch the pendulum string when the string is vertical.

Predict height.

Step 4: Predict what height the ball will reach if the ball is released at the same height as the horizontal string and the pendulum string is stopped by the rod. Check one:

Prediction Observation

- | | | |
|--------------------------|--------------------------|--|
| <input type="checkbox"/> | <input type="checkbox"/> | a. The ball will go higher than the horizontal string. |
| <input type="checkbox"/> | <input type="checkbox"/> | b. The ball will go just as high as the horizontal string. |
| <input type="checkbox"/> | <input type="checkbox"/> | c. The ball will not go as high as the horizontal string. |

Release pendulum.

Step 5: Release the pendulum! Record whether you observe a, b, or c.

Raise rod.

Step 6: Predict what would happen if the rod were attached higher than the string. Perform the experiment to confirm or deny your prediction.

Prediction: _____

Observation: _____

Lower rod.

Step 7: Predict what would happen if the rod were attached lower than the string. Perform the experiment to confirm or deny your prediction.

Prediction: _____

Observation: _____

Analysis

1. Explain your observations in terms of potential and kinetic energy and the conservation of energy.

2. Is there an upper limit on how high the rod can be? If so, explain why you think there are limits.

3. Is there a lower limit on how low the rod can be? If so, explain why you think there are limits.

Chapter 8: Energy**Conservation of Energy****24****Conserving Your Energy****Purpose**

To measure the potential and kinetic energies of a pendulum in order to see whether energy is conserved.

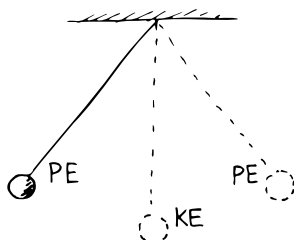
Required Equipment/Supplies

ring stand
pendulum clamp
pendulum bob
balance
string
meterstick
photogate timer or
computer
light probe with interface
light source

Experiment**Discussion**

In Activity 23, “Cut Short,” you saw that the height to which a pendulum swings is related to its initial height. The work done to elevate it to its initial height (the force times the distance) becomes stored as potential energy with respect to the bottom of the swing. At the top of the swing, all the energy of the pendulum is in the form of potential energy. At the bottom of the swing, all the energy of the pendulum is in the form of kinetic energy.

The *total energy* of a system is the sum of its kinetic and potential energies. If energy is conserved, the sum of the kinetic energy and potential energy at one moment will equal their sum at any other moment. For a pendulum, the kinetic energy is zero at the top, and the potential energy is minimum at the bottom. Thus, if the energy of a pendulum is conserved, the extra potential energy at the top must equal the kinetic energy at the bottom. For convenience, potential energy at the bottom can be defined to be zero. In this experiment, you will measure kinetic and potential energy and see if their sum is conserved.



Procedure

Step 1: Devise an experiment with the equipment listed to test the conservation of energy. Write down your procedure in the space following. Include a diagram of your pendulum and label it with all the quantities, such as the height, potential energy, kinetic energy, speed, and so on.

Step 2: Perform your experiment. Record your data below in the form of a table.

Analysis

1. What units of potential energy did you use for the pendulum bob?

Name

Period

Date

2. What units of kinetic energy did you use for the pendulum bob?

3. List the sources of error in your experiment. Which one do you think is the most significant?

4. Based on your data, does the total energy of the pendulum remain the same throughout its swing?

25

How Hot Are Your Hot Wheels?

Purpose

To measure the efficiency of a toy car on an inclined track.

Required Equipment/Supplies

toy car
3 m of toy car track
meterstick
tape
2 ring stands
2 clamps

Discussion

According to the law of energy conservation, energy is neither created nor destroyed. Instead, it *transforms* from one kind to another, finally ending up as heat energy. The potential energy of an elevated toy car on a track transforms into kinetic energy as the car rolls to the bottom of the track, but some energy becomes heat because of friction. The kinetic energy of the car at the bottom of the track is transformed back into potential energy as the car rolls to higher elevation, although again some of the energy becomes heat. The car does not reach its initial height when it moves back up the incline, because some of its energy has been transformed into heat.

Procedure

Step 1: Set up a toy car track as shown in Figure A. Both ends of the track should be elevated to a height of 1 meter above the table or floor. Secure the track to the table or floor and supporting ring stands with tape to eliminate motion of the track.

Step 2: Mark starting point A with a piece of masking tape and record its height h_1 . Release the car from starting point A. Record the height h_2 of point B to which the car rises on the other end of the track.

$$h_1 = \underline{\hspace{2cm}}$$

$$h_2 = \underline{\hspace{2cm}}$$

Step 3: Efficiency is defined as the useful energy out divided by the total energy in. It is a ratio or a percentage. In this activity, we can define the total energy *in* as the change in potential energy as the car rolls from its

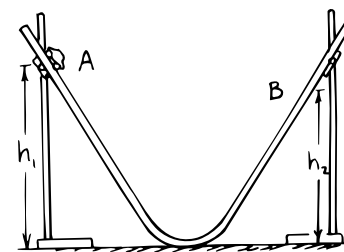


Fig. A

Set up track.

Measure the initial and final height of the car.

Compute efficiency.

highest to its lowest point. This is energy supplied by earth's gravity. The useful energy out we can take to be the potential energy change as the car rolls from its lowest point until it stops at point B. This is energy that the car now possesses relative to the lowest point of its travel. Since the potential energy at any height h above a reference level is mgh , the ratio of the potential energy transferred back into the car at point B (the output energy) to the potential energy lost by the car in rolling down to point A (the input energy) is equal to the ratio of the final height h_2 to the initial height h_1 . This ratio of h_2 to h_1 can be called the "efficiency" of the car-and-track system from point A to point B. It shows the fraction of the energy supplied by gravity in rolling down the track that is retained after it rolls up the track. Compute this efficiency.

$$\text{efficiency} = \frac{\text{PE}_{\text{point B}}}{\text{PE}_{\text{point A}}} = \frac{h_2}{h_1}$$

Analysis

1. Is the efficiency of the car-and-track system changed if the track is not taped?

2. In what units is efficiency measured?

3. Is the efficiency of the car-and-track system changed if the height of the track is altered?

26

Wrap Your Energy in a Bow

Purpose

To determine the energy transferred into an archer's bow as the string is pulled back.

Required Equipment/Supplies

archer's recurve or compound bow
large-capacity spring scale
meterstick
clamp
graph paper

Discussion

The kinetic energy of an arrow is obtained from the potential energy of the drawn bow, which in turn is obtained from the work done in drawing the bow. This work is equal to the average force acting on the bowstring multiplied by the distance it is drawn.

In this experiment, you will measure the amounts of force required to hold the center of a bowstring at various distances from its position of rest, and plot these data on a force vs. distance graph. The force is relatively small for small deflections, and becomes progressively larger as the bow is bent further. The area under the force vs. distance curve out to some final deflection is equal to the average force multiplied by the total distance. This equals the work done in drawing the bow to that distance. Therefore, your graph will show not only the relationship of the force to the distance stretched, but also the potential energy possessed by the fully drawn bow.

The effect of a constant force of 10 N acting over a distance of 2 m is represented in the graph of Figure A. The work done equals the area of the rectangle.

$$\text{work} = F \times d = (20 \text{ N}) \times (2 \text{ m}) = 40 \text{ N}\cdot\text{m} = 40 \text{ J}$$

When the force is not constant, as in Figure B, the work done on the system still equals the area under the graph (between the graph and the horizontal axis). In this case, the total area under the graph equals the area of the triangle plus the area of the rectangle.

$$\begin{aligned} \text{work} &= \text{total area} = \text{area of triangle} + \text{area of rectangle} \\ &= [(1/2) (\text{base}) \times (\text{height})] + [(\text{base}) \times (\text{height})] \\ &= [(1/2) (2 \text{ m}) \times (20 \text{ N})] + [(3 \text{ m}) \times (20 \text{ N})] \\ &= (20 \text{ N}\cdot\text{m}) + (60 \text{ N}\cdot\text{m}) \\ &= 80 \text{ N}\cdot\text{m} \\ &= 80 \text{ J} \end{aligned}$$

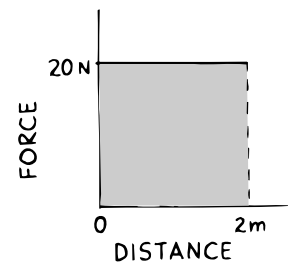


Fig. A

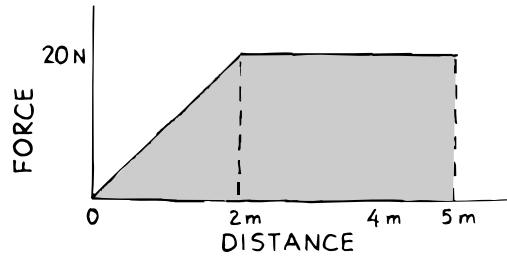


Fig. B

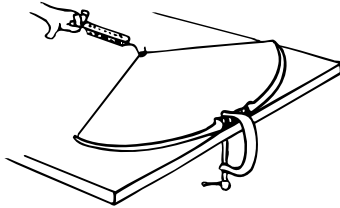


Fig. C

Procedure

Step 1: Fasten the bow at its handle with a clamp in a vertical position, as shown in Figure C. You will pull horizontally on the bowstring with a spring scale. You will measure the distance the bowstring is stretched from its original position and the force required to hold the bowstring that far out. Prepare a table in which to record your data. Show the stretch distances in centimeters in the first column, and their equivalent values in meters in the second column. Show the force readings in the third column. If they are not in newtons, show the equivalent force values in newtons in a fourth column. Leave 10 rows for data in your table.

Stretch bowstring and measure forces.

Make a graph.

Compute area.

Step 2: Stretch the bowstring by 1.0 cm, and record the stretch distance and force reading. Continue to stretch the bowstring in 1.0-cm increments, and record your data in the table. Compute the stretch distances in meters and the equivalent force values in newtons.

Step 3: Plot a graph of the force (vertical axis) vs. distance (horizontal axis). Use the units newtons and meters.

Step 4: Estimate the area under the graph in units of newtons times meters, $\text{N}\cdot\text{m}$. Since $1 \text{ N}\cdot\text{m} = 1 \text{ J}$, this area is the total energy transferred to the bow. When the bow is drawn, this energy is in the form of elastic potential energy.

area = _____

Analysis

1. If a 50-g arrow were shot straight up with the bow stretched to the maximum displacement of your data, how high would it go? (To find the answer in meters, express 50 g as 0.05 kg.)

2. How high would a 75-g arrow go?

3. At what speed would the 50-g arrow leave the bow?

4. List three other devices that transform potential energy into work on an object.

Chapter 8: Energy**Friction and Energy****27****On a Roll****Purpose**

To investigate the relationship between the stopping distance and the height from which a ball rolls down an incline.

Required Equipment/Supplies

6-ft length of 5/8-inch aluminum channel
support about 30 cm high
marble
wood ball
steel ball
tennis ball
meterstick
piece of carpet (10 to 20 feet long and a few feet wide)
graph paper or overhead transparency

Optional Equipment/Supplies

computer
light probe with interface
light source
data plotting software

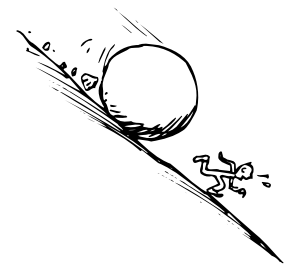
Discussion

When a moving object encounters friction, its speed decreases unless a force is applied to overcome the friction. The greater the initial speed, the more work by the friction force is necessary to reduce the speed to zero. The work done by friction is the force of friction multiplied by the distance the object moves. The friction force remains more or less constant for different speeds as long as the object and the surface stay the same.

In this experiment, you will investigate the relationship between the initial height of a rolling ball and the distance it takes to roll to a stop.

Procedure

Step 1: Assemble the apparatus shown in Figure A. Elevate the ramp to a height that keeps the marble on the carpet when started at the top of the ramp.



Assemble apparatus.

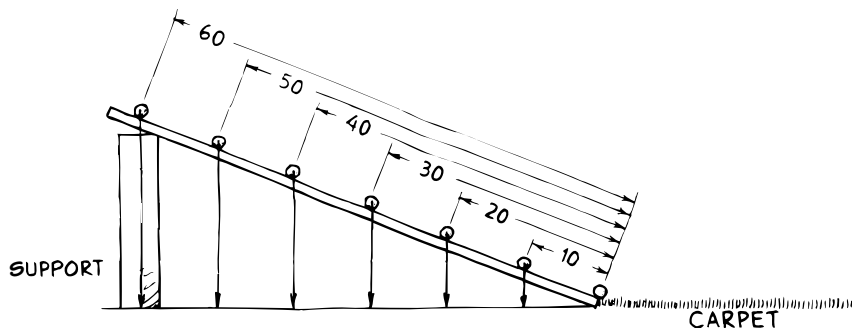


Fig. A

Roll marble onto carpet.

Step 2: Release the marble at intervals of 10 cm along the ramp as shown in Figure A. Measure the vertical height from the floor or table to the release point on the ramp. Also measure the distance required for the marble to roll to a complete stop on the carpet. Roll the marble three times from each height and record the stopping distances in Data Table A.

Repeat using different balls.

Step 3: Repeat Step 2 using a wood ball, a steel ball, and a tennis ball. Record the heights and distances in Data Table A.

Graph data.

Step 4: On the graph paper provided by your teacher, construct a graph of average stopping distance (vertical axis) vs. height (horizontal axis) for each of the four balls.

1. Describe the shapes of the four graphs you made.

2. How did the stopping distances of the different types of balls compare?

3. Compare your results with those of the rest of the class. Does the mass of the ball affect the stopping distance?

Data Table A

OBJECT	POSITION ON RAMP	HEIGHT	STOPPING DISTANCE			AVERAGE STOPPING DISTANCE	SPEED AT BOTTOM	SPEED SQUARED
			TRIAL 1	TRIAL 2	TRIAL 3			
MARBLE								
STEEL BALL								
TENNIS BALL								
WOOD BALL								

4. Based on your data, what factors would seem to determine the stopping distance of automobiles?

Going Further (Optional)

Graph speed vs. height.

Step 5: Use a light probe to time the marble at the bottom of the incline. Repeat for each of the release heights. Compute the speeds by dividing the diameter of the marble by the measured times. Record the speeds in Data Table A. Make a graph of speed (vertical axis) vs. height (horizontal axis) on graph paper.

Repeat using different balls.

Step 6: Repeat Step 5 for the steel ball, wood ball, and tennis ball.

5. Describe the shape of the four graphs you made.

Graph square of speed vs. height.

Step 7: Compute the square of the speed and record in Data Table A or use data plotting software to plot the square of the speed (vertical axis) vs. height (horizontal axis) for the marble, steel ball, wood ball, and tennis ball.

6. Describe the shape of the four graphs you made.

Chapter 8: Energy**Conservation of Energy****28****Releasing Your Potential****Purpose**

To find relationships among the height, speed, mass, kinetic energy, and potential energy.

Required Equipment/Supplies

pendulum apparatus as in Figure A
 2 steel balls of different mass
 graph paper or overhead transparencies
 meterstick

Optional Equipment/Supplies

computer
 light probe with interface
 light source

Discussion

Drop two balls of different mass and they fall together. Tie them separately to two strings of the same length and they will swing together as pendulums. The speeds they achieve in falling or in swinging do not depend on their mass, but only on the vertical distance they have moved downward from rest. In this experiment, you will use a rigid pendulum (see Figure A) raised to a certain height. At the bottom of the pendulum's swing, a crossbar stops the pendulum, but the ball leaves the holder and keeps going.

How far downrange does the ball travel? The horizontal distance from the crossbar depends on *how fast* the ball is going and *how long* it remains in the air. How fast it is launched depends on *the launcher*. How long it remains in the air depends on how high it is above the floor or table.

Procedure 

Step 1: Devise an appropriate method for measuring the vertical height h the pendulum ball falls. Record your method in the following space.

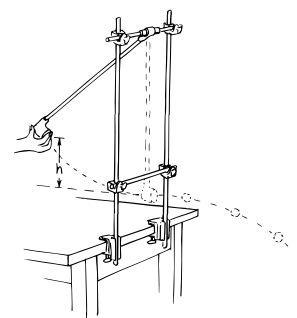


Fig. A

Measure vertical height.

Launch ball with pendulum.

Step 2: Raise the pendulum to the desired vertical height, using your finger to hold the ball in place. Take your finger away in such a manner that you do not push the pendulum up or down. Both the ball and pendulum swing down together, and the ball is launched upon impact with the crossbar. Practice your technique until you get consistent landings of the ball downrange.

Measure the range.

Step 3: When your results have become consistent, release the ball three times from the same height. Use a meterstick to measure the downrange distance for each trial. Repeat the experiment for six different heights. Record each average distance and height in Data Table A.

HEIGHT	DISTANCE			
	TRIAL 1	TRIAL 2	TRIAL 3	AVERAGE

Data Table A

Calculate minimum launch speed.

Step 4: Suppose the ball were attached to a lightweight string (as in a simple pendulum) that struck a razor mounted on the crossbar as shown in Figure A. If the ball is released from a sufficient height, its inertia will cause the string to be cut as it strikes the crossbar, projecting the ball horizontally. From the law of conservation of energy, the kinetic energy of the ball as it is launched from the low point of its swing is equal to the potential energy that it lost in swinging down, so $KE_{\text{gained}} = PE_{\text{lost}}$ or $\frac{1}{2}mv^2 = mgh$.

The launcher pictured in Figure A has its mass distributed along its length, so strictly speaking it isn't a *simple* pendulum. We'll see in Chapter 11 that it has less "rotational inertia" and swings a bit faster than if all its mass were concentrated at its bottom. For simplicity, we won't treat this complication here, and acknowledge that the speed calculated for a simple pendulum, $v = \sqrt{2gh}$, is a *lower limit*—the *minimum* launch speed. Record your computation of the minimum launch speed for each height from which the pendulum was released, in the second column of Data Table B.

HEIGHT	LAUNCH SPEED COMPUTED	LAUNCH SPEED AS MEASURED BY PHOTOGATE

Data Table B

Step 5: (Optional) Use a single light probe to measure the launch speed of the ball at each of the six heights. Record your results in the third column of Data Table B.

- How do the minimum and measured speeds of the ball compare?

Step 6: In this step, you will investigate the relationship between the mass of the ball and its launch speed. Use a ball with a different mass, and release it from the same six heights as before. Record the downrange distances in Data Table C.

Use balls of different mass.

HEIGHT	DISTANCE			
	TRIAL 1	TRIAL 2	TRIAL 3	AVERAGE

Data Table C

Graph data.

Step 7: You now have a tremendous amount of data. What does it mean? What is the pattern? You can often visualize a pattern by making a graph. Graph the pairs of variables suggested. You may want to graph other quantities instead. Use overhead transparencies or graph paper. Each member of your team should make one graph, then all of you can pool your results. If a computer and data plotting software are available, use them to make your graphs.

Suggested graphs

- (a) Distance or range (vertical axis) vs. height from which the pendulum is released (horizontal axis) for the same mass.
- (b) Launch speed (vertical axis) vs. release height (horizontal axis) for the same mass.
- (c) Mass (vertical axis) vs. distance (horizontal axis) for the same height. If you are using data plotting software, vary the powers of the x and y values until the graph is a straight line.

Analysis

- 2. Describe what happens to the kinetic energy of the ball as it swings from the release height to the launch position.

- 3. Describe what happens to the potential energy of the ball as it swings from the release height to the launch position.

- 4. Describe what happens to the total energy of the ball as it swings from the release height to the launch position.

Going Further

Have your teacher assign you a specified distance downrange. Try to predict the angle from the vertical or height at which the pendulum must be released in order to score a bull's-eye.

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Chapter 8: Energy**Coefficients of Friction****29****Slip-Stick****Purpose**

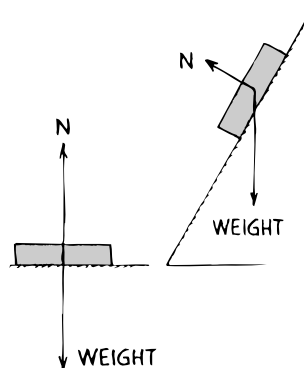
To investigate three types of friction and to measure the coefficient of friction for each type.

Required Equipment/Supplies

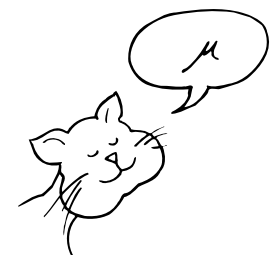
friction block (foot-long 2×4 with an eye hook)
 spring scale with maximum capacity greater than the weight of the friction block
 set of slotted masses
 flat board
 meterstick
 shoe

Discussion

The force that presses an object against a surface is the entire weight of the object only when the supporting surface is horizontal. When the object is on an incline, the component of gravitational force pressing the object against the surface is *less* than the object's weight. This component that is perpendicular (normal) to the surface is the *normal force*. For a block on an incline, the normal force varies with the angle. Although an object presses with its full weight against a horizontal surface, it presses with only half its weight against a 60° incline. So the normal force is half the weight at this angle. The normal force is zero when the incline is vertical because then the surfaces do not press against each other at all.



The normal force can be greater than the object's weight if you press down on the object. In general, the coefficient of friction is defined by replacing weight in the formula above by the normal force, whatever the



source of the force. So, in general, the force of friction F_f depends on the coefficient of friction μ and the normal force N :

$$F_f = \mu N$$

so that the coefficient of friction, μ , equals

$$\mu = \frac{\text{friction force}}{\text{weight}}$$

The coefficient of friction μ is greatest when the two surfaces are at rest, just before motion starts. (Then the ridges and valleys have had time to sink into each other and are meshed.) Once sliding begins, μ is slightly less. The coefficient of friction for sliding objects is called the *coefficient of sliding friction* (or coefficient of kinetic friction). When friction holds an object at rest, we define the *coefficient of static friction* as the greatest friction force than can act without motion divided by the normal force. A partial list of coefficients of both sliding and static friction is shown in Figure A.

SURFACES	μ_s (STATIC)	μ_k (KINETIC)
STEEL ON STEEL, DRY	0.6	0.3
STEEL ON WOOD, DRY	0.4	0.2
STEEL ON ICE	0.1	0.06
WOOD ON WOOD, DRY	0.35	0.15
METAL ON METAL, GREASED	0.15	0.08

Fig. A

Friction also occurs for objects moving through fluids. This friction, known as *fluid friction*, does not follow laws as simple as those that govern sliding friction for solids. Air is a fluid, and the motion of a leaf falling to the ground is quite complicated! In this experiment, you will be concerned only with the friction between two solid surfaces in contact.

Friction always acts in a direction to oppose motion. For a ball moving upward in the air, the friction force is downward. When the ball moves downward, the friction force is upward. For a block sliding along a surface to the right, the friction force is to the left. Friction forces are always opposite to the direction of motion.

Part A: Computing the Coefficients of Static and Sliding Friction

Procedure

Step 1: Weigh the friction block by suspending it from the spring scale. Record the weight in Data Table A. Determine the coefficients of static and sliding friction by dragging the friction block horizontally with a spring scale. Be sure to hold the scale horizontally. The static friction force F_f is the maximum force that acts just before the block starts moving. The sliding friction force F_f is the force it takes to keep the block moving at *constant velocity*. Your scale will vibrate around some average

Drag friction block.



value; make the best judgment you can of the values of the static and sliding friction forces. Record your data in Data Table A.

F_f FORCE TO JUST GET GOING	F_f' DRAG FORCE AT CONSTANT VELOCITY	W WEIGHT OF CART	$\mu_{\text{STATIC}} = \frac{F_f}{W}$	$\mu_{\text{SLIDING}} = \frac{F_f'}{W}$

Data Table A

Step 2: Drag the block at different speeds. Note any changes in the sliding friction force.

Change dragging speed.

- Does the dragging speed have any effect on the coefficient of sliding friction, μ_{sliding} ? Explain.

Step 3: Increase the force pressing the surfaces together by adding slotted masses to the friction block. Record the weight of both the block and the added masses in Data Table A. Find both friction forces and coefficients of friction for at least six different weights and record in Data Table A.

Add weights to block.

Analysis

- At each weight, how does μ_{static} compare with μ_{sliding} ?

3. Does μ_{sliding} depend on the weight of the friction block? Explain.

4. Tables in physics books rarely list coefficients of friction with more than two significant figures. From your experience, why are more than two significant figures not listed?

5. If you press down upon a sliding block, the force of friction increases but μ does not. Explain.

6. Why are there no units for μ ?

Part B: The Effect of Surface Area on Friction

Procedure

Drag friction block.

Step 4: Drag a friction block of known weight at constant speed by means of a horizontal spring scale. Record the friction force and the weight of the block in Data Table B.

CONFIGURATION	F_f FORCE OF FRICTION	W NORMAL FORCE	A AREA OF CONTACT	μ COEFFICIENT OF FRICTION
1				
2				
AVERAGE				

Data Table B

Step 5: Repeat Step 4, but use a different side of the block (with a different area). Record the friction force in Data Table B.

Use different side of friction block.

Step 6: Compute μ_{sliding} for both steps and list in Data Table B.

Compute μ .

7. Does the area make a difference in the coefficient of friction?

Going Further: Friction on an Incline

Place an object on an inclined plane and it may or may not slide. If friction is enough to hold it still, then tip the incline at a steeper angle until the object just begins to slide.

The coefficient of friction of a shoe is critical to its function. When will a shoe on an incline start to slip? Study Figure B. To make the geometry clearer, a cube can represent the shoe on the incline, as in Figure C. Triangle B shows the vector components of the shoe's weight. The component perpendicular to the incline is the normal force N ; it acts to press the shoe to the surface. The component parallel to the incline, which points downward, tends to produce sliding. Before sliding starts, the friction force F_f is equal in magnitude but opposite in direction to this component. By tilting the incline, we can vary the normal force and the friction force on the shoe.

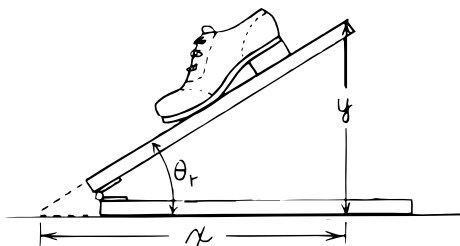


Fig. B

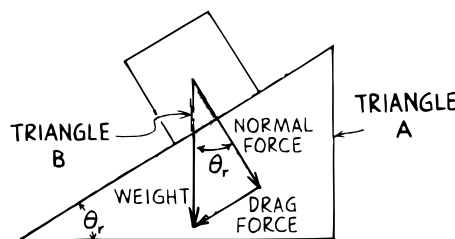


Fig. C

At the angle at which the shoe starts to slip (the *angle of repose*) θ_r , the component of weight parallel to the surface is just enough to overcome friction and the shoe breaks free. At that angle, the parallel weight component and the friction force are at their maximum. The ratio of this friction force to the normal force gives the coefficient of static friction.

In Figures B and C, the angle of incline has been set to be the angle of repose, θ_r . With the help of geometry, it can be proven that triangles A and B in Figure C are *similar triangles*—that is, they have the same angles—and triangle B is a shrunken version of triangle A. The importance of similar triangles is that the *ratios* of corresponding parts of the two triangles are *equal*. Thus, the ratio of the parallel component to the normal force equals the ratio of the height y to the horizontal distance x . The coefficient of static friction is the ratio of those sides.

$$\mu_{\text{static}} = \frac{F_f}{N} = \frac{y}{x}$$

Procedure

Tilt incline until shoe slips.

Step 7: Put your shoe on the board, and slowly tilt the board up until the shoe just begins to slip. Using a meterstick, measure the horizontal distance x and the vertical distance y . Compute the coefficient of static friction μ_{static} from the equation in the preceding paragraph.

$$\mu_{\text{static}} = \underline{\hspace{2cm}}$$

Tap the incline.

Step 8: Repeat Step 7, except have a partner tap the board constantly as you approach the angle of repose. Adjust the board angle so that the shoe slides at constant speed. Compute the coefficient of sliding (kinetic) friction, μ_{sliding} , which equals the ratio of y to x at that board angle.

$$\mu_{\text{sliding}} = \underline{\hspace{2cm}}$$

8. Did you measure any difference between μ_{static} and μ_{sliding} ?

Drag shoe on level.

Step 9: With a spring scale, drag your shoe along the same board when it is level. Compute μ_{sliding} by dividing the force of friction (the scale reading) by the weight of the shoe. Compare your result with that of Step 8.

$$\mu_{\text{sliding}} = \underline{\hspace{2cm}}$$

9. Are your values for μ_{sliding} from Steps 8 and 9 equal? Explain any differences.

10. Does the force of sliding friction between two surfaces depend on whether the supporting surface is inclined or horizontal?

11. Does the coefficient of sliding friction between two surfaces depend on whether the supporting surface is inclined or horizontal?

12. Explain why Questions 10 and 11 are different from each other.

Chapter 9: Circular Motion**Centripetal Acceleration****30****Going in Circles****Purpose**

To determine the relative magnitude and direction of acceleration of an object at different positions on a rotating turntable.

Required Equipment/Supplies

dynamics cart
 accelerometer
 mass
 pulley
 string
 support for pulley and mass
 phonograph turntable
 masking tape

Discussion

How can a passenger in a smooth-riding train tell when the train undergoes an acceleration? The answer is easy: He or she can simply watch to see whether the surface of the liquid in a container is disturbed, or look for motion at the bottom of the hanging curtains. These are two simple accelerometers.

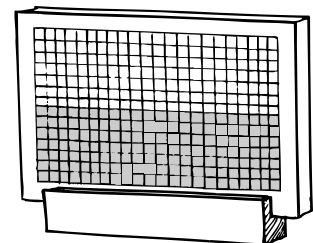
Procedure

Step 1: Attach the accelerometer securely to a cart, and place the cart on a smooth surface such as a table.

Step 2: Attach the cart to the mass with a string. Attach a pulley to the edge of the table and place the string on the pulley.

Step 3: Allow the liquid in the accelerometer to settle down (level) while holding it in position ready to release. Allow the mass to fall and cause the cart to accelerate. Observe and sketch the surface of the liquid in the accelerometer. Label the direction of the acceleration of the cart.

Observe accelerometer moving in straight line.



1. What happens to the surface as the cart continues to accelerate?

Repeat the experiment several times.

2. Does the surface behave the same way each time?

Observe accelerometer on turntable.

Step 4: Remove the accelerometer from the cart, and securely attach the accelerometer to the turntable. Make sure that the accelerometer will not fly off.

Step 5: Place the center of the accelerometer at the center of the turntable, and rotate the turntable at various speeds. Observe and sketch the surface of the liquid each time.

3. What do you conclude about the magnitude and direction of the acceleration on the rotating turntable?

Analysis

4. Figures A, B, C, and D show the surface of the liquid for a particular situation. What situation of the ones you observed most closely matches these figures?

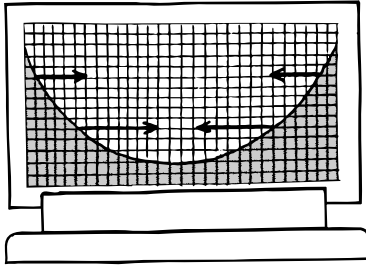


Fig. A

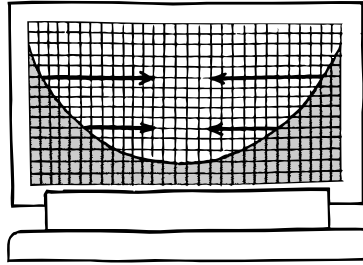


Fig. B

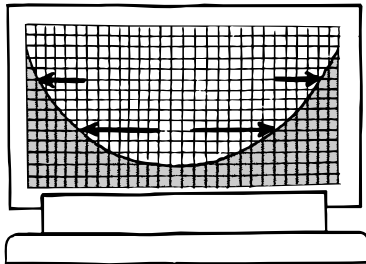


Fig. C

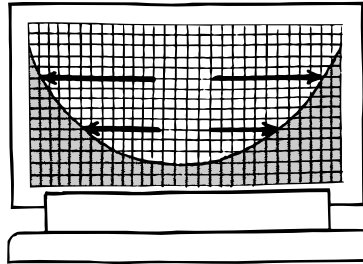


Fig. D

5. The four figures show four possible sets of arrows representing the magnitude and direction of the acceleration at different points. Which figure is most correct? Explain the reason(s) for your choice.

Chapter 10: Center of Gravity**Center of Gravity****31****Where's Your CG?****Purpose**

To locate your center of gravity.

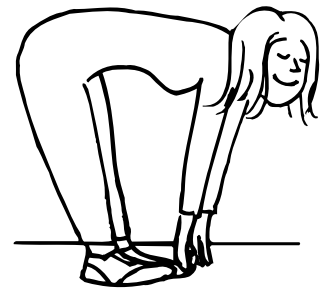
Required Equipment/Supplies

2 bathroom scales
 8' × 2" × 12" "reaction" board
 meterstick
 bricks or old books
 2 large triangular supports (such as 1-inch angle iron or machine-shop files)

Discussion

For a symmetrical object such as a ball or donut, the center of gravity, or CG, is located in the geometric center of the object. For asymmetrical objects, such as a baseball bat or a person, the CG is located closer to the heavier end. When your arms are at your side, your center of gravity is near your navel, where your umbilical cord was attached. This is no coincidence—unborns sometimes rotate about their CG.

Your CG is a point that moves when you move. When you raise your hands above your head, your CG is a little higher than when your hands are by your sides. In this activity, you will locate your CG when your hands are by your sides.

**Activity****Procedure** 

Step 1: Using a bathroom scale, weigh yourself and then a reaction board. Record these weights.

weight of self = _____ weight of board = _____

Step 2: Measure your height in centimeters.

height = _____

Step 3: Place one triangular support on each bathroom scale. You may need to add bricks or books between the scale and the support if the bubble on the scale causes the support to rock. Position the scales so that the tops of the triangular supports are separated by a distance equal to your height. Place the reaction board on the two supports. *The overhangs of the ends of the reaction board on each support should be equal.*

Weigh yourself.

Measure your height.

Position reaction board.

Read the weight reading on each bathroom scale. These readings should each be half the weight of the reaction board (plus the books or bricks, if any). If they are not, either adjust the calibration knob on one scale until the readings are equal or record the readings for future calculations.

Position yourself on reaction board.

Step 4: Lie down on the reaction board so that the tip of your head is over one support and the bottoms of your feet are over the other support, as in Figure A. Remain flat on the board with your hands by your sides. Have someone record the reading on each bathroom scale.

weight at head = _____ weight at feet = _____

Adjust your position.

Step 5: After you are informed of the weight readings, adjust your position along the length of the board until the two readings become equal. Have someone measure how far the bottoms of your feet are from the support near your feet.

distance from support to feet = _____



Fig. A

1. Did you have to move toward the foot end or toward the head end?

2. When the readings on the scales are equal, where is your CG in relation to the supports?

Determine your CG.

Step 6: Determine the location of your CG, in relation to the bottoms of your feet.

location of CG = _____ cm from the feet

Place your finger on your navel and have someone measure the distance from the bottom of your feet to your navel.

location of navel = _____ cm from the feet

Analysis

3. How close is your CG to your navel?

4. What would happen if the two weight readings of the board were not equal?

5. When an astronaut spins when doing acrobatics aboard an orbiting space vehicle, what point does the body spin about?

Chapter 11: Rotational Mechanics**Torque**

32 Torque Feeler

Purpose

To illustrate the qualitative differences between torque and force.

Required Equipment/Supplies

meterstick
meterstick clamp
1-kg mass
mass hanger

Discussion

Torque and force are sometimes confused because of their similarities. Their differences should be evident in this activity.

Procedure

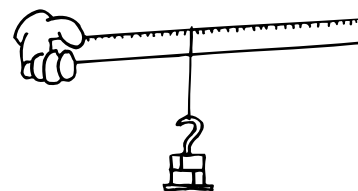
Step 1: Hold the end of a meterstick in your hand so that your index finger is at the 5-cm mark. With the stick held horizontally, position the mass hanger at the 10-cm mark, and suspend the 1-kg mass from it. Rotate the stick to raise and lower the free end of the stick. Note how hard or easy it is to raise and lower the free end.

Rotate meterstick.

Step 2: Move the mass hanger to the 20-cm mark. Rotate the stick up and down about the pivot point (your index finger) as before. Repeat this procedure with the mass at the 40-cm, 60-cm, 80-cm, and 95-cm marks.

Move mass farther from pivot point.

- Does it get easier or harder to rotate the stick as the mass gets farther from the pivot point?



Analysis

2. Does the weight of the mass increase as you move the mass away from the pivot point (your index finger)?

3. If the weight of the mass is not getting any larger, why does the difficulty in rotating the stick increase in Step 2?

33

Weighing an Elephant

Purpose

To determine the relationship between masses and distances from the fulcrum for a balanced seesaw.

Required Equipment/Supplies

meterstick
wedge or knife-edge
2 50-g mass hangers
slotted masses or set of hook masses
knife-edge level clamps

Discussion

An object at rest is in equilibrium (review Section 4.7 of the text). The sum of the forces exerted on it is zero. The resting object also shows another aspect of equilibrium. Because the object has no rotation, the sum of the torques exerted on it is zero. When a force causes an object to start turning or rotating (or changes its rotation), a nonzero net torque is present.

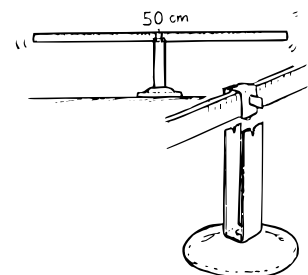
The seesaw is a simple mechanical device that rotates about a pivot or fulcrum. It is a type of lever. Although the work done by a device can never be more than the work or energy invested in it, levers make work *easier* to accomplish for a variety of tasks.

Suppose you are an animal trainer at the circus. You have a very strong, very light, wooden plank. You want to balance a 600-kg baby elephant on a seesaw using only your own body weight. Suppose your body has a mass of 50 kg. The elephant is to stand 2 m from the fulcrum. How far from the fulcrum must you stand on the other side in order for you to balance the elephant?

Laboratories do not have elephants or masses of that size. They do have a variety of smaller masses, metersticks, and fulcrums that enable you to discover how levers work, describe their forces and torques mathematically, and finally solve the elephant problem.

Procedure

Step 1: Carefully balance a meterstick horizontally on a wedge or knife-edge. Suspend a 200-g mass 10 cm from the fulcrum. Suspend a 100-g mass on the opposite side of the fulcrum at the point that balances the meterstick. Record the masses and distances from the fulcrum in Data Table A.



1. Can a heavier mass be balanced by a lighter one? Explain how.

Step 2: Make more trials to fill in Data Table A. You can do this by using the masses of Step 1 and changing their positions. For instance, you can move the heavier mass to a new location 5 cm farther away, and then rebalance the meterstick with the lighter mass.

You can also change the magnitudes of the masses. Replace the heavier mass with another mass and rebalance the lever by moving the lighter mass. Record the masses and distances from the fulcrum in Data Table A. Be sure to take into account the mass of any hanger or clamp.

TRIAL	SMALL MASS (g)	DISTANCE FROM FULCRUM (cm)	LARGE MASS (g)	DISTANCE FROM FULCRUM (cm)

Data Table A

Analyze data for pattern.

Step 3: Use any method you can devise to discover a pattern in the data of Data Table A. You can try graphing the large mass vs. its distance from the fulcrum, the small mass vs. its distance from the fulcrum, or another pair of variables. You can also try forming ratios or products.

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Step 4: After you have convinced yourself and your laboratory partners that you have discovered a pattern, convert this pattern into a word statement.

Express pattern as statement.

Step 5: Now convert this word statement into a mathematical equation. Be sure to explain what each symbol stands for.

Convert statement into equation.

Step 6: With the help of your partners or your teacher, use your equation to find the distance a 50-kg person should stand from the fulcrum in order to balance the 600-kg elephant. Show your work (neglect the mass of the supporting board).

Solve for unknown distance.

$$d = \text{_____} \text{ m}$$

Analysis

- Why must the mass of the hangers and clamps be taken into account in this experiment?

3. If you are playing seesaw with your younger sister (who weighs much less than you), what can you do to balance the seesaw? Mention at least two things.

4. Taking account of the fact that the board holding up the elephant and the trainer (see sketch in the Discussion section) has weight, would the actual position of the trainer be farther from or closer to the fulcrum than calculated in Step 6?

34 Keeping in Balance

Purpose

To use the principle of balanced torques to find the value of an unknown mass.

Required Equipment/Supplies

meterstick	fulcrum
standard mass with hook	fulcrum holder
rock or unknown mass	string
triple-beam balance	masking tape

Discussion

Gravity pulls on every part of an object. It pulls more strongly on the more massive parts of objects and more weakly on the less massive parts. The sum of all these pulls is the weight of the object. The average position of the weight of an object is its center of gravity, or CG.

The whole weight of the object is effectively concentrated at its center of gravity. The CG of a uniform meterstick is at the 50-cm mark. In this experiment, you will balance a meterstick with a known and an unknown mass, and compute the mass of the unknown. Then you will simulate a “solitary seesaw.”

Procedure

Step 1: Balance the meterstick horizontally with nothing hanging from it. Record the position of the CG of the meterstick.

Balance the meterstick.

position of meterstick CG = _____

Using a string, attach an object of unknown mass, such as a rock, at the 90-cm mark of the meterstick, as shown in Figure A. Place a known mass on the other side to balance the meterstick. Record the mass used and its position.

mass = _____ position = _____

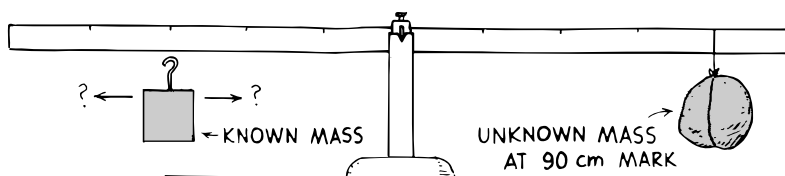


Fig. A

Compute unknown mass.

Step 2: Compute the distances from the fulcrum to each object.

distance from fulcrum to unknown mass = _____

distance from fulcrum to known mass = _____

These two distances are known as lever arms. The lever arm is the distance from the fulcrum to the place where the force acts.

In the following space, write an equation for balanced torques, first in words and then with the known values. Compute the unknown mass.

mass_{computed} = _____

Measure mass of unknown.

Step 3: Measure the unknown mass, using a triple-beam balance.

mass_{measured} = _____

Calculate percent error.

Step 4: Compare the measured mass to the value you computed in Step 2, and calculate the percentage difference.

$$\% \text{ error} = \frac{|\text{mass}_{\text{computed}} - \text{mass}_{\text{measured}}|}{\text{mass}_{\text{measured}}} \times 100\%$$

= _____

Set up "solitary seesaw."

Step 5: Place the fulcrum exactly on the 85-cm mark. Balance the meterstick using a single mass hung between the 85-cm and 100-cm marks, as in Figure B. Record the mass used and its position.

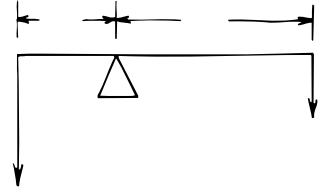
Fig. B



mass = _____ position = _____

Step 6: Draw a lever diagram of your meterstick system in the following space. Be sure to label the fulcrum, the masses whose weights give rise to torques on each side of the fulcrum, and the lever arm for each mass.

Draw lever diagram.



1. Where is the mass of the meterstick effectively located?

Compute the mass of the meterstick. Show your work in the following space.

$$\text{mass}_{\text{computed}} = \underline{\hspace{2cm}}$$

Step 7: Remove the meterstick and measure its mass on a triple-beam balance.

Measure mass of meterstick.

$$\text{mass}_{\text{measured}} = \underline{\hspace{2cm}}$$

Step 8: Find the percent error for the computed value of the mass of the meterstick.

Calculate percent error.

$$\% \text{ error} = \frac{|\text{mass}_{\text{computed}} - \text{mass}_{\text{measured}}|}{\text{mass}_{\text{measured}}} \times 100\%$$

$$= \underline{\hspace{2cm}}$$

Going Further

For a uniform, symmetrical object the CG is located at its geometrical center. The CG of a uniform meterstick is at the 50-cm mark. But for an asymmetrical object such as a baseball bat, the CG is nearer the heavier end. In this part of the experiment, you will learn how to find the location of the center of gravity for an asymmetrical rigid object.

Step 9: If a rock is attached to your meterstick away from the midpoint, the new CG of the *combined* meterstick plus rock is *not* in the center. Use masking tape to attach the rock to the meterstick between the 0-cm and 50-cm mark. Move the fulcrum to the 60-cm mark, as shown in Figure C. Hang a known mass between the 60-cm and 100-cm mark to balance the meterstick. Record the mass used and its position.

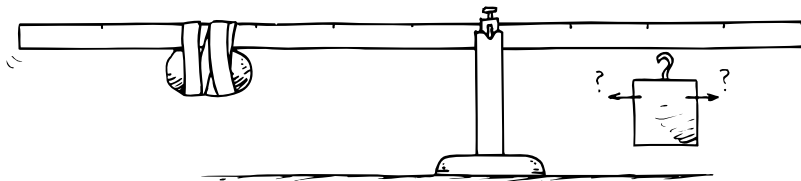


Fig. C

mass = _____ position = _____

Step 10: Find the mass of the meterstick/rock combination with a triple-beam balance.

mass of meterstick/rock combination = _____

Find the CG of the meterstick/rock combination using an equation for balanced torques. In the following space, write down the equation first in words and then with known values.

distance from CG to fulcrum = _____

computed position of CG = _____

Step 11: Verify the location of the CG by removing the added known mass and placing the fulcrum at the predicted CG point.

2. Does the meterstick balance?

3. How far was your predicted location of the CG from its actual location?

35

Rotational Derby

Purpose

To observe how round objects of various shapes and masses roll down an incline and how their rotational inertias affect their rate of rotation.

Required Equipment/Supplies

- smooth, flat board, 1 m in length
- ring stand or metal support with clamp and rod
- balance
- meterstick
- 3 solid steel balls of different diameter (3/4" minimum)
- 3 empty cans of different diameter, with both the top and the bottom removed
- 3 unopened cans of different diameter, filled with nonsloshing contents (such as chili or ravioli)
- 2 unopened soup cans filled with different kinds of soup, one liquid (sloshing) and one solid (nonsloshing)

Discussion

Why is most of the mass of a flywheel, a gyroscope, or a Frisbee concentrated at its outer edge? Does this mass configuration give these objects a greater tendency to resist changes in rotation? How does their “rotational inertia” differ from the inertia you studied when you investigated linear motion? Keep these questions in mind as you do this activity.

The *rotational speed* of a rotating object is a measure of how fast the rotation is taking place. It is the angle turned per unit of time and may be measured in degrees per second or in radians per second. (A radian is a unit similar to a degree, only bigger; it is slightly larger than 57 degrees.) The *rotational acceleration*, on the other hand, is a measure of how quickly the rotational speed changes. (It is measured in degrees per second squared or in radians per second squared.) The rotational speed and the rotational acceleration are to rotational motion what speed and acceleration are to linear motion.

Procedure

Step 1: Make a ramp with the board and support. Place the board at an angle of about 10°.

Set up ramp.



Roll balls down ramp.

Step 2: Select two balls. Predict which ball will reach the bottom of the ramp in the shorter time.

predicted winner: _____

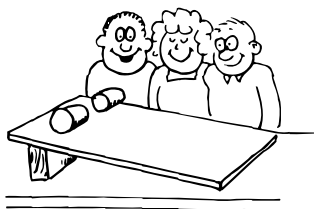
Place a meterstick across the ramp near the top, and rest the balls on the stick. Quickly remove the stick to allow the balls to roll down the ramp. Record your results.

actual winner: _____

Repeat the race for the other pair of balls.

1. What do you conclude about the time it takes for two solid steel balls of different diameter to roll down the same incline?

Roll hollow cylinders.



Step 3: Repeat the race for two hollow cylinders (empty cans). Record your predictions and results.

predicted winner: _____

actual winner: _____

Repeat the race for the other pairs of hollow cylinders.

2. What do you conclude about the time it takes for two hollow cylinders of different diameter to roll down the same incline?

Roll solid cylinders.

Step 4: Repeat the race for two solid cylinders (filled cans with non-sloshing contents). Record your predictions and results.

predicted winner: _____

actual winner: _____

Repeat the race for the other pairs of solid cylinders.

3. What do you conclude about the time it takes for two solid cylinders of different diameter to roll down the same incline?

Step 5: Repeat the race for a hollow cylinder and a solid one. Before trying it, predict which cylinder will reach the bottom of the ramp first.

Roll hollow and solid cylinders.

predicted winner: _____

Now try it, and record your results.

actual winner: _____

Repeat for other pairs of hollow vs. solid cylinders.

4. What can you conclude about the time it takes for a hollow and a solid cylinder to roll down the same incline?

5. How do you explain the results you observed for the hollow and solid cylinders?

Step 6: Repeat the race for a solid ball and a solid cylinder. Record your prediction and result.

Roll balls and solid cylinders.

predicted winner: _____

actual winner: _____

6. What do you conclude about the time it takes for a solid ball and a solid cylinder to roll down the same incline?

Step 7: Repeat the race for a solid ball and a hollow cylinder. Record your prediction and result.

Roll balls and hollow cylinders.

predicted winner: _____

actual winner: _____

7. What can you conclude about the time it takes for a solid ball and a hollow cylinder to roll down the same incline?

Roll cans of different kinds of soup.

Step 8: Repeat the race for two soup cans, one with liquid (sloshing) contents and the other with solid (nonsloshing) contents. Record your prediction and results.

predicted winner: _____

actual winner: _____

8. How can you explain the results you observed for the sloshing vs. nonsloshing kinds of soup?

Analysis

9. Of all the objects you tested, which took the least time to roll down the incline?

10. Gravity caused the objects to turn faster and faster—that is, they had rotational acceleration. Of the objects you tested, what shape of objects had the greatest rotational inertia—that is, the greatest *resistance* to rotational acceleration?

Chapter 13: Gravitational Interactions**Acceleration of Gravity**

36 Acceleration of Free Fall

Purpose

To measure the acceleration of an object during free fall with the help of a pendulum.

Required Equipment/Supplies

Free Fall apparatus from Arbor Scientific Co. or
 meterstick with 2 eye hooks in one end
 3-inch-long, 3/4-inch-diameter wooden dowel with 2 nails in it
 ring stand
 condenser clamp
 C clamp
 stopwatch
 drilled steel or brass ball
 string
 masking tape
 carbon paper
 white paper

Discussion

Measuring the acceleration g of free fall is not a simple thing to do. Galileo had great difficulty in his attempts to measure g because he lacked good timing devices and the motion was too fast. His measurements were done on inclined planes, to slow the motion down.

Galileo would have appreciated the technique you will use in this lab. He was the first to note that the time it takes a pendulum to swing to and fro depends only on the length of the pendulum (provided the angle of swinging is not too great). The time it takes for a pendulum to make a complete to-and-fro swing is called its *period*. How long does a pendulum take to swing from its lowest position to an angle of maximum deflection? The answer is one fourth of its period. If the period is known, it can be used as a unit of time. If a freely falling object and a pendulum are released from elevated positions at the same time, their times can be compared.

Procedure 

Step 1: Assemble the meterstick pendulum shown in Figure A, attaching the dowel to the ring stand with a condenser clamp. Suspend the meterstick from the lower of the two nails in the wooden dowel.

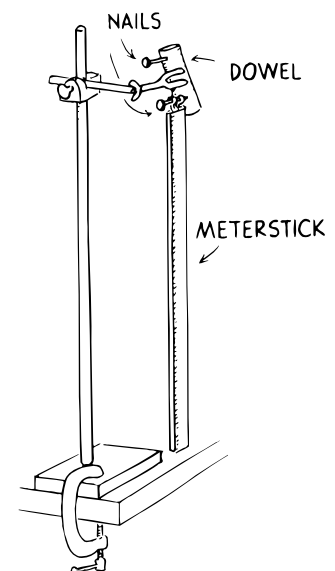


Fig. A

Assemble pendulum.

Measure period.

Step 2: Displace the bottom of the meterstick 20 cm from the vertical. With a stopwatch, measure and record the time it takes for the meterstick to swing back and forth 10 times.

time for 10 complete swings = _____

Compute the period of the meterstick. Show your computation and record the period.

period = _____

Attach ball.

Step 3: Using a string 210 cm long, connect one end of the string to the bottom of the meterstick and attach the other end to a drilled steel or brass ball. Loop the string over the upper nail in the dowel, as in Figure B.

Check alignment.

Step 4: Pull the ball up so that it barely touches the 0-cm mark on the meterstick (see Figure C). Check the alignment of the apparatus by slowly lowering the ball along the meterstick. It should just graze the stick all the way down.

Make trial run.

Step 5: Hold the string with the center of the ball at the 0-cm mark of the meterstick and the bottom of the meterstick displaced 20 cm from the vertical (see Figure C). With the apparatus in this position, you will release the string to simultaneously release the ball and start the meterstick swinging. The instant that the meterstick reaches its vertical position, the ball and the meterstick will collide (Figure D). The interval between the time of release and the time of collision is exactly one-fourth the period of the meterstick. The distance that the ball falls is measured from the top of the meterstick to the point of collision

Make a trial run to determine the approximate point of the collision between the ball and the meterstick. At this location, tape a strip of white paper to the meterstick and cover it with a strip of carbon paper, taping the carbon side *against the white paper*. When the experiment is repeated, the ball will leave a mark on the white paper where it collides with the meterstick. This provides a more exact measurement.

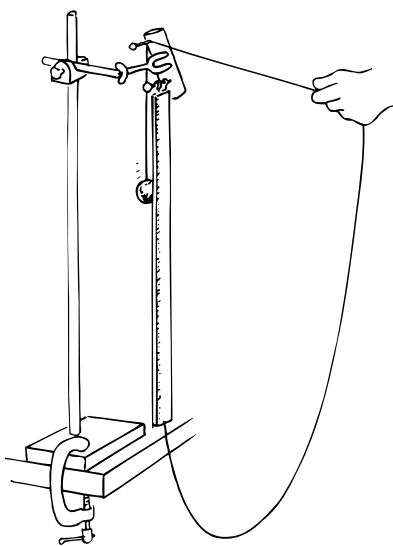


Fig. B

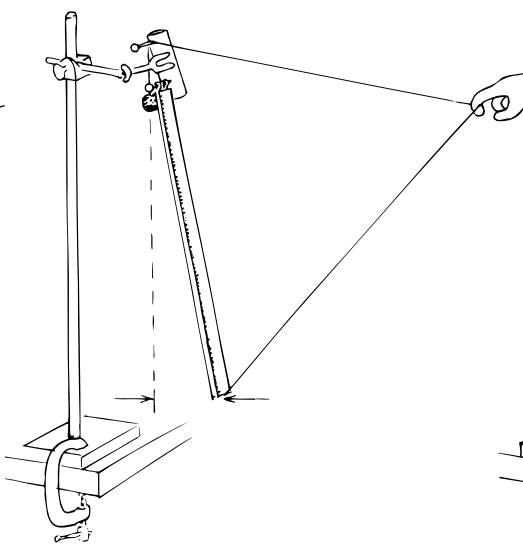


Fig. C

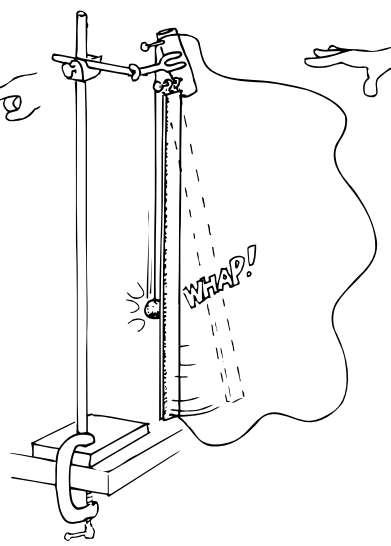


Fig. D

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Step 6: With the carbon paper in position on the meterstick, make three trials. Remove the carbon paper and measure the distances from the 0-cm mark on the meterstick to the marks on the white paper. Record the distances in Data Table A.

Measure distance.

TRIAL	DISTANCE		ACCELERATION OF GRAVITY (m/s^2)
	(cm)	(m)	
1			
2			
3			
			AVERAGE :

Data Table A

1. When the ball and the meterstick collide, the mark left on the white paper is a vertical line approximately 0.5 cm long, rather than a dot. In measuring the distance that the ball fell, should you measure to the top, the middle, or the bottom of this line?

Step 7: The equation for the distance d traveled by an object that starts from rest and undergoes the acceleration g of gravity for time t is

Compute g .

$$d = \frac{1}{2} g t^2$$

When this equation is solved for g , it becomes

$$g = \frac{2d}{t^2}$$

Compute the acceleration of gravity for three trials and record in Data Table A. Record your average value for g .

Analysis

2. What effect does the friction of the cord against the upper support have on your value of g ?

3. Why doesn't the air resistance on the meterstick affect your value of g ?

37

Computerized Gravity

Purpose

To measure the acceleration due to gravity using the computer.

Required Equipment/Supplies

computer
light probe with interface
light source
2 ring stands
2 clamps
cardboard or metal letter “g”
Plexiglas® acrylic plastic strip with black electrical tape on it
printer

Part A: The Letter “g” Method

Discussion

If you know the initial and final speeds of a falling object, and the time interval between them, you can compute the object’s acceleration. In this experiment, you will exploit the computer’s ability to time events accurately using its game port. The falling object is a square letter “g” cut out of stiff cardboard or sheet metal (see Figure A). The computer has been programmed to clock the time t_1 it takes for the figure to fall the first distance, d_1 , and the time t_2 it takes to fall the second distance, d_2 .

The measurement of how long it takes to fall each distance past a light probe enables you to compute the average speed for each interval. The average acceleration is then easily computed. From the definition of acceleration as the *change* in velocity per second, the acceleration g of a freely falling object is

$$g = a = \frac{(v_{2av} - v_{1av})}{t_{av}}$$

where $v_{1av} = \frac{d_1}{t_1}$

$$v_{2av} = \frac{d_2}{t_2}$$

$$t_{av} = \frac{(t_1 + t_2)}{2}$$

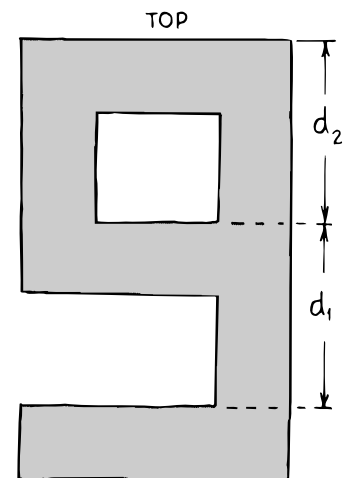


Fig. A

Procedure

Measure d_1 and d_2 .

Set up light probe.

Step 1: Measure the distances d_1 and d_2 of the letter “g” with a meterstick to the nearest thousandth of a meter (millimeter).

Step 2: Set up the computer with a light probe. Drop the letter “g” through the light beam, as in Figure B. If your computed values for g are not within 2% of the accepted value, repeat the experiment.

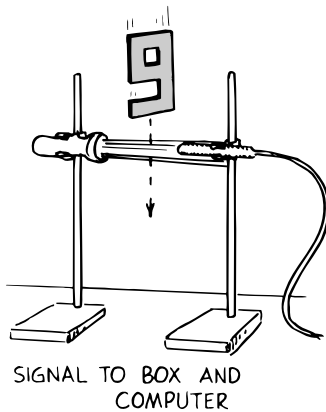


Fig. B

Analysis

1. List the possible sources of error in this experiment. Assume that the computer has been programmed with 100% accuracy!

2. Why would a letter “g” made of sheet metal probably be better than one made of cardboard?

3. What are the advantages of using a square letter “g” instead of a round one?

4. If the letter “g” were held at one corner, so that the edges were no longer vertical and horizontal, and then dropped through the light beam, how would the calculation of the acceleration due to gravity be affected?

Part B: The Picket Fence Method

Discussion

This method of measuring g is an extension of the method used in Part A. A long strip of Plexiglas acrylic plastic is dropped past the light probe instead of a letter “g”. The Plexiglas strip has eight dark strips spaced 5 cm from one edge to the next, as shown in Figure C. The strips of tape create alternating opaque and transparent regions (“picket fence”) as the Plexiglas strip falls past the light probe. The same light probe arrangement as in Part A is used here.

The computer measures the time it takes for the Plexiglas strip (“fence”) to fall from the top of one dark strip (“picket”) to the top of the next. If the spaces between the dark strips of tape are all the same (equidistant), this experiment becomes the “undiluted” incline of Experiment 4, “Merrily We Roll Along.” In that experiment, you rolled a steel ball down an incline. In this one, you simply drop the picket fence through the light probe! (Wouldn’t Galileo have loved to see you do this!)

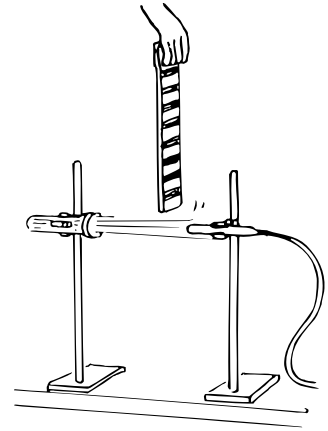


Fig. C

Procedure

Step 3: Measure the distance from picket to picket. Enter this distance in meters into the program. Position something squishy such as a piece of foam under the light probe to cushion the stop of the dropped fence.

Step 4: Drop the picket fence through the light probe. Be sure to pinch the top of the fence and release it so that it falls as nearly vertically as possible. For best results, hold the bottom of the fence as close as possible to the light probe without triggering it.

Step 5: After you successfully acquire data, save it and then plot distance (vertical axis) vs. time (horizontal axis) using data plotting software.

Use data plotting software to plot d vs. t^2 .

5. Describe your graph.

Save your data and make a printout of your graph.

Step 6: Plot velocity (vertical axis) vs. time (horizontal axis).

6. Describe your graph.

Save your data and make a printout of your graph; include it with your report.

Analysis

7. Are either of your graphs straight lines? If so, ask your teacher how to measure the slope of the graph. What is the significance of the slope of your graph?

Chapter 13: Gravitational Interactions**Free Fall**

38 Apparent Weightlessness

Purpose

To observe the effects of gravity on objects in free fall.

Required Equipment/Supplies

2 plastic foam or paper cups	masking tape
2 long rubber bands	large paper clip
2 washers or other small masses	water

Discussion

Some people believe that *because* astronauts aboard an orbiting space vehicle appear weightless, the pull of gravity upon them is zero. This condition is commonly referred to as “zero-g.” While it is true that they *feel* weightless, gravity *is* acting upon them. It acts with almost the same magnitude as on the earth’s surface.

The key to understanding this condition is realizing that both the astronauts and the space vehicle are in free fall. It is very similar to how you would feel inside an elevator with a snapped cable! The primary difference between the runaway elevator and the space vehicle is that the runaway elevator has no *horizontal velocity* (relative to the earth’s surface) as it falls toward the earth, so it eventually hits the earth. The horizontal velocity of the space vehicle ensures that as it falls *toward* the earth, it also moves *around* the earth. It falls without getting closer to the earth’s surface. Both cases involve free fall.

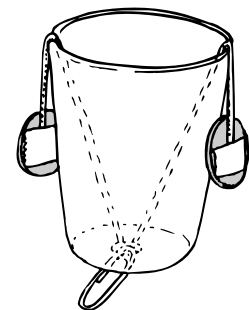


Fig. A

Procedure 

Step 1: Knot together two rubber bands to make one long rubber band. Knot each end around a washer, and tape the washers to the ends. Bore a small hole about the diameter of a pencil through the bottom of a Styrofoam or paper cup. Fit the rubber bands through the hole from the inside. Use a paper clip to hold the rubber bands in place under the bottom of the cup (see Figure A). Hang the washers over the lip of the cup. The rubber bands should be taut.

Attach washers.

Step 2: Drop the cup from a height of about 2 m.

Drop cup.

1. What happens to the washers?

Fill cup with water.



Fig. B

Step 3: Remove the rubber bands from the cup and fill the cup half-full with water, using your finger as a stopper over the hole. Hold the cup directly over a sink. Drop the cup into the sink.

2. What happens to the water as the cup falls?

Step 4: Repeat Step 3 for a second cup half-filled with water with two holes poked through its *sides* (Figure B). You may wish to place a piece of masking tape over the hole on the bottom of the cup.

3. What happens to the water as the cup falls?

Analysis

4. Explain why the washers acted as they did in Step 2.

5. Explain why the draining water acted as it did in Steps 3 and 4.

6. Suppose you were standing on a bathroom scale inside an elevator. Based on your observations in this activity, predict what would happen to your weight reading when the elevator:

a. accelerated upward.

b. accelerated downward at an acceleration less than g .

c. moved upward at a constant speed.

d. moved downward at a constant speed.

e. accelerated downward at an acceleration greater than g .

Chapter 14: Satellite Motion**Elliptical Orbits****39****Getting Eccentric****Purpose**

To get a feeling for the shapes of ellipses and the locations of their foci by drawing a few.

Required Equipment/Supplies

20 cm of string
2 thumbtacks or small pieces of masking tape
pencil
graph paper

Discussion

The path of a planet around the sun is an ellipse, the shadow of a sphere cast on a flat table is an ellipse, and the trajectory of Halley's comet around the sun is an ellipse.

An ellipse is an oval-shaped curve for which the distances from any point on the curve to two fixed points (the *foci*) in the interior have a constant sum. One way to draw an ellipse is to place a loop of string around two thumbtacks and pull the string taut with a pencil. Then slide the pencil along the string, keeping it taut.

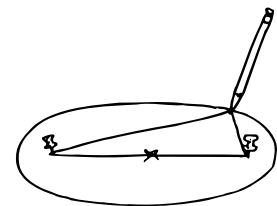
Procedure 

Step 1: Using graph paper, a loop of string, and two thumbtacks (you may wish to use a small piece of masking tape instead), draw an ellipse. Label the two foci of your ellipse.

Step 2: Repeat twice, using different separation distances for the foci.

Step 3: A circle is a special case of an ellipse. Determine the positions of the foci that would give you a circle, and construct a circle.

Step 4: A straight line is a special case of an ellipse. Determine the positions of the foci that would give you a straight line, and construct a straight line.



Analysis

1. Which of your drawings is closest to the earth's nearly circular orbit around the sun?

2. Which of your drawings is closest to the orbit of Halley's comet around the sun?

40

Trial and Error

Purpose

To discover Kepler's third law of planetary motion through a procedure of trial and error using the computer.

Required Equipment/Supplies

computer
data plotting software

Discussion

Pretend you are a budding astronomer. In order to earn your Ph.D. degree, you are doing research on planetary motion. You are looking for a relationship between the time it takes a planet to orbit the sun (the *period*) and the average radius of the planet's orbit around the sun. Using a telescope, you have accumulated the planetary data shown in Table A.

You have access to a program that allows you to plot data easily on a computer. It can also plot many different relations between the variables. You can plot the period T vs. the radius R . You can also plot T vs. R^2 , T vs. R^3 , and so on. You can even plot R vs. T , R vs. T^2 , and R vs. T^3 , and so on, just as easily.

Procedure

Step 1: Using data plotting software, try to make a graph involving T and R that is a straight line. A linear (straight-line) relationship shows that the two plotted variables are directly proportional to each other. Try plotting T vs. R , T vs. R^2 , T vs. R^3 , R vs. T , R vs. T^2 , and R vs. T^3 to see whether any of these relationships form a straight line when graphed.

Step 2: If the relationship between T and R cannot be discovered by modifying the power of only one variable at a time, try modifying the power of both variables at the same time.

If you find the exact relationship between T and R during this lab period, feel *good*. It took Johannes Kepler (1571–1630) ten years of painstaking effort to discover the relationship. Computers were not around in the seventeenth century!

PLANET	PERIOD (YEARS)	AVERAGE RADIUS (AU)
MERCURY	0.241	0.39
VENUS	0.615	0.72
EARTH	1.00	1.00
MARS	1.88	1.52
JUPITER	11.8	5.20
SATURN	29.5	9.54
URANUS	84.0	19.18
NEPTUNE	165.	30.06
PLUTO	248.	39.44

Table A

1. Did you discover a linear relationship between some power of T and some power of R using the program? What powers of T and R graph as a straight line?

2. Make a printout of the graph closest to a straight line and include it with your report.

41

Flat as a Pancake

Purpose

To estimate the diameter of a BB.

Required Equipment/Supplies

75 mL of BB shot
100-mL graduated cylinder
tray
rulers
micrometer

Discussion

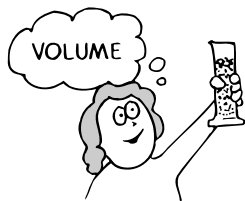
Consider 512 cubes, each with sides one centimeter long. If all the cubes are packed closely with no spaces between them to make a large cube with sides 8 cubes long, the volume of the large cube is $(8 \text{ cm}) \times (8 \text{ cm}) \times (8 \text{ cm})$, or 512 cm^3 . If the cubes are stacked to make a block 4 cm by 16 cm by 8 cm, the volume remains the same but the outside surface area becomes greater. In a block 2 cm by 16 cm by 16 cm, the area of the surface is greater still. If the cubes are spread out so that the stack is only one cube high, the area of the surface is the greatest it can be.

The different configurations have different surface areas, but the volume remains constant. The volume of pancake batter is also the same whether it is in the mixing bowl or spread out on a surface (except that on a hot griddle the volume increases because of the expanding bubbles that form as the batter cooks). The volume of a pancake equals the surface area of one flat side multiplied by the thickness. If both the volume and the surface area are known, then the thickness can be calculated from the following equations.

$$\text{volume} = \text{area} \times \text{thickness} \qquad \text{thickness} = \frac{\text{volume}}{\text{area}}$$

Instead of cubical blocks or pancake batter, consider a shoe box full of marbles. The total volume of the marbles equals the volume of the box (length times width times height). Suppose you computed the volume and then poured the marbles onto a large tray. Can you think of a way to *estimate* the diameter (or thickness) of a single marble without measuring the marble itself? Would the same procedure work for smaller size balls such as BB's? Try it in this activity and see. It will be simply another step smaller to consider the size of molecules.





Procedure

Step 1: Use a graduated cylinder to measure the volume of the BB's. (Note that $1 \text{ mL} = 1 \text{ cm}^3$.)

volume = _____

Step 2: Spread the BB's to make a compact layer one pellet thick on the tray. If trays are not available, try taping three rulers together in a U-shape on your lab table. Determine the area covered by the BB's. Describe your procedure and show your computations.

area = _____ cm^2

Step 3: Using the area and volume of the BB's, estimate the diameter of a BB. Show your computations.

estimated diameter = _____ cm

Step 4: Check your estimate by using a micrometer to measure the diameter of a BB.

measured diameter = _____ cm

Analysis

1. What assumptions did you make when estimating the diameter of the BB?

2. How do the measured and estimated diameters of the BB compare?

3. Oleic acid is an organic substance that is insoluble in water. When a drop of oleic acid is placed on water, it usually spreads out over the water surface, creating a layer one molecule thick. Describe a method to estimate the size of an oleic acid molecule.

Chapter 17: The Atomic Nature of Matter**The Size of a Molecule****42****Extra Small****Purpose**

To estimate the size of a molecule of oleic acid.

Required Equipment/Supplies

chalk dust or lycopodium powder	tray
oleic acid solution	water
10-mL graduated cylinder	eyedropper

Discussion

An oleic acid molecule is not spherical but elongated like a hot dog. One end is attracted to water, and the other end points away from the water surface.

During this investigation, you will estimate the length of a single molecule of oleic acid, to determine for yourself the extreme smallness of a molecule. The length can be calculated by dividing the volume of oleic acid used by the area of the *monolayer*, or layer one molecule thick. The length of the molecule is the depth of the monolayer.

$$\text{volume} = \text{area} \times \text{depth}$$

$$\text{depth} = \frac{\text{volume}}{\text{area}}$$

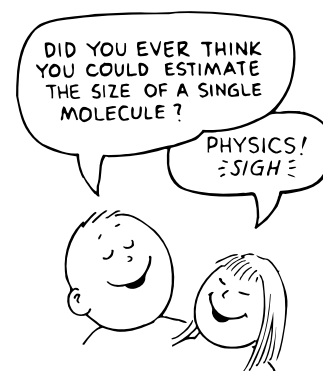
Procedure

Step 1: Pour water into the tray to a depth of about 1 cm. Spread chalk dust or lycopodium powder very lightly over the surface of the water; too much will hem in the oleic acid.

Step 2: Using the eyedropper, gently add a single drop of the oleic acid solution to the surface of the water. When the drop touches the water, the alcohol in it will dissolve in the water, but the oleic acid will not. The oleic acid spreads out to make a circle on the water. Measure the diameter of the oleic acid circle in three places, and compute the average diameter of the circle. Also, compute the area of the circle.

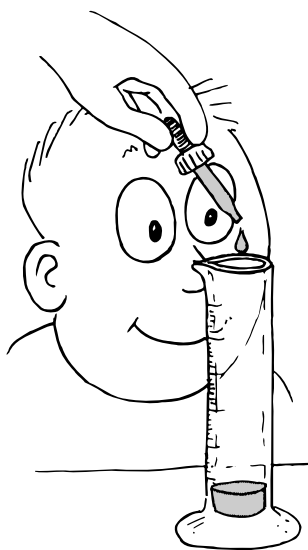
$$\text{average diameter} = \text{_____ cm}$$

$$\text{area of circle} = \text{_____ cm}^2$$



Set up tray.

Compute area of film.



Step 3: Count the number of drops of solution needed to occupy 3 mL (or 3 cm³) in the graduated cylinder. Do this three times, and find the average number of drops in 3 cm³ of solution.

number of drops in 3 cm³ = _____

Divide 3 cm³ by the number of drops in 3 cm³ to determine the volume of a single drop.

volume of drop = _____ cm³

Step 4: The volume of the oleic acid alone in the circular film is much less than the volume of a single drop of the solution. The concentration of oleic acid in the solution is 5 cm³ per 1000 cm³ of solution. Every cubic centimeter of the solution thus contains only 5/1000 cm³ of oleic acid. The ratio of oleic acid to total solution is 0.005 for any volume. Multiply the volume of a drop by 0.005 to find the volume of oleic acid in the drop. This is the volume of the layer of oleic acid in the tray.

volume of oleic acid = _____ cm³

Compute length of molecule.

Step 5: Estimate the length of an oleic acid molecule by dividing the volume of oleic acid by the area of the circle.

length of molecule = _____

Analysis

1. What is meant by a monolayer?

2. Why is it necessary to dilute the oleic acid?

3. Which substance forms the monolayer film—the oleic acid or the alcohol?

4. The shape of oleic acid molecules is more like that of a rectangular hot dog than a cube or marble. Furthermore, one end is attracted to water so that the molecule actually “floats” vertically like a log with a heavy lead weight at one end. If each of these rectangular molecules is 10 times as long as it is wide, how would you compute the volume of one oleic acid molecule?

Chapter 18: Solids**Elasticity and Hooke's Law**

43 Stretch

Purpose

To verify Hooke's law and determine the spring constants for a spring and a rubber band.

Required Equipment/Supplies

ring stand or other support with rod and clamp
 3 springs
 paper clip
 masking tape
 meterstick
 set of slotted masses
 large rubber band
 graph paper
 computer, printer, and data plotting software (optional)

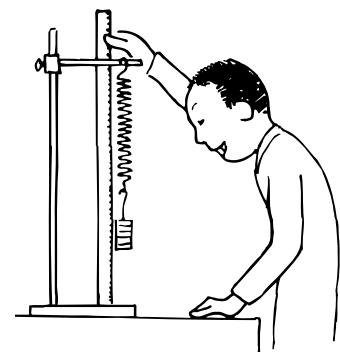
Discussion

When a force is applied, an object may be stretched, compressed, bent, or twisted. The internal forces between atoms in the object resist these changes. These forces become greater as the atoms are moved farther from their original positions. When the outside force is removed, these forces return the object to its original shape. Too large a force may overcome these resisting forces and cause the object to deform permanently. The minimum amount of stretch, compression, or torsion needed to do this is called the *elastic limit*.

Hooke's law applies to changes below the elastic limit. It states that the amount of stretch or compression is directly proportional to the applied force. The proportionality constant is called the *spring constant*, k . Hooke's law is written $F = kx$, where x is the displacement (stretch or compression). A stiff spring has a high spring constant and a weak spring has a small spring constant.

Procedure

Step 1: Hang a spring from a support. Attach a paper clip to the free end of the spring with masking tape. Clamp a meterstick in a vertical position next to the spring. Note the position of the bottom of the paper clip relative to the meterstick. Place a piece of masking tape on the meterstick with its lower edge at this position.



Set up apparatus.

Attach masses to spring.

Step 2: Attach different masses to the end of the spring. With your eye level with the bottom of the paper clip, note its position each time. The stretch in each case is the difference between the positions of the paper clip when a load is on the spring and when no load is on the spring. Be careful not to exceed the elastic limit of the spring. Record the mass and stretch of each trial in the first section of Data Table A.

Data Table A		MASS	FORCE	STRETCH	SPRING CONSTANT
SPRING 1					
SPRING 2					
SPRING 3					
RUBBER BAND					
SPRINGS IN SERIES					

Repeat using different springs.

Step 3: Repeat Steps 1 and 2 for two more springs. Record the masses and strains in the next two sections of Data Table A.

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Step 4: Repeat Steps 1 and 2 using a large rubber band. Record the masses and the corresponding stretches in the fourth section of Data Table A.

Repeat using rubber band.

Step 5: Calculate the forces, and record them in Data Table A. On graph paper, make a graph of force (vertical axis) vs. stretch (horizontal axis) for each spring and the rubber band. If available, use data plotting software to plot your data and print out your graph.

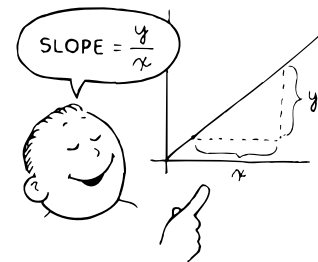
Graph data.

Step 6: For each graph that is an upward sloping straight line, draw a horizontal line through one of the lowest points on the graph. Then draw a vertical line through one of the highest points on the graph. Now you have a triangle. The slope of the graph equals the vertical side of the triangle divided by the horizontal side. The slope of a force vs. stretch graph is equal to the spring constant. By finding the slope of each of your graphs, determine the spring constant k for each spring, and record your values in Data Table A.

Measure slope of graphs.

1. How is the value of k related to the stiffness of the springs?

2. Are all your graphs straight lines? If they are not, can you think of a reason why?



Going Further

Step 7: Repeat Steps 1 and 2 for two springs connected in series (end to end). Record the masses and stretches in the last section of Data Table A.

Connect several springs in series.

Step 8: Repeat Steps 5 and 6 to determine the spring constant for the combination.

Graphically determine the spring constant.

3. How does the spring constant of two springs connected in a series compare with that of a single spring?

44**Geometric Physics****Purpose**

To investigate ratios of surface area to volume.

Required Equipment/Supplies

Styrofoam (plastic foam) balls of diameter 1", 2", 4", 8"	water
4 sheets of paper	10 g granulated salt
stopwatch or clock with second hand	10 g rock salt
50-mL beaker	2 stirrers
hot plate	thermometer or computer
2 200-mL beakers	2 temperature probes with interface
400-mL beaker	printer
800-mL beaker	

Discussion

Why do elephants have big ears? Why does a chunk of coal burn, while coal dust explodes? Why are ants not the size of horses? This activity will give you insights into some secrets of nature that may at first appear to have no direct connection to physics.

Part A**Procedure**  

Step 1: Drop pairs of different-size Styrofoam balls from a height of about 3 m. Drop the balls at the same moment with no push or retardation. Compare their falling times by observing when one ball strikes the ground relative to another. Summarize your observations in Data Table A.

FALLING TIME	BALL DIAMETER
HITS THE GROUND 1 ST	
HITS THE GROUND 2 ND	
HITS THE GROUND 3 RD	
HITS THE GROUND LAST	

Data Table A

Drop Styrofoam balls.



1. Describe any regularity you observe.

Analysis

2. Which size Styrofoam ball had the greatest average speed when dropped?

3. Which size Styrofoam ball had the least average speed when dropped?

4. Which size Styrofoam ball has the greatest surface area?

5. Which size Styrofoam ball has the greatest volume?

6. Which size Styrofoam ball has the greatest ratio of surface area to volume?

7. Which size Styrofoam ball has the smallest ratio of surface area to volume?

8. A Styrofoam ball falling through the air has two forces acting on it. One is the downward force due to gravity—its weight. The weight of the ball is proportional to its volume. The other force is the upward force of air resistance—drag—which opposes the fall. Drag is proportional to the surface area of the ball.

a. To what is the upward force due to drag proportional?

b. Which size Styrofoam ball should have experienced the greatest upward force due to drag?

c. Which size Styrofoam ball should have experienced the greatest *net* downward force per unit mass (due to gravity *and* drag)—that is, which should show the greatest acceleration?

d. Does your answer to (c) agree with your observations?

9. Predict which will fall to the ground faster—a heavier raindrop or a lighter one. Why?

Part B

Procedure

Dissolve salt in water.

Step 2: Record the number of seconds it takes to dissolve 10 g of granulated salt in 100 mL of water at room temperature that is being stirred vigorously. Repeat, substituting 10 g of rock salt for the granulated salt.

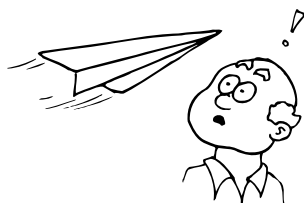
time for granulated salt = _____

time for rock salt = _____

Analysis

10. Which salt dissolved more quickly—the granulated salt or the rock salt? Why?

11. Suggest a relationship for predicting dissolving times for salt granules of different size, such as rock salt and table salt.



Part C

Procedure

Step 3: Make similar paper airplanes from whole, half, and quarter sheets of paper. Record which one flies the farthest.

airplane that flies farthest: _____

Analysis

12. Which paper airplane generally traveled farthest? Why?

Part D**Procedure**

Step 4: Heat 500 mL of water to 40°C. Then pour 50 mL into a 50-mL beaker and 400 mL into a 400-mL beaker. Allow the beakers to cool down by themselves on the lab table. Measure the temperature of both every 30 seconds, using either a thermometer or temperature probes connected to a computer. (If you are using the computer, use two temperature probes to monitor the temperatures of the two beakers of water. Save your data, and print a copy of your graph; include it with your lab report.) Record your findings in Data Table B.

Monitor cooling water.

TIME (s)	TEMPERATURE (°C)	
	50 mL	400 mL
0		
30		
60		
90		
120		
150		
180		
210		
240		
270		
300		

Data Table B

Analysis

13. Which beaker of warm water cooled faster?

14. Which beaker has more surface area?

15. Which beaker has the greater volume?

16. Which beaker has the larger ratio of surface area to volume?

17. Which beaker has the smaller ratio of surface area to volume?

18. The cooling of a beaker of warm water takes place at the surface. The total amount of heat that must leave the water for it to cool to room temperature depends on the volume. Therefore, on what ratio does the rate of cooling (the temperature drop with time) depend?

19. Suppose that a small wading pool is next to a swimming pool. Predict which pool will heat up faster during the day. Why?

Chapter 19: Liquids**Displacement and Density****45****Eureka!****Purpose**

To explore the displacement method of finding volumes of irregularly shaped objects and to relate their masses to their volumes.

Required Equipment/Supplies

two 35-mm film canisters (prepared by the teacher): one of which is filled with lead shot, and the other with a bolt just large enough to cause the canister to sink when placed in water

triple-beam balance

string

graduated cylinder

water

masking tape

5 steel bolts of different size

irregularly shaped piece of scrap iron

1000-mL beaker

Discussion

The volume of a block is easy to compute. Simply measure its length, width, and height. Then, multiply length times width times height. But how would you go about computing the volume of an irregularly shaped object such as a bolt or rock? One way is by the displacement method. Submerge the object in water, and measure the volume of water displaced, or moved elsewhere. This volume is also the volume of the object. Go two steps further and (1) measure the mass of the object; (2) divide the mass by the volume. The result is an important property of the object—its *density*.

Part A**Procedure**

Step 1: Your teacher has prepared two film canisters for you. Each canister should have a piece of string attached to it. Use a triple-beam balance to find the mass of each one.

mass of lighter canister = _____

mass of heavier canister = _____

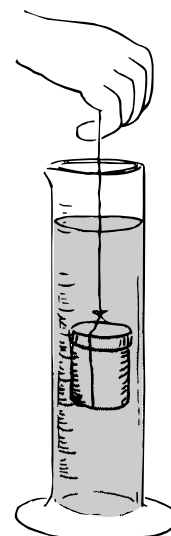


Fig. A

Find the mass of each canister.

Observe rise in water level.

Step 2: Place a strip of masking tape vertically at the water level of a graduated cylinder about 2/3 full of water. Mark the water level on the tape. Submerge the lighter canister in the water, as shown in Figure A. Observe the rise in water level. Mark the new water level on the tape. Remove the canister.

Predict rise in water level.

Step 3: Predict what you think the rise in the water level for the heavier canister will be when it is submerged. Do you think it will be less than, the same as, or greater than the rise in water level for the lighter canister?

prediction: _____

Observe rise in water level.

Step 4: Test your prediction by submerging the heavier canister. Write down your findings.

findings: _____

Analysis

1. How do the amounts of water displaced by each canister compare?

2. Does the amount of water displaced by a submerged canister depend on the mass of the canister? On the volume of the canister?

Part B

Procedure

Measure mass and volume of bolts.

Step 5: Measure the masses of five different-sized bolts and then measure their volumes using the displacement method. Record your data in Data Table A.

BOLT NUMBER	MASS (g)	VOLUME (mL)	----- (g/mL OR g/cm ³)
1			
2			
3			
4			
5			

Data Table A

Step 6: For each bolt, divide its mass by its volume and enter the results in the last column of Data Table A.

Analysis

3. How do the ratios of mass to volume compare for each of the bolts?

4. Would you expect the ratio of mass to volume to be the same for bolts of different metals?

5. What name is given to the ratio of mass to volume? (Fill this name in at the top of the last column in Data Table A.)

Part C

Going Further

Pretend that you are living in ancient Greece during the time of Archimedes. The king has commissioned a new crown to be made of pure gold. The king is worried that the goldsmith may have cheated him by replacing some of the gold with less precious metals. You are asked to devise a way to tell, without damaging the crown, whether the king was cheated or not.

Unfortunately, your school cannot supply you with an actual gold crown for this activity. A less valuable piece of scrap iron will simulate the crown.

Write down your procedure and any measurements you make.



Chapter 19: Liquids**Archimedes' Principle and Flotation**

46 Sink or Swim

Purpose

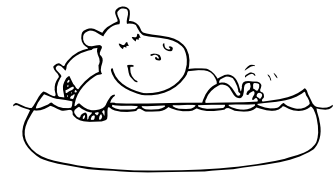
To introduce Archimedes' principle and the principle of flotation.

Required Equipment/Supplies

spring scale	water
triple-beam balance	masking tape
string	chunk of wood
rock or hook mass	modeling clay
600-mL beaker	toy boat
500-mL graduated cylinder	50-g mass
clear container	2 100-g masses

Discussion

An object submerged in water takes up space and pushes water out of the way. The water is said to be displaced. Interestingly enough, the water that is pushed out of the way, in effect, pushes back on the submerged object. For example, if the object pushes a volume of water with a weight of 10 N out of its way, then the water reacts by pushing back on the object with a force of 10 N. We say that the object is buoyed upward with a force of 10 N. In this experiment, you will investigate what determines whether an object sinks or floats in water.



Procedure

Step 1: Use a spring scale to determine the weight of an object (rock or hook mass) first in air and then underwater. The difference in weights is the buoyant force. Record the weights and the buoyant force.

weight of object in air = _____

apparent weight of object in water = _____

buoyant force on object = _____

Step 2: Devise an experimental setup to find the volume of water displaced by the object. Record the volume of water displaced. Compute the mass and weight of this water. (Remember, 1 mL of water has a mass of 1 g and a weight of 0.01 N.)

volume of water displaced = _____

mass of water displaced = _____

weight of water displaced = _____

Weigh an object in air and submerged in water.

Measure the water displaced.

1. How does the buoyant force on the submerged object compare with the weight of the water displaced?

Float a piece of wood.

Step 3: Find the mass of a piece of wood with a triple-beam balance, and record the mass in Data Table A.

NOTE: To keep the calculations simple, from here on in this experiment, you will measure and determine masses, without finding the equivalent weights. Keep in mind, however, that an object floats because of a buoyant force. This force is due to the *weight* of the water displaced.

Measure the volume of water displaced when the wood floats. Record the volume and mass of water displaced in Data Table A.

OBJECT	MASS (g)	VOLUME OF WATER DISPLACED (mL)	MASS OF WATER DISPLACED (g)
WOOD			
WOOD AND 50-g MASS			
CLAY BALL			
FLOATING CLAY			

Data Table A

2. What is the relation between the buoyant force on any floating object and the weight of the object?

3. How does the mass of the floating wood compare to the mass of water displaced?

4. How does the buoyant force on the wood compare with the weight of water displaced?

Step 4: Add a 50-g mass to the wood so that the wood displaces more water *but still floats*. The 50-g mass needs to float on top of the wood. Measure the volume of water displaced and calculate its mass, recording them in Data Table A.

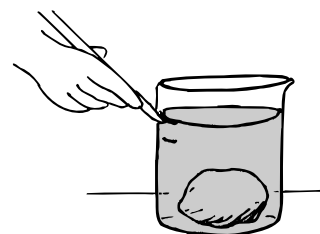
Float wood plus 50-g mass.

5. How does the combined buoyant force on the wood and the 50-g mass compare with the weight of water displaced?

Step 5: Find the mass of a ball of modeling clay. Measure the volume of water it displaces when it sinks to the bottom. Calculate the mass of water displaced, and record all volumes and masses in Data Table A.

Measure displacement of clay.

6. How does the mass of water displaced by the clay compare to the mass of the clay?



7. Is the buoyant force on the submerged clay greater than, equal to, or less than its weight in air? Explain.

Step 6: Retrieve the clay from the bottom, and mold it into a shape that allows it to float. Sketch or describe this shape.

Mold the clay so that it floats.

Measure the volume of water displaced by the floating clay. Calculate the mass of the water, and record in Data Table A.

8. Does the clay displace more, less, or the same amount of water when it floats as it did when it sank?

9. Is the buoyant force on the floating clay greater than, equal to, or less than its weight in air?

10. What can you conclude about the weight of water displaced by a floating object compared with the weight in air of the object?

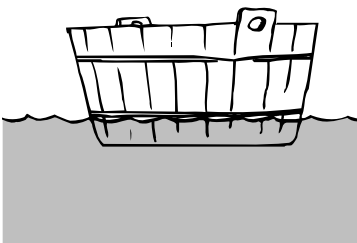
Predict new water level in canal lock.

- Step 7:** Suppose you are on a ship in a canal lock. If you throw a ton of bricks overboard into the canal lock, will the water level in the canal lock go up, down, or stay the same? Write down your answer *before* you proceed to Step 8.

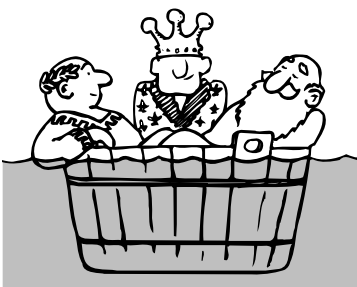
prediction for water level in canal lock: _____

- Step 8:** Float a toy boat loaded with “cargo” (such as one or two 100-g masses) in a container filled with water deeper than the height of the masses. Mark and label the water levels on masking tape placed on the container and on the sides of the boat. Remove the masses from the boat and put them in the water. Mark and label the new water levels.

11. What happens to the water level on the side of the boat when you place the cargo in the water?



12. If a large freighter is riding high in the water, is it carrying a relatively light or heavy load of cargo?



13. What happens to the water level in the container when you place the cargo in the water? Explain why it happens.

14. What will happen to the water level in the canal lock when the bricks are thrown overboard?

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Weighty Stuff

Purpose

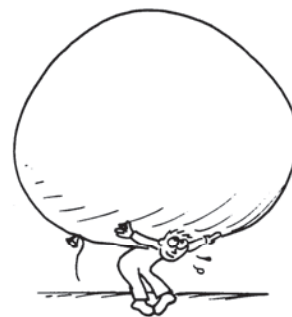
To recognize that air has weight.

Required Equipment/Supplies

centigram balance
sheet of paper
basketball
hand pump
needle valve
tire pressure gauge (preferably scaled in 1-lb increments)

Discussion

If you hold up an empty bottle and ask your friends what's in it, they will probably say that nothing is in the bottle. But strictly speaking, there is something in the "empty" bottle: air. Perhaps a fish would say similarly that there is nothing in an "empty" bottle at the bottom of the ocean. We don't ordinarily notice the presence of air unless it is moving. And we don't notice that air has mass and weight, like all matter on earth. In this activity, you will focus attention on the mass and weight of air.



Activity

Procedure

Step 1: Flatten out a basketball so that there is no air in it. Place a sheet of paper on a centigram balance. (In Step 3, you will crumple the paper and use it to keep the basketball from rolling off the balance.) *Carefully* measure the mass of the flattened basketball and paper.

mass of flattened basketball and paper = _____

Find mass of deflated basketball.

Step 2: Remove the basketball from the balance. Inflate it with air to a pressure of 7.5 lb/in.², as measured by the pressure gauge.

Inflate basketball.

Step 3: Crumple the piece of paper so that it will keep the inflated basketball from rolling off the balance. Measure the mass of the inflated basketball and paper.

Find mass of inflated basketball.

mass of inflated basketball and paper = _____

Step 4: Compute the mass of the air pumped into the basketball.

Compute mass of air in basketball.

mass of air = _____

Measure pressure of deflated basketball.

Step 5: Insert a needle valve in the inflated basketball, and allow the air to escape without flattening the ball. Wait until you no longer hear air escaping. Then, measure the final pressure inside the basketball.

pressure after air escapes = _____ lb/in.²

1. A pressure gauge measures the *difference* between pressures at the two ends of the gauge. Is there still air in the basketball?

Compute volume of extra air.

Step 6: You really inflated the flattened basketball in two stages. First you inflated it out to its full spherical shape. When it reached a spherical shape, the basketball displaced an amount of air *equal* to the air added. Therefore, *the buoyant force on the ball equaled the weight of the air added*. The reading on the balance would have been the same as for the flattened basketball. In the second stage, you increased the pressure above normal air pressure (14.7 lb/in.²) by forcing *extra* air into the basketball without appreciably changing its volume. The basketball did not displace any additional air, so the buoyant force did not increase any further. The reading on the balance increased by the mass of the air added during the second stage.

If you had, hypothetically, raised the pressure—the amount by which the pressure exceeds atmospheric pressure—to 14.7 lb/in.², then the *extra* air pumped into the basketball during the second stage would have been just enough to inflate a second flattened basketball to full volume at zero final gauge pressure. However, you actually inflated the basketball to a gauge pressure of about 7.5 lb/in.². Compute what size flattened ball would just be inflated to full size at zero gauge pressure by the *extra* air in the basketball.

CAUTION: Do NOT attempt to inflate a basketball to a gauge pressure of 14.7 lb/in.²! It may burst violently.

volume of extra air pumped into basketball at zero gauge pressure = _____

2. When air is added to a flattened basketball, why does a balance measure only the mass of the *extra* air that increases the gauge pressure above zero?

3. Does the air in your classroom have weight as well as mass?

Chapter 20: Gases**Pressure and Force**

48 Inflation

Purpose

To distinguish between pressure and force, and to compare the pressure that a tire exerts on the road with the air pressure in the tire.

Required Equipment/Supplies

automobile
owner's manual for vehicle (optional)
graph paper
tire pressure gauge (preferably scaled in 1-lb increments)

Discussion

People commonly confuse the two words *force* and *pressure*. Tire manufacturers add to this confusion by saying “inflate to 45 pounds” when they really mean “inflate to 45 pounds *per square inch*.” The amount of pressure depends on how a force is distributed over a certain area. It decreases as the area increases.

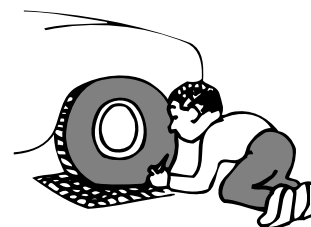
$$\text{pressure} = \frac{\text{force}}{\text{area}}$$

In this activity, you will determine the pressure that an automobile tire exerts on the road. Then you'll find out how that compares with the pressure of the air in the tire. If it weren't for the support given by the sidewalls of the tire, the two pressures would be the same. You can directly measure the air pressure in the tire with a pressure gauge. You can measure and calculate the pressure of the tire against the road by dividing the weight of the car by the area of contact for the four tires (the tires' “footprints”). Although there are gaps between the treads that don't support the car, their role is small compared with that of the sidewalls, so will be neglected.

Procedure

Step 1: Position a piece of graph paper directly in front of the right front tire. Roll the automobile onto the paper.

Step 2: Trace the outline of the tire where it makes contact with the graph paper. Roll the vehicle off the paper. Compute the area inside the trace in square inches. Record your data in Data Table A.



Data Table A

TIRE	AREA OF CONTACT (in ²)	WEIGHT / 4	PRESSURE CALCULATED (lb/in ²)	PRESSURE MEASURED (lb/in ²)
LEFT FRONT				
RIGHT FRONT				
LEFT REAR				
RIGHT REAR				

Repeat for each tire.

Step 3: Repeat Steps 1 and 2 for the other tires. Record your data in Data Table A.

Determine the force.

Step 4: Ascertain the weight of the vehicle from the owner's manual or the dealer. Often times the weight of the vehicle is stamped onto the front door jam on the driver's side. If information on the weight distribution between front and rear tires is available, use it to find the weight supported by each tire. Otherwise, assume that each tire supports one fourth of the weight. Enter the force exerted by each tire in Data Table A.

Compute the pressures.

Step 5: For each tire, divide the force exerted by the tire by the "foot-print" area of the tire to get the actual pressure exerted on the ground by the tire. Record in Data Table A.

Measure tire pressure.

Step 6: Use a tire gauge to measure the pressure in each tire in pounds per square inch. Record the pressures of the tires in Data Table A.

Compare pressures.

Step 7: Compare the pressure exerted by each tire with the air pressure in the tire. What percentage of the pressure exerted by the tire is accounted for by the air pressure? Air pressure as a percentage of tire pressure on ground for the four tires:

_____, _____, _____, _____

Analysis

1. The pressure exerted by the tire on the road is greater than the air pressure in the tire. Do you think this would be the case if the tire were a membrane with no strength of its own?

2. Consider the other extreme. Suppose the tire were a strong rigid structure that required little or no air. Would air pressure in the tire correspond to the pressure the tire exerts against the road? Explain.

3. How might the weight given in the owner's manual be different from the actual weight of the car?

4. We ignored the tire tread in computing pressures. One should not ignore the role of tire treads in practice—particularly in rainy weather. Why?

5. A tire gauge measures the *difference* between the pressure in the tire and atmospheric pressure (14.7 lb/in.^2) outside the tire (*for example, a perfectly "flat tire" reads zero on the gauge, but atmospheric pressure exists in it*). What is the total pressure *inside* the front tire?

6. Why was the atmospheric pressure (14.7 lb/in.^2) not added to the pressure of the tire gauge when the tire pressure and air pressures were compared?

Going Further

Repeat the above with one of the tires deflated, say to half its normal air pressure. You'll note its footprint is larger. Find out if the lower air pressure accounts for a greater or lesser percentage of the actual tire pressure on the ground.

49 Heat Mixes: Part I

Purpose

To predict the final temperature of a mixture of cups of water at different temperatures.

Required Equipment/Supplies

3 Styrofoam (plastic foam) cups
 liter container
 thermometer (Celsius)
 pail of cold water
 pail of hot water

Discussion

If you mix a pail of cold water with a pail of hot water, the temperature of the mixture will be between the two initial temperatures. What information would you need to predict the final temperature? This lab investigates what factors are involved in changes of temperature.

Your goal is to find out what happens when you mix equal masses of water at different temperatures. Before actually doing this, imagine a cup of hot water at 60°C and a pail of room-temperature water at 20°C.

(circle one)

- | | | |
|--|-----|------|
| 1. Which do you think is hotter—the cup or the pail? | cup | pail |
| 2. Which do you think has more thermal energy? | cup | pail |
| 3. Which would take longer to change its temperature by 10°C if the cup and pail were set outside on a winter day? | cup | pail |
| 4. If you put the same amount of red-hot iron into the cup and the pail, which one would change temperature more? | cup | pail |



Procedure

Step 1: Two pails filled with water are in your room, one with cold water and one with hot water. Fill one cup 3/4 full with water from the cold-water pail. Mark the water level along the inside of the cup. Pour the cup's water into a second cup. Mark it as you did the first one. Pour the cup's water into a third cup, and mark it as before. Now all three cups have marks that show nearly equal measures. *Mark cups.*

5. Why don't the marks show exactly equal measures?

Measure temperature of two cups.

Step 2: Fill the first cup to the mark with water from the hot-water pail. Measure and record the temperature of both cups of water.

temperature of cold water = _____°C

temperature of hot water = _____°C

Predict temperature of mixture.

Step 3: What will be the temperature if you mix the two cups of water in the liter container? Record your prediction.

predicted temperature of mixture = _____°C

Measure temperature of mixture.

Step 4: Pour the two cups of water into the liter container, stir the mixture, and measure and record its temperature.

actual temperature of mixture = _____°C



6. If there was a difference between your prediction and your observation, what might have caused it?

Pour the mixture into the sink or waste pail. Do not pour it back into the pail of either cold or hot water!

Measure temperature of three cups.

Step 5: Fill one cup to its mark with water from the cold-water pail. Fill the other two cups to their marks with hot water from the hot-water pail. Measure and record their temperatures.

temperature of cold water = _____°C

temperature of hot water (cup 1) = _____°C

temperature of hot water (cup 2) = _____°C

Predict temperature of mixture.

Step 6: What will be the temperature when all three cups of water are mixed in one container? Record your prediction.

predicted temperature of mixture = _____°C

Measure temperature of mixture.

Step 7: Pour the three cups of water into the liter container, stir the mixture, and measure and record its temperature.

actual temperature of mixture = _____°C

7. How did your observation compare with your prediction?

8. Which of the water samples (cold or hot) changed more when it became part of the mixture? Why do you think this happened?

Pour the mixture into the sink or waste pail. Do *not* pour it back into the pail of either cold or hot water!

Step 8: Fill one cup to its mark with *hot* water. Fill the other two cups to their marks with *cold* water. Measure and record their temperatures.

Reverse Step 5.

temperature of hot water = _____°C

temperature of cold water (cup 1) = _____°C

temperature of cold water (cup 2) = _____°C

Step 9: Record your prediction of the temperature when these three cups of water are mixed in one container.

Predict temperature of mixture.

predicted temperature of mixture = _____°C

Step 10: Pour the three cups of water into the liter container, stir the mixture, and measure and record its temperature.

actual temperature of mixture = _____°C

9. How did this observation compare with your prediction?

10. Which of the water samples (cold or hot) changed more when it became part of the mixture? Why do you think this happened?

50**Heat Mixes: Part II****Purpose**

To predict the final temperature of water and nails when mixed.

Required Equipment/Supplies

Harvard trip balance
 2 large insulated cups
 bundle of short, stubby nails tied with string
 thermometer (Celsius)
 hot and cold water
 paper towels

Discussion

If you throw a hot rock into a pail of cool water, you know that the temperature of the rock will go down. You also know that the temperature of the water will go up—but will its rise in temperature be more than, less than, or the same as the temperature drop of the rock? Will the temperature of the water go up as much as the temperature of the rock goes down? Will the changes of temperature instead depend on how much rock and how much water are present and how much energy is needed to change the temperature of water and rock by the same amount?

You are going to study what happens to the temperature of water when hot nails are added to it. Before doing this activity, think about the following questions.

- Suppose that equal masses of water and iron are at the same temperature. Suppose you then add the same amount of heat to each of them. Would one change temperature more than the other?

(circle one) yes no

If you circled “yes,” which one would warm more?

(circle one) water iron

- Again, suppose that equal masses of water and iron are at the same temperature. Suppose you then take the same amount of heat away from each of them. Would one cool more than the other?

(circle one) yes no

If you circled “yes,” which one would cool more?

(circle one) water iron



Procedure

Balance nails with cold water.

Step 1: Place a large cup on each pan of the balance. Drop the bundle of nails into one of the cups. Add cold water to the other cup until it balances the cup of nails. When the two cups are balanced, the same mass is in each cup—a mass of nails in one, and an equal mass of water in the other.

Warm nails in hot water.

Step 2: Set the cup of cold water on your work table. Lift the bundle of nails out of its cup and place it beside the cup of cold water.

Measure temperature of cold and hot water.

Step 3: Fill the empty cup 3/4 full with hot water. Lower the bundle of nails into the hot water and leave it there for two minutes to allow the nails to come to the temperature of the hot water.

Step 4: Measure and record the temperature of the cold water and the temperature of the hot water around the nails.

temperature of cold water = _____°C

temperature of hot water = _____°C

3. Is the temperature of the hot water equal to the temperature of the nails? Why do you think it is or is not? Can you think of a better way to heat the nails to a known temperature?



Predict temperature of mixture.

Step 5: Predict what the temperature of the mixture will be when the hot nails are added to the cold water.

predicted temperature of mixture = _____°C

Measure temperature of mixture.

Step 6: Lift the nails from the hot water and put them quickly into the cold water. When the temperature of the mixture stops rising, record it.

actual temperature of mixture = _____°C

4. How close is your prediction to the observed value?

Balance nails with hot water.

Step 7: Now you will repeat Steps 1 through 6 for hot water and cold nails. First, dry the bundle of nails with a paper towel. Then, balance a cup with the dry bundle of nails with a cup of *hot* water.

Step 8: Remove the nails and fill the cup 3/4 full with *cold* water. Record the temperature of the hot water in the first cup.

Record temperature.

temperature of hot water = _____ °C

Step 9: Lower the bundle of nails into the cup of cold water, wait one minute (why?), and then record the temperature of the water around the nails.

Cool nails in cold water.

temperature of cold water = _____ °C

Step 10: Predict what the temperature of the mixture will be when the cold nails are added to the hot water.

Predict temperature of mixture.

predicted temperature of mixture = _____ °C

Step 11: Lift the nails from the cold water and put them quickly into the hot water. When the temperature of the mixture stops changing, record it.

Measure temperature of mixture.

actual temperature of mixture = _____ °C

5. How close is your prediction to the observed value?

Analysis

6. Discuss your observations with the rest of your team, and write an explanation for what happened.

7. Suppose you have equal masses of water and nails at the same temperature. Suppose you then light similar candles and place a candle under each of the masses, letting the candles burn for equal times. Would one of the materials change temperature more than the other?

(circle one) yes no

If your answer to the question is “yes,” which one would reach a higher temperature?

(circle one) water nails

8. Suppose you have cold feet when you go to bed, and you want something to warm your feet. Would you prefer to have a hot-water bottle filled with hot water, or one filled with an equal mass of nails at the same temperature as the water? Explain.

9. Why does the climate of a mid-ocean island stay nearly constant, getting neither very hot nor very cold?

51 Antifreeze in the Summer?

Purpose

To investigate what effect antifreeze (ethylene glycol) has on the cooling of a car radiator during the summer.

Required Equipment/Supplies

400 mL (400 g) water
 timer
 380 mL (400 g) 50% mixture of antifreeze and water
 500-mL graduated cylinder
 2 600-mL beakers
 single-element electric immersion heater
 thermometer (Celsius) or
 computer
 temperature probe with interface

Part A

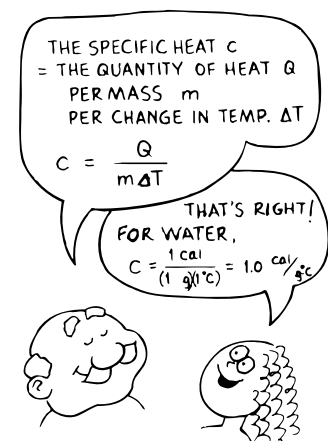
Discussion

Put an iron frying pan on a hot stove, and very quickly it will be too hot to touch. But put a pan of water on the same hot stove, and the time for a comparable rise in temperature is considerably longer, even if the pan contains a relatively small amount of water. Water has a very high capacity for storing internal energy. We say that water has a high *specific heat capacity*. The specific heat capacity c of a substance is the quantity of heat required to increase the temperature of one gram of the substance by one degree Celsius. This means that the amount of heat Q needed to increase the temperature of a mass m of material by a temperature difference ΔT is

$$Q = mc\Delta T$$

Turning this formula around, the specific heat capacity is related to the quantity of heat absorbed, the mass of the material, and the temperature change by

$$c = \frac{Q}{m\Delta T}$$



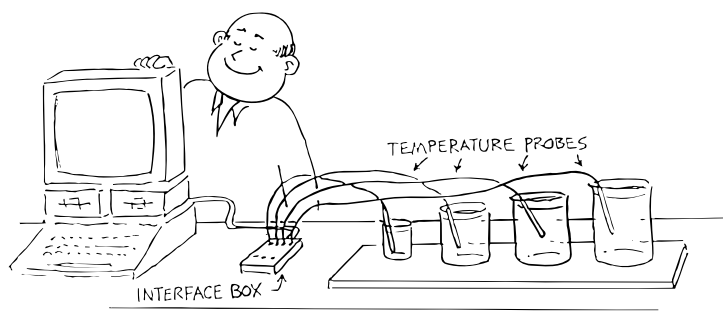
Each substance has its own specific heat capacity, which is characteristic of that substance. The specific heat capacity of pure water is 1.0 cal/g°C. So, if 1 calorie (cal) of heat is absorbed by 1 g of water, its temperature will rise by 1°C; or if 1 calorie of heat is extracted from 1 gram of water, its temperature will fall by 1°C.

Water has a higher specific heat capacity than most other materials. The high specific heat capacity of water makes it an excellent coolant. That's why it is used in an automobile to keep the engine from overheating. But water has a striking disadvantage in winter. It freezes at 0°C, and, what's even worse, it expands when it freezes. This expansion can crack the automobile engine block or fracture the radiator. To prevent such a mishap, antifreeze (ethylene glycol) is mixed with the water. The mixture has a much lower freezing point than water. The mixture has its lowest freezing point when the proportions are about 50% water and 50% antifreeze. But what effect does adding the antifreeze have on the mixture's specific heat capacity? In Part A of this experiment, you will determine the specific heat capacity of a 50% mixture of antifreeze and water.

To find the specific heat capacity, you will simply measure the quantity of heat that is absorbed and the corresponding temperature change. To supply heat, you will use an electric immersion heater.

An immersion heater is a small coil of nichrome wire commonly used to heat small amounts of liquids. It heats up much like the wire in a toaster. This is a very efficient device, for unlike a hot plate or flame, it transfers all of its energy to the material being heated, in this case a liquid. The energy dissipated by a heater is the same regardless of whether the liquid is pure water or a mixture of water and antifreeze.

You can use a computer with a temperature probe instead of a thermometer. Hook up a temperature probe to an interface box. Be sure to calibrate the temperature probe.



Procedure

Heat water.

Step 1: Heat 400 mL (400 g) of water with the heater for 200 seconds (a little over 3 minutes).

CAUTION: *Plug and unplug the immersion heater only when the heater element is submerged in liquid. Operating it in air destroys it immediately.*

Record the initial and final temperatures, and compute the change in temperature.

initial temperature = _____ °C

final temperature = _____ °C

change in temperature (ΔT) = _____ °C**Step 2:** Find the quantity of heat transferred to the water from the equation*Compare energy dissipated.*

$$Q = mc\Delta T$$

where m = mass of water c = specific heat capacity of water = 1 cal/g°C ΔT = change in temperature

$$Q = \text{_____ calories}$$

Step 3: Pour 380 mL of a mixture of 50% antifreeze and 50% water into a beaker. Since antifreeze is slightly denser than water, 380 mL of 50% antifreeze mixture has a mass of 400 g. Heat the 400 g of antifreeze mixture for 200 seconds. Record the initial and final temperatures and the change in temperature.*Heat antifreeze mixture.*

initial temperature = _____ °C

final temperature = _____ °C

change in temperature (ΔT) = _____ °C**Step 4:** With these data, compute the specific heat capacity of 50% antifreeze mixture from the equation*Compare specific heat capacities of antifreeze mixture.*

$$c = \frac{Q}{m\Delta T}$$

specific heat c of antifreeze mixture = _____ cal/g°C

Analysis

- Which liquid has the lower specific heat capacity—pure water or a 50% mixture of antifreeze?

- Which would warm from 25°C to 40°C faster with the same rate of energy input—pure water or a 50% mixture of antifreeze?

Part B

Discussion

By now you have found that the specific heat capacity of a mixture of antifreeze and water is lower than that of pure water. This suggests it is a poorer coolant than pure water. Yet it is advisable to continue using antifreeze in summer months. Is there an advantage, other than convenience, to leaving antifreeze in the radiator during summer, or should it be replaced with pure water?

To answer this question, you need to understand the role of the coolant in an automobile. Coolant draws heat from the engine block and then circulates it to the radiator, where it is dissipated to the atmosphere. The coolant is then recycled back to the engine.

The temperature of the coolant increases as it absorbs heat from the engine. But if it reaches its boiling point, the system boils over. So a coolant is effective only at temperatures below boiling. If the coolant is pure water at atmospheric pressure, this temperature is 100°C. (With a pressure cap on the radiator, both the pressure and the boiling point are higher.) Could an antifreeze mixture have a higher boiling point than pure water? If so, this would lessen the likelihood of boil-overs when the engine is overworked. You will experiment to find out.

Heat antifreeze mixture to its boiling point.

Step 5: Heat a sample of 50% antifreeze mixture with the immersion heater, and measure its boiling point. Record this temperature.

boiling point of antifreeze mixture = _____ °C

Analysis

3. What effect does the boiling point of the antifreeze mixture have on the mixture's ability to act as a coolant?

4. Would it be appropriate to call ethylene glycol "antiboil" instead of "antifreeze" in climates where the temperature never goes below freezing?

52

Gulf Stream in a Flask

Purpose

To observe liquid movement due to temperature differences.

Required Equipment/Supplies

safety goggles
paper towels
250-mL flask
food coloring
stirring rod
hot plate
thermometer (Celsius)
2-hole rubber stopper (with glass tubing as shown in Figure A)
battery jar or a large pickle jar
water

Discussion

The air near the floor of a room is cooler than the air next to the ceiling. The water at the bottom of a swimming pool is cooler than the water at the surface. You can feel these different temperatures that result from fluid motion, but you cannot see the fluid motion in these cases. In this activity, you will be able to see the movements of two liquids with different temperatures.

Procedure



Step 1: Read Steps 2 through 5 completely before conducting the activity, and predict what you expect to observe.

Step 2: Put on safety goggles. Mix some food coloring into a flask filled completely with water. Stir well. Heat the colored water to a temperature of 70°C.

Heat colored water.

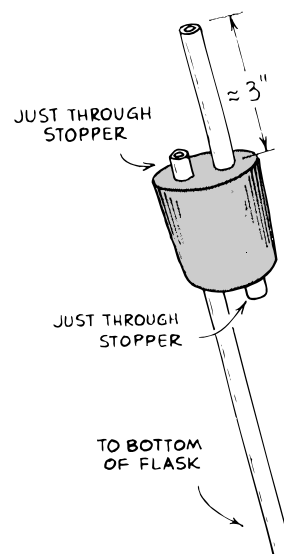


Fig. A

Insert stopper.

Step 3: Make sure that the glass tubing in the stopper arrangement is as shown in Figure A. With a damp paper towel, firmly grasp the neck of the flask and insert the stopper into the flask.

CAUTION: *The flask will be very hot. Be careful not to burn yourself.*

Immerse flask.

Step 4: As shown in Figure B, immerse the hot flask carefully into a large jar filled with plain water at room temperature. The water level should be above both pieces of tubing.

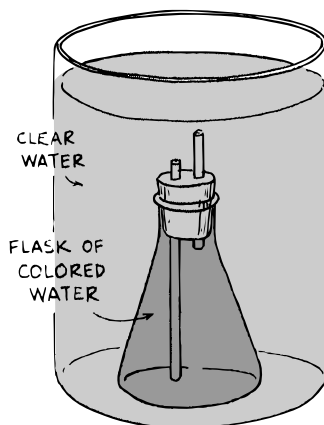


Fig. B

Record observations.

Step 5: Record your observations over the next 10 minutes.

1. What caused the movements of liquid you observed?

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The Bridge Connection

Purpose

To calculate the minimum length of the expansion joints for the Golden Gate Bridge.

Required Equipment/Supplies

safety goggles	micrometer
hollow steel rod	steam generator
thermal expansion apparatus (roller form)	bunsen burner
	rubber tubing

Discussion

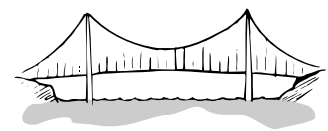
Gases of the same pressure and volume expand equally when heated, and contract equally when cooled—regardless of the kinds of molecules that compose the gas. That's because the molecules of a gas are so far apart that their size and nature have practically no effect on the amount of expansion or contraction. However, liquids and solids are individualists! Molecules and atoms in the solid state are close together in a variety of definite crystalline structures. Different liquids and solids expand or contract at different rates when their temperature is changed.

Expansions or contractions of metal can be critical in the construction of bridges and buildings. Temperatures at the Golden Gate Bridge in San Francisco can vary from -5°C in winter to 40°C in the summer. On this very long bridge, the change in length from winter to summer can be almost 2 meters! Clearly, engineers must keep thermal expansion in mind when designing bridges and other large structures.

Suppose you owned an engineering firm *before* the Golden Gate Bridge was built and you were asked for advice on the minimum length to make expansion joints for the proposed bridge. (See a typical expansion joint in Figure 21.9 in your textbook.) Consider two expansion joints that connect the bridge to land at each end. The steel to be used is the same as that in the steel rods you will use in this experiment. You are to measure how much the steel expands per meter for each degree increase in temperature. This ratio is called the *coefficient of linear expansion*. Then, compute the amount that the 2740-m structure will expand as its temperature increases. Now you can advise a minimum size of the expansion joints needed, to assure the success of the bridge.

You will determine the coefficient of linear expansion for steel by measuring the expansion of a steel rod when it is heated with steam at 100°C . The amount of expansion ΔL depends on the original length L , the change in temperature ΔT , and the coefficient of linear expansion α (which is characteristic of the type of material).

$$\Delta L = \alpha L \Delta T$$



The temperature change ΔT is simply 100°C minus room temperature. By measuring L , the original length of the rod before heating, and ΔL , the change of the length after heating, you can compute α , the coefficient of linear expansion, by rearranging the equation.

$$\alpha = \frac{\Delta L}{L\Delta T}$$

It is difficult to measure how much the rod expands because the expansion is small. One way to measure it is shown in Figure A. The end of the steel rod is arranged to be perpendicular to the axle of the pointer. When the steel rod resting on the axle expands, it rotates the axle and the pointer through an angle.

The pointer turns 360° (one full rotation) when the axle has rotated a distance equal to its circumference. The circumference C of the axle equals its diameter d times the number π .

$$C = \pi d$$

If the expansion rotates the pointer through 180° (a half rotation), then the increase ΔL in length of the rod is equal to half the circumference of the axle. Ratio and proportion give you ΔL for other expansions. The ratio of the actual distance ΔL rotated to the distance πd rotated in one complete rotation equals the ratio of the angle θ through which the pointer rotates through to 360° .

$$\frac{\Delta L}{\pi d} = \frac{\theta}{360^\circ}$$

Solve this equation for ΔL . Substituting this value into the second equation enables you to compute the coefficient of linear expansion. Once you have computed the value of α , you can compute the minimum length of the bridge and the estimated temperature difference for summer and winter.

Procedure

Measure axle diameter.

Step 1: Using a micrometer, measure the diameter of the axle of the pointer.

$$d = \text{_____ mm}$$

Assemble apparatus.

Step 2: Assemble your apparatus as in Figure A, with the steam generator ready to go. Make sure the rod has a place to drain. Measure the distance in millimeters from the groove in the steel rod to the axle of the pointer (since you are sampling expansion between these two points). Do *not* measure the length of the entire rod.

$$L = \text{_____ mm}$$

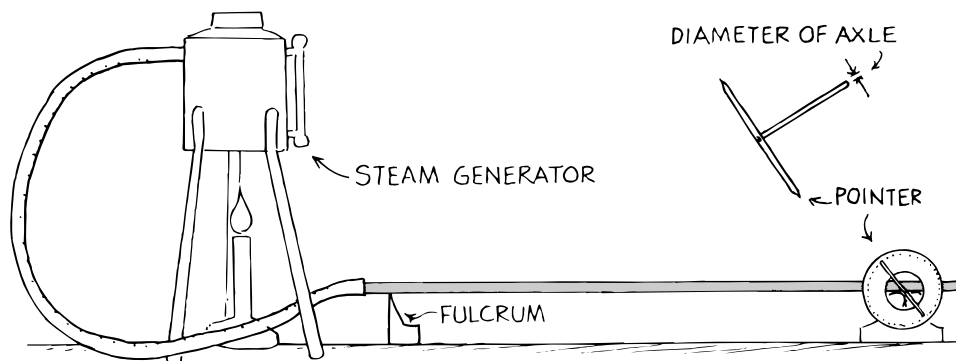


Fig. A

Step 3: Connect the steam generator, and observe the change in length of the rod. Is the increase sudden or gradual? Record the change in temperature of your rod, assuming it started at room temperature.

Record temperature change and angle pointer turns.

$$\Delta T = \text{_____}^{\circ}\text{C}$$

Record the angle θ through which the pointer turned due to the expansion of the rod.

$$\text{angle } \theta = \text{_____}^{\circ}$$

Step 4: Compute the increase ΔL in length of the rod by substituting your measured values of θ and d into the following equation.

Compute increase in length of rod.

$$\Delta L = \frac{\pi \theta d}{360^{\circ}} = \text{_____ mm}$$

Step 5: Compute the coefficient of linear expansion using your measured values of L , ΔT , and ΔL .

Compute coefficient of linear expansion.

$$\alpha = \frac{\Delta L}{L \Delta T} = \text{_____}$$

Step 6: Express the coefficient of linear expansion in scientific notation (that is, as a number times a power of ten).

$$\alpha = \text{_____}$$

Step 7: Compute the minimum length of the expansion joint(s). Show your work.

Compute length of expansion joint.

$$\Delta L = \text{_____}$$

Analysis

- Why do you measure the diameter of the axle of the pointer in Step 1 instead of the diameter of the steel rod?

2. Why do you measure the distance L from the groove in the steel rod to the point of contact with the axle instead of the entire length of the rod?

3. Suppose you placed the pointer device in the middle of the rod. Would the coefficient of linear expansion for the steel rod be larger, less, or the same? Why?

4. What are the units of α ?

5. What are the sources of error in your experiment? List them along with an estimate of the percent contribution of each.

6. In your consultation, suppose you experimentally determined that the expansion joints had to be a minimum of 2 m long. How large would you recommend them to be, taking your margin of error into account for safety?

7. What do you think would be a good design for an expansion joint?

Chapter 22: Heat Transfer**Comparing Cooling Curves****54****Cooling Off****Purpose**

To compare the rates of cooling of objects of different colors and surface reflectances.

Required Equipment/Supplies

4 empty soup cans of the same size (one covered with aluminum foil, one painted black, one white, and one any other color)
 100-watt lightbulb and receptacle
 4 thermometers (Celsius) or
 computer
 temperature probes with interface
 printer
 large test tube
 one-hole rubber stopper, with thermometer or temperature probe mounted in it, to fit test tube
 600-mL beaker
 graduated cylinder
 Styrofoam (plastic foam) cups with covers
 hot water
 crushed ice and water mixture
 variety of different size, color, and shape containers made of various materials
 meterstick
 graph paper
 computer and data plotting software (optional)

Discussion

When you are confronted with a plate of food too hot to eat, you may have noticed that some things cool faster than others. Mashed potatoes can be comfortably eaten when boiled onions are still too hot. And blueberries in a blueberry muffin are still hot when the rest of the muffin has cooled enough to eat. Different materials cool at different rates. Explore and see.

Procedure

Step 1: Place the four cans 20 cm from an unshielded lightbulb. Place a thermometer in each can, and turn on the light. Record the temperature of each can after 1 minute, 2 minutes, and 3 minutes in Data Table A.

CAN	TEMPERATURE (°C)		
	1 MIN	2 MIN	3 MIN
1			
2			
3			
4			

Data Table A

As an alternative, if a computer is available, use a temperature probe to read your data. Calibrate your probes, and monitor the temperature rise of each can. Save your data and make a printout.

1. For which can was the temperature rise the fastest?

2. For which can was the temperature rise the slowest?

3. After several minutes the temperatures of all the cans level off and remain constant. Does this mean that the cans stop absorbing radiant energy from the lightbulb?

4. For a can at constant temperature, what is the relationship between the amount of radiant energy being absorbed by the can and the amount of radiant energy being radiated and convected away from the can?

Monitor cooling of water in test tube.

Step 2: Place 25 mL of hot water from the tap in a test tube. Insert the thermometer mounted in the rubber stopper. Place the test tube in a beaker filled with crushed ice and water. Record the temperatures over the next 5 minutes every 30 seconds in Data Table B. (Once again, if you have a computer, use a temperature probe instead of a thermometer.) Draw a graph of temperature (vertical axis) vs. time (horizontal axis).

TIME (MIN)	0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
TEMP. (°C)											

Data Table B

5. Describe your graph.

Monitor cooling of water in Styrofoam cup.

Step 3: Fill a Styrofoam (plastic foam) cup with hot tap water. Monitor the temperature drop with either a thermometer or temperature probe. Make a graph of temperature (vertical axis) vs. time (horizontal axis).

Step 4: Repeat, but cover the cup with a plastic lid. Poke a hole (if it doesn't already have one), and insert the probe in the water to monitor the temperature.

6. How do the two cooling curves compare?

7. What cooling process is primarily responsible for the difference?

Going Further

Step 5: Place 200 mL of hot tap water in each of a variety of containers. You may want to wrap them with various materials. List the containers used.

Predict cooling rates of a variety of containers

Predict which container will cool fastest and which container will cool most slowly.

Predicted fastest: _____

Predicted slowest: _____

Step 6: Monitor the cooling with either temperature probes or thermometers. Record which cooled the fastest and which the most slowly.

Observed fastest: _____

Observed slowest: _____

8. What factors determine the rate of cooling, based on your data from Step 6?

Extra for Experts

Plot temperature vs. time.

Step 7: Using data plotting software, plot data from Step 6 for each of your samples. Let time be the independent variable (horizontal axis), and, for convenience, set $t = 0$ at the origin. Let $T - T_2$ be the dependent variable (vertical axis), where T is the temperature of the sample and T_2 is room temperature. Can you think of a way to make your graph a straight line? *Hint:* Try using some function of the vertical variable (temperature difference), such as its square or its square root or its logarithm.

9. What does your graph look like? What mathematical relationship exists between the cooling rate and time? (The answer to this question requires some heavy-duty math—ask your teacher for help on this one!)

55

Solar Equality

Purpose

To measure the sun's power output and compare it with the power output of a 100-watt lightbulb.

Required Equipment/Supplies

2-cm by 6-cm piece of aluminum foil with one side thinly coated with flat black paint
 clear tape
 meterstick
 two wood blocks
 glass jar with a hole in the metal lid
 one-hole stopper to fit the hole in the jar lid
 thermometer (Celsius, range -10°C to 110°C)
 glycerin
 100-watt lightbulb with receptacle

Discussion

If you told some friends that you had measured the power output of a lightbulb, they would not be too excited. However, if you told them that you had computed the power output of the whole sun using only household equipment, they would probably be quite impressed (or not believe you). In this experiment, you will estimate the power output of the sun. You will need a sunny day to do this experiment.

Procedure

Step 1: With the blackened side facing out, fold the middle of the foil strip around the thermometer bulb, as shown in Figure A. The ends of the metal strip should line up evenly.

Assemble apparatus.

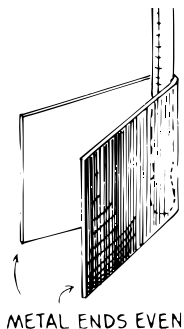


Fig. A

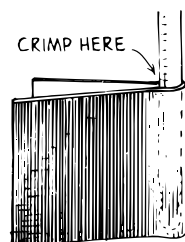


Fig. B

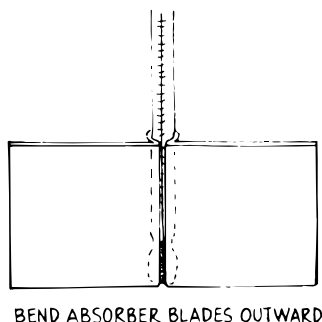


Fig. C

Step 2: Crimp the foil so that it completely surrounds the bulb, as in Figure B. Bend each end of the foil strip outward (Figure C). Use a meterstick to make a flat, even surface. Use a piece of clear tape on the unpainted side to hold the foil on the thermometer.

Step 3: Use glycerin to insert the free end of the thermometer into the one-hole stopper. Remove the lid from the jar, and place the stopper in the lid from the bottom side. Slide the thermometer until the foil strip is located in the middle of the jar. Place the lid on the jar.

Place apparatus outdoors in sun.

Step 4: Take your apparatus outdoors. Prop it at an angle so that the blackened side of the foil strip is exactly perpendicular to the rays of the sun.

Record maximum temperature reached.

Step 5: Leave the apparatus in this position in the sunlight until the maximum temperature is reached. Record this temperature.

maximum temperature = _____

Allow apparatus to cool to room temperature.

Step 6: Return the apparatus to the classroom, and allow the thermometer to cool to room temperature.

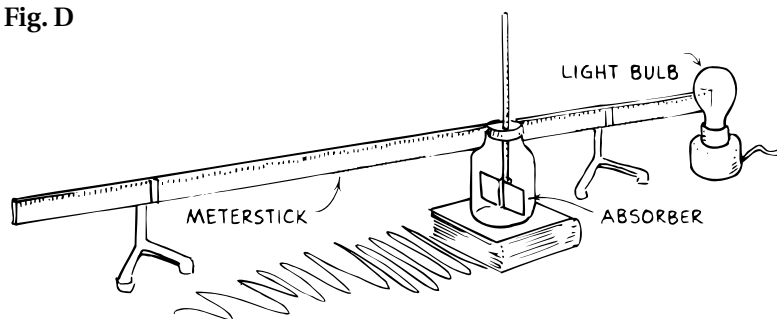
Set up apparatus using lightbulb.

Step 7: Set the meterstick on the table. Place the lightbulb with its filament located at the 0-cm mark of the meterstick (Figure D). Center the jar apparatus at the 95-cm mark with the blackened side of the foil strip exactly perpendicular to the light rays from the bulb. You may need to put some books under the jar apparatus.

Match outdoor temperature with lightbulb.

Step 8: Turn the lightbulb on. Slowly move the apparatus toward the lightbulb, 5 cm at a time, allowing the thermometer temperature to stabilize each time. As the temperature approaches that reached in Step 5, move the apparatus only 1 cm at a time. Adjust the distance of the apparatus 0.1 cm at a time until the temperature obtained in Step 5 is maintained for two minutes. Turn the lightbulb off.

Fig. D



Measure distance to lightbulb.

Step 9: Measure as exactly as possible the distance in meters between the absorber strip of the apparatus and the filament of the lightbulb. Record this value.

distance from light filament to foil strip = _____ m

Step 10: For the distance obtained, use the following equation to compute the wattage of the sun. The sun's distance in meters is 1.5×10^{11} m. Show your work.

Compute wattage of the sun.

$$\text{sun's wattage} = (\text{bulb's wattage}) \times \frac{(\text{sun's distance})^2}{(\text{bulb's distance})^2}$$

$$\text{sun's wattage} = \text{_____} \text{ W}$$

Step 11: Use the value of the sun's wattage to compute the number of 100-watt lightbulbs needed to equal the sun's power. Show your work.

Compute number of lightbulbs.

$$\text{number of 100-watt lightbulbs} = \text{_____}$$

Analysis

1. Re-express the equation in Step 10 as a relationship between two ratios. Express the new equation as a sentence that begins, "The ratio of . . ."

2. Would it be possible to turn on the number of 100-watt lightbulbs you computed in Step 11 at once? Explain.

3. The accepted value for the sun's wattage is 3.83×10^{26} W. List at least three factors that might account for the difference between your experimental value and the accepted value.

56 Solar Energy

Purpose

To find the daily amount of solar energy reaching the earth's surface and relate it to the daily amount of solar energy falling on an average house.

Required Equipment/Supplies

2 Styrofoam (plastic foam) cups	plastic wrap
graduated cylinder	rubber band
water	thermometer (Celsius)
blue and green food coloring	meterstick

Discussion

How do we know how much total energy the sun emits? First, we assume that it emits energy equally in all directions. Imagine a heat detector so big that it completely surrounds the sun—like an enormous basketball with the sun at its center. Then, the amount of heat reaching the detector would be the same as the total solar output. Or if our detector were half a basketball and caught half the sun's energy, then we would multiply the detector reading by 2 to compute the total solar output. If our detector encompassed a quarter of the sun and caught one-fourth its energy, then the sun's total output would be four times the detector reading.

Now that you have the concept, suppose that our detector is the water surface area of a full Styrofoam cup here on earth facing the sun. Then it comprises only a tiny fraction of the area that surrounds the sun at this distance. If you figure what that fraction is and also measure the amount of energy captured by your cup, you can tell how much total energy the sun emits. That's how it's done! In this activity, however, you will measure the amount of solar energy that reaches a Styrofoam cup and relate it to the amount of solar energy that falls on a housetop. You will need a sunny day to do this activity.

Procedure

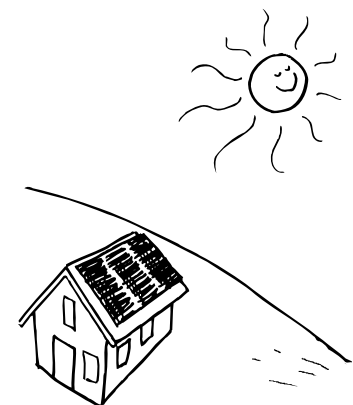


Step 1: Fill a Styrofoam cup, adding small equal amounts of blue and green food coloring to the water until it is dark (and a better absorber of solar energy). Then measure and record the amount of “water” in your cup.

volume of water = _____

mass of water = _____

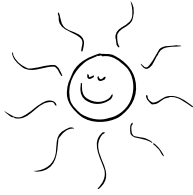
Nest the cup in a second Styrofoam cup (for better insulation).



Activity

Add food coloring.

Measure temperature.



Step 2: Measure the water temperature and record it. Cover the cup with plastic wrap sealed with a rubber band.

initial water temperature = _____

Step 3: Put the cup in the sunlight for 10 minutes.

Step 4: Remove the plastic wrap. Stir the water in the cup gently with the thermometer, and record the final water temperature.

final water temperature = _____

Step 5: Find the difference in the temperature of the water before and after it was set in the sun.

temperature difference = _____

Step 6: Measure and record the diameter in centimeters of the top of the cup. Compute the surface area of the top of the cup in square centimeters.

diameter = _____ cm

surface area of water = _____ cm^2

Step 7: Compute the energy in calories that was collected in the cup. You may assume that the specific heat of the mixture is the same as the specific heat of water. Show your work.

THE QUANTITY Q OF HEAT ENERGY COLLECTED BY THE WATER = MASS OF THE WATER \times ITS SPECIFIC HEAT ($c = 1 \text{ cal/g}^\circ\text{C}$) $\times \Delta T$, ITS CHANGE IN TEMPERATURE



energy = _____ cal

Compute solar energy flux.

Step 8: Compute the solar energy flux, the energy collected per square centimeter per minute. Show your work.

solar energy flux = _____ $\text{cal}/\text{cm}^2 \cdot \text{min}$

Step 9: Compute how much solar energy reaches each square meter of the earth per minute at your present time and location. Show your work. (*Hint:* There are 10 000 cm² in 1 m².)

solar energy flux = _____ cal/cm²•min

Step 10: Use your data to compute the rate at which solar energy falls on a flat 6-m by 12-m roof located in your area at the time when you made your measurement. Obtain the answer first in calories per second, then in watts. Show your work.

Compute solar energy received by roof.

solar power received by roof = _____ cal/s

solar power received by roof = _____ W

- How does this solar power compare with typical power consumption within the house?

Analysis

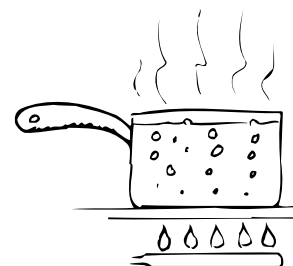
Scientists have measured the amount of solar energy flux outside our atmosphere to be 2 calories per square centimeter per minute on an area perpendicular to the direction of the sun's rays. This energy flux is called the *solar constant*. Only 1.5 calories per square centimeter per minute reaches the earth's surface after passing through the atmosphere. What factors could affect the amount of sunlight reaching the earth's surface and decrease the flux of solar energy that you measure?

Chapter 23: Change of Phase**Boiling of Water****57****Boiling Is a Cooling Process****Purpose**

To observe water changing its phase as it boils and then cools.

Required Equipment/Supplies

safety goggles
 paper towels
 ring stand
 wire gauze
 2 plastic-coated test-tube clamps
 1000-mL Florence flask (flat-bottomed) or Franklin's flask (crater-bottomed)
 one-hole rubber stopper to fit flask, fitted with short (15-cm) thermometer or temperature probe
 water
 crushed ice or beaker of cool tap water
 Bunsen burner
 thermometer (Celsius), regular length (30 cm), or computer
 temperature probe with interface
 printer
 pan or tub
 computer and data plotting software (optional)
 graph paper (if computer is not used)

**Activity****Discussion**

When water evaporates, the more energetic molecules leave the liquid. This results in a lowering of the average energy of the molecules left behind. The liquid is cooled by the process of evaporation. Is this also true of boiling? Try it and see.

Procedure

Step 1: Attach an empty flask to the ring stand with a test-tube clamp. Insert the teacher-prepared stopper with the thermometer or temperature probe into the neck of the flask. Loosen the wing nut on the clamp so that when the flask is rotated upside down, the end of the thermometer clears the table top by about 3 cm.

Adjust height of flask.

Step 2: Before filling the flask with water, you need to practice the procedure you will be performing later. Remove the stopper from the flask. Attach a ring and gauze below the flask, and place an unlit Bunsen

Prepare setup for dry run.

burner below the ring. Attach a second thermometer or probe to the ring stand, and suspend it inside the flask.

Practice inverting flask.

Step 3: Imagine that you have been boiling water in the flask, and have just turned off the burner. Move the burner aside. Remove the second thermometer or probe and its clamp from the stand. Loosen the screw on the ring, and lower it and the gauze to the tabletop. Firmly grasp the clamp and neck of the “hot” flask with a damp paper towel. Insert the stopper into the neck. Loosen the wing nut on the clamp. Holding the flask firmly with a damp paper towel, rotate it in the clamp until it is upside down. Tighten the wing nut to keep it in this position.

Practice this procedure a few times so that you will be comfortable manipulating the apparatus in this way when the flask is filled with boiling-hot water.

Place the stopper aside for use in Step 5.

Monitor water temperature.

Step 4: Put on safety goggles. Fill the flask half full of water, and attach it to the ring stand. The ring and gauze should be below it for safety.

If you are using thermometers, attach a thermometer to the ring stand so that its bulb is in the water but not touching the flask. Make a data table so that you can record the temperature every 30 seconds until 3 minutes after the water begins boiling vigorously. Heat the water, and record your data.

Alternatively, if you are using a computer, attach a temperature probe to the ring stand in place of the thermometer. Calibrate your probe before heating the water. If available, use data plotting software to make a graph of temperature vs. time. Print out your graph.

Insert rubber stopper.

Step 5: When you stop heating the flask, remove the second thermometer. Drop the ring. Firmly grasp the clamp and neck with a damp paper towel. Insert the stopper with the thermometer or probe into the flask. Atmospheric pressure will make it fit snugly. Loosen the wing nut on the clamp. *Carefully* hold the flask, using a damp paper towel, and invert it by rotating it in the clamp. Tighten the wing nut on the clamp to keep the flask in the inverted position, as shown in Figure A.

Fig. A



Step 6: Place a pan or tub under the flask. Pour cool tap water over the top half of the flask, or place crushed ice on it. Repeat the pouring several times. If you are using a computer, monitor the temperature of the water in the flask.

Cool flask.

1. What do you observe happening inside the flask?

2. What happens to the temperature of the water in the flask?

Step 7: Prepare a graph of temperature (vertical axis) vs. time (horizontal axis), either plotting data from your table or making a printout from the computer.

Make graph.

Analysis

3. Does the temperature of boiling water increase when heat continues to be applied?

4. Explain your observations of the temperature of the water as it continues to boil.

5. How does the amount of heat energy absorbed by a pot of water boiling on a stove compare with the amount of energy removed from the water by boiling?

6. Explain your observations of the inside of the inverted flask after cool water or ice was put on it.

58 Melting Away

Purpose

To measure the heat of fusion of water.

Required Equipment/Supplies

250-mL graduated cylinder
8-oz. Styrofoam (plastic foam) cup
water
ice cube (about 25 g)
paper towel
thermometer (Celsius) or
computer
temperature probe with interface
computer and data plotting software (optional)
printer
graph paper (if computer is not used)

Discussion

If you put heat into an object, will its temperature increase? Don't automatically say yes, for there are exceptions. If you put heat into water at 100°C, its temperature will not increase until all the water has become steam. The energy per gram that goes into changing the phase from liquid to gas is called the *heat of vaporization*. And when you put heat into melting ice, its temperature will not increase until all the ice has melted. The energy per gram that goes into changing the state from solid to liquid is called the *heat of fusion*. That's what this experiment is about.

Procedure

Step 1: Use a graduated cylinder to measure 200 mL of water, and pour it into a Styrofoam cup. The water should be about 5°C warmer than room temperature. If you are using a thermometer, make a data table for temperature and time. With the thermometer or temperature probe, measure and record the temperature of the water every 10 seconds for 3 minutes.

Step 2: Dry an ice cube by patting it with a paper towel. Add it to the water. Continue monitoring the temperature of the water every 10 seconds while gently stirring it until 3 minutes *after* the ice cube has melted. Record the data in a table or with the computer. Note the time at which the ice cube has *just* melted.

Monitor temperature of water.



Determine the final volume of water.

Step 3: Determine the final volume of the water.

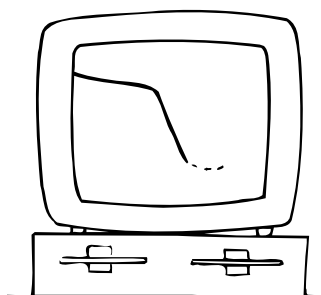
final volume = _____

1. What was the mass of the water originally? What was the mass of the ice cube originally? Explain how you determined these masses.

Make graph.

Step 4: Plot your data to make a temperature (vertical axis) vs. time (horizontal axis) graph. If you are using a computer with data plotting software, print a copy for your analysis and report.

Study your graph. Draw vertical dashed lines to break your graph into three distinct regions. Region I covers the time before the ice cube was placed in the water. Region II covers the time while the cube was melting. Region III covers the time after the cube has melted.



2. What was the total temperature change of the water while the cube was melting (Region II)?

3. How did placing the ice cube in the water affect the rate at which the water was cooling?

Compute the energy lost by water.

Step 5: Compute the total amount of heat energy Q lost by the water as the ice cube was melting. Use the relation $Q = mc\Delta T$, where m is the initial mass of the water, c is the specific heat capacity of water (1.00 cal/g \cdot °C), and ΔT is the magnitude of the water's temperature change from the beginning of Region II to the end of Region III where the temperature is stabilized.

heat energy lost by original water = _____ cal

Compute heat energy absorbed during warming.

Step 6: Compute the amount of heat energy absorbed as the water from the melted ice warmed from 0°C to its final temperature.

heat energy absorbed by melted ice during warming = _____ cal

Step 7: From the difference between the values found in Steps 5 and 6, compute the amount of heat energy that was absorbed by the ice as it melted.

Compute heat energy absorbed during melting.

heat energy absorbed
by ice during melting = _____ cal

Step 8: Compute the heat by fusion by dividing the value found in Step 7 by the mass of ice that melted in the cup.

Compute heat of fusion.

heat of fusion = _____ cal/g

4. Compare this value to the standard value, 80 cal/g, and calculate the percentage difference.

Analysis

5. In order for the ice cube to melt, it has to extract heat energy from the warmer water, first a small amount of heat to warm up to 0°C (which we neglect in this experiment), then a larger amount to melt. The melting ice absorbs heat energy, and thus cools the water. The heat energy absorbed per gram when a substance changes from a solid to a liquid is called the heat of fusion. How is the amount of heat energy absorbed by the solid related to the heat of fusion and the mass of the solid?

6. The total amount of heat energy lost by the water is equal to the amounts of heat energy it took to do what things?

7. What are some sources of error in this experiment?

59

Getting Steamed Up

Purpose

To determine the heat of vaporization of water.

Required Equipment/Supplies

safety goggles
 Bunsen burner
 steam generator with rubber tubing and steam trap
 3 large Styrofoam (plastic foam) cups
 water
 balance
 thermometer (Celsius)

Discussion

The condensation of steam liberates energy that warms many buildings on cold winter days. In this lab, you will make steam by boiling water and investigate the amount of heat energy given off when steam condenses into liquid water. You will then determine the heat energy released per gram, or *heat of vaporization*, for the condensation of steam.

Procedure

Step 1: Make a calorimeter by nesting 3 large Styrofoam cups. Measure the mass of the empty cups and record it in Data Table A.

Measure mass of cups.

Data Table A

MASS OF EMPTY CUPS	
MASS OF CUPS AND COOL WATER	
MASS OF COOL WATER	
TEMPERATURE OF COOL WATER	
TEMPERATURE OF WARM WATER	
MASS OF WARM WATER	
SPECIFIC HEAT OF WATER	$1.00 \frac{\text{cal}}{\text{g} \cdot ^\circ\text{C}}$

Measure initial temperature and mass.

Step 2: Fill the inner cup half-full with cool water. Measure the mass of the triple cup and water to the nearest 0.1 g and record it in Data Table A. Also record the original temperature of the water to the nearest 0.5°C.

Assemble apparatus.

Step 3: Fill the steam generator half-full with water, and put its cap on. Place the end of the rubber tubing in the water in the calorimeter (Figure A).

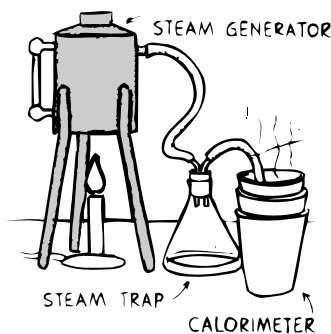


Fig. A

Ignite Bunsen burner.

Step 4: Put on safety goggles. Place the burner under the steam generator and ignite it to heat the water inside.

Adjust steam generator.

Step 5: Once the water in the steam generator starts boiling, adjust the rate at which steam comes out of the tubing so that it does not gurgle water out of the calorimeter. The steam should make the water bubble vigorously, but not violently. Gently stir the water with the thermometer. Bubble steam into the calorimeter until the water reaches a temperature no higher than 50°C.

Measure final temperature and mass.

Step 6: Shut off the burner, and remove the tubing from the water. Immediately determine the final mass and temperature of the warm water, and record them in Data Table A.

Compute mass of steam.

Step 7: Compute the mass of steam that condensed in your calorimeter from the change in mass of the water in the calorimeter.

$$\text{mass of steam} = \text{_____ g}$$

Compute heat energy gained.

Step 8: Compute the total amount of heat energy Q gained by the cool water using the relation $Q = mc\Delta T$, where m is the initial mass of the water, c is the specific heat of water (1.00 cal/g°C), and ΔT is the change in the temperature of the water. This heat comes in two steps: from the condensation of steam, and then from the condensed steam (now water) as it cools from 100°C to the final temperature. Show your work.

$$\text{heat energy gained} = \text{_____ cal}$$

Compute the energy lost during cooling.

Step 9: Compute the amount of heat energy lost by the water from the condensed steam as it cooled from 100°C down to its final temperature. Show your work.

$$\text{heat energy lost during cooling of water from the condensed steam} = \text{_____ cal}$$

Step 10: From the difference between the values found in Steps 8 and 9, compute the amount of heat energy that was released by the steam as it condensed.

heat energy released during condensation = _____ cal

Step 11: Compute the heat of vaporization by dividing the value found in Step 10 by the mass of steam that condensed in the cup.

Compute heat of vaporization.

heat of vaporization = _____ cal/g

1. Compare this value to the standard value, 540 cal/g, and calculate the percentage difference.

Analysis

2. There are two major energy changes involved in this experiment. One happens in the generator, and the other in the calorimeter. Where does the energy come from or go to during these changes?

3. Does the amount of steam that escapes into the air make any difference in this experiment?

4. Why does keeping the cap on when heating the water in the steam generator cause the water to boil more quickly?

60

Changing Phase

Purpose

To recognize, from a graph of the temperature changes of two systems, that energy is transferred in changing phase even though the temperature remains constant.

Required Equipment/Supplies

hot plate
 2 15-mm × 125-mm test tubes
 heat-resistant beaker
 paraffin wax
 2 ring stands
 2 test-tube clamps
 hot tap water
 2 thermometers (Celsius) in #3 stoppers to fit test tubes or
 computer
 2 temperature probes in slotted corks to fit test tubes
 printer
 graph paper (if computer is not used)

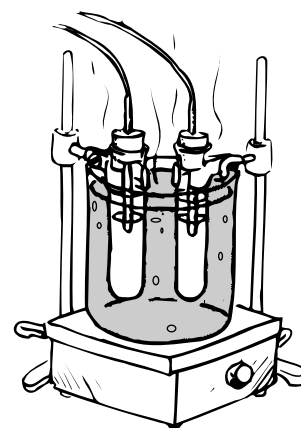
Discussion

When water is at its freezing point, cooling the water no longer causes its temperature to drop. The temperature remains at 0°C until all the water has frozen. After the water has frozen, continued cooling lowers the temperature of the ice. Is this behavior also true of other substances with different freezing temperatures?

Procedure

Step 1: Fill one test tube 3/4 full with wax (moth flakes). Fill another test tube with water to the same level. Fasten the test tubes in clamps fastened to a ring stand, and place them in hot tap water in a heat-resistant beaker. The beaker should be heated with a hot plate. Place a stopper with a thermometer or a cork with a temperature probe in each of the test tubes. Calibrate the temperature probes before using them. The thermometer or probe in wax should reach only just below the surface.

Step 2: Heat the water until all the wax has melted. Both thermometers or temperature probes should show nearly the same temperature. Turn the heat off, and record the temperatures.



Set up apparatus.

Melt wax.

Monitor temperature of wax and water.

Plot your data.

Step 3: Record the times and temperatures of the wax and water every 30 seconds until 5 minutes after the wax has entirely solidified. Note the temperature at which the wax begins to solidify (freeze).

Step 4: On a single piece of graph paper, plot the temperature (vertical axis) vs. time (horizontal axis) of (1) the water and (2) the wax. Use different colors for the curve of each material. Alternatively, use the computer to plot the data. Print out the data and graph, and include them with your lab report.

Analysis

1. How is the temperature curve of the wax similar to that of the water?

2. How do the temperature curves of the wax and the water differ?

3. What physical change occurred while the wax temperature remained constant?

4. When the temperature of the wax was constant, it was higher than that of the surrounding water bath. What was the heat source responsible for this?

Chapter 23: Change of Phase**Energy Transfer****61****Work for Your Ice Cream****Purpose**

To measure the energy transfers occurring during the making and freezing of homemade ice cream.

Required Equipment/Supplies

homemade ice cream machine
ice
rock salt
thermometer

insulated cups
ice cream mix
triple-beam balance
spring scale with maximum
capacity of 50 N or 10 lb

Discussion

Energy must be supplied to a home to heat it on a cold winter day. Energy must also be supplied to an air conditioner that is cooling a home on a hot summer day. The air conditioner is transferring heat from the cooler indoors to the warmer outdoors. Energy input is always required to move heat from a region of lower temperature to a region of higher temperature.

Energy must be taken away from a liquid to make it a solid. If the liquid is cooler than the surrounding air, additional energy must be added to move heat from the liquid to the warmer air, just as extra energy is needed to move heat from a room to the warmer outdoors in summer. When the liquid is sweet cream, the solid that results is ice cream. (Making ice cream also involves swirling in air; ice cream is actually a mixture of a solid and a gas.)

The freezing of homemade ice cream involves several energy transfers.

1. Energy (work) is expended in turning the crank to overcome inertia and friction.
2. The slush of ice and rock salt takes up energy as it melts.
3. The ice cream mix cools from its original to its final temperature.
4. The metal container cools from its original to its final temperature.
5. The ice cream mix gives up energy as it freezes.

Procedure

Each group in the class should determine how it will make the measurements to determine the amount of energy transferred in one of the five processes above. If some constants for ice cream are needed, a group



also should do a separate experiment to determine those constants. The constants might be the specific heat of the ice cream mix and the heat of fusion of ice cream. Each group should also carry out its method to determine the energy transferred.

You may have to sacrifice some of the ice cream you make to determine these constants and the energy transferred. Don't forget that many of the advances of science came only after great sacrifices! Organize your data to share with the class to make a profile of all the energy transfers.

Describe your procedure.

Questions

1. Which process of the five listed is the greatest absorber of energy?

2. How did the energy absorbed by the melting slush of ice and rock salt compare with the energy released by the other processes?

3. Salt is put on icy roads to promote melting. When you make home-made ice cream, salt is used to help promote freezing. Is this practice paradoxical, or does it make good physics sense?

62

The Drinking Bird

Purpose

To investigate the operation of a toy drinking bird.

Required Equipment/Supplies

toy drinking bird
cup of water

Discussion

Toys often illustrate fundamental physical principles. The toy drinking bird is an example.

Procedure

Step 1: Set up the toy drinking bird with a cup of water as in Figure A. Position the cup to douse the bird's beak with each dip. The fulcrum may require some adjustment to let it cycle smoothly.



Fig. A

Step 2: After the bird starts “drinking,” study its operation carefully. Your goal is to explain how it works. Answering the questions in the “Analysis” section will help you understand how it works.

Analysis

1. What causes the fluid to rise up the toy bird's neck?

2. What causes the bird to dip?

3. What causes the bird to make itself erect?

4. What is the purpose of the fuzzy head?

5. Will the bird continue to drink if the cup is removed?

6. Will the relative humidity of the surrounding air affect the rate of dipping?

7. Will the bird dip faster indoors or outdoors? Why?

8. Under what conditions will the bird fail to operate?

Name _____

Period _____

Date _____

9. Brainstorm with your lab partners about practical applications of the drinking bird.

10. Explain how the bird works.

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63 The Uncommon Cold

Purpose

To use linear extrapolation to estimate the Celsius value of the temperature of absolute zero.

Required Equipment/Supplies

safety goggles
paper towel
Bunsen burner
wire gauze
ring stand with ring
250-mL Florence flask
flask clamp
short, solid glass rod
one-hole rubber stopper to fit flask
500-mL beaker
water
thermometer (Celsius)
ice bucket or container (large enough to submerge a 250-mL flask)
ice
large graduated cylinder
graph paper

Optional Equipment/Supplies

computer
data plotting software

Discussion

Under most conditions of constant pressure, the volume of a gas is proportional to the absolute temperature of the gas. As the temperature of a gas under constant pressure increases or decreases, the volume increases or decreases, in direct proportion to the change of absolute temperature. If this relationship remained valid all the way to absolute zero, the volume of the gas would shrink to zero there. This doesn't happen in practice because all gases liquefy when they get cold enough. Also, the finite size of molecules prevents liquids or solids from contracting to zero volume (which would imply infinite density).

In this experiment, you will discover that you can find out how cold absolute zero is even though you can't get close to that temperature. You will cool a volume of air and make a graph of its temperature-volume



relation. Then you will extrapolate the graph to zero volume to predict the temperature, in degrees Celsius, of absolute zero.

Procedure

Set up ice bath.

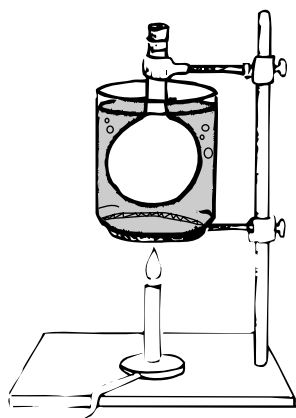


Fig. A

Step 1: Make an ice bath of ice and water, using a bucket or container large enough to submerge a 250-mL flask. (Do not put the flask in it yet.)

Step 2: Put on safety goggles. Select a *dry* 250-mL Florence flask, and fit a *dry* single-hole stopper into the flask. Half-fill a 500-mL beaker with water, set it on the ring stand, and clamp the flask to the ring stand in the water with the water level approximately 4 cm below the top of the beaker (see Figure A). Boil the water for at least 3 minutes to make sure that the air in the flask is heated to the water temperature. Measure and record the water temperature.

temperature of boiling water = _____

Step 3: Turn off the burner. Use a damp paper towel to grasp the clamp, and quickly place a solid glass rod into the hole of the rubber stopper to trap all the air molecules. Do this quickly while the air in the flask has the same temperature as the boiling water. Loosen the clamp from the ring stand, and lift the flask, stopper, and clamp assembly. Allow the flask to cool for a minute or so until it can be handled comfortably. Remove the clamp from the flask, and lower the flask upside down into the ice bath. Hold the flask and stopper below the water surface of the ice bath, and remove the glass rod.

Record bath temperature.

Step 4: Hold the flask upside down under the water surface for at least 3 minutes. Measure and record the temperature of the ice bath.

temperature of ice bath = _____

Remove flask from bath.

Step 5: Some water has entered the flask to take the place of the contracted air. The air in the flask now has the same temperature as the ice bath. With the flask totally submerged and the neck of the flask just under the water surface, place the glass rod or your finger over the hole of the stopper, and remove the flask from the ice bath.

Measure volumes of air.

Step 6: Devise a method to determine the volume of the trapped air at both temperatures. Record the volumes.

volume of air at temperature of boiling water = _____

volume of air at temperature of ice bath = _____

Graph and extrapolate.

Step 7: Plot the volume of air in the flask (vertical axis) vs. the temperature (horizontal axis) for the two conditions. Use a scale of -400 degrees Celsius to $+100$ degrees Celsius on the horizontal axis and a scale of 0 mL to 250 mL on the vertical axis. Draw a straight line through the two points and to the x -axis (where the extrapolated value for the volume of the gas is zero).

Analysis

1. Why did water flow into the flask in the ice bath?

2. What is your predicted temperature for absolute zero in degrees Celsius? Explain how the graph is used for the prediction.

3. In what way does this graph suggest that temperature cannot drop below absolute zero?

4. What can be done to improve the accuracy of this experiment?

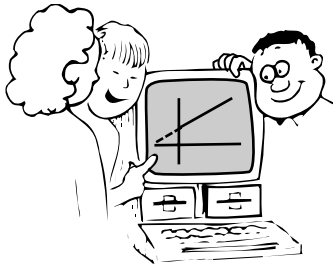
5. What are some assumptions that you made in conducting the experiment and analyzing the data?

6. What happens to air when it gets extremely cold?

Going Further

Use data plotting software to plot your data. Use the computer-drawn graph to check your prediction of the temperature of absolute zero.

7. How does the computer prediction compare with your earlier prediction?



64 Tick-Tock

Purpose

To construct a pendulum with a period of one second.

Required Equipment/Supplies

ring stand
pendulum clamp
pendulum bob
string

stopwatch or wristwatch
balance
meterstick

Discussion

A simple pendulum consists of a small heavy ball (the bob) suspended by a lightweight string from a rigid support. The bob is free to oscillate (swing back and forth) in any direction. A pendulum completes one cycle or oscillation when it swings forth from a position of maximum deflection and then back to that position. The time it takes to complete one cycle is called its *period*.

If, during a 10-second interval, a pendulum completes 5 cycles, its period T is 10 seconds divided by 5 cycles, or 2 seconds. The period is then 2 seconds for this pendulum.

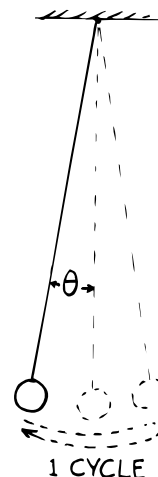
What determines the period of a pendulum? You will find out the factors by trying to make your pendulum have a period of exactly one second.

Procedure

Construct a pendulum with a period of *exactly* one second. To do this, change one variable at a time and keep track of which ones affect the period and which ones do not.

Questions

- Briefly describe the method you used to construct your pendulum.



2. What was the mass of your pendulum?

3. What effect, if any, does mass have on the period of a pendulum?

4. What effect, if any, does amplitude (size of swing) have on the period of a pendulum?

5. What was the length of your pendulum?

6. What effect, if any, does length have on the period of a pendulum?

7. If you set up your pendulum atop Mt. Everest, would the period be less than, the same as, or greater than it would be in your lab? Why?

8. If you set up your pendulum aboard an orbiting space vehicle, would the period be less than, the same as, or greater than it would be in your lab?

65

Grandfather's Clock

Purpose

To investigate how the period of a pendulum varies with its length.

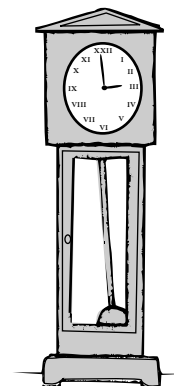
Required Equipment/Supplies

ring stand	stopwatch or
pendulum clamp	computer
pendulum bob	light probe with interface
string	ring stands with clamps
graph paper or data plotting	light source
software and printer	

Discussion

What characteristics of a pendulum determine its period, the time taken for one oscillation? Galileo timed the swinging of a chandelier in the cathedral at Pisa using his pulse as a clock. He discovered that the time it took to oscillate back and forth was the same regardless of its amplitude, or the size of its swing. In modern terminology, the period of a pendulum is independent of its amplitude (for small amplitudes, angles less than 10°).

Another quantity that does not affect the period of a pendulum is its mass. In Activity 64, "Tick-Tock," you discovered that a pendulum's period depends only on its length. In this experiment, you will try to determine exactly *how* the length and period of a pendulum are related. Replacing Galileo's pulse, you will use a stopwatch or a computer.



Procedure

Step 1: Set up a pendulum using the listed equipment. Make its length 65 cm. Measure its period three times by timing the oscillations with the stopwatch or the computer system. (If you are using a computer to measure the period of your pendulum, set up the light probe. Use clamps and ring stands to position a light source (such as a flashlight) so that the pendulum bob eclipses the light probe somewhere in its path.) Record the average period in Data Table A.

Set up pendulum.

Step 2: Shorten the pendulum length by 5 cm. Measure its period as in Step 1, and record the average period in Data Table A.

Shorten pendulum and repeat.

LENGTH (cm)	PERIOD (s)
65	
60	
55	
50	
45	
40	
35	
30	
25	
20	
15	
10	

Data Table A

Step 3: Complete Data Table A for the remaining pendulum lengths indicated there. Measure periods as you did in Step 1.

Step 4: Make a graph of the period (vertical axis) vs. the length of the pendulum (horizontal axis).

- Describe your graph. Is it a straight line that shows that the period is directly proportional to the length? Or is it a curve that shows that the relationship between period and length is not a direct proportion?

Step 5: Often data points lie on a curve that is not a straight line. It is very difficult to determine the relationship between two variables from such a curve. It is virtually impossible to extrapolate accurately from a curve. Experimenters instead try to produce a straight-line graph by plotting appropriate functions (squares, cubes, logarithms, etc.) of the variables originally used on the horizontal and vertical axes. When they succeed in producing a straight line, they can more easily determine the relationship between variables.

The simplest way to try to “straighten out” a curve is to see if one of the variables is proportional to a power of the other variable. If your graph of period vs. length curves upward (has increasing slope), perhaps period is proportional to the square or the cube of the length. If your graph curves downward (has decreasing slope), perhaps it is the other way around; perhaps the square or the cube of the period is proportional to the length. Try plotting simple powers of one variable against the other to see if you can produce a straight line from your data. If you have a computer with data plotting software, use it to discover the mathematical relationship between the length and the period. A straight-line plot shows that the relationship between the variables chosen is a direct proportion.

- What plot of powers of length and/or period results in a straight line?

Predict pendulum length.

Step 6: From your graph, predict what length of pendulum has a period of exactly two seconds.

predicted length = _____

Measure pendulum length.

Step 7: Measure the length of the pendulum that gives a period of 2.0 s.

measured length = _____

- Compute the percentage difference between the measured length and the predicted length.

66

Catch a Wave

Purpose

To observe important wave properties.

Required Equipment/Supplies

Slinky™ spring toy, long form
tuning fork resonators
portable stereo with two detachable speakers
Doppler ball (piezoelectric speaker with 9-volt battery mounted inside 4"-diameter foam ball)

Discussion

When two waves overlap, the composite wave is the sum of the two waves at each instant of time and at each point in space. The two waves are still there and are separate and independent, not affecting each other in any way. If the waves overlap only for some duration and in some region, they continue on their way afterward exactly as they were, each one uninfluenced by the other. This property is characteristic of waves and is not observable for particles the size of billiard balls. Obviously, you've never seen a cue ball collide with another billiard ball and reappear on the other side! However, sound and water waves, if they are weak enough, behave this way. That is, two sound waves can overlap so that *no* sound results! Impressive!

Procedure

Part A: Longitudinal vs. Transverse Waves

Light is a *transverse* wave, meaning that the wave vibrates back and forth perpendicular to the line of propagation. Sound is a *longitudinal* wave, meaning that the wave vibrates along the line of propagation.

Step 1: Have your partner hold one end of a long Slinky and carefully—so as not to get it tangled or kinked—stretch it out on a smooth (non-carpeted) floor or a long counter top. Give the Slinky a rapid jerk by shaking it to one side then back so that you create a wave pulse that travels to your partner. Be sure your partner holds the other end fixed. Repeat several times, observing what happens to the wave pulse as it travels to your partner and back.

Observe transverse waves.

1. How does the Slinky move with respect to the wave pulse?

2. Is the pulse transverse or longitudinal?

3. Why does the amplitude of the pulse decrease as it travels from its source?

4. How does the reflected pulse differ from the original pulse?

5. What happens to the wavelength of the pulse as it travels to and from your partner?

Observe reflection of waves.

Step 2: Attach a piece of string about 50 cm long to one end of the Slinky. Have your partner hold the free end of the string. Send a pulse along the Slinky.

6. How does the reflected pulse differ from the original pulse?

Observe change in wave speed.

Step 3: Increase the tension in the Slinky by stretching it. Send a pulse along the Slinky. How does the tension affect the speed of the pulse? Does the tension in the Slinky affect other wave properties as well?

Observe longitudinal waves.

Step 4: Repeat steps 1 through 3 but this time jerk the Slinky back and forth along the direction of the outstretched Slinky. What kind of wave is produced? Record your observations.

Step 5: Now for some real fun! This time you and your partner will create equal-sized pulses at the same time from opposite ends of the Slinky. It may require some practice to get your timing synchronized. Try it both ways—that is, with the pulses on the same side and then with the pulses on opposite sides of the line of propagation. Pay special attention to what happens as the pulses overlap. Record your observations.

Observe the sum of two waves.

Step 6: Detach two speakers from a portable stereo with both speakers in phase (that is, with the plus and minus connections to each speaker the same). Play in a mono mode so the signals of each speaker are identical. Note the fullness of the sound. Now reverse the polarity of one of the speakers by interchanging the plus and minus wires. Note that the sound is different—it lacks fullness. Some of the waves from one speaker are arriving at your ear out of phase with waves from the other speaker.

Observe interference of sound waves.

Now place the pair of speakers facing each other at arm's length apart. The long waves interfere destructively, detracting from the fullness of sound. Gradually bring the speakers closer to each other. What happens to the volume and fullness of the sound? Bring them face to face against each other. What happens to the volume now?

Part B: Standing Waves—Resonance

Have your partner hold one end of the Slinky. Shake the Slinky slowly back and forth until you get a wave that is the combination of a transmitted wave and its reflection—a standing wave—like the *fundamental* (or the first harmonic) shown in Figure A.

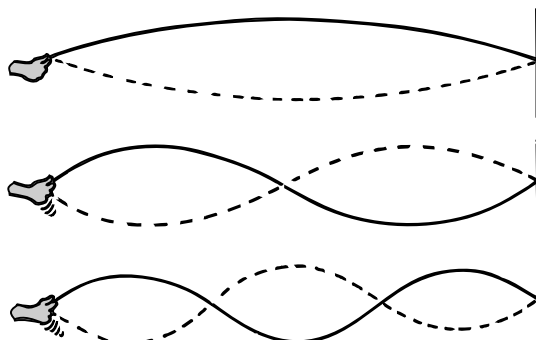


Fig. A

7. How long is the wave compared to the length of the Slinky?

Observe standing waves.

Step 7: Now shake the Slinky at a higher frequency so that a second-harmonic standing wave is created.

8. How long is the wave compared to the length of the Slinky?

Observe harmonics.

Step 8: See how many other harmonics you can create. Record your observations.

Part C: The Doppler Effect

You are now going to investigate what happens when either the source or the receiver of waves is moving. For example, when a car whizzes by on the road, the pitch of its engine is higher when approaching and lower when receding. This change of frequency due to motion is called the Doppler effect.

Similarly, the whine of an airplane engine changes its pitch as it passes overhead. If the plane moves faster than the speed of sound, the Doppler shift is replaced by a shock wave, which produces a “sonic boom.” It is interesting to note that any object traveling at supersonic speed creates its own shock wave—whether or not it is a sound emitter.

The Doppler effect occurs with *any* wave phenomenon (including light and other electromagnetic radiation) whenever there is relative motion between the source and receiver. For example, the decrease of frequency for the light of a receding star gives it a *red shift*. An approaching star is seen to be *blue shifted*. The Doppler effect is far reaching.

Observe Doppler effect.

Step 9: Play catch with your partner using a Doppler ball. How does the movement of the ball affect the pitch of the sound?

67**Ripple While You Work****Purpose**

To observe wave phenomena in a ripple tank.

Required Equipment/Supplies

ripple tank with light source and bottom screen
 3/4-inch dowel
 paraffin blocks
 medicine dropper
 length of large-diameter rubber hose
 wave generator
 large glass plate
 cut rubber stoppers

Discussion

Water waves have simple properties when they have small amplitude, and they are familiar to everyone. Observing the behavior of water waves in a ripple tank will introduce you to the analysis of wave motion.

Procedure 

Step 1: The ripple tank is set up for you. Turn on its light. Observe the screen at the base of the tank as you produce a pulse by touching your finger or pencil tip once to the water surface.

1. What is the shape of the pulse?

2. Does the speed of the pulse seem to be the same in all directions?

Step 2: Place the dowel in the water. Produce a straight wave front by rolling the dowel forward 1 cm, with the flat of your hand.



Observe pulse.

Generate straight wave front.

3. What is the shape of the pulse?

Observe reflections.

Step 3: Place a paraffin block in the tank. With the dowel generate a pulse that strikes the barrier straight on.

4. What does the pulse do when it reaches the barrier?

5. After the pulse strikes the barrier, what is the new direction of the pulse?

Step 4: Move the paraffin block to change the angle at which the pulse strikes it.

6. What is the shape of the reflected pulse?

Generate circular wave pulses.

Step 5: Produce circular wave pulses with water drops from the medicine dropper.

7. How do the pulses reflect from the paraffin block?

8. From what point do the reflected pulses appear to be originating?

Observe wave pulses reflected by a parabola.

Step 6: Bend a length of large-diameter rubber hose into the approximate shape of a parabola. Place it in the tank.

9. What do you observe when you use this tubing as a reflector for straight pulses?

Step 7: Find the *point* at which the straight pulses reflected by the hose meet and mark it on the screen with your finger. This is the *focus* of the parabola. Generate a circular pulse with the dropper held straight above the focus of the parabola.

Observe wave pulses originating at the focus.

10. What is the shape of the reflected pulse?

11. Do any other points give the same pulse shape?

Step 8: Start the wave generator to produce a straight wave. The distance between bright bars in the wave is the wavelength. Adjust the frequency of the wave generator.

Observe frequency change.

12. What effect does increasing the frequency have on the wavelength?

Step 9: Place a paraffin barrier halfway across the middle of the tank. Observe the part of the straight wave that strikes the barrier as well as the part that passes by it. Adjust the frequency of the wave generator so that the combination of the incoming and reflected wave appears to stand still. The combination then forms a standing wave.

Observe standing wave.

13. How does the wavelength of the standing wave compare with the wavelength of the wave traveling past the barrier?

Step 10: Support a piece of rectangular slab of glass with rubber stoppers so that it is 1.5 cm from the bottom of the tank and its top is *just* covered with water. Arrange the glass so that incoming wave fronts are parallel to one edge of the glass.

14. What happens as waves pass from deep to shallow water?

Compare wave speeds.

Step 11: Now turn the glass so that its edge is no longer parallel to the incoming wave fronts.

15. Are the wave fronts straight both outside and over the glass?

16. How do the speeds of the waves compare?

Observe wave spreading.

Step 12: Place paraffin blocks across the tank until they reach from side to side with a small opening in the middle. Generate straight waves with the wave generator.

17. How does the straight wave pattern change as it passes through the opening?

Step 13: Using a piece of paraffin about 4 cm long, modify your paraffin barrier so that it has two openings about 4 cm apart near the center. Generate a straight wave and allow it to pass through the pair of openings.

18. What wave pattern do you observe?

Step 14: Put two point sources about 4 cm apart on the bar of the wave generator. Turn on the wave generator to produce overlapping circular waves.

19. What pattern do you now observe?

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68

Chalk Talk

Purpose

To explore the relationship between sound and the vibrations in a material.

Required Equipment/Supplies

new piece of chalk
chalkboard

masking tape
meterstick

Discussion

Every sound has its source in a vibrating object. Some very unusual sounds are sometimes produced by unusual vibrating objects!

Procedure

Step 1: Tape the chalk tightly to the thin edge of the meterstick. The end of the chalk should extend beyond the end of the meterstick by 1 cm.

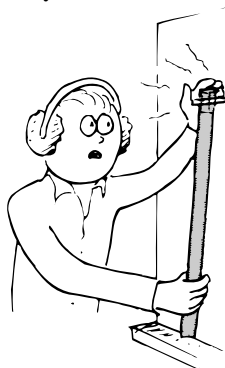
Tape chalk to meterstick.

Step 2: Position the chalk perpendicular to the chalkboard's surface. Hold the meterstick firmly with one hand 15 cm from the chalk; very lightly support the far end with the other hand. Pull the meterstick at a constant speed while maintaining firm contact with the board.

Push or pull on meterstick.

Step 3: Modify the procedure of Step 2 by changing the angle, the contact force, or the distance the chalk protrudes beyond the meterstick. Also try making wavy lines. With the proper technique, the sounds of a trumpet, oboe, flute, train whistle, yelping dog, and a sick Tarzan yell can be produced.

Conclude the activity when your instructor can't stand it any longer!



Analysis

1. What is producing the sound?

2. The end of the meterstick that is loosely supported by the hand should vibrate in different ways for a high and low pitch. Are high or low pitches easier to feel? Explain.

3. What combinations of angle and pressure tend to produce high pitches?

4. What combinations of angle and pressure tend to produce low pitches?

69

Mach One

Purpose

To determine the speed of sound using the concept of resonance.

Required Equipment/Supplies

resonance tube approximately 50 cm long or golf club tube cut in half
 1-L plastic graduated cylinder
 meterstick
 1 or 2 different tuning forks of 256 Hz or more
 rubber band
 Alka-Seltzer® antacid tablet (optional)

Discussion

You are familiar with many applications of *resonance*. You may have heard a vase across the room rattle when a particular note on a piano was played. The frequency of that note was the same as the natural vibration frequency of the vase. Your textbook has other examples of resonating objects.

Gases can resonate as well. A vibrating tuning fork held over an open tube can cause the air column to vibrate at a natural frequency that matches the frequency of the tuning fork. This is resonance. The length of the air column can be shortened by adding water to the tube. The sound is loudest when the natural vibration frequency of the air column is the same as (resonates with) the frequency of the tuning fork. For a tube open at one end and closed at the other, the lowest frequency of natural vibration is one for which the length of the air column is one fourth the wavelength of the sound wave.

In this experiment, you'll use the concept of resonance to determine the wavelength of a sound wave of known frequency. You can then compute the speed of sound by multiplying the frequency by the wavelength.

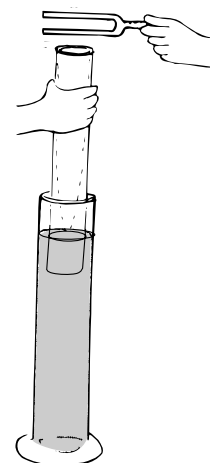
Procedure



Step 1: Fill the cylinder with water to about two thirds of its capacity. Place the resonance tube in the cylinder. You can vary the length of the air column in the tube by moving the tube up or down.

Step 2: Select a tuning fork, and record the frequency that is imprinted on it.

frequency = _____ Hz



Strike the tuning fork on the heel of your shoe (NOT on the cylinder). Hold the tuning fork about 1 cm above the open end of the tube, horizontally, with its tines one above the other. Move both the fork and the tube up and down to find the air column length that gives the loudest sound. (There are several loud spots.) Mark the water level on the tube for this loudest sound with a rubber band stretched around the cylinder.

Measure air column length.

Step 3: Measure the distance from the top of the resonance tube to the water-level mark.

length of air column = _____ m

Measure the diameter.

Step 4: Measure the diameter of the resonance tube.

diameter of the resonance tube = _____ m

Compute corrected length.

Step 5: Make a corrected length by adding 0.4 times the diameter of the tube to the measured length of the air column. This corrected length accounts for the air just above the tube that also vibrates.

corrected length = _____ m

Compute the wavelength.

Step 6: The corrected length is one fourth of the wavelength of the sound vibrating in the air column. Compute the wavelength of that sound.

wavelength = _____ m

Compute the speed of sound.

Step 7: Using the frequency and the wavelength of the sound, compute the speed of sound in air. Show your work.

speed of sound in air = _____ m/s

Repeat using different tuning fork.

Step 8: If time permits, repeat Steps 2 to 7 using a different tuning fork.

frequency = _____ Hz length of air column = _____ m

corrected length = _____ m wavelength = _____ m

speed of sound in air = _____ m/s

Analysis

1. The accepted value for the speed of sound in dry air is 331 m/s at 0°C. This speed increases by 0.6 m/s for each additional degree Celsius above zero. Compute the accepted value for the speed of sound in dry air at the temperature of your room.

2. How does your computed speed of sound compare with the accepted value? Compute the percentage difference.

Chapter 27: Light**Formation of Shadows****70****Shady Business****Purpose**

To investigate the nature and formation of shadows.

Required Equipment/Supplies

bright light source
book or other opaque object
screen or wall
meterstick

Discussion

If you look carefully at a shadow, you will notice that it has a dark central region and a fuzzy and less dark band around the edge of the central region. Why do shadows have two different regions?

Procedure

Step 1: Arrange a small light source so that a solid object such as a book casts a shadow on a screen or wall. Sketch the shadow formed, noting both its regions. Sketch the relative positions of the book, light source, and shadow.

Step 2: Move the light source away from the object while keeping the position of the object fixed. Note and sketch any changes in the shadow. Sketch the new relative position of the light source.

1. What happens to the size of the fuzzy region around the edge of the central region when the light source is moved farther away?



Sketch shadow.

Move light source.

Move object.

Step 3: Move the object closer to the light source while keeping the screen and the light source in the same position. Note and sketch any changes in the shadow. Sketch the new relative position of the object.

2. What happens to the size of the fuzzy region around the edge when the object is moved closer to the light source?

Analysis

3. Which relative positions of the object, light source, and screen result in a sharp distinct shadow with little or no fuzzy region around its edge?

4. Which relative positions of the object, light source, and screen result in a large fuzzy region around a small or nonexistent central dark region?

5. What causes the fuzzy region around the edge of a shadow?

71

Absolutely Relative

Purpose

To investigate how light intensity varies with distance from a light source.

Required Equipment/Supplies

computer
light probe with interface
data plotting software
3-socket outlet extender
3 night-lights with clear 7-watt bulbs
2 ring stands
2 clamps
meterstick

Discussion

The light from your desk lamp may seem almost as bright as the sun. If your desk were only a meter away from the sun, your lamp would not seem bright at all. The *brightness* of the sun is far greater than that of the lamp, but the *intensity* of the lamp is almost as great as that of the sun.

The intensity of light decreases with distance from the source. In this experiment, you will use a light probe to measure the intensity of light at various distances to see exactly how the intensity varies with the distance.

Procedure

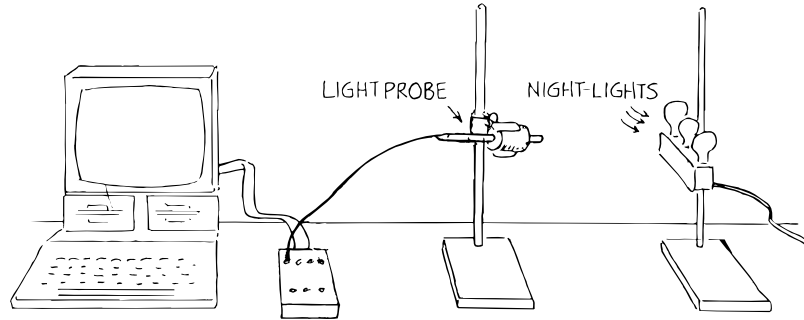
Step 1: Install three night-lights in an outlet extender. Use a clamp to secure the extender on a ring stand at least 20 cm above the table. This height is necessary to minimize the effect of the light reflected from the table surface.

Clamp the light probe to another ring stand so that it is at the same height as the night lights and is directly facing them 30 cm away. Connect the light probe to the interfacing box. The setup is shown in Figure A.

Step 2: Set up the light probe so that the computer automatically measures the intensity of light falling on the light probe and displays the intensity.

Set up light source and light probe.

Fig. A



BULB	RELATIVE INTENSITY
A	
B	
C	
A+B	
A+C	
B+C	
A+B+C	

Data Table A

Turn on the center bulb (Bulb A). Calibrate the light probe so that the computer automatically compares all other light intensities to the light intensity of Bulb A at this distance. All future intensity readings are, therefore, expressed relative to Bulb A.

Now turn off Bulb A and turn on one of the side bulbs (Bulb B). Leave the light probe in the same position. Record the intensity reading in Data Table A. Turn off Bulb B and turn on the third bulb (Bulb C). Record the intensity reading.

Step 3: Predict what intensity the light probe will read when you turn on Bulbs A and B.

predicted intensity reading = _____

Try it and record your data.

Step 4: Now try all other combinations of the bulbs to complete Data Table A.

BULB A	
DISTANCE	INTENSITY
30 cm	

Data Table B

1. How do the intensity readings for the different bulb combinations compare with their individual intensity readings?

2. What might account for any differences in the readings of the bulbs separately compared with when they are combined?

Step 5: Take an intensity reading with the light probe 30 cm away from Bulb A. Take nine more readings with the light probe, moving it 5 cm farther away from the bulb each time. Record your data in Data Table B.

3. What happens to the light intensity as the probe gets farther away from the source?

Step 6: Plot the light intensity (vertical axis) vs. distance (horizontal axis) for Bulb A. If available, use data plotting software to plot the graph.

Plot data.

4. What does the graph look like? What relationship does your graph suggest between the light intensity and the distance?

Step 7: Use data plotting software to vary the power of the x - y values so that the plot of intensity vs. distance is a straight line.

Vary the power of x - y values.

5. What does the graph look like?

6. What relationship does your graph suggest between the light intensity and the distance?

Analysis

7. Imagine a point source of light, such as a small 1.5-volt flashlight bulb, at the center of a balloon of radius r . All the light leaving the bulb strikes the inside surface of the balloon. Also imagine the same light source inside a balloon of twice that radius, $2r$. All the light leaving the bulb again strikes the inside surface of the balloon. Does the brightness of the bulb increase, decrease, or remain the same?

8. How many times greater is the inside surface area of the larger balloon than that of the smaller balloon?

9. If all the light spreads out evenly onto the surface of the larger balloon, what is the intensity of the light at the inside surface of the larger balloon relative to that for the smaller balloon?

Chapter 27: Light**Polarization**

72 Shades

Purpose

To investigate the effects of polarized light.

Required Equipment/Supplies

3 small polarizing filters
light source
small plane mirror

Discussion

The vibrations of light waves reaching your eyes are mostly randomly oriented; they vibrate in many planes at once. In polarized light, the light waves vibrate in one plane only. Polarized light can be made by blocking all the waves except those in one plane with polarizing filters. The filters can also be used to detect polarized light.

Procedure

Step 1: Position one polarizing filter between your eyes and a light source. Slowly rotate the filter 360° . Observe the intensity of the light as seen through the filter. Note any intensity changes as you rotate the filter.

1. What happens to the intensity of the light as you rotate the filter?

Step 2: Arrange one filter in a fixed position in front of the light source. Slowly rotate a second filter held between your eyes and the fixed filter. Note any intensity changes of the light as you rotate the filter 360° .

2. What happens to the intensity of the light as you rotate the filter?



Activity

Rotate second filter.

Rotate other filter.

Step 3: Hold the filter at your eye in a fixed position while your partner slowly rotates the other filter next to the light source 360°. Note any intensity changes of the light as the filter as rotated.

3. What happens to the intensity of the light as the filter as rotated?

Rotate both filters.

Step 4: Rotate both of the filters through one complete rotation in the same direction at the same time. Note any intensity changes.

4. What happens to the intensity of the light as you rotate both filters together?

Rotate both filters in opposite directions.

Step 5: Rotate both of the filters through one complete rotation at the same time, but in opposite directions. Note any intensity changes.

5. What happens to the intensity of the light as you rotate both filters in opposite directions?

Rotate single filter for light reflected off a mirror.

Step 6: Repeat Step 1, except arrange the light source and a mirror so that you observe only the light coming from the mirror surface. Note any intensity changes of the light as you rotate the filter.

6. What happens to the intensity of the light as you rotate the filter?

7. Is the light reflected off a mirror polarized?

View sky through filter.

Step 7: View different regions of the sky on a sunny day through a filter. Rotate the filter 360° while viewing each region.

CAUTION: *Do not look at the sun!*

8. What happens to the intensity of the light as you rotate the filter?

9. Is the light of the sky polarized? If so, where is the region of maximum polarization in relation to the position of the sun?

Step 8: View a liquid crystal display (LCD) on a wristwatch or calculator using a filter. Rotate the filter 360° , and note any intensity changes.

View LCD with filter.

10. What happens to intensity of the light as you rotate the filter?

11. Is the light coming from a liquid crystal display polarized?

Analysis

12. Why do polarized lenses make good sunglasses?

13. Explain why the effects seen in Steps 1 to 3 occur.

Going Further

Step 9: Position a pair of filters so that a minimum of light from a light source gets through. Place a third filter between the light source and the pair.

14. Does any light get through?

Step 10: Place the third filter beyond the pair.

15. Does any light get through?

Step 11: This time, sandwich the third filter between the other two filters at a 45° angle.

16. Does any light get through?

Chapter 28: Color**Atomic Spectra**

73 Flaming Out

Purpose

To observe the spectra of some metal atoms.

Required Equipment/Supplies

safety goggles	7 20-cm pieces of platinum or nichrome wire with a small loop at one end
spectroscope	
incandescent lamp	6 labeled bottles containing salts of lithium, sodium, potassium, calcium, strontium, and copper
Bunsen burner with matches or igniter	
small beaker	

Discussion

Auguste Compte, a famous French philosopher of the nineteenth century stated that humans would never know what elements made up the distant stars. Soon thereafter, the understanding of spectra made this knowledge easy to obtain. An element emits light of certain frequencies when heated to high enough temperatures. Different frequencies are seen as different colors, and each element emits (and absorbs) its own pattern of colors. This allows us to identify these elements, whether they are nearby or far away.

Procedure



Step 1: Practice using the spectroscope by looking at an incandescent lamp. The spectrum will appear as a rainbow of colors. Adjust the spectroscope until the spectrum is horizontal and clear.

Step 2: Put on safety goggles. Ignite the Bunsen burner. Adjust it until a blue, nearly invisible flame is obtained.

Step 3: Dip a loop of wire into the bottle of solid sodium chloride. Hold the loop in the flame until the sodium chloride melts and vaporizes. Observe the spectrum of the sodium atoms through the spectroscope. You may also see a long, broad band image due to the glowing wire. Ignore this image. In Data Table A, sketch any major lines you see, in the appropriate position, for the color of the lines.

Step 4: Test each of the other salts as in Step 3. Each wire is to stay in its proper bottle. Mixing the test wires contaminates them. If you should make a mistake and place a wire in the wrong bottle, burn off all the salt until the wire glows red hot, then return it to its proper bottle. In Data Table A, sketch the major lines emitted by each salt.

Adjust spectroscope.



Sketch spectral lines.

Data Table A

SALT OF:	MAJOR SPECTRAL LINES				
	RED	YELLOW	GREEN	BLUE	VIOLET
LITHIUM					
SODIUM					
POTASSIUM					
CALCIUM					
STRONTIUM					
COPPER					

Observe spectrum of mixture.

Step 5: Mix small and equal amounts of the copper and lithium salts in the small beaker. Using the extra test wire, hold a loopful of the mixture in the flame, and observe the resulting spectrum through the spectroscope.

1. Does the spectrum of the mixture of copper and lithium salts contain a combination of the copper and lithium lines?

Step 6: Mix a trace of lithium salt with a larger amount of copper salt. Observe the resulting spectrum through the spectroscope, using the same wire.

2. Did you see the characteristic colors of both copper and lithium?

Analysis

3. How do you know that the bright yellow lines you observed when looking at sodium chloride are due to the sodium and not to the chlorine in the compound?

4. From your observations in Steps 5 and 6, draw conclusions about the relative amounts of metal elements present in each mixture.

5. In steel mills, large amounts of scrap steel of unknown composition are melted to make new steel. Explain how the laboratory technicians in the steel mills can tell exactly what is in any given batch of steel in order to adjust its composition.

74 Satellite TV

Purpose

To investigate a model design for a satellite TV dish.

Required Equipment/Supplies

small transistor radio
large umbrella
aluminum foil

Discussion

When you can barely hear something, you may cup your hand over your ear to capture more sound energy. Does this really work? The answer is yes. In this activity, you will use an umbrella similarly to capture a signal.

Procedure

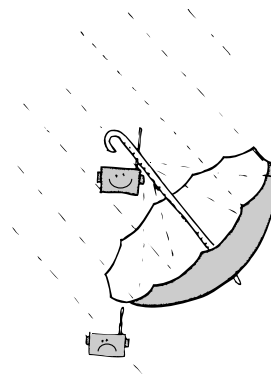
Step 1: Line the inside surface of an open umbrella with aluminum foil.

Step 2: Stand near one of the windows of your classroom. Turn on the radio and locate a weak station. Tune the radio until you get the best reception for that weak station.

Step 3: Have a classmate hold the umbrella horizontally, with the handle pointed at, and just touching, the radio.

Step 4: Move the radio back slowly along the line of the handle until you find the most improved reception for the weak station.

Step 5: Repeat the process in other locations and for other stations.



Repeat with other stations.

Analysis

1. Why did the umbrella improve the reception of the radio?

2. The umbrella is a model of a satellite TV dish. Draw a diagram to show how the model satellite TV dish acts like a concave mirror.

Chapter 29: Reflection and Refraction**Formation of Virtual Images****75 Images****Purpose**

To formulate ideas about how reflected light travels to your eyes.

Required Equipment/Supplies

2 small plane mirrors
 supports for the mirrors
 2 single-hole rubber stoppers
 2 pencils
 2 sheets of paper
 transparent tape

Discussion

Reflections are interesting. Reflections of reflections are fascinating. Reflections of reflections of reflections are . . . you will see for yourself in this activity.

Procedure

Step 1: Place the pencils in the rubber stoppers. Set one plane mirror upright in the middle of a sheet of paper, as shown in Figure A. Stand one pencil vertically in front of the mirror. Hold your eye steady at the height of the mirror. Locate the image of the pencil formed by the mirror. Place the second pencil where the image of the first appears to be. If you have located the image correctly, the image of the first pencil and the second pencil itself will remain “together” as you move your head from side to side.

1. How does the distance from the first pencil to the mirror compare with the distance of the mirror to the image?

Step 2: On the sheet of paper, draw the path you think the light takes from the first pencil to your eye as you observe the image. Draw a dotted line to where the image appears to be located as seen by the observing eye.

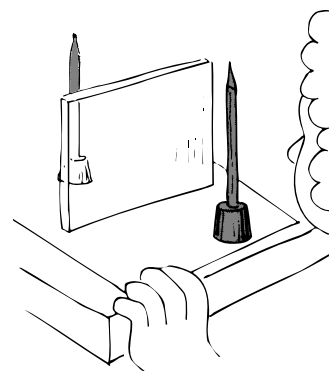


Fig. A

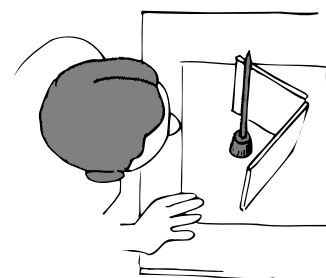


Fig. B

Step 3: Hinge two mirrors together with transparent tape. Set the mirrors upright and at right angles to each other in the middle of a second sheet of paper. Place a pencil in its stopper between the mirrors, as in Figure B.

2. How many images do you see?

Draw ray diagram.

Step 4: On the paper, show where the images are located. Draw the paths you think the light takes as it goes from the pencil to your eye.

Decrease angle between mirrors.

Step 5: Decrease the angle between the two mirrors.

3. What happens to the number of images you get when you decrease the angle between the two mirrors?

Chapter 29: Reflection and Refraction**Multiple Reflections**

76 Pepper's Ghost

Purpose

To explore the formation of mirror images by a plate of glass.

Required Equipment/Supplies

safety goggles
two candles of equal size, in holders
1 thick plate of glass, approximately 30 cm × 30 cm × 1 cm
2 supports for the glass plate
matches

Discussion

John Henry Pepper (1821–1900), a professor in London, used his knowledge of image formation to perform as an illusionist. One of his illusions was based on the fact that glass both reflects and transmits light.

Procedure



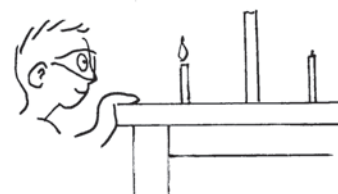
Step 1: Put on safety goggles. Light one candle, and place it about 6 cm in front of a vertical thick glass plate. Place a similar, but unlighted, candle at the position on the other side of the glass plate at the point where the flame of the lighted candle appears to be on the unlighted candle.

1. How does the distance from the lighted candle to the glass plate compare with the distance from the glass plate to the unlighted candle?

Step 2: Look carefully, and you should see a double image of the candle flame.

Find double image.

2. How would you explain the double image?



Activity

Find multiple images.

Step 3: Look at the glass plate such that your line of vision makes a small angle with the surface of the glass. You will see three or more “ghost” images of the candle flame.

3. Explain these “ghost” images.

Chapter 29: Reflection and Refraction**Multiple Reflections****77****The Kaleidoscope****Purpose**

To apply the concept of reflection to a mirror system with multiple reflections.

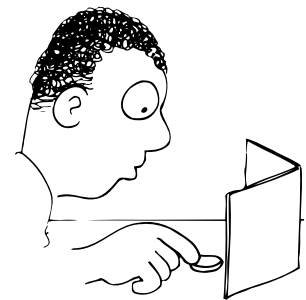
Required Equipment/Supplies

2 plane mirrors, 4 in. \times 5 in.
transparent tape
clay

viewing object
protractor
toy kaleidoscope (optional)

Discussion

Have you ever held a mirror in front of you and another mirror in back of you in order to see the back of your head? Did what you saw surprise you?

**Procedure**

Step 1: Hinge the two mirrors together with transparent tape to allow them to open at various angles. Use clay and a protractor to hold the two mirrors at an angle of 72° . Place the object to be observed inside the angled mirrors. Count the number of images resulting from this system and record in Data Table A.

Step 2: Reduce the angle of the mirrors by 5 degrees at a time, and count the number of images at each angle. Record your findings in Data Table A.

Step 3: Study and observe the operation of a toy kaleidoscope, if one is available.

Analysis

1. Explain the reason for the multiple images you have observed.

ANGLE	NUMBER OF IMAGES
72°	
67°	
62°	
57°	
52°	
47°	
42°	
37°	
32°	
27°	

Data Table A

2. What effect does the angle between the mirrors have on the number of images?

3. Using the information you have gained, explain the construction and operation of a toy kaleidoscope.

Chapter 29: Reflection and Refraction**Images Formed by a Curved Mirror****78 Funland****Purpose**

To investigate the nature, position, and size of images formed by a concave mirror.

Required Equipment/Supplies

concave spherical mirror
cardboard
night-light with clear 7-watt bulb
small amount of modeling clay
meterstick

Optional Equipment/Supplies

computer
data plotting software

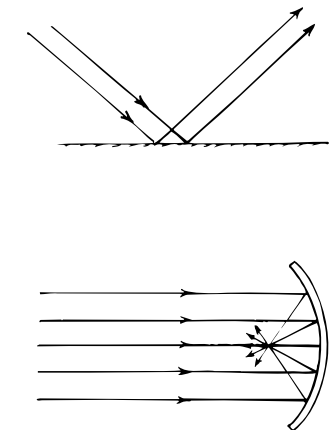
Discussion

The law of reflection states that the angle of reflection equals the angle of incidence. Parallel light rays that strike a plane mirror head on bounce directly backward and are still parallel. If the parallel rays strike that mirror at another angle, each bounces off at the same angle and the rays are again parallel. A plane mirror cannot bring light rays to a focus because the reflected light rays are still parallel and do not converge. Images observed in a plane mirror are always *virtual* images because *real* images are made only by converging light.

A parabolic mirror is able to focus parallel rays of light to a single point (the *focal point*) because of its variable curvature. A small spherical mirror has a curvature that deviates only a little from that of a parabolic curve and is cheaper and easier to make. Spherical mirrors can, therefore, be used to make real images, as you will do in this experiment.

Procedure

Step 1: The distance from the center of a spherical mirror surface to the focal point is called the *focal length*. Measure the focal length of your mirror by having it convert a parallel beam of light into a converging beam that comes to a point on a screen. Use the filament of a lit, clear 7-watt bulb as a source of approximately parallel light and a piece of



Measure focal length of mirror.

cardboard as a screen. Record your measurement below to the nearest 0.1 cm. Also, record the number of your mirror.

focal length = _____ cm

mirror number = _____

Step 2: The rays of light striking your mirror from the bulb may not be exactly parallel. What effect, if any, would this have on your measured value for the focal length? What effect would moving the light source farther away from the mirror have? Increase the distance between the mirror and the light source to see if the focal length changes. (If a better source of parallel light is available, use it to find the focal point of your mirror). Record your measurement to the nearest 0.1 cm.

focal length f = _____ cm

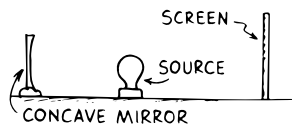


Fig. A

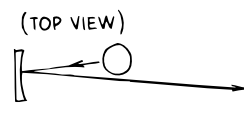


Fig. B

Find a real image with mirror.

Step 3: Use a small amount of modeling clay at the bottom of the mirror to act as a mirror holder. Arrange a screen and a light source as shown in Figure A. Position your screen so that the image is slightly off to one side of the object, as shown in Figure B. Move the mirror so that it is farther than one focal length f from the nightlight. Move the screen to form a sharp image of the filament on the screen. Can a real image be formed on the screen? Is it magnified or reduced, compared with the object? Is the image erect (right-side up) or inverted (upside down)? Record your findings in Data Table A.

Data Table A

POSITION OF OBJECT	NATURE OF IMAGE		
	REAL OR VIRTUAL?	MAGNIFIED?	INVERTED OR ERECT?
BEYOND f			
AT f			
WITHIN f			

d_o (cm)	d_i (cm)

Data Table B

Step 4: Where, in relation to one focal length from the mirror, is the object when the image appears right-side up (erect)? What is the relative size of the image (magnified or reduced) compared with the object? Is the image real or virtual? Record your findings in Data Table A.

Step 5: Is there a spacing between object and mirror for which no image appears at all? Where is the object in relation to the focal length? Record this position in Data Table A.

Step 6: Position the mirror two focal lengths away from the light source. The mirror will then form an image of the filament on a screen placed slightly to one side of the light source. The distance between the focal point and the object is the object distance d_o and the distance between

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the focal point and the image is the image distance d_i . Record the distances d_o and d_i in Data Table B. Move the mirror 5 cm farther away from the light source, and reposition the screen until the image comes back into focus. Progressively extend d_o by repeating these 5-cm movements five more times. Record d_o and d_i each time.

Step 7: Plot d_i (vertical axis) vs. d_o (horizontal axis), then different powers of each to discover the mathematical relation between d_i and d_o . Is there any combination that makes a linear graph through the origin and thus a direct proportion? If available, use data plotting software to plot your data.

1. What mathematical relationship exists between d_i and d_o ?

Step 8: You can locate the position of the image of the object in Figure C using the ray-diagram method. Draw the path of the light rays that leaves the tip of the arrow parallel to the principal axis.

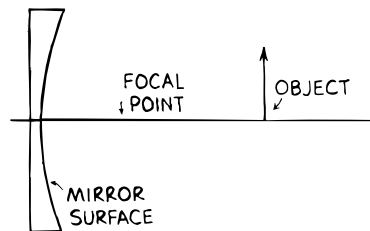


Fig. C

2. Where does this ray go after it is reflected?

Draw the light ray that leaves the tip of the arrow and passes through the focal point.

3. Where does this light ray go after it is reflected?

Now draw the paths of these two light rays after they are reflected. At the point where they cross, an image of the tip of the arrow is formed.

Step 9: Use the ray-diagram method to locate the image of the object in Figure D. Draw the path of the ray that leaves the tip of the arrow parallel to the principal axis and is reflected by the mirror. Trace another ray that heads toward the mirror in the same direction as if it *originated* from the focal point and is reflected by the mirror.

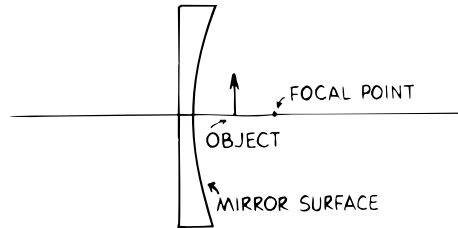


Fig. D

4. Where do the two reflected rays *appear* to cross?

5. Could the image be projected onto a screen? Explain.

79 Camera Obscura

Purpose

To observe images formed by a pinhole camera and to compare images formed with and without a lens.

Required Equipment/Supplies

covered shoe box with a pinhole and a converging lens set in one end,
 an open end opposite, and glassine paper inside the box (as in Figure A)
 piece of masking tape

Discussion

The first camera, known as a *camera obscura*, used a pinhole opening to let light in. The light that passes through the pinhole forms an image on the inner back wall of the camera. Because the opening is small, a long time is required to expose the film sufficiently. A lens allows more light to pass through and still focuses the light onto the film. Cameras with lenses require much less time for exposure, and the pictures have come to be called “snapshots.”

Procedure

Step 1: Use a pinhole camera constructed as in Figure A. Tape the foil flap down over the lens so that only the pinhole is exposed. Hold the camera with the pinhole toward a brightly illuminated scene, such as the scene through a window during the daytime. Light enters the pinhole and falls on the glassine paper. Observe the image of the scene on the glassine paper.

1. Is the image on the screen upside down (inverted)?

2. Is the image on the screen reversed left to right?

Step 2: Now seal off the pinhole with a piece of masking tape, and open the foil door to allow light through the lens. Move the camera around. You can watch people or cars moving by.

Observe images on screen of camera with pinhole.

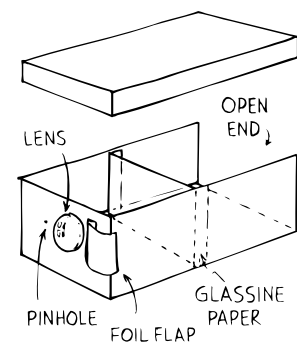


Fig. A

Observe images with lens.

3. Is the image on the screen upside down (inverted)?

4. Is the image on the screen reversed left to right?

Step 3: A pinhole camera focuses equally well on objects at all distances. Point the camera lens at a nearby object to determine whether the lens focuses on nearby objects.

5. Does the lens focus on nearby objects?

Draw ray diagram.

Step 4: Draw a ray diagram as follows. Draw a ray for light that passes from the top of a distant object through a pinhole and onto a screen. Draw another ray for light that passes from the bottom of the object through the pinhole and onto the screen. Show the image created on the screen by the pinhole.

Analysis

6. Why is the image created by the pinhole dimmer than the one created by the lens?

7. How is a pinhole camera similar to your eye? Do you think that the images formed on the retina of your eye are upside down?

Chapter 30: Lenses**Convex and Concave Lenses**

80 Thin Lens

Purpose

To acquire a qualitative understanding of concave and convex lenses.

Required Equipment/Supplies

convex lens
concave lens

Good Stuff software
computer

Discussion

Lenses are not to read about, but to experiment with. Before studying Chapter 30 in the text, some hands-on experience is important for understanding lenses. This activity should help guide you to discover some of their interesting properties.

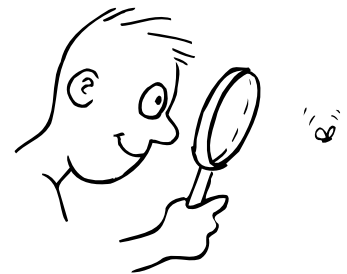
Procedure 

Move an object to different distances from a convex lens and observe the image formed. Select the “Thin Lens” program from *Good Stuff* and the option for a converging lens. A ray diagram consisting of an object arrow and its image as formed by the rays will appear. The *focal length*, f , of the lens is the distance from its center to the point where light parallel to the lens axis (principal axis) converges to a *focus*.

Initially, the object and image are located at a distance $2f$ from the lens. Use the arrow keys to move the object along the principal axis. Is the image larger or smaller than the object? Is the image *erect* (right-side up) or *inverted* (upside down)? Can the image be projected (a *real* image) or not (a *virtual* image)? Is there any position of the object for which no image is formed? Record your observations as to the nature of the image you observe on the computer in Data Table A and Data Table B for both kinds of lenses. Check to see how the image on the screen corresponds to images of objects formed by real lenses in your hand!

Analysis

1. When the image appears right-side up (erect) using a converging lens, how many focal lengths is the object from the lens?
-



2. Under what circumstances is the image formed by a converging lens magnified? Under what circumstances is it reduced? When is it real? When is it virtual?

3. Can an object be located in a position where a converging lens forms no real image?

4. For a diverging lens, is the virtual image enlarged or reduced?

5. Can you form a real image with a diverging lens?

6. When the object is moved, does the image formed by a converging lens always move in the same direction? What about the image formed by a diverging lens?

Data Table A

NATURE OF IMAGE - CONVERGING LENS			
POSITION OF OBJECT	REAL OR VIRTUAL	MAGNIFIED OR REDUCED	INVERTED OR ERRECT
BEYOND 2f			
AT 2f			
AT f			
WITHIN f			

Data Table B

NATURE OF IMAGE - DIVERGING LENS			
POSITION OF OBJECT	REAL OR VIRTUAL	MAGNIFIED OR REDUCED	INVERTED OR ERRECT
BEYOND 2f			
AT 2f			
AT f			
WITHIN f			

Chapter 30: Lenses**Pinhole "Lens"****81****Lensless Lens****Purpose**

To investigate the operation of a pinhole "lens."

Required Equipment/Supplies

3" × 5" card
straight pin
meterstick

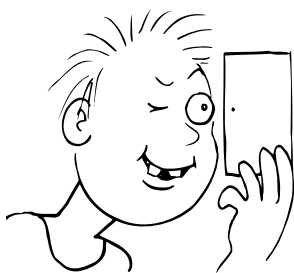
Discussion

The image formed through a pinhole is in focus no matter where the object is located. In this activity, you will use a pinhole to enable you to see nearby objects more clearly than you can without it.

Procedure

Step 1: Bring this printed page closer and closer to your eye until you cannot focus on it any longer. Even though your pupil is relatively small, your eye does not function as a pinhole camera because it does not focus well on nearby objects.

Look at print close up.



Step 2: With a straight pin, poke a pinhole about 1 cm from the edge of a 3" × 5" card. Hold the card in front of your eye and read these instructions through the pinhole. Bright light is needed. Bring the page closer and closer to your eye until it is a few centimeters away. You should be able to read clearly. Quickly take the pinhole away and see if you can still read the words.

1. Did the print appear magnified when observed through the pinhole?

Analysis

2. Did the pinhole actually magnify the print?

3. Why was the page of instructions dimmer when seen through the pinhole than when seen using your eye alone?

4. A nearsighted person cannot see distant objects clearly without corrective lenses. Yet, such a person can see distant objects clearly through a pinhole. Explain how this is possible. (And if you are nearsighted yourself, try it!)

Chapter 30: Lenses**Images Formed by a Convex Lens****82****Bifocals****Purpose**

To investigate the nature, position, and size of images formed by a converging lens.

Required Equipment/Supplies

converging lens
small amount of modeling clay
cardboard
meterstick
night-light with clear, 7-watt bulb

Optional Equipment/Supplies

data plotting software
computer

Discussion

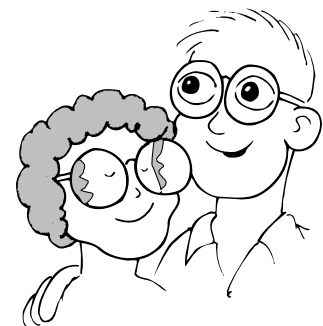
The use of lenses to aid vision may have occurred as early as the tenth century in China. Eyeglasses came into more common use in Europe in the fifteenth century. Have you ever wondered how they work? In Experiment 78, “Funland,” you learned that the size and location of an image formed by a concave mirror is determined by the size and location of the object. In this experiment, you will investigate these relationships for a converging glass lens.

Procedure

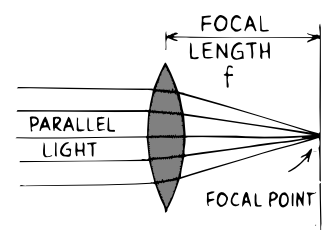
Step 1: A converging lens focuses parallel light rays to a *focal point*. The distance from the center of a lens to the focal point is called the *focal length*, f . Measure the focal length of the lens by having it convert a parallel beam of light into a converging beam that comes to a small spot on a screen. Use the filament of a lit, clear, 7-watt bulb as a source of approximately parallel light and a piece of cardboard as a small screen. Record your measurement below to the nearest 0.1 cm. Also, record the number of your lens.

focal length = _____ cm

lens number = _____



Measure focal length.



Step 2: The rays of light striking the lens may not be parallel. What effect, if any, would this have on your measured value for the focal length? What effect would moving the light source farther away have? Move it farther away and record the focal length to the nearest 0.1 cm. (If a better source of parallel light is available, use it to find the focal length of your lens.)

focal length $f =$ _____ cm

Find inverted image with lens.

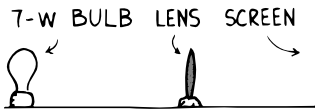


Fig. A

Step 3: Use a small amount of modeling clay at the bottom of the lens as a lens holder. Arrange a screen and a light source as shown in Figure A. Observe the image of the filament on the screen, and move the screen until the image of the filament is as sharp as possible. Where, in relation to one focal length from the lens, is the object when the image appears upside down (inverted)? What is the relative size of the image (magnified or reduced) and the object (the filament)? Is the image real or virtual? Record your findings in Data Table A.

Data Table A

POSITION OF OBJECT	NATURE OF IMAGE		
	REAL OR VIRTUAL?	MAGNIFIED?	INVERTED OR ERECT?
BEYOND f			
AT f			
WITHIN f			

Find erect image with lens.

Step 4: Where, in relation to one focal length from the lens, is the object when the image appears right-side up (erect)? What is the relative size of the image compared with the object? Is the image real or virtual? Record your findings in Data Table A.

Step 5: Is there a distance of the object from the lens for which no image appears at all? If so, what is this distance relative to the focal length? Record this position in Data Table A.

Measure d_i and d_o .

d_o (cm)	d_i (cm)

Step 6: Position the lens two focal lengths away from the light source to form an image on the screen on the other side of the lens as in Figure A. The distance between the object and the focal point closest to it is the distance d_o , and the distance between the other focal point and the image is the image distance d_i . Record the distances d_o and d_i in Data Table B. Move the lens 5 cm farther away from the light source, and reposition the screen until the image comes back into focus. Repeat these 5-cm movements five more times, recording d_o and d_i each time.

Step 7: Plot d_i (vertical axis) vs. d_o (horizontal axis), then different powers of each, to discover the mathematical relation between d_i and d_o . Does any combination give a linear graph through the origin and, thus, a direct proportion? If available, use data plotting software to plot your data.

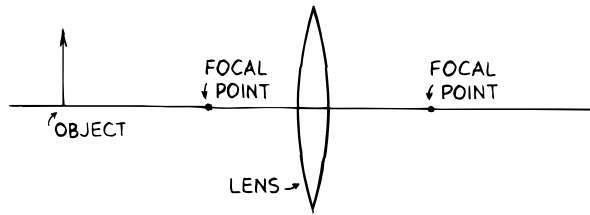
1. What mathematical relationship exists between d_i and d_o ?

Data Table B

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Step 8: You can locate the position of the image in Figure B using the ray-diagram method. Draw the path of the light ray that leaves the tip of the arrow parallel to the principal axis.

Fig. B



2. Where does this ray go after it is refracted?

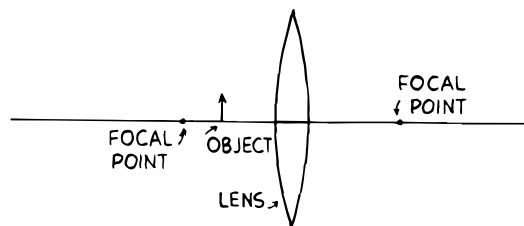
Draw the light ray that leaves the tip of the arrow and passes through the focal point.

3. Where does this light ray go after it is refracted?

Now, draw the paths of these two light rays after they are refracted. At the point where they cross, an image of the tip of the arrow is formed.

Step 9: Use the ray-diagram method to locate the image of the object in Figure C. Draw the path of the ray that leaves the tip of the arrow parallel to the principal axis and is refracted by the lens. Trace another ray that

Fig. C



heads toward the lens in the same direction as if it *originated* from the focal point and is refracted by the lens.

4. Do the refracted rays *actually* cross?

5. Where do they *appear* to cross?

6. Could the image be projected onto a screen?

Going Further

Step 10: Use two converging lenses to see if you can create a magnified image of a distant object. Sketch your arrangement of lenses with their relative positions and focal lengths. (Had you been the *first* person to have discovered, 400 years ago, that two converging lenses can make a telescope, your name would be the answer to questions in science classes today!)

Chapter 30: Lenses**Focal Length of a Diverging Lens**

83 Where's the Point?

Purpose

To measure the focal length of a diverging lens.

Required Equipment/Supplies

low-powered helium-neon laser
diverging lens
sheet of white paper
meterstick
graph paper (if computer is not used)

Optional Equipment/Supplies

computer
data plotting software
printer

Discussion

Parallel light rays are brought to a focus at the focal point of a converging lens. Ray diagrams are useful for understanding this. Parallel light rays are *not* brought to a focus by a diverging lens. Ray diagrams or other techniques are essential for understanding this. In this experiment, you will use a laser to simulate a ray diagram for a diverging lens. Lasers are fun!

Procedure



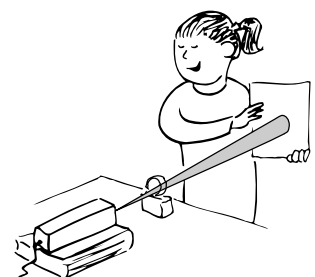
Step 1: Carefully (lasers are delicate!) place the laser on a table. Do not point it at any mirrors, windows, or persons.

Step 2: Place a diverging lens in front of the laser. Turn on the laser. Use the sheet of white paper to observe that the beam is very narrow as it comes out of the laser, but after going through the lens, it spreads out into an ever-widening cone.

Step 3: Place the sheet of paper against a book. Hold the paper 5 cm beyond the lens that is in the laser beam. The red spot made by the beam should be in the center of the paper. With a pen or pencil, trace the outline of the red spot. Label the outline “distance 5 cm.”

Set up laser.

Observe diverging laser beam.



DISTANCE FROM LENS (cm)	DIAMETER OF LASER SPOT(cm)
5	
10	
15	
20	

Data Table A

Step 4: Move the paper 5 cm farther away from the lens, and again trace the outline of the spot that is produced. Label the outline with the new distance. Repeat this procedure, increasing the distance between the lens and the paper by 5-cm intervals, until the spot completely fills the paper.

Step 5: Measure the diameters of the traces of the laser beam on the paper for each position of the paper. Record these diameters and distances from the lens in Data Table A.

Step 6: Plot a graph of the beam diameter (vertical axis) vs. the distance (horizontal axis) between the lens and the paper. Allow room on your graph for negative distances (to the left of the vertical axis.) If available, use data plotting software to plot your data.

Step 7: To find the distance from the lens at which the beam diameter would be zero, extend your line until it intersects the horizontal axis. The negative distance along the horizontal axis is the focal length of the diverging lens. If you are using data plotting software, include a printout of the graph with your lab report.

focal length of lens = _____ cm

Analysis

The focal length of a convex lens is the distance from the lens where parallel light rays are brought to a focus. Why is it impossible to find the focal length of a diverging lens in this manner?

84 Air Lens

Purpose

To apply your knowledge of light behavior and glass lenses to a different type of lens system.

Required Equipment/Supplies

2 depression microscope slides
light source
screen

Discussion

Ordinary lenses are made of glass. A glass lens that is thicker at the center than at the edge is convex in shape, converges light, and is called a converging lens. A glass lens that is thinner at the middle than at the edge is concave in shape, diverges light, and is called a diverging lens.

Suppose you had an air space that was thicker at the center than at the edges and was surrounded by glass. This would comprise a sort of “convex air lens.” What would it do to light? This activity will let you find out.

Procedure

Step 1: A convex air lens encased in glass can be produced by placing two depression microscope slides together, as shown in Figure A.

1. Predict whether this arrangement makes a diverging or converging lens. Explain your prediction.

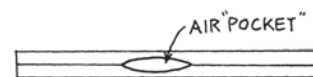


Fig. A

Construct convex air lens.

Step 2: Use your lens with a light source and screen to check your prediction.

2. What do you discover?

Analysis

3. Why is the statement “The shape of a lens determines whether it is a converging or diverging lens” not always true?

4. Draw ray diagrams for both a *convex* and a *concave* air lens encased in glass to show what these lenses do to light rays passing through them.

Chapter 31: Diffraction and Interference**Thin-Film Interference****85****Rainbows Without Rain****Purpose**

To observe and develop a hypothesis about a phenomenon of light interference.

Required Equipment/Supplies

soap-bubble solution
 wire frame for soap films
 large, flat, rimmed pan (such as a cookie sheet)
 oil
 2 microscope slides or glass plates
 2 rubber bands

Discussion

A rainbow is produced by the refraction and reflection of light from drops of water in the sky. Rainbow colors, however, can be produced in a variety of ways. Some of these ways will be explored in this lab activity.

Procedure

Step 1: Pour some of the bubble solution into the flat pan. Place the loop of the wire frame into the solution. Hold the frame in a vertical position. Look at the soap film with the room lights behind you, reflecting off the film.

1. List as many observations as you can of what you saw in the soap film.

2. How would you explain these observations?

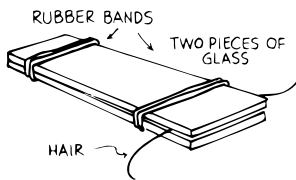
Step 2: During or after a rainfall, you may have noticed brilliant colors on a wet driveway or parking lot where oil has dripped from a car engine. To reproduce this situation, cover the bottom of the pan with a



thin layer of water. Place a drop of oil on the water, and look at the oil slick with various angles of incident light.

3. List as many observations as you can of the oil on the water.

4. How would you explain these observations?



Step 3: Make a very thin wedge of air between two glass plates or microscope slides. You can do this by placing a hair across one end between the two. Fasten both ends together with rubber bands. Try to observe small repeating colored bands in the air wedge.

5. List your observations.

6. How would you explain these observations?

Analysis

7. Summarize any patterns in your observations.

86 Static Cling

Purpose

To observe some of the effects of static electricity.

Required Equipment/Supplies

electroscope
 hard rubber rod and fur *or* glass rod and silk
 plastic golf-club tube
 foam rubber
 Styrofoam (plastic foam) “peanuts” or packing material
 coin with insulated connected string
 empty can from soup or soda pop, with insulated connecting string

Discussion

Have you ever been shocked after walking on a carpet and reaching for a doorknob? Have you ever found your sock hiding inside one of your shirts just after it came out of the clothes dryer? Have you ever seen a lightning bolt from closer range than you might like? All of these situations arise due to *static electricity*. After this activity, you should understand its behavior a bit better.

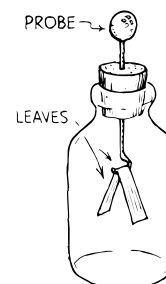
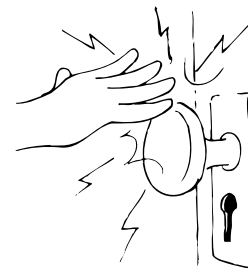
Procedure

Step 1: Make sure the electroscope is discharged (neutral) by touching the probe with your finger. The leaves will drop down as far as possible.

CAUTION: *Do not open the electroscope in an effort to adjust the position of the leaves. NEVER touch the leaves.*

Step 2: Rub a hard rubber rod with fur, or a glass rod with silk. The rubber rod will become negatively charged, while the glass rod will become positively charged. Touch the probe of the electroscope with the charged rod.

1. What happens to the leaves of the electroscope?



2. What kind of charge is on the leaves?

Charge plastic tube.

Step 3: Discharge the electroscope by touching the probe with your finger. Charge a plastic tube by rubbing it with a piece of foam rubber. Observe what happens when you bring the charged tube close to (but not touching) the electroscope, and then move the tube away.

3. Record what happens.

Charge electroscope by induction.

Step 4: Devise a way to leave a charge on the electroscope, using the charged plastic tube but without touching the tube to the probe.

4. Record the method you used to charge the electroscope by induction.

Test charge on electroscope.

Step 5: Test whether the charge on the electroscope is positive or negative by bringing a charged glass or rubber rod close to (but not touching) the probe.

5. Is the charge on the electroscope positive or negative? Explain how you can tell.

Explore Styrofoam "peanuts."

Step 6: Charge the plastic tube. Now put some Styrofoam packing "peanuts" out on the table. Try to pick them up with the charged tube, or pour some over the charged tube. See how many different ways you can make the "peanuts" interact with the charged tube.

6. Describe and explain the behavior of the "peanuts."

Explore charge on tube.

Step 7: Charge the plastic tube by rubbing it with different materials. Each time, charge the electroscope by induction, as in Step 4, and test whether the charge on the electroscope is positive or negative.

Chapter 34: Electric Current**Simple Series and Parallel Circuits****87****Sparky, the Electrician****Purpose**

To study various arrangements of a battery and bulbs and the effects of those arrangements on bulb brightness.

Required Equipment/Supplies

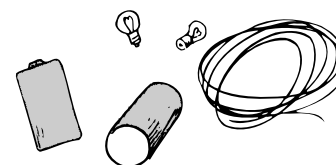
size-D dry cell (battery)
 6 pieces of bare copper wire
 3 flashlight bulbs
 3 bulb holders
 second size-D dry cell (optional)

Discussion

A dry cell (commonly called a battery) is a source of electric energy. Many arrangements are possible to get this energy from dry cells to flashlight bulbs. In this activity, you will test these arrangements to see which makes the bulbs brightest.

Procedure

Step 1: Arrange one bulb (without a holder), one battery, and wire in as many ways as you can to make the bulb emit light. Sketch each of your arrangements, including failures as well as successes. Label the sketches of the successes.



1. Describe the similarities among your successful trials.

Step 2: Use a bulb in a bulb holder (instead of a bare bulb), one battery, and wire. Arrange these in as many ways as you can to make the bulb light.

2. What two parts of the bulb does the holder make contact with?

Step 3: Using one battery, light as many bulbs in holders as you can. Sketch each of your arrangements, and note the ones that work.

3. Compare your results with those of other students. What arrangement(s), using only one battery, made the most bulbs glow?

Step 4: Diagrams for electric circuits use symbols like the ones in Figure A.

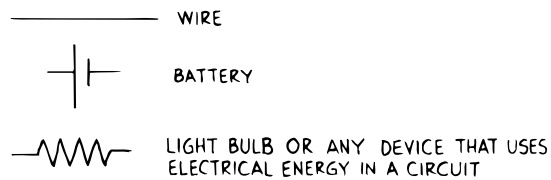


Fig. A

Connect the bulbs in holders, one battery, and wire as shown in each circuit diagram of Figure B. Circuits like these are examples of *series circuits*.

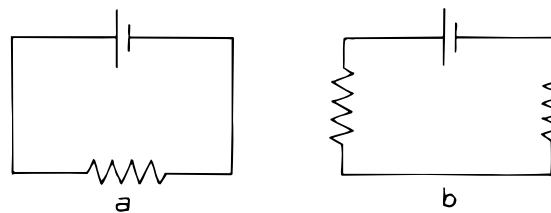


Fig. B

4. Do the bulbs light in each of these series circuits?

Step 5: In the circuit with two bulbs, unscrew one of the bulbs.

5. What happens to the other bulb?

Step 6: Set up the circuit shown in the circuit diagram of Figure C. A circuit like this is called a *parallel circuit*.

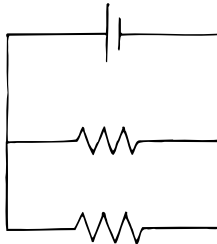


Fig. C

6. Do both bulbs light in this parallel circuit?

Step 7: Unscrew one of the bulbs in the parallel circuit.

7. What happens to the other bulb?

8. In your own words, describe the differences between series and parallel circuits.

Going Further



Step 8: Using two batteries, light as many bulbs as you can. Sketch each of your arrangements, and note the ones that work.

9. What arrangement(s), using two batteries, lit the most bulbs?

Step 9: Using three bulbs and two batteries, discover the arrangements that give different degrees of bulb brightness. Sketch each of your arrangements, and note the bulb brightness on the sketches.

10. How many different degrees of brightness could you obtain using three bulbs and two batteries? Did other students use different arrangements?

88

Brown Out

Purpose

To investigate charging and discharging a capacitor through a bulb.

Required Equipment/Supplies

CASTLE Kit (available from PASCO)

or

- 1 25,000 μF capacitor (20 volts nonpolar)
- 2 #14 lightbulbs (round) (no substitutions allowed!)
- 2 #48 lightbulbs (long) (no substitutions allowed!)
- 4 lightbulb sockets
- 1 packet of 12 alligator leads
- 1 D-cell battery holder and 3 D-cells

Discussion

When you switch on a flashlight, the maximum brightness of the bulb occurs immediately. If a capacitor is in the circuit, however, there is a noticeable delay before maximum brightness occurs. When the circuit contains a capacitor, the flow of charge through the circuit may take a noticeable time. How much time depends upon the resistance of the resistor and the charge capacity of the capacitor. In this activity, we will place a resistor (lightbulb) between the battery and the capacitor to be charged. By using bulbs of different resistances, the charging and discharging times are easily observed.

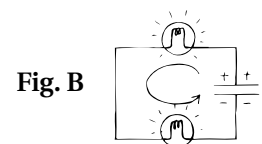
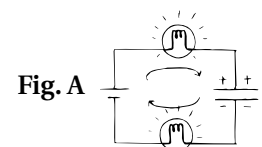
Procedure

Step 1: Connect a battery, two long bulbs, and a blue capacitor (25,000 μF) as shown in Figure A. Leave one wire (lead) to the battery disconnected. Close the circuit by connecting the lead to the battery and observe how long the bulb remains lit. You are *charging the capacitor*.

Step 2: Disconnect the leads from the battery and remove the battery from the circuit. Connect the two leads that were connected to the battery to each other as shown in Figure B. Observe the length of time the bulbs remain lit. This process is called *discharging the capacitor*.

Step 3: Replace the long (#48) bulbs in the circuit with round (#12) bulbs and charge the capacitor. Observe the length of time the bulbs remain lit. Remove the battery from the circuit as in Step 2 and discharge the capacitor through the round bulbs. Observe the time the bulbs remain lit. Which bulbs remain lit longer as the capacitor charges and discharges—long or round bulbs?

Assemble the circuit and charge the capacitor.



To account for the different times the bulbs are lit, we can make the following hypotheses:

- If bulbs affect the amount of charge that passes through them, bulbs that remain lit longer allow more charge to pass through them. The charge would be stored in the capacitor.
- If, however, bulbs affect the rate of charge flow rather than the amount of charge that flows, then bulbs that remain lit longer will increase the time during which charge flows through them.

Charge the capacitor.

Step 4: Charge the capacitor through two long bulbs. Now remove the long bulbs from their sockets and replace them with round bulbs, being careful not to accidentally discharge the capacitor.

1. Suppose the capacitor stores the same amount of charge no matter what type of bulbs are used during charging. Will discharging through round bulbs take more, less, or the same time as in Step 3—when the capacitor was *charged* through round bulbs?

-
2. If, instead, a longer charging time indicates more charge is stored in the capacitor than occurs with a shorter charging time, will discharging now through round bulbs take more, less, or the same time as it did in Step 4?

Discharge the capacitor.

Step 5: Remove the battery from the circuit and discharge the capacitor. Is the time the bulbs remain lit longer, shorter, or the same as in Step 3?

Analysis

3. (a) What is one use of a capacitor?

(b) Does the amount of charge stored in a capacitor depend on the type of bulbs through which it was charged? Explain.

4. Is it true that the type of bulb affects the rate charge flows through it? Why or why not?

89

Ohm Sweet Ohm

Purpose

To investigate how the current in a circuit varies with voltage and resistance.

Required Equipment/Supplies

nichrome wire apparatus with bulb
 2 1.5-volt batteries
 or
 2 Genecon® handheld generators

Discussion

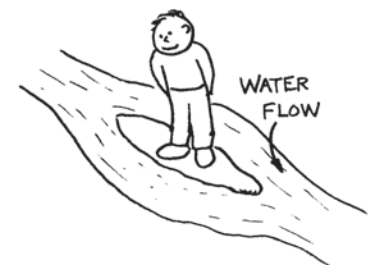
Normally, it is desirable for wires in an electric circuit to stay cool. Red-hot wires can melt and cause short circuits. There are notable exceptions, however. Nichrome wire is a high-resistance wire capable of glowing red-hot without melting. It is commonly used as the heating element in toasters, ovens, stoves, hair dryers, and so forth. In this experiment, nichrome wire is used as a variable resistor. Doubling the length of a piece of wire doubles the resistance; tripling the length triples the resistance, and so on.

Tungsten wire is capable of glowing white-hot and is used as filaments in lightbulbs. Light and heat are generated as the current heats the high-resistance tungsten filament. The hotter the filament, the brighter the bulb. For the same voltage, a bright bulb (such as a 100-watt bulb) has a *lower* resistance than a dimmer bulb (such as a 25-watt bulb). Just as water flows with more difficulty through a thinner pipe, electrical resistance is greater for a thinner wire. Manufacturers make bulbs of different wattages by varying the thickness of the filaments, so we find that a 100-W bulb has a lower resistance and a thicker filament than a 25-W bulb.

In this lab, the brightness of the bulb will be used as a current indicator. A bright glow indicates a large current is flowing through the bulb; a dim glow means a small current is flowing.

Procedure

Step 1: Connect four D-cell batteries in series, so that the positive terminal is connected to the negative terminal in a battery holder as shown in Figure A. This arrangement, with Terminal #1 as ground, will provide you with a variable voltage supply as indicated in Table A.



Assemble the battery with four D-cells.

Data Table A

TERMINAL #'s	VOLTAGE
1-2	1.5
1-3	3.0
1-4	4.5
1-5	6.0

Assemble the circuit and draw a circuit diagram.

Step 2: Assemble the circuit as shown in Figure B. Label one binding post of the nichrome wire "A" and the other "B". Attach the ground lead (#1) of the voltage supply to one side of a knife switch. Connect the other side of the switch to binding Post A on the thickest nichrome wire. Connect the 3-volt lead (#3) from the voltage supply to a clip lead of a test bulb. Attach the other clip lead of the test bulb to the other binding Post B on the nichrome wire.

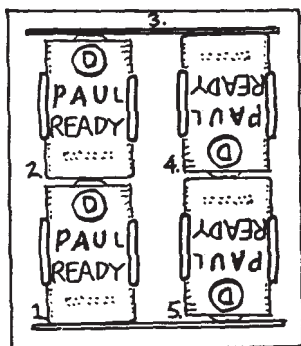


Fig. A

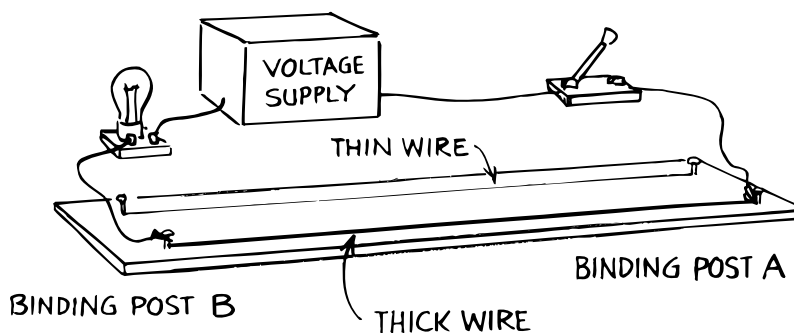


Fig. B

The voltage supply is now connected so that the current passes through two resistances: the bulb and the nichrome wire. You will vary the resistance in the circuit by moving the clip lead of the test bulb from binding Post B to binding Post A. Using the standard symbols for the circuit elements, draw a diagram that represents this *series* circuit.

Note: Always apply power from battery packs by closing a switch and make your measurements quickly. Leave the power on just long enough to make your measurements and then open the switch. Leaving the power on in the circuit for long periods of time will drain your batteries and heat the wire, thereby changing its resistance.

Observe the brightness of the bulb.

Step 3: After carefully checking all your connections, apply power to the circuit by closing the switch. Observe the intensity of the bulb as you move the test bulb lead from binding Post B toward A.

1. What happens to the brightness of the bulb as you move it from Binding Post B to A?

Repeat with thinner wire.

Step 4: Repeat using the thinner nichrome wire. Observe the relative brightness of the bulb as you move the bulb's lead closer to Binding Post A.

2. How does the brightness of the bulb with the thinner wire compare with the brightness of the bulb when connected to a thicker wire?

3. What effects do the thickness and length of the wire have on its resistance?

4. Does the current of the circuit increase or decrease as you move the lead closer to Binding Post B? As you move the lead from B to A, does the resistance of the circuit increase or decrease?

Step 5: Repeat Steps 1–2 using the 4.5 and 6-volt leads instead of the 3-volt leads.

5. How does the brightness of the test bulb compare for the two nichrome wires using 4.5 volts instead of 3 volts?

6. Combining your results from Questions 4 and 5, how does the current in the circuit depend upon voltage and resistance?

Going Further

Step 6: Now insert an ammeter into the circuit as illustrated in Figure C. With the thicker piece of nichrome wire in the circuit, place the ammeter in series with the voltage supply between Terminal #1 of the voltage supply and the switch. The ammeter will read total current in the circuit. Measure the current in the circuit as you move the test bulb lead from B to A. Be sure to apply power *only* while making the measurements to prevent draining the batteries. Repeat using the thinner wire.

Note: *If you are not using a digital meter, you may have to reverse the polarity of the leads if the needle of the meter goes the wrong way (–) when power is applied.*

Install ammeter in the circuit and measure current.

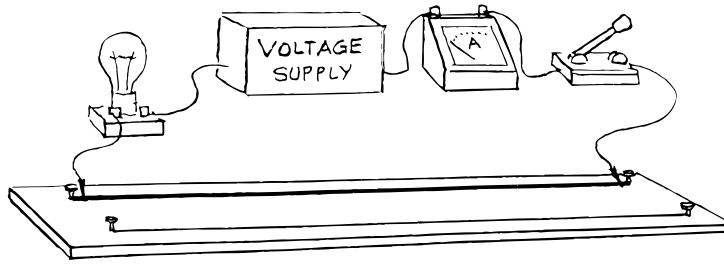


Fig. C

7. Do your results show a decrease in current as the resistance (or length of the wire) is increased?

8. Do your results show an increase in current as the voltage is increased?

9. How do the currents in the thicker and thinner wires compare when the same voltage is applied to the same lengths of wire?

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Getting Wired

Purpose

To build a model that illustrates electric current.

Required Equipment/Supplies

4 D-cells (1.5 volt)
D-cell battery holder
3 alligator clip leads
2 bulbs and bulb holders

Discussion

While we can float on a raft gliding down the Mississippi or ride in cars moving in traffic, nobody can *see* electric current flow. Even in the case of lightning, we are seeing the flash of hot glowing gases produced by electric current—not the current itself. However, we can infer the presence of electric current using lightbulbs and magnetic compasses in much the same way as a flag indicates the presence of wind. In this activity, you will build a *model* to study electric current.

Part A: What Is Happening in the Wires?

Procedure

Step 1: With the circuit arranged as shown in Figure A, turn the bulbs on and off by connecting and disconnecting one of the wires.

Observe the wires when the circuit is closed.

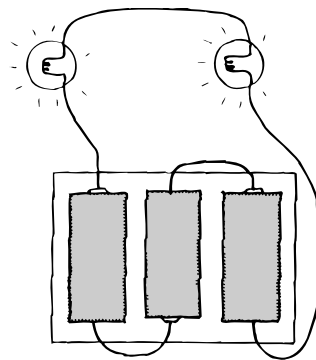


Fig. A

1. Is there any visual evidence that something is moving around the circuit when the bulbs are lit? For example, does one bulb light before the other? Does one bulb go out before the other? Is one bulb brighter than the other?

Position a compass underneath the wire.

Step 2: Place a magnetic compass on the table near the circuit with the needle pointing to the “N.” With the bulbs unlit, place one of the wires on top of the compass parallel to the needle as in Figure B. Connect and disconnect a lead in the circuit several times while you observe the compass needle. Observe what happens to the needle when the bulb lights. Observe what happens to the needle when the bulbs go out.

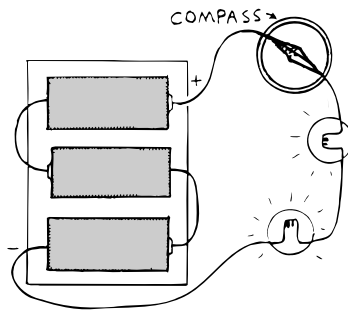


Fig. B

Step 3: Place the compass beneath the wire in different parts of the circuit. Be sure the needle is parallel to the wire when the bulbs are not lit. Observe the needle as you open and close the circuit several times. Look to see if the needle deflects in the same direction as before. Look to see if the amount of the needle’s deflection is the same as before. Also, observe whether the bulbs must be lit to deflect the compass needle.

2. What evidence supports the notion that something is happening in the wires while the bulbs are energized?

3. What evidence supports the notion that whatever is happening occurs uniformly in all parts of the circuit?

Part B: Is There Directionality to What Is Happening in the Circuit?

Step 4: Arrange the circuit as in Figure A. Place one of the wires on top of the compass parallel to the needle. Open and close the circuit while you carefully observe the needle. Note whether the needle deflects clockwise or counterclockwise.

Observe the deflection of the compass.

Step 5: Reverse the leads from the battery without altering the circuit and compass. Do this by simply exchanging the lead connected to the positive terminal of the battery with the lead connected to the negative terminal. Open and close the circuit while you watch the compass needle. Watch the needle deflect and note whether it is clockwise or counterclockwise.

Reverse the leads from the battery and observe the deflection of the compass.

4. Is the direction of the deflection the same as in Step 4, before the leads to the battery were reversed? Is the amount of the needle's deflection the same as before?

5. Suppose something is flowing in the wires. Do you think the *direction* the needle is deflected is caused by the amount of the flow or the direction of the flow?

Step 6: Remove one of the D-cells from the battery holder so that the battery holder only has two cells instead of three. Carefully observe deflection of the needle while you repeat Steps 4 and 5.

Remove one of the cells from the battery.

6. How do the size and direction of the compass needle's deflections compare when you use two cells instead of three?

Step 7: Install two more D-cells in the battery holder so that it has four D-cells. Carefully observe deflection of the needle as you repeat Steps 4 and 5.

Add two cells to the battery.

7. How do the deflections of the compass needle compare with those with two and three D-cells? Do you think the *size* of the needle's deflection is caused by *amount of the flow* or the *direction of the flow*?

Analysis

8. Hypothesize what is happening in the circuit when bulbs are lit.

9. Hypothesize what is happening in the circuit when the direction of the compass deflection reverses.

10. Hypothesize what is happening in the wires when the amount of the needle's deflection increases or decreases.

11. What do you think the battery does?

91 Cranking Up

Purpose

To observe and compare the work done in a series circuit and the work done in a parallel circuit.

Required Equipment/Supplies

4 lightbulbs, sockets and clip leads
Genecon
parallel bulb apparatus

voltmeter
ammeter

Discussion

Part A: Qualitative Investigation

Step 1: Assemble four bulbs in series as shown in Figure A. Screw all the bulbs into their sockets. Connect the sockets with clip leads.

Connect one lead of a Genecon to one end of the string of bulbs and the other lead to the other end of the string. Crank the Genecon so that all the bulbs light up. Now, disconnect one of the bulbs from the string and reconnect the Genecon. Crank the Genecon so that the three remaining bulbs are energized to the same brightness as the four-bulb arrangement. How does the crank feel now? Repeat, removing one bulb at a time and comparing the cranking torque each time.

Assemble the circuit and crank the Genecon as you unscrew bulbs in series.

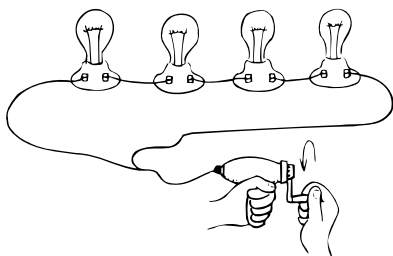


Fig. A

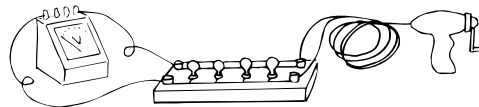


Fig. B

Step 2: Assemble the circuit with the parallel bulb apparatus as shown in Figure B. Each end of the bulb apparatus has two terminals. Connect the leads of a voltmeter to one pair of terminals on one end of the apparatus. Connect the leads of the Genecon to the terminals on the other end of the apparatus. Crank the Genecon with all the bulbs unscrewed in the sockets so that they don't light. Then, have your partner screw them in one at a time as you crank on the Genecon. Try to keep the bulbs energized at the same brightness as each bulb is screwed into its socket.

Assemble the parallel circuit and crank the Genecon as you screw in the bulbs.

1. What do you notice about the *torque* required to crank the Genecon at a constant speed as more bulbs are added to the circuit?

2. How would you describe the amount of torque required to crank the Genecon to energize four bulbs in series compared with that required for four bulbs in parallel?

3. If all the bulbs in the series and parallel circuits are glowing equally brightly, is the energy expended (the work you are doing to crank the Genecon) the same?

Part B: Quantitative Investigation— Resistors in Series

Now repeat Part A in a quantitative fashion using a voltmeter and an ammeter.

Assemble the circuit in series.

Step 3: Assemble four bulbs in a series circuit and connect the meters as shown in Figure C. Connect the voltmeter in parallel with all four bulbs so you can measure the total voltage applied to the circuit. Then you will connect it in parallel with single bulbs to measure the voltage across each bulb. Connect the 3-volt lead from the voltage supply to one terminal of the bulbs and the ground connection to one lead of an ammeter. Connect the other lead of the ammeter to the second terminal of the bulbs. The ammeter will measure the *total* current in the circuit.

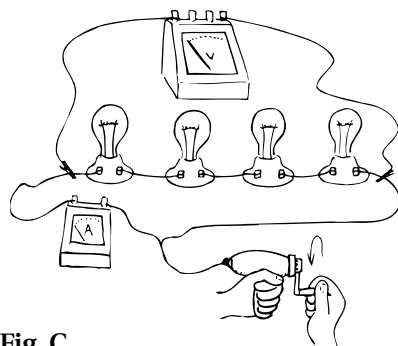


Fig. C

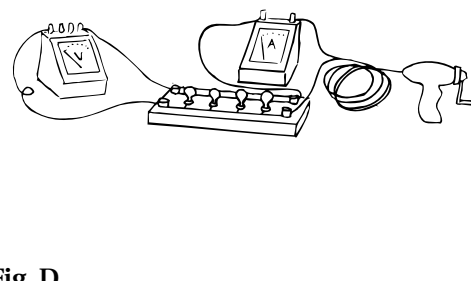


Fig. D

Note: If you are not using digital meters, you may have to reverse the polarity of the leads if the needle of the meter goes the wrong way (–) when power is applied.

Close the switch, apply power to the circuit, and measure the current in the circuit, the voltage applied to the circuit, and the voltage across each bulb. Record your results in Data Table A.

Step 4: Now remove one of the bulbs from the string, close the gap in the circuit, and repeat your measurements for three bulbs. Then remove the other bulbs one at a time, closing the gap in the circuit each time, and repeat the measurements. Record your data in Data Table A.

# BULBS	TOTAL CURRENT (A)	TOTAL VOLTAGE (V)	VOLTAGE ACROSS EACH BULB (V)			
1						
2						
3						
4						

Data Table A

# BULBS	TOTAL CURRENT (A)	TOTAL VOLTAGE (V)	VOLTAGE ACROSS EACH BULB (V)			
1						
2						
3						
4						

Data Table B

Step 5: Repeat using the 4.5-volt terminal of the voltage supply instead of the 3-volt terminal. Record your data in Data Table B.

Repeat using a different voltage.

4. Is there any change in brightness as the number of bulbs changes?

5. Does the voltage applied in the circuit change as you add more bulbs?

6. How are the voltages across each bulb related to the applied voltage?

7. How does the current supplied by the battery change when more bulbs are added?

8. Did any of the rules you discovered relating voltages and currents change when you applied 4.5 volts instead of 3 volts?

Part C: Quantitative Investigation—Resistors in Parallel

Step 6: Assemble the circuit and connect the meters as shown in Figure D. Connect the voltmeter in parallel with the bulbs by connecting the voltmeter to two terminals on one end of the parallel bulb apparatus. Connect the 3-volt lead from the voltage supply to one terminal of the parallel bulb apparatus. Connect the ground lead from the voltage supply to one lead of an ammeter; connect the other lead of the ammeter to the second terminal of the parallel bulb apparatus. The ammeter will measure the total current in the circuit.

Assemble the circuit in parallel.

Make sure the bulbs are not loose in their sockets. Close the switch and apply power to the circuit. Observe the brightness of the bulbs, then unscrew the bulbs one at a time.

Record your measurements of current and voltage.

Step 7: Screw the bulbs back in, one at a time, each time measuring the current in the circuit, the voltage applied to the circuit, and the voltage drop across each bulb. Record your data in Data Table C.

# BULBS	TOTAL CURRENT (A)	TOTAL VOLTAGE (V)	VOLTAGE ACROSS EACH BULB (V)		
1					
2					
3					
4					

Data Table C

# BULBS	TOTAL CURRENT (A)	TOTAL VOLTAGE (V)	VOLTAGE ACROSS EACH BULB (V)		
1					
2					
3					
4					

Data Table D

Repeat using a different voltage.

Step 8: Repeat Steps 3 and 4 using the 4.5-volt terminal of the voltage supply instead of the 3-volt terminal. Record your data in Data Table D.

9. Is there any change in brightness as the number of bulbs changes?

10. Does the voltage across each bulb change as more bulbs are added to or subtracted from the circuit?

11. Does the applied voltage to the circuit change as you add more bulbs?

12. How does the current supplied by the battery change as the number of bulbs in the circuit changes?

13. Did the ratio of voltage and current change when you applied 4.5 volts instead of 3 volts?

92

3-Way Switch

Purpose

To explore ways to turn a lightbulb on or off from either one of two switches.

Required Equipment/Supplies

2.5-V dc lightbulb with socket
 connecting wire
 2 single-pole double-throw switches
 2 1.5-V size-D dry cells connected in series in a holder

Discussion

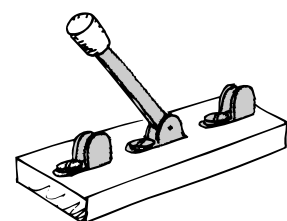
Frequently, multistory homes have hallways with ceiling lights. It is convenient if you can turn a hallway light on or off from a switch located at either the top or bottom of the staircase. Each switch should be able to turn the light on or off, regardless of the previous setting of either switch. The same arrangement is often adopted in a room with two doors. In this activity, you will see how simple, but tricky, such a common circuit really is!

Procedure

Step 1: Examine a 3-volt battery (formed from two 1.5-volt dry cells with the positive terminal of one connected to the negative terminal of the other). Connect a wire from the positive terminal of the battery to the center terminal of a single-pole double-throw switch. Connect a wire from the negative terminal of the same battery to one terminal of the lightbulb socket. Connect the other terminal of the lightbulb socket to the center terminal of the other switch.

Step 2: Now interconnect the free terminals of the switches so that the bulb turns on or off from either switch. That is, when both switches are closed in either direction, moving either switch from one side to the other will always turn an unlit bulb on or a lit bulb off.

Step 3: Draw a simple circuit diagram of your successful circuit.



SINGLE POLE
DOUBLE-THROW SWITCH

Devise working circuit.

Diagram 3-way switch.

Reverse polarity of battery.

Step 4: The polarity of a battery can be reversed in a circuit by switching the connections to the positive and negative terminals. Predict whether your successful circuit will work if you reverse the polarity of the battery.

prediction: _____

Now reverse the polarity and record the result.

result: _____

Interchange battery and bulb.

Step 5: Predict whether your successful circuit will work if you reconnect the circuit so that the battery is where the lightbulb is now, and vice versa.

prediction: _____

Now try it and record your results.

results: _____

Analysis

An ordinary switch has an “on” setting, which closes the circuit at that point, and an “off” setting, which opens the circuit at that point. On the switches you used in this activity, what function do the two “closed” settings on each switch have? Can either setting keep the circuit open independently of how the other switch is set?

Chapter 36: Magnetism**Magnetic Field Lines****93****3-D Magnetic Field****Purpose**

To explore the shape of magnetic fields.

Required Equipment/Supplies

2 bar magnets
iron filings
strong horseshoe magnet
sheet of clear plastic

5 to 10 small compasses
jar of iron filings in oil
paper

Discussion

A magnetic field cannot be seen directly, but its overall shape can be seen by the effect it has on iron filings.

Procedure

Step 1: Vigorously shake the jar of iron filings. Select the strongest horseshoe magnet available. Place the jar over one of the poles of the magnet and observe carefully. Place the jar at other locations around the magnet to observe how the filings line up.

1. What happened to the iron filings when they were acted upon by the magnetic field of the magnet?

Step 2: From all your observations, draw a sketch showing the direction of the magnetic field all around your magnet, as observed from the side. Also, draw a sketch as viewed from the end of the magnet.



Sketch magnetic field.

Observe orientation of compasses.

Step 3: Obtain two bar magnets and 5 to 10 small compasses. Note which end of each compass points toward the north. As you proceed with the activity, represent each compass as an arrow whose point is the north-pointing end.

Trace magnetic field lines.

Step 4: Trace one of the bar magnets on a piece of paper. Move the compasses around the magnet, and use arrows to draw the directions they point at each location. Link the arrows together by continuous lines to show the magnetic field.

Sketch magnetic field lines.

Step 5: Obtain a small quantity of iron filings and a sheet of clear plastic. Place the plastic on top of one of the bar magnets, and sprinkle a small quantity of iron filings over the plastic. It may be necessary to gently tap or jiggle the plastic sheet. The filings will line themselves up with the magnetic field. In the following space, sketch the pattern that the filings make. Repeat this step using the other bar magnet.

Repeat using two magnets.

Step 6: Repeat Step 5 for two bar magnets with like poles facing each other, such as N and N or S and S, and with unlike poles facing each other. Sketch the pattern of the filings in both situations.

2. Compare the methods of Steps 4 and 5 in terms of their usefulness in obtaining a quick and accurate picture of the magnetic field.

3. Are there any limitations to either method?

4. What generalizations can you make about magnetic field lines?

Chapter 36: Magnetism**Force on Moving Charges**

94 You're Repulsive

Purpose

To observe the force on an electric charge moving in a magnetic field, and the current induced in a conductor moving in a magnetic field.

Required Equipment/Supplies

cathode ray oscilloscope or computer with monitor
 horseshoe magnet
 bar magnet
 compass
 50 cm insulated wire
 galvanometer or sensitive milliammeter
 masking tape

Discussion

In this lab activity, you will explore the relationship between the magnetic field of a horseshoe magnet and the force that acts on a beam of electrons that move through the field. You will see that you can deflect the beam with different orientations of the magnet. If you had more control over the strength and orientation of the magnetic field, you could use it to “paint” a picture on the inside of a cathode ray tube with the electron beam. This is what happens in a television set.

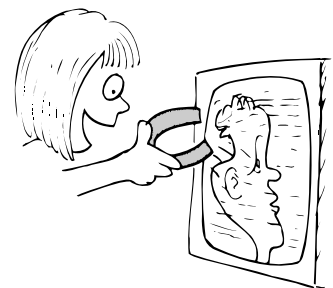
A moving magnetic field can do something besides make a television picture. It can induce the electricity at the generating station to power the television set. You will explore this idea, too.

Procedure

Step 1: If you are using an oscilloscope, adjust it so that only a spot occurs in the middle of the screen. This will occur when there is no horizontal sweep.

If you are using a computer monitor for the cathode ray tube, use a graphics program to create a spot at the center of the screen. Make a white spot on a black background.

CAUTION: Do not bring a strong, demonstration magnet near a color TV or monitor.



Adjust monitor or oscilloscope so dot is centered.

1. The dot on the screen is caused by an electron beam that hits the screen. In what direction are the electrons moving?

Make sketches of different orientations of the magnet.

Step 2: If the north and south poles of your magnets are not marked, use a compass to determine whether a pole is a north or south pole, and label it with tape.

CAUTION: *Do not use large, demonstration magnets in this activity. Such magnets should not be brought close to any cathode ray tube, as they can cause permanent damage.*

Place the poles of the horseshoe magnet 1 cm from the screen. Try the orientations of the magnet shown in Figure A. Sketch arrows on Figure A to indicate the direction in which the spot moves in each case. Try other orientations of the magnet, and make sketches to show how the spot moves.

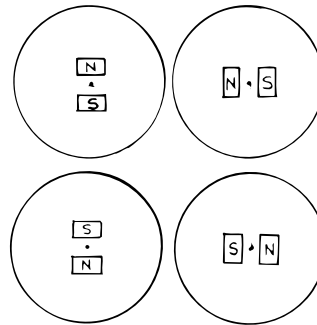


Fig. A

2. Recall that the magnetic field lines outside a magnet run from the north pole to the south pole. The spot moves in the direction of the magnetic force on the beam. How is the direction of the magnetic force on the beam related to the direction of the magnetic field?

Note effects of bar magnet on spot.

Step 3: Aim one pole of a bar magnet directly toward the spot. Record your observations.

Step 4: Change your aim so that the pole of the bar magnet points to one side of the spot. Record your observations.

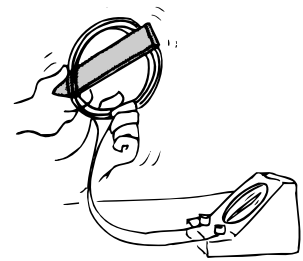
3. In general, what are the relative directions of the electron beam, the magnetic field, and the magnetic force on the beam for maximum deflection of the electron beam?

Step 5: With a long insulated wire, make a three-loop coil with a diameter of approximately 8 cm. Tape the loops together. Connect the ends of the wire to the two terminals of a galvanometer or sensitive milliammeter. Explore the effects of moving a bar magnet into and out of the coil to induce electric current and cause the galvanometer to deflect. Vary the directions, poles, and speeds of the magnet. Also, vary the number of loops in the coil, and try different strengths of magnets.

4. Under what conditions can you induce the largest current and get the largest deflection of the galvanometer?

5. What do you need to do to cause the galvanometer to deflect in the opposite direction?

Explore how moving magnet affects coil of wire.



95

Jump Rope Generator

Purpose

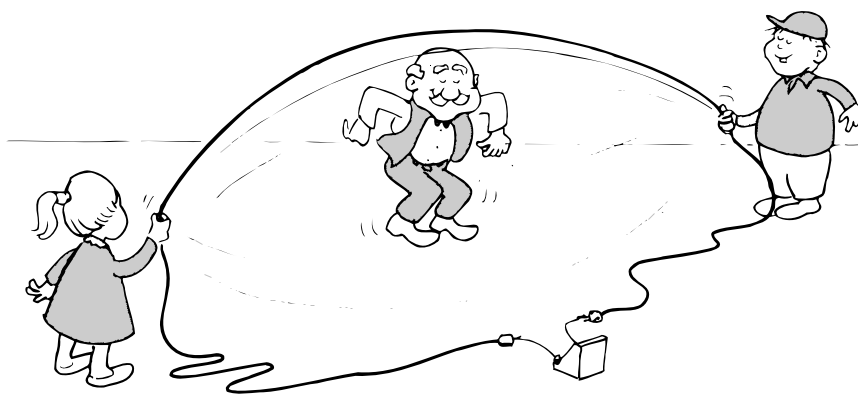
To demonstrate the generator effect of a conductor cutting through the earth's magnetic field.

Required Equipment/Supplies

50-ft extension cord with ground prong
galvanometer
2 lead wires with alligator clips at one end

Discussion

When the net magnetic field threading through a loop of wire is changed, a voltage and, hence, a current are induced in the loop. This is what happens when the armature in a generator is rotated, when an iron car drives over a loop of wire embedded in the roadway to activate a traffic light, and when a piece of wire is twirled like a jump rope in the earth's magnetic field.

**Procedure**

Step 1: Attach an alligator clip to the ground prong of the extension cord (see Figure A). Attach the wire's other end to the galvanometer. Jam the other alligator clip into the ground receptacle on the other end of the extension cord. Attach the other end of this second wire to the other contact on the galvanometer.

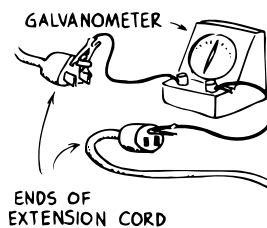


Fig. A

Jump rope with the extension cord.

Step 2: Align the extension cord in the east-west direction. Leaving both ends of the extension cord on the ground, pick up the middle half and twirl it like a jump rope with the help of another person. Observe the galvanometer. Twirl the cord faster, and observe the galvanometer.

1. What effect does the rotational speed of the cord have on the deflection of the galvanometer?

Change directions.

Step 3: Repeat Step 2, but align the extension cord in the north-south direction. Observe the difference in the deflection on the galvanometer.

2. Is it harder to spin the cord in one direction or the other?

Analysis

3. Describe the conditions in which you had maximum current through the galvanometer.

4. Describe the conditions in which you had minimum current through the galvanometer.

96

Particular Waves

Purpose

To observe the photoelectric effect.

Required Equipment/Supplies

electroscope
 electrostatic kit, containing strips of white plastic and clear acetate and swatches of wool and silk
 zinc plate (approximately 5 cm × 5 cm × 0.1 cm) or magnesium ribbon, 10 cm long
 steel wool
 lamp with 200-watt bulb
 60-watt ultraviolet light source (mercury vapor lamp)

Discussion

Albert Einstein was best known for his discovery of special and general relativity. Interestingly enough, he was awarded the Nobel Prize for something entirely different—the rules governing the photoelectric effect. In this activity, you will observe the photoelectric effect, which is the ejection of electrons from certain metals (in this case, zinc or magnesium) when exposed to light.



Activity

Procedure

Step 1: Scrub the zinc plate (or magnesium ribbon) with the steel wool to make it shiny; then place the plate on the probe of the electroscope.

Scrub metal until shiny.

Step 2: Rub the white plastic strip with the wool cloth to charge the strip negatively. Touch the strip to the zinc plate on the electroscope. Notice that the leaves separate—evidence that the electroscope is charged.

Observe electroscope.

Step 3: Observe the leaves of the electroscope for one minute.

1. Did the electroscope discharge by itself during that time?

Step 4: Touch the zinc plate on the electroscope with your finger. Note that the electroscope discharges.

2. Why did the electroscope discharge when you touched it?

Step 5: Rub the clear acetate strip with the silk cloth to charge the strip positively. Touch the strip to the zinc plate on the electroscope. Observe the leaves for one minute. Now touch the zinc plate to see whether the electroscope discharges.

3. Describe what happened to the electroscope from the time you touched the charged acetate strip to the zinc plate.

Shine white light from 200-watt bulb on zinc plate.

Step 6: Perhaps electrons can be “blown away” from a negatively charged electroscope by bombarding it with high-intensity light. Charge the electroscope negatively, as in Step 2. Shine white light from a 200-watt lightbulb onto the zinc plate from a distance of 10 cm.

4. How does the electroscope react to the high-intensity white light?

Shine weak ultraviolet light on zinc plate.

Step 7: Recharge the electroscope negatively if its leaves have dropped. Now shine light from a 60-watt ultraviolet light source on the zinc plate.

5. How does the electroscope react to the weak, ultraviolet light?

Step 8: Possibly the ultraviolet light is somehow making the air conductive. Charge the strip with a positive charge as in Step 5, and shine the ultraviolet light on the zinc plate again.

6. Does the electroscope discharge?

Step 9: In Data Table A, indicate in each box whether or not the electroscope discharged during your tests.

	BRIGHT VISIBLE LIGHT CAUSED THE ELECTROSCOPE TO:	WEAK ULTRAVIOLET LIGHT CAUSED THE ELECTROSCOPE TO:
NEGATIVELY CHARGED ELECTROSCOPE		
POSITIVELY CHARGED ELECTROSCOPE		

Data Table A

Analysis

7. If the *intensity* of the light is responsible for discharging the electroscope, which light source should discharge the electroscope better?

8. If the electroscope could not be discharged by high-intensity white light, but was discharged by weak, ultraviolet light, the *intensity* of the light did not cause it to discharge. How is ultraviolet light different from visible light?

9. Although light is a wave phenomenon, it also behaves like a stream of particles called *photons*. Each photon carries a discrete amount of energy. When a photon is absorbed, its energy is given to whatever absorbs it. According to your data, which type of photons seem to have more energy—those of visible light or those of ultraviolet light?

10. The energy of a photon is proportional to the frequency of the light. Photons of ultraviolet light possess enough energy to “kick free” electrons trapped in the zinc metal. When the electroscope was positively charged, why did it not discharge when it was exposed to ultraviolet light?

11. Which would be better at discharging a negatively charged electroscope, an infrared heat lamp or a dentist’s X-ray machine? Why?

97

Nuclear Marbles

Purpose

To determine the diameter of a marble by indirect measurement.

Required Equipment/Supplies

7 to 10 marbles

3 metersticks

Discussion

People sometimes have to resort to something besides their sense of sight to determine the shape and size of things, especially for things smaller than the wavelength of light. One way to do this is to fire particles at the object to be investigated, and to study the paths of the particles that are deflected by the object. Physicists do this with particle accelerators. Ernest Rutherford discovered the tiny atomic nucleus in his gold-foil experiment. In this activity, you will try a simpler but similar method with marbles.

You are not allowed to use a ruler or meterstick to measure the marbles directly. Instead, you will roll other marbles at the target “nuclear” marbles and, from the percentage of rolls that lead to collisions, determine their size. This is a little bit like throwing snowballs at a tree trunk while blindfolded. If only a few of your throws result in hits, you can infer that the trunk is small.

First, use a bit of reasoning to arrive at a formula for the diameter of the nuclear marbles (NM). Then, at the end of the experiment, you can measure the marbles directly and compare your results.

When you roll a marble toward a nuclear marble, you have a certain probability of a hit between the rolling marble (RM) and the nuclear marble (NM). One expression of the probability P of a hit is the ratio of the path width required for a hit to the width L of the target area (see Figure A). The path width is equal to two RM radii plus the diameter of the NM, as shown in Figure B. The probability P that a rolling marble will hit a lone nuclear marble in the target area is

$$P = \frac{\text{path width}}{\text{target width}}$$

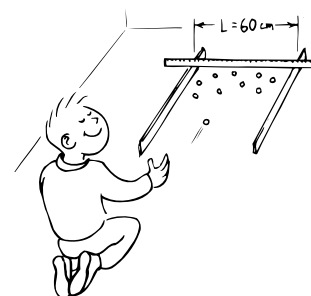
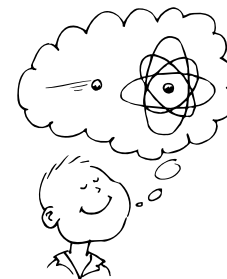


Fig. A

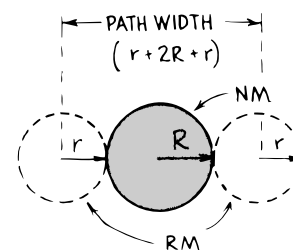


Fig. B

$$= \frac{2R + 2r}{L} = \frac{2(R + r)}{L}$$

where R = the radius of the NM

r = the radius of the RM

$R + r$ = the distance between the centers of an RM and an NM that are touching

and L = the width of the target area.

If the number of nuclear marbles is increased to N , the probability of a hit is increased by a factor of N (provided N is small enough that the probability of multiple collisions is small). Thus, the probability that the rolling marble will hit one of the N widely spaced nuclear marbles is

$$P = \frac{2N(R + r)}{L}$$

The probability of a hit can also be determined experimentally by the ratio of the number of hits to the number of trials.

$$P = \frac{H}{T}$$

where H = the number of hits

and T = the number of trials.

You now have two expressions for the probability of a hit. These two expressions may be equated. If the radii of the rolling marble and nuclear marble are equal, then $R + r = d$, where d is the diameter of any of the marbles. Combine the last two equations for P , and write an expression for d in terms of H , T , N , and L .

marble diameter $d =$ _____

This is the formula you are now going to test.

Procedure

Set up nuclear targets.

Step 1: Place 6 to 9 marbles in an area 60 cm wide ($L = 60$ cm), as in Figure A. Roll additional marbles randomly, one at a time, toward the whole target area from the release point. If a rolling marble hits two nuclear marbles, count just one hit. If a rolling marble goes outside the 60-cm-wide area, do not count that trial. A significant number of trials—more than 200—need to be made before the results become statistically significant. Record your total number of hits H and total number of trials T .

$H =$ _____

$T =$ _____

Step 2: Use your formula from the Discussion to find the diameter of the marble. Show your work.

computed diameter = _____

Step 3: Measure the diameter of one marble.

measured diameter = _____

Analysis

1. Compare your results for the diameter determined indirectly in the collision experiment and directly by measurement. What is the percentage difference in these two ways of measuring the diameter?

2. State a conclusion you can draw from this experiment.

Chapter 39: The Atomic Nucleus and Radioactivity**Half-Life****98****Half-Life****Purpose**

To develop an understanding of half-life and radioactive decay.

Required Equipment/Supplies

shoe box and lid
200 or more pennies
graph paper

Optional Equipment/Supplies

jar of 200 brass fasteners
computer
data plotting software

Discussion

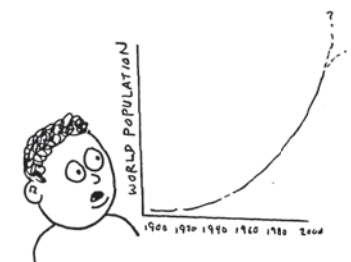
Many things grow at what is called an exponential rate: population, money bearing interest in the bank, and the thickness of paper that is repeatedly folded over onto itself. Many other things decrease exponentially: the value of money stuffed under a mattress, the amount of vacant area in a place where population is growing, and the remaining amount of a material that is undergoing radioactive decay. A useful way to describe the rate of decrease is in terms of *half-life*—the time it takes for the quantity to be reduced to half its initial value. For *exponential* decrease, the half-life stays the same. This means that the time to go from 100% of the quantity to 50% is the same as the time to go from 50% to 25% or from 25% to 12.5%, or from 4% to 2%.

Radioactive materials are characterized by their rates of decay and are rated in terms of their half-lives. You will explore this idea in this activity.

Procedure

Step 1: Place the pennies in a shoe box, and place the lid on the box. Shake the box for several seconds. Open the box and remove all the pennies with the head-side up. Count these and record the number in Data Table A. Do *not* put the removed pennies back in the box.

Step 2: Repeat Step 1 over and over until one or no pennies remain. Record the number of pennies removed each time in Data Table A.



Remove all pennies with head-side up.

Repeat Step 1.

TOTAL PENNIES:					
SHAKE NUMBER	NUMBER OF PENNIES REMOVED	NUMBER OF PENNIES REMAINING	SHAKE NUMBER	NUMBER OF PENNIES REMOVED	NUMBER OF PENNIES REMAINING
1			6		
2			7		
3			8		
4			9		
5			10		

Data Table A

Compute number of pennies remaining each time.

Step 3: Add the numbers of pennies removed to find the total number of pennies. Now, find the number of pennies remaining after each shake by subtracting the number of pennies removed each time from the previous number remaining, and record in Data Table A.

Plot your data.

Step 4: Graph the number of pennies remaining (vertical axis) vs. the number of shakes (horizontal axis). Draw a smooth line that best fits the points.

Analysis

1. What is the meaning of the graph you obtained?

2. Approximately what percent of the remaining pennies were removed on each shake? Why?

3. Each shake represents a half-life for the pennies. What is meant by a half-life?

Going Further

Step 5: Shake a jar of brass paper fasteners and pour them onto the table. Remove the fasteners that are standing on their heads, as you did the pennies with the head side up. Repeat until all the fasteners are gone.

Step 6: Plot your data on the computer, using data plotting software. Try to discover what changes in the value of your vertical or horizontal axis will make your graph come out a straight line. Ask your teacher for assistance if you need help.

99

Chain Reaction

Purpose

To simulate a simple chain reaction.

Required Equipment/Supplies

100 dominoes
large table or floor space
stopwatch

Discussion

You could give your cold to two people; they in turn could give it to two others, each of whom in turn could give it to two others. Before you knew it, everyone in school would be sneezing. You would have set off a chain reaction. Similarly, electrons in a photomultiplier tube in an electronic instrument multiply in a chain reaction so that a tiny input produces a huge output. Another example of a chain reaction occurs when one neutron triggers the release of two or more neutrons in a piece of uranium, and each of these neutrons triggers the release of more neutrons (along with the release of nuclear energy). The results of this kind of chain reaction can be devastating.

In this activity, you will explore chain reactions using dominoes.

Procedure

Step 1: Set up a string of dominoes about half a domino length apart in a straight line, as you did back in Activity 3, “The Domino Effect.” Push the first domino and measure how long it takes for the entire string to fall over. Also notice whether the number of dominoes being knocked over per second increases, decreases, or remains about the same as the pulse runs down the row of dominoes.

Step 2: Set up the dominoes in an arrangement similar to the one in Figure A. When one domino falls, another one or two will be knocked over. When you finish setting up all your dominoes, push the first domino over, and time how long it takes for all or most of the dominoes to fall over. Also, notice whether the number of dominoes being knocked over per unit time increases, decreases, or remains about the same.

Set up dominoes in a straight line.

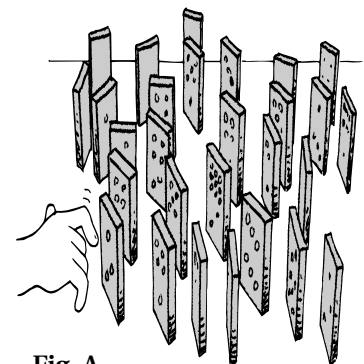


Fig. A

Analysis

1. Which approach results in the shorter time to knock over all the dominoes, the one with a line of dominoes or the one with randomly arranged dominoes?

2. How did the number of dominoes being knocked over per unit time change in each procedure?

3. What made each sequence of falling dominoes?

4. Imagine that the dominoes represent the neutrons released by uranium atoms when they fission (split apart). Neutrons from the nucleus of each fissioning uranium atom hit other uranium nuclei and cause them to fission. In a big enough piece of uranium, this chain reaction continues to grow if there are no controls. An atomic explosion would then result in a split second. How is the domino reaction in Step 2 similar to the atomic fission process?

5. How is the domino reaction in Step 2 dissimilar to the atomic fission process?

Appendix: Significant Figures and Uncertainty in Measurement

Units of Measurement

All measurements consist of a unit that tells what was measured and a number that tells how many units were measured. Both are necessary. If you say that a friend is going to give you 10, you are telling only *how many*. You also need to tell *what*: 10 fingers, 10 cents, 10 dollars, or 10 corny jokes. If your teacher asks you to measure the length of a piece of wood, saying that the answer is 36 is not correct. She or he needs to know whether the length is 36 centimeters, feet, or meters. All measurements must be expressed using a number and an appropriate unit. Units of measurement are more fully covered in Appendix A of the *Conceptual Physics* text.

Numbers

Two kinds of numbers are used in science—those that are counted or defined and those that are measured. There is a great difference between a counted or defined number and a measured number. The exact value of a counted or defined number can be stated, but the exact value of a measured number cannot be known.

For example, you can count the number of chairs in your classroom, the number of fingers on your hand, or the number of nickels in your pocket with absolute certainty. Counted numbers are not subject to error (unless the number counted is so large that you can't be sure of the count!).

Defined numbers are about exact relations, defined to be true. The exact number of seconds in an hour and the exact number of sides on a square are examples. Defined numbers also are not subject to error.

Every measured number, no matter how carefully measured, has some degree of uncertainty. What is the width of your desk? Is it 98.5 centimeters, 98.52 centimeters, 98.520 centimeters, or 98.5201 centimeters? You cannot state its exact measurement with absolute certainty.

Uncertainty in Measurement

The uncertainty in a measurement depends on the precision of the measuring device and the skill of the person who uses it. There are nearly always some human limitations in a measurement. In addition, uncertainties contributed by limited pre-

cision of your measuring instruments cannot be avoided.

Uncertainty in a measurement can be illustrated by the two different metersticks in Figure A. The measurements are of the length of a tabletop. Assuming that the zero end of the meterstick has been carefully and accurately positioned at the left end of the table, how long is the table?

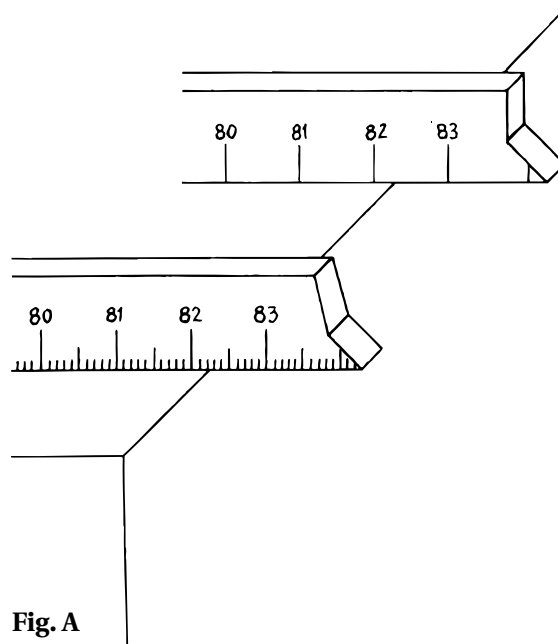


Fig. A

The upper scale in the figure is marked off in centimeter intervals. Using this scale, you can say with certainty that the length is between 82 and 83 centimeters. You can say further that it is closer to 82 centimeters than to 83 centimeters; you can estimate it to be 82.2 centimeters.

The lower scale has more subdivisions and has a greater precision because it is marked off in millimeters. With this meterstick, you can say that the length is definitely between 82.2 and 82.3 centimeters, and you can estimate it to be 82.25 centimeters.

Note how both readings contain some digits that are exactly known, and one digit (the last one) that is estimated. Note also that the uncertainty in the reading of the lower meterstick is less than that of the top meterstick. The lower meterstick can give a reading to the hundredths place, and the top meterstick to the tenths place. The lower meterstick is more precise than the top one.

No measurements are exact. A reported measurement conveys two kinds of information: (1) the magnitude of the measurement and (2) the precision of the measurement. The location of the decimal point and the number value gives the magnitude. The precision is indicated by the number of significant figures recorded.

Significant Figures

Significant figures are the digits in any measurement that are known with certainty plus one digit that is uncertain. The measurement 82.2 centimeters (made with the top meterstick in Figure A) has three significant figures, and the measurement 82.25 centimeters (made with the lower meterstick) has four significant figures. The right-most digit is always an estimated digit. Only one estimated digit is ever recorded as part of a measurement. It would be incorrect to report that, in Figure A, the length of the table as measured with the lower meterstick is 82.253 centimeters. This five-significant-figure value would have two estimated digits (the 5 and 3) and would be incorrect because it indicates a precision greater than the meterstick can provide.

Standard rules have been developed for writing and using significant figures, both in measurements and in values calculated from measurements.

Rule 1: In numbers that do not contain zeros, all the digits are significant.

Examples:

3.1428	five significant figures
3.14	three significant figures
469	three significant figures

Rule 2: All zeros between significant digits are significant.

Examples:

7.053	four significant figures
7053	four significant figures
302	three significant figures

Rule 3: Zeros to the left of the first nonzero digit serve only to fix the position of the decimal point and are not significant.

Examples:

0.0056	two significant figures
0.0789	three significant figures
0.000001	one significant figure

Rule 4: In a number with digits to the right of a decimal point, zeros to the right of the last nonzero digit are significant.

Examples:

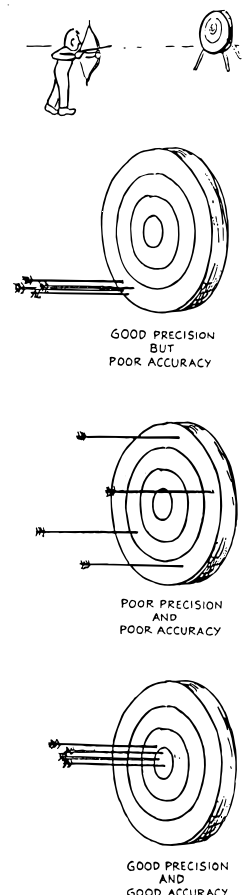
43	two significant figures
43.0	three significant figures
43.00	four significant figures
0.00200	three significant figures
0.40050	five significant figures

Rule 5: In a number that has no decimal point, and that ends in one or more zeros (such as 3600), the zeros that end the number may or may not be significant. The number is ambiguous in terms of significant figures. Before the number of significant figures can be specified, further information is needed about how the number was obtained. If it is a measured number, the zeros are probably not significant. If the number is a defined or counted number, all the digits are significant (assuming perfect counting!).

Confusion is avoided when numbers are expressed in scientific notation. All digits are taken to be significant when expressed this way.

Examples:

3.6×10^5	two significant figures
3.60×10^5	three significant figures
3.600×10^5	four significant figures
2×10^{-5}	one significant figure
2.0×10^{-5}	two significant figures
2.00×10^{-5}	three significant figures



Rounding Off

A calculator displays eight or more digits. How do you round off such a display of digits to, say, three significant figures? Three simple rules govern the process of deleting unwanted (nonsignificant) digits from a calculator number.

Rule 1: If the first digit to be dropped is less than 5, that digit and all the digits that follow it are simply dropped.

Example:

54.234 rounded off to three significant figures becomes 54.2.

Rule 2: If the first digit to be dropped is a digit greater than 5, or if it is a 5 followed by digits other than zero, the excess digits are all dropped and the last retained digit is increased in value by one unit.

Example:

54.36, 54.359, and 54.3598 rounded off to three significant figures all become 54.4.

Rule 3: If the first digit to be dropped is a 5 not followed by any other digit, or if it is a 5 followed only by zeros, an odd-even rule is applied. That is, if the last retained digit is even, its value is not changed, and the 5 and any zeros that follow are dropped. But if the last digit is odd, its value is increased by one. The intention of this odd-even rule is to average the effects of rounding off.

Examples:

54.2500 to three significant figures becomes 54.2.

54.3500 to three significant figures becomes 54.4.

Significant Figures and Calculated Quantities

Suppose that you measure the mass of a small wooden block to be 2 grams on a balance, and you find that its volume is 3 cubic centimeters by poking it beneath the surface of water in a graduated cylinder. The density of the piece of wood is its mass divided by its volume. If you divide 2 by 3 on your calculator, the reading on the display is 0.6666666. It would be incorrect to report that the density of the block of wood is 0.6666666 gram per cubic centimeter. To do so would be claiming a degree of precision that is not warranted. Your answer should be rounded off to a sensible number of significant figures.

The number of significant figures allowable in a calculated result depends on the number of significant figures in the data used to obtain the result, and on the type of mathematical operation(s) used to obtain the result. There are separate rules for

multiplication and division, and for addition and subtraction.

Multiplication and Division For multiplication and division, an answer should have the number of significant figures found in the number with the fewest significant figures. For the density example above, the answer would be rounded off to one significant figure, 0.7 gram per cubic centimeter. If the mass were measured to be 2.0 grams, and if the volume were still taken to be 3 cubic centimeters, the answer would still be rounded to one significant figure, 0.7 gram per cubic centimeter. If the mass were measured to be 2.0 grams and the volume to be 3.0 or 3.00 cubic centimeters, the answer would be rounded off to two significant figures: 0.67 gram per cubic centimeter.

Study the following examples. Assume that the numbers being multiplied or divided are measured numbers.

Example A:

$$8.536 \times 0.47 = 4.01192 \text{ (calculator answer)}$$

The input with the fewest significant figures is 0.47, which has two significant figures. Therefore, the calculator answer 4.01192 must be rounded off to 4.0.

Example B:

$$3840 \div 285.3 = 13.459516 \text{ (calculator answer)}$$

The input with the fewest significant figures is 3840, which has three significant figures. Therefore, the calculator answer 13.459516 must be rounded off to 13.5.

Example C:

$$360.0 \div 3.000 = 12 \text{ (calculator answer)}$$

Both inputs contain four significant figures. Therefore, the correct answer must also contain four significant figures, and the calculator answer 12 must be written as 12.00. In this case, the calculator gave too few significant figures.

Addition and Subtraction For addition or subtraction, the answer should not have digits beyond the last digit position common to all the numbers being added and subtracted. Study the following examples:

Example A:

$$\begin{array}{r} 34.6 \\ 17.8 \\ + 15 \\ \hline 67.4 \text{ (calculator answer)} \end{array}$$

The last digit position common to all numbers is the units place. Therefore, the calculator answer of 67.4 must be rounded off to the units place to become 67.

Example B:

$$\begin{array}{r} 20.02 \\ 20.002 \\ + \underline{20.0002} \\ 60.0222 \text{ (calculator answer)} \end{array}$$

The last digit position common to all numbers is the hundredths place. Therefore, the calculator answer of 60.0222 must be rounded off to the hundredths place, 60.02.

Example C:

$$345.56 - 245.5 = 100.06 \text{ (calculator answer)}$$

The last digit position common to both numbers in this subtraction operation is the tenths place. Therefore, the answer should be rounded off to 100.1.

Percentage Uncertainty

If your aunt told you that she had made \$100 in the stock market, you would be more impressed if this gain were on a \$100 investment than if it were on a \$10 000 investment. In the first case, she would have doubled her investment and made a 100% gain. In the second case, she would have made a 1% gain.

In laboratory measurements, the *percentage* uncertainty is usually more important than the *size* of the uncertainty. Measuring something to within 1 centimeter may be good or poor, depending on the length of the object you are measuring. Measuring the length of a 10-centimeter pencil to ± 1 centimeter is quite a bit different from measuring the length of a 100-meter track to the same ± 1 centimeter. The measurement of the pencil shows a relative uncertainty of 10%. The track measurement is uncertain by only 1 part in 10 000, or 0.01%.

Percentage Error

Uncertainty and error can easily be confused. *Uncertainty* gives the range within which the actual value is *likely* to lie relative to the measured value. It is used when the actual value is not known for sure, but is only inferred from the measurements. Uncertainty is reflected in the number of significant figures used in reporting a measurement.

The *error* of a measurement is the amount by which the measurement differs from a known, accepted value as determined by skilled observers using high-precision equipment. It is a measure of the accuracy of the method of measurement as well as the skill of the person making the measurement. The *percentage* error, which is usually more important than the actual error, is found by dividing the difference between the measured value and the accepted value of a quantity by the accepted value, and then multiplying this quotient by 100%.

% error =

$$\frac{|\text{accepted value} - \text{measured value}|}{\text{accepted value}} \times 100\%$$

For example, suppose that the measured value of the acceleration of gravity is found to be 9.44 m/s^2 . The accepted value is 9.80 m/s^2 . The difference between these two values is $(9.80 \text{ m/s}^2) - (9.44 \text{ m/s}^2)$, or 0.36 m/s^2 .

$$\begin{aligned} \% \text{ error} &= \frac{0.36 \text{ m/s}^2}{9.80 \text{ m/s}^2} \times 100\% \\ &= 3.7\% \end{aligned}$$