Instructor Notes for Laboratory Experiments

UNIT B

Contents for Unit B

Reading Assignments in *Physics,* Sixth Edition

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INSTRUCTOR NOTES

1 Vernier and Micrometer Calipers

Process Skills

Observing, measuring, using significant digits, interpreting data, inferring, and computing.

Troubleshooting

Micrometer and vernier calipers that have been in use for a length of time frequently need adjusting to assure that they work properly. If a student notices a zero reading on the micrometer caliper that is off by as much as ±0.05 mm, it will be extremely difficult to make accurate readings. Read the instructions that came with the instrument and make the adjustments.

Teaching Suggestions

1. Before the lab begins, make sure that all the necessary materials are available. It is not essential that everyone has the same kind of wooden block or metal cylinder, but each object must have dimensions that do not exceed the capacity of the measuring instrument.
2. Even if students have received previous instruction on significant figures, a quick review is helpful. Encourage the use of scientific notation; it provides an excellent method for indicating only those digits that are significant.
3. A discussion of the uncertainty of a measurement is important. Students must recognize that the last digits assigned to measurements are estimated. The meter stick reads to the nearest millimeter with the estimated digit between two millimeter marks on the meter stick. Address similar concerns for vernier and micrometer calipers.
4. Some students may ask about the uncertainty of the calculated values of area and volume. Point out that they do not have instruments that directly measure area or volume, and, therefore, the uncertainty in those quantities must be calculated based on the proportional errors of the measured lengths. The procedure is quite complicated, but very important, and you may wish to expand the lab to include such an analysis.

Observations and Data

Table 1 The Meter Stick

(Sample data are given.)

Laboratory Manual	Measurement	Number of Significant Digits	Uncertainty (±)
Length (mm)	280.5 mm	4	±1 mm
Width (mm)	231.3 mm	4	±1 mm
Area (mm^2)	64880 mm^2	4	

Table 2 The Vernier Caliper

(The data shown are for a particular block.)

Wooden Block	Measurement	Number of Significant Digits	Uncertainty (±)
Length (cm)	2.65 cm	3	±0.01 cm
Width (cm)	1.03 cm	3	±0.01 cm
Height (cm)	0.980 cm	3	±0.01 cm
Volume (cm^3)	2.67 cm^3	3	

Table 3 The Micrometer Caliper

(Again the data will vary.)

Metal Cylinder	Measurement	Number of Significant Digits	Uncertainty (±)
Length (mm)	23.020 mm	5	±0.01 mm
Diameter (mm)	8.925 mm	4	±0.01 mm
Volume (mm^3)	1440 mm^3	4	

Analysis

1. The vernier caliper allows a *precise* reading to ±0.01 cm. The last digit, which would otherwise be "estimated," is accurately provided by the moving scale. The micrometer caliper, on the other hand, allows for an extra estimated digit between two marks on the circular scale.
2. The zero correction is made by subtracting the zero reading (algebraically) from the indicated value. Thus, measurement (a) is 20.000 mm and measurement (b) is 22.000 mm.
3. The answers are given in the following table:

Measurement	Instrument of choice	Uncertainty of measurement
Depth of a small cup	Vernier caliper	±0.01 cm
Height of a table	Meter stick	±0.01 cm
Diameter of a wire	Micrometer caliper	±0.001 cm

INSTRUCTOR NOTES

2 Addition of Force Vectors

Process Skills

observing, using numbers, formulating models, classifying, communicating, interpreting data, measuring, predicting, questioning, defining operationally

Troubleshooting

Make sure students check that the scales register zero at no load. Explain how to make zero corrections if the scales are off.

Teaching Suggestions

1. The activity and data collection are easily and quickly performed. Even with a limited number of equipment set-ups, all students should be able to obtain data in a class period if they have previously read and prepared for the experiment.
2. Remind students that the lengths of the vectors are proportional to the forces, not to the lengths of the strings or the spring scales.

Observations and Data

Students drawing will vary, but should be similar to what is shown in Figure 2.

Analysis

1. Student answers will vary.
2. Student answers will vary. Students should have good results, but they will not be perfect. The resultant of $A + B$ should be nearly equal to and opposite C. Relative error should be less than 15%.
3. Student diagrams will vary.
4. The sum of $A + B + C$ is a closed triangle indicating equilibrium. (No net force is exerted on point **P**.)
5. If B is added to C, the resultant should be the negative of the value of A.
6. If C is added to A, the resultant should be the negative of the value of B.
7. The addition of $C + B + A$ should give the same result as the addition of $B + C + A$. The resultant is zero. It might be helpful at this time to remind students that, in vector addition, the order of addition does not affect the final result (commutative law). Also, in the case of two or more vectors, the grouping of vectors as they are added does not affect the final result (associative law).

Application

When a body falls through a fluid such as air, a frictional or drag force acts on it, slowing its downward velocity. As it first begins to fall through the air, its velocity increases, but so does the frictional force acting on it. When the upward frictional force equals the downward force due to gravity, the net force acting on the body becomes zero. At this point, equilibrium is reached, and the body falls at its constant terminal velocity. The frictional force of the air that acts on the skydiver's body, or the body and the parachute, depends on the configuration of the body. When the total surface area of the falling body exposed to the frictional force is increased, the terminal velocity is decreased.

Extension

The results should be the same as those obtained earlier. The sum of $A + B + C$ is zero.

INSTRUCTOR NOTES

3 Friction

Process Skills

observing, measuring, using numbers, communicating, interpreting data, predicting, questioning, controlling variables

Teaching Suggestions

1. The large wood blocks used for storage of mass sets are the correct size and weight to use for objects. Chalkboard erasers work well for objects of small mass.
2. Demonstrate another method for determining the coefficient of static friction without using a protractor. The tangent of θ is the ratio of the height of the plane above the horizontal (at which sliding begins) to the length of the plane. Thus

$$\frac{h}{l} = \tan\theta = \mu.$$

Observations and Data

Table 1 (Sample data are given.)

	Description
Object	chalkboard eraser
Surface	cardboard

Table 2 (Sample data are given.)

	1	2	3	Average
Weight of object (N)				1.86
Force of sliding friction (N)				0.39

Table 3 (Sample data are given.)

Motion	Angle (degrees)	$\mu = \tan \theta$
Static	20	0.36
Sliding	13	0.23

Analysis

1. $\mu_{static} = \tan 20° = 0.36$
   $\mu_{sliding} = \tan 13° = 0.23$
2. The coefficient of static friction should be greater. The force needed to overcome the frictional force of an object at rest (static frictional force) is greater than the force needed to keep an object in motion (kinetic frictional force).
3. $\mu = F_{\parallel}/F_{\perp} = 0.39/1.86 = 0.21$
4. They should be the same (or nearly identical). Student explanations for differences will vary.
5. The angles at which the brick begins sliding should be the same regardless of the area of the surfaces in contact. The weight of the brick, $F_{\perp}$, perpendicular to the surface influences the force of friction; the coefficient of static friction is independent of the area of contact.
6. An unwrapped brick begins to slide at an angle greater than that required by a waxed paper-wrapped brick. The waxed paper changes the nature of the surfaces in contact, essentially acting as a lubricant to reduce the coefficient of static friction, and, thus, the force of friction.
7. The type of surface and the force normal to the surface (perpendicular component of weight) influence the force of friction.

Application

Brand *Y* will give better service since it will have greater traction in wet weather than brand X. Both tires have nearly the same coefficient of friction on a dry pavement and, thus, the same amount of traction in dry weather.

Extension

The predicted angle should be very close to the angle at which sliding begins (at a constant speed).

INSTRUCTOR NOTES

4 Accelerated Motion

Process Skills

observing, using numbers, communicating, interpreting data, measuring, questioning, defining operationally

Troubleshooting

The recording timer must make accurate marks. If distinguishable marks do not show up, try replacing the carbon disc.

Alternative Materials

In place of the recording timer, an electronic blinky can be attached to the cart, and the moving cart can be photographed by using an instant developing camera. The dots can be measured on the developed film.

Teaching Suggestions

1. Prior to the experiment, review with students the three basic graphs of motion (displacement vs. time, velocity vs. time, acceleration vs. time).
2. This experiment is easily accomplished because the period of the recording timer is not required. If the period is known, the actual times may be substituted for each interval.
3. The sequence of dots (left to right or right to left) varies with the set-up. Students should make sure they count and mark the intervals in the direction of the movement.

Observations and Data

Table 1 (Sample data are given.)

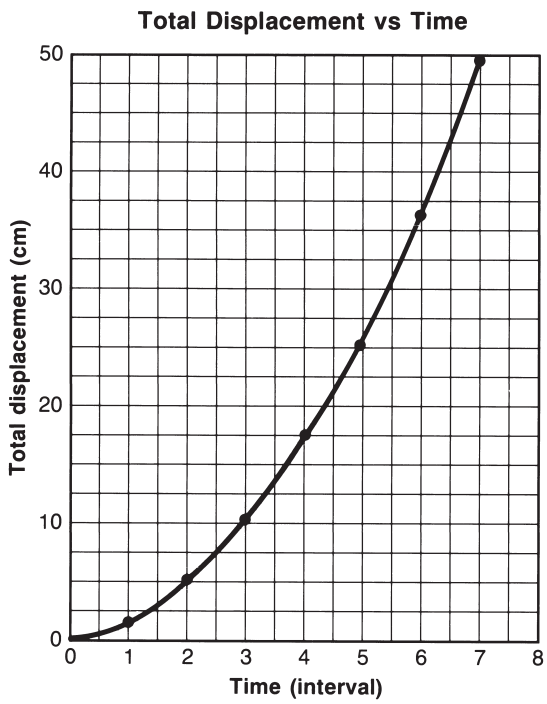
Time (interval)	Displacement (cm)	Total displacement (cm)
1	1.80	1.80
2	3.50	5.30
3	5.55	10.85
4	6.90	17.75
5	8.95	26.70
6	10.55	37.25
7	12.30	49.55
8		
9		
10		
11		
12		

Table 2 (Sample data are given.)

Time (interval)	Average velocity (cm/interval)	Acceleration ($\Delta v/\Delta t$)
1	1.80	1.80
2	3.50	1.75
3	5.55	1.85
4	6.90	1.73
5	8.95	1.79
6	10.55	1.76
7	12.30	1.76
8		
9		
10		
11		
12		

Analysis

1.



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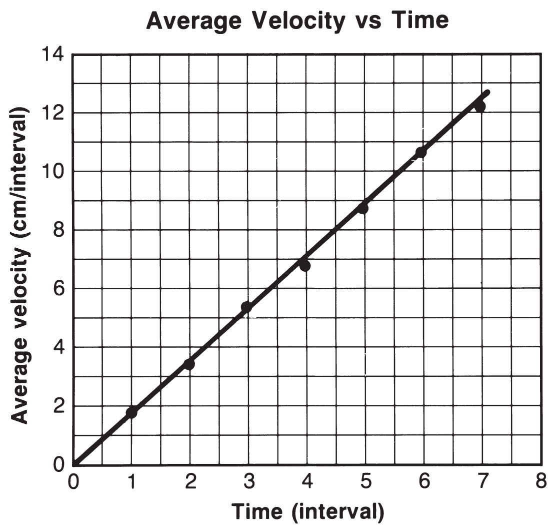
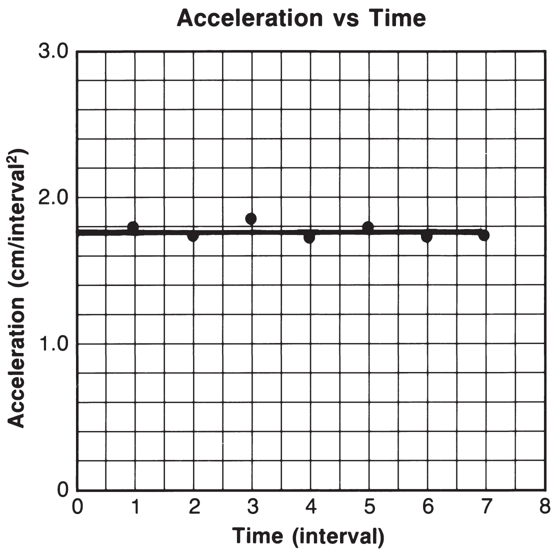


3. The slope of the curve is a parabola. The constantly increasing slope indicates that the cart was traveling greater distances during successive intervals of time.
4. The graph is a straight line passing through the origin. It indicates that the velocity of the cart is increasing at a constant rate.
5. Student answers will vary. The unit for the slope should be cm/interval^2.

6. The graph is a straight line parallel to the *x*-axis. Acceleration is uniform.



Application

Passengers would experience the same acceleration that exists on Earth. A greater rate of acceleration might cause physical discomfort. If the spacecraft were able to accelerate at that rate for a year, it would be traveling at close to the velocity of light, 3×10^8 m/s.

Extension

1. Student answers will vary. The slopes should be close to the values for average velocity.
2. Student answers will vary. The acceleration of the cart will be less than the acceleration due to gravity since the falling mass is accelerating itself and the cart.

INSTRUCTOR NOTES 5

Acceleration Due to Gravity

Process Skills

observing, measuring, communicating, using numbers, interpreting data, questioning, controlling variables

Alternative Materials

For Part B, a less expensive and simpler method is to use a PASCO Digital Free Fall apparatus, #ME-9202B, instead of the Apple or IBM computer, game port interface, computer software, and Free Fall Adapter. It is a simple electronic timing device that accurately measures the time required for a steel ball to fall.

Teaching Suggestions

Part A

1. It is important that the mass be stationary before it is dropped to ensure that the initial velocity of the falling mass is zero.
2. Students must not exert any force on the mass by tossing or throwing it to the floor; it must simply be dropped.
3. If student results in Part A have a large relative error, explain that, since the mass falls 1 m or less and the velocity is computed in m/s, even a small error in measurement or technique can have a significant effect.

Observations and Data

Table 1 (Sample data are given.)

Period of recording timer __0.0167__ s

Interval	Time (s)	Displacement (m)	Total displacement (m)	Average velocity (m/s)
1	0.017	0.0030	0.0030	0.18
2	0.033	0.0065	0.0095	0.39
3	0.050	0.0090	0.0185	0.54
4	0.067	0.0120	0.0305	0.72
5	0.083	0.0145	0.0450	0.87
6	0.100	0.0170	0.0620	1.02
7	0.117	0.0195	0.0815	1.17
8	0.133	0.0220	0.1035	1.32
9	0.150	0.0250	0.1285	1.50
10	0.167	0.0280	0.1565	1.68
11	0.183	0.0300	0.1865	1.80
12	0.200	0.0330	0.2195	1.98
13	0.217	0.0360	0.2555	2.16
14	0.233	0.0380	0.2935	2.28
15	0.250	0.0410	0.3345	2.46
16	0.267	0.0435	0.3780	2.61
17	0.283	0.0460	0.4240	2.76

Interval	Time (s)	Displacement (m)	Total displacement (m)	Average velocity (m/s)
18	0.300	0.0490	0.4730	2.94
19	0.317	0.0510	0.5240	3.06
20	0.333	0.0540	0.5780	3.24

Table 2 (Sample data are given.)

Free fall distance 0.905 m

Trial	Time (s)
1	0.4285
2	0.4290
3	0.4288
4	0.4282
5	0.4291
Average	0.4287

g = 9.849 m/s^2

Table 3 (Sample data are given.)

Free fall distance 1.900 m

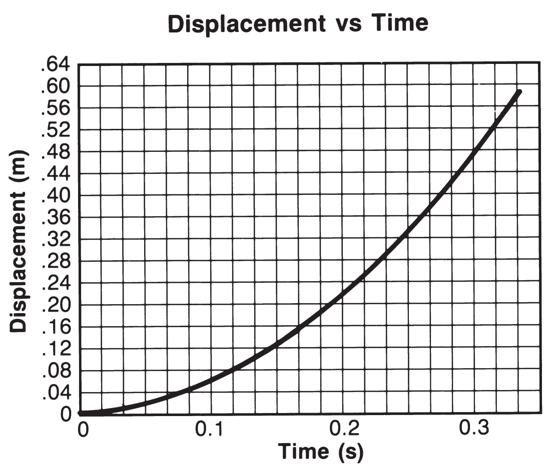
Trial	Time (s)
1	0.6226
2	0.6227
3	0.6231
4	0.6222
5	0.6230
Average	0.6227

g = 9.799 m/s^2

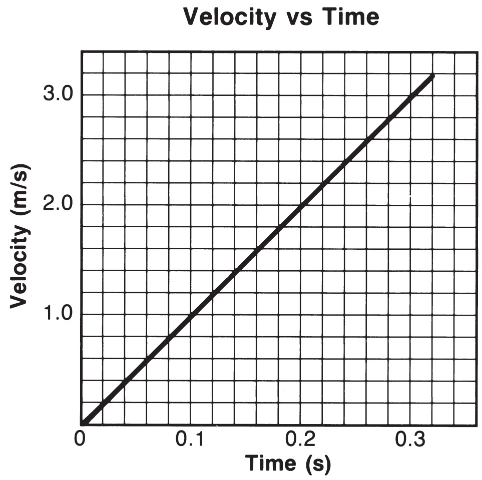
Analysis

Part A

1.



2.



3. The shape of the curve is parabolic. The constantly increasing slope indicates that the mass was traveling greater distances during each successive time interval.
4. The graph is a straight line passing through the origin. It indicates that the velocity of a falling mass increases at a constant rate.
5. $$\text{slope} = \frac{3.24\text{ m/s} - 0}{0.333\text{ s} - 0} = 9.82\text{ m/s}^2$$

$$\text{relative error} = \frac{9.82\text{ m/s}^2 - 9.80\text{ m/s}^2}{9.80\text{ m/s}^2} \times 100$$

$$= 0.2\%$$

Part B

1. a. $$\text{relative error} = \frac{9.849\text{ m/s}^2 - 9.80\text{ m/s}^2}{9.80\text{ m/s}^2} \times 100\%$$

$$= 0.5\%$$

b. $$\text{relative error} = \frac{9.80\text{ m/s}^2 - 9.799\text{ m/s}^2}{9.80\text{ m/s}^2} \times 100\%$$

$$= 0.01\%$$

Student results should have an error of less than 5% for the measurement of g.

2. The uncertainty in measuring the free fall distance is a smaller percent of the larger distance, so the results for 2 m may be slightly better.
3. Free fall distance was constant. Time was responding.

Application

At higher elevations, the acceleration due to gravity is usually somewhat diminished. A smaller acceleration due to gravity would permit an object, such as the hammer or javelin in the track and field events, to remain in the air slightly longer, yielding a better distance.

INSTRUCTOR NOTES

6 Range of a Projectile

Process Skills

observing, measuring, predicting, interpreting data, communicating, questioning, defining operationally

Alternative Materials

Shelving brackets, grooved rulers, or curtain rods can be substituted for the U-channel.

Teaching Suggestions

1. If your laboratory tables are not level, students should use a level to adjust the horizontal sections of track. The leveling assures that there is no initial vertical component of motion.
2. If the steel ball just misses the cup, have students recheck all their measurements and calculations. If the cups are too tall, the ball may hit the edge of the cup. Predictions by students should be within 5% to 10% of the actual distances.

Observations and Data

Table 1 (Sample data are given.)

Trial	Distance (m)	Time (s)
1	0.20	0.153
2	0.20	0.153
3	0.20	0.153
Average	0.20	0.153

Vertical distance, y, = 0.96 m

Analysis

1. $v_x = \Delta d/\Delta t = 0.20$ m/0.153 s = 1.3 m/s
2. $t = [(2)(0.96 \text{ m})/(9.80 \text{ m/s}^2)]^{1/2} = 0.44$ s
3. $x = v_x t = (1.3 \text{ m/s})(0.44 \text{ s}) = 0.57$ m
4. The ball lands in the cup.
5. Yes. The equations used to calculate the horizontal and vertical positions of the ball were based on the premise that the components of motion are independent of each other.
6. The results would probably be different. The displacement of the sponge ball or ping-pong ball will be affected by the significantly large frictional resistance of the air.

Application

$t_{air} = [(2)(6 \text{ m})/(9.80 \text{ m/s}^2)]^{1/2} = 1.1$ s

$x = v_x t = (3.75 \text{ m/s})(1.1 \text{ s}) = 4.1$ m

The diver will land in the water at a point 4.1 m from the edge of the platform.

Extension

1. If $\theta_i = 45°$, $2\theta_i = 90°$and sin 90° = 1. For all other values of θ_i, sin $2\theta_i$ will be less than 1. Student examples will vary. Some possible answers: If $\theta_i = 60°$, sin $2\theta_i = 0.8660$; if $\theta_i = 53°$, sin $2\theta_i = .9612$; if $\theta_i = 75°$, sin $2\theta_i = 0.4999$; and if $\theta_i = 32°$, sin $2\theta_i = 0.8829$.
2. $v_i = \dfrac{160\ 000 \text{ m/h}}{3600 \text{ s/h}} = 44.4$ m/s

   $$x = \frac{(44.4 \text{ m/s})^2}{9.8 \text{ m/s}^2} \times 2(0.8910 \times 0.4540)$$

   $x = 162.7$ m

INSTRUCTOR NOTES

7 Newton's Second Law

Process Skills

observing, using numbers, measuring, communicating, interpreting data, questioning, controlling variables

Teaching Suggestions

1. A large-capacity electronic balance (4 kg) will speed the process of determining the mass of the carts and attached tape and string.
2. Be sure that students begin measuring the zero dot as close as possible to the beginning cluster of dots so that the initial velocity is zero.

Observations and Data

Table 1 (Sample data are given.)

	Value
Period of timer (s)	1/60
Mass of laboratory cart (kg)	1.292
Mass needed to equalize friction of cart (kg)	0.015

Table 2 (Sample data are given.)

Trial	Accelerating force (N)	Distance (m)	Number of dots	Time (s)
1	9.80	0.610	33	0.55
2	9.80	0.493	30	0.50
3	9.80	0.550	30	0.50

Table 3 (Sample data are given.)

Trial	Acceleration (m/s^2)	Total mass (kg)	(m)(a) (N)
1	4.03	2.308	9.30
2	3.94	2.308	9.09
3	4.40	2.308	10.2

Analysis

1. See Table 2.
2. Trial 1: $a = 2(0.610\ m)/(0.55\ s)^2 = 4.03\ m/s^2$
   Trial 2: $a = 2(0.493\ m)/(0.50\ s)^2 = 3.94\ m/s^2$
   Trial 3: $a = 2(0.55\ m)/(0.50\ s)^2 = 4.40\ m/s^2$
3. less than. The falling mass must move itself plus the cart. Therefore, the force of the falling mass is diminished by that amount of force required to move the cart's mass.
4. total mass = 1.293 kg (cart + string + tape) + 1.000 kg (falling mass) + 0.015 kg (small masses) = 2.308 kg
5. Trial 1: (2.308 kg)(4.03 m/s^2) = 9.30 N
   Trial 2: (2.308 kg)(3.94 m/s^2) = 9.09 N
   Trial 3: (2.308 kg)(4.40 m/s^2) = 10.2 N
6. Error should be less than 20% and, with careful technique, it can be less than 10%. Using the sample data from the three trials, the values for relative error were 5%, 7%, and 4%.
7. $F = mg = (0.015\ kg)(9.8\ m/s^2) = 0.15\ N$
8. Frictional forces oppose the force (weight) of the falling mass; the net force is thus reduced by this friction.

Application

The frictional forces acting on an automobile include sliding friction between tires and the road and air resistance to automobile movement. When the frictional forces are equal to the force produced by the engine, the net force is zero. Therefore, there will be no acceleration, and the automobile will travel at a constant velocity.

INSTRUCTOR NOTES 8

Conservation of Energy

Processing Skills

observing, measuring, using numbers, communicating, interpreting data, questioning, defining operationally

Alternative Materials

A non-stick cooking spray can be substituted for the silicone spray.

Teaching Suggestions

1. Emphasize the importance of moving the block up and down the incline at constant speed. If the block is accelerated, the scale reading will be wrong.
2. The quantity $F_{\parallel}d$ is the work done going up the frictionless inclined plane. $F_{up}d$ represents the work input including the work done against friction.

Observations and Data

Weight of the block = 6.0 N

Table 1 (Sample data are given.)

Trial	Length, d (m)	Height, h (m)	F_{up} (N)	F_{down} (N)
1	0.96	0.46	5.0	1.0
2	0.73	0.46	5.5	2.0
3				

Table 2 (Sample data are given.)

Trial	$F_{\parallel}$ (N)	Work done without friction, $F_{\parallel}d$ (J)	Potential energy mgh (J)	Work input $F_{up}d$ (J)
1	3.0	2.9	2.8	4.8
2	3.8	2.8	2.8	4.0
3				

Analysis

1.
$$F_{up} = F_{\parallel} + F_f$$
$$\underline{F_{down} = F_{\parallel} - F_f}$$
$$F_{up} + F_{down} = 2F_{\parallel}$$
$$F_{\parallel} = (F_{up} + F_{down})/2$$

2. Trial 1: $F_{\parallel} = (5.0\ \text{N} + 1.0\ \text{N})/2 = 3.0\ \text{N}$
   Trial 2: $F_{\parallel} = (5.5\ \text{N} + 2.0\ \text{N})/2 = 3.8\ \text{N}$
3. Trial 1: $W = (3.0\ \text{N})(0.96\ \text{m}) = 2.9\ \text{J}$
   Trial 2: $W = (3.8\ \text{N})(0.73\ \text{m}) = 2.8\ \text{J}$
4. $PE = (6.0\ \text{N})(0.46\ \text{m}) = 2.8\ \text{J}$
5. In the absence of friction, the energy within the system is conserved. Students should have nearly the same values for work and potential energy.

Application

Since the hill is frictionless, the gravitational force converts the stored potential energy of the skier at the top of the hill to kinetic energy.

$$mgh = \tfrac{1}{2}mv^2$$
$$(60.0\ \text{kg})(9.80\ \text{m/s}^2)(10.0\ \text{m}) = \tfrac{1}{2}(60.0\ \text{kg})v^2$$
$$v^2 = 196\ \text{m}^2$$
$$v = 14\ \text{m/s}$$

Extension

Trial 1: $F_{\parallel} = W \sin\theta = (6\ \text{N})(0.46/0.96) = 2.9\ \text{N}$
Trial 2: $F_{\parallel} = W \sin\theta = (6\ \text{N})(0.46/0.73) = 3.7\ \text{N}$

Student answers for differences will vary, but most students will suggest that they may have pulled too hard, causing some acceleration of the block, or they pulled at an angle to the direction parallel to the plane, thus increasing the force reading.

INSTRUCTOR NOTES

9 Conservation of Momentum

Process Skills

observing, formulating models, interpreting, defining operationally, using numbers, questioning, communicating, measuring

Troubleshooting

If students have trouble making the steel balls land on their paper sheets, lower the starting position of the ball on the incline so that it has a smaller initial velocity.

Teaching Suggestions

1. Use this laboratory investigation only after students are comfortable with the concept of conservation of momentum for a collision in one direction.
2. Remind students that their results may not be perfect, as evidenced by a clustering of the points where the steel balls land. Students will have and should expect some discrepancy between the magnitude and direction of the momentum vector after the collision and those of the momentum vector before the collision.

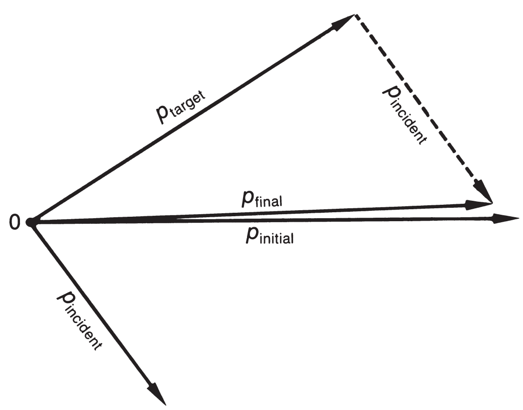
Observations and Data

Table 1 (Sample data are given.)

Magnitude of Vectors		
$p_{initial}$ (cm)	p_{target} (cm)	$p_{incident}$ (cm)
29.4	23.1	13.4

Analysis

1. $p_{target} + p_{incident} = 23.1\ \text{cm} + 13.4\ \text{cm}$. The sum, 36.5 cm, does not equal $p_{initial}$. These are vector quantities; their sum is the resultant, not the numerical sum of their magnitudes.
2. p_{final} is represented by 27.7 cm.
3. The magnitude of the initial momentum is represented by 29.4 cm while that of the final momentum is represented by 27.7 cm. These values are close. Students should have values that are within 20% of each other.



4. The directions of the initial and final momentum vectors are nearly the same. Ideally, the resultant should be equal in magnitude and identical in direction to the initial momentum vector of the incident ball before the collision. Students should realize that their experimental results may not be perfect.

Application

Assuming that the ball is thrown with the same velocity each time, the momentum will be the same. If you let your hands move backwards as you catch the ball, the transfer of momentum will occur over a longer period of time. This extension will relieve the sting your hands feel.

Extension

1. The final momentum of the incident ball and the two target balls will be equal to the initial momentum of the incident ball. The total momentum of a closed, isolated system always remains constant no matter how many objects there are in the system. This relationship is shown by the following:

$$p_{\mathrm{a}} = p'_{\mathrm{a}} + p_{\mathrm{b}} + p_{\mathrm{c}}.$$

2. Mass can be canceled out, and the equation can be recognized as a form of the Pythagorean theorem, $v_{\mathrm{a}}{}^2 = v'_{\mathrm{a}}{}^2 + v_{\mathrm{b}}{}^2$, for a right triangle. Therefore, if this equality holds, the angle between the velocity vectors after the collision must be a right angle.

INSTRUCTOR NOTES

10 Kepler's Laws

Process Skills

formulating models, interpreting data, inferring, communicating, questioning, defining operationally

Teaching Suggestions

1. Students should plot data precisely. When plotting radius vectors, they should strive for an error of no more than the width of a sharpened pencil lead. The better the plot, the easier it will be to interpret the result.

2. The eccentricity of an orbit is a measure of the roundness of an orbit. The closer the eccentricity is to zero, the more circular the orbit becomes. The closer the eccentricity is to one, the more oval the ellipse becomes as it approaches a straight line. The eccentricity of an orbit is computed with the following:

$$e = \frac{(\text{longest radius} - \text{shortest radius})}{\text{length of the major axis}}$$

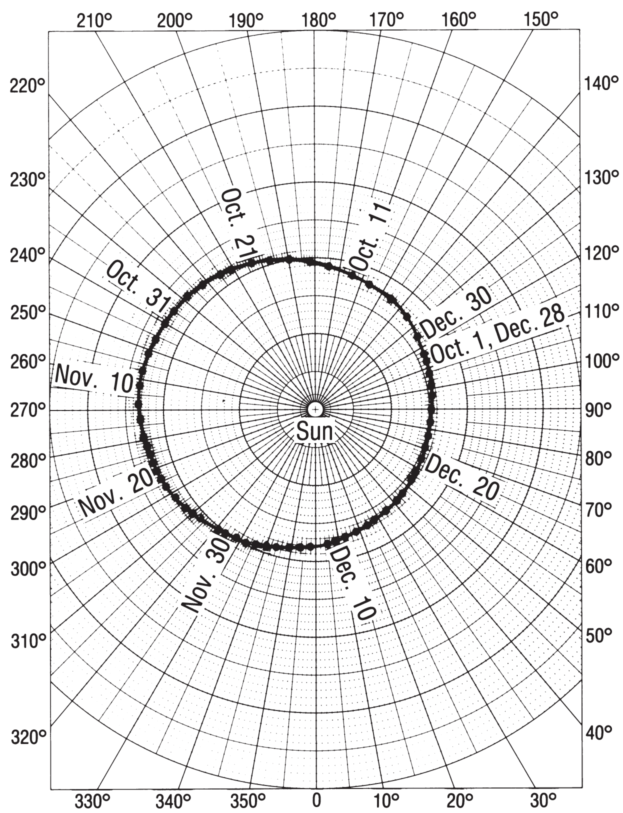
The eccentricity of Mercury's orbit is 0.206 and of Earth's orbit is 0.0167.

Observations and Data

Table 1 is found in the student edition.

Analysis

1. Yes. Mercury's orbit is an ellipse, with the center of the sun at one focus.



The orbit of Mercury.

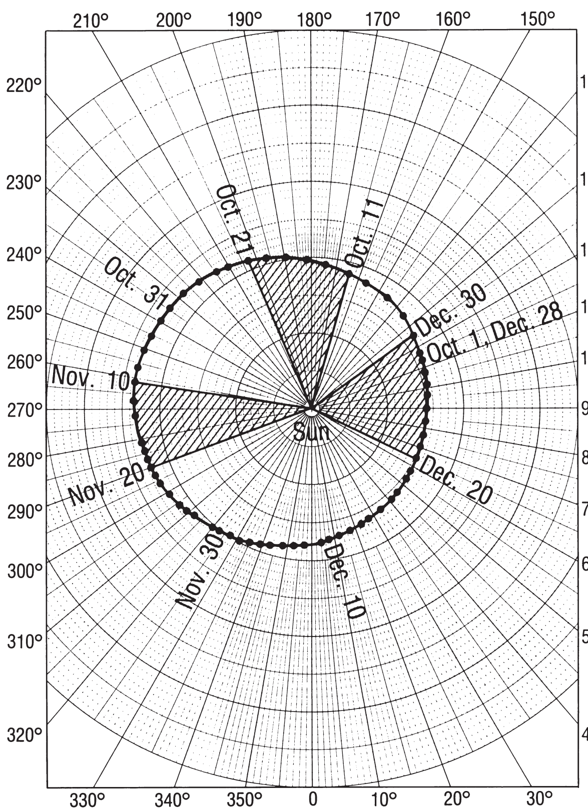
2. The area for the section of Mercury's orbit between December 20 and December 30 is found with

$$\begin{aligned} \text{area} &= (61°/360°)(\pi)(0.318 \text{ AU})^2 \\ &= 0.054 \text{ AU}^2/10 \text{ days.} \end{aligned}$$

3. Student choices for areas may vary. Two choices are the following:

   Oct. 11–21,
   area = $(38°/360°)(\pi)(0.396\ \text{AU})^2$
   $= 0.052\ \text{AU}^2/10$ days
   Nov. 10–20,
   area = $(29°/360°)(\pi)(0.457\ \text{AU})^2$
   $= 0.053\ \text{AU}^2/10$ days

4. The average area should be about $0.053\ \text{AU}^2/10$ days. Students should have errors of less than 5% if their graphs are carefully plotted. Yes, the orbit supports Kepler's law of areas.



Three areas of the orbit of Mercury.

5. Average radius = (0.307 AU + 0.467 AU)/2
   = 0.387 AU

$$\frac{T_M^2}{T_E^2} = \frac{r_M^3}{r_E^3},$$

$$T_M^2 = \frac{(0.387\ \text{AU})^3(365.25\ \text{days})^2}{(1.0\ \text{AU})^3}$$

$$T_M = 88\ \text{days}$$

6. From the graph, the period = 30 days + 30 days + 28 days = 88 days. The values from Questions 5 and 6 for the period of Mercury are the same (88 days). Thus, the results from the graph are consistent with Kepler's law of periods.

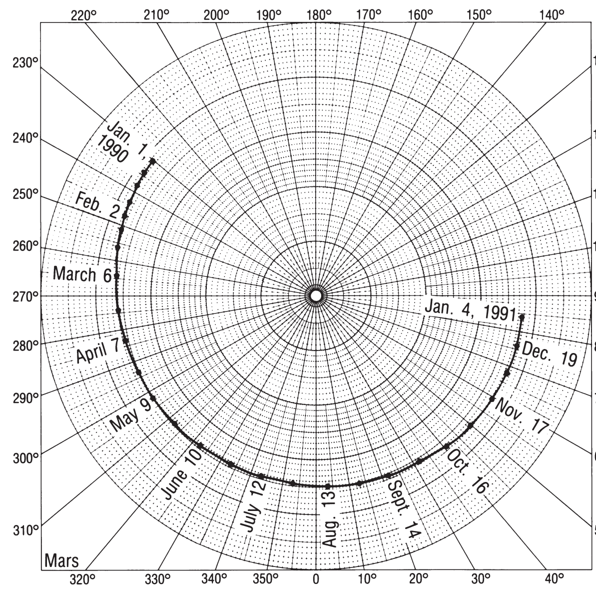
Application

$$T_x^2 = \frac{(1.0\ \text{AU})^3(1.0\ \text{yr})^2}{(1.0\ \text{AU})^3} = (1.0\ \text{yr})^2$$

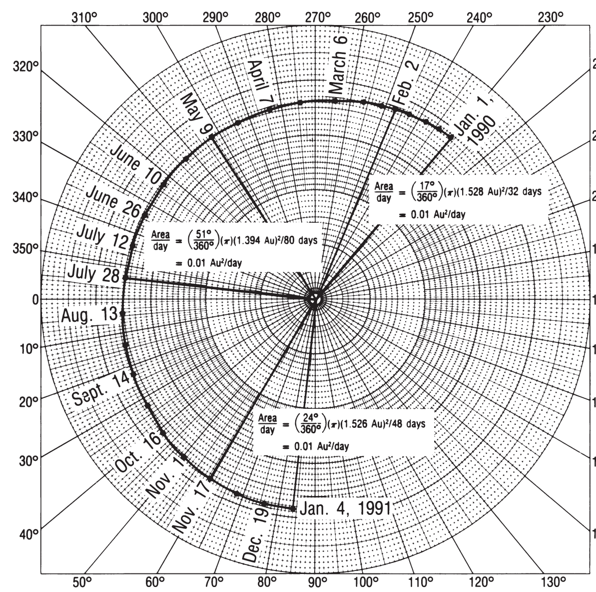
$$T_x = 1.0\ \text{yr}$$

Extension

The orbit of Mars and three different areas of the orbit of Mars are shown in the figures below. The area per day = $0.01\ \text{AU}^2$/day. The orbit is an ellipse. Yes, Kepler's law of areas applies.



The orbit of Mars.



Three areas of the orbit of Mars.

INSTRUCTOR NOTES

11 Pulleys

Process Skills

observing, using numbers, communicating, interpreting data, measuring, inferring, questioning, defining operationally, designing experiments

Teaching Suggestions

1. Grade the results reasonably. Although this investigation should work out well, there are several sources of error in doing the laboratory activity, mostly in getting accurate spring scale readings. Consequently, results usually do not show very close agreement. Demonstrate the proper use of the spring scale in each arrangement. Emphasize the necessity for using the least pull required to keep the mass moving upward at a slow and steady rate. Tell students to consider other potential sources of error and to take precautions that will minimize their effect on results.
2. Demonstrate the measurement of *W, h, F,* and *d.* Students often have difficulty measuring *d,* the distance the force moves.
3. If time and equipment permit, you may want to let students experiment with the pulley systems they have designed in response to the Application suggestion.

Observations and Data

Table 1 (Sample data are given.)

Pulley arrangement	Mass raised (kg)	Weight (*W*) of mass (N)	Height (*h*) mass is raised (m)	Force (*F*) of spring scale (N)	Distance (*d*) through which force acts (m)
(a)	0.50	4.9	0.25	5.0	0.27
(b)	0.50	4.9	0.25	2.8	0.50
(c)	1.0	9.8	0.25	5.0	0.53
(d)	1.0	9.8	0.25	2.7	1.02

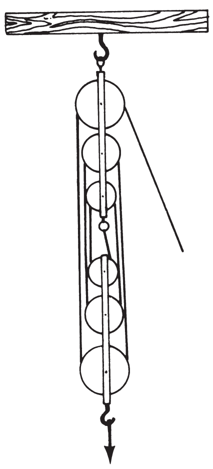
Table 2 (Sample data are given.)

Pulley arrangement	Work output (*Wh*) (J)	Work input (*Fd*) (J)	*IMA* (d_e/d_e)	*MA* Number of lifting strands	Efficiency %
(a)	1.2	1.4	1	1	86
(b)	1.2	1.4	2	2	86
(c)	2.5	2.7	2	2	93
(d)	2.5	2.8	4	4	89

Analysis

1. Inaccuracies in reading the spring scale, accuracy of the spring scale, and friction are the largest causes of error.
2. The force gets smaller as the mechanical advantage gets larger.
3. The *IMA* and the efficiency should be the same.
4. As the number of pulleys increases, the *IMA* increases. The efficiency may or may not decrease.
5. The values for *IMA* and *MA* should be the same.
6. The amount of work is not reduced, but the force that must be applied is reduced. Considering the losses of energy due to friction, more, not less, work usually must be done.

Application



INSTRUCTOR NOTES

12 Hooke's Law and Simple Harmonic Motion

Process Skills

Observing, measuring, using significant digits, interpreting data, inferring, computing, and comparing.

Troubleshooting

Conversion of units is often the source of problems with this experiment. Make sure that the units of force are *newtons* and the units of displacement are *meters.* Additionally, you might caution the students to be careful that the vibrating spring oscillates vertically with no possibility of striking the support.

Teaching Suggestions

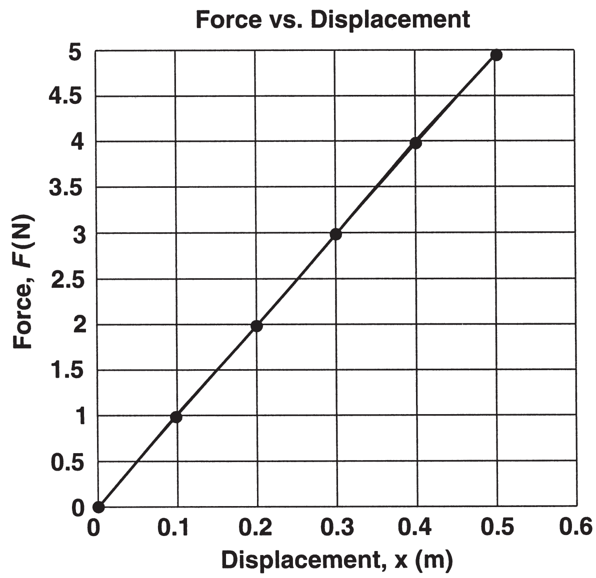
1. Take a little time before the exercise to review the correct procedures for plotting data on a graph. Make sure that they use a straight edge to draw the best straight line fitting the data and that they determine the slope independent of any specific data points.
2. Emphasize that the spring constant k is the ratio of the *change* in force to the *change* in displacement. It is not necessary to consider what weight might be already attached to the hanger; consider only how *additional* mass causes *additional* displacements.
3. Explain that the spring itself is a part of the vibrating system, and its mass must also be considered in a theoretical determination of the period of vibration.

Observations and Data

Table 1

Mass added to the weight hanger (kg)	Applied force due to added mass (N)	Scale reading (cm)	Displacement x of mass (m)
0	0	zero reading = 15.12	0
0.100 kg	0.980 N	24.92 cm	0.098 m
0.200 kg	1.96 N	35.12 cm	0.200 m
0.300 kg	2.94 N	45.22 cm	0.301 m
0.400 kg	3.92 N	55.22 cm	0.401 m
0.500 kg	4.90 N	65.42 cm	0.503 m

GRAPH (The following graph represents the sample data given above.)



The slope from your graph $\dfrac{\Delta F}{\Delta x}$ = 9.72 N/m.

The spring constant k = 9.72 N/m.

Table 2 (In this example, the mass of the spring was 171.72 g.)

Total mass m suspended from the spring (kg)	Effective mass $m' = m + m_s/3$ (kg)	Time for 50 vibrations (s)	Period T (s) Experimental	Period T (s) Calculated	Percent error
0.200 kg	0.257 kg	48.50 s	0.970 s	1.02 s	4.9%
0.400 kg	0.457 kg	66.10 s	1.32 s	1.36 s	2.9%

Analysis

1. The spring constant is determined by the change in applied force, and, therefore does not depend on the initial force that may already be present. At any time you can determine the spring constant by simply adding mass and recording the corresponding increase in the stretch of the spring.
2. If you had ignored the mass of the spring, the additional correction factor would not be present. In our example, this means that $m' = m$. We would have used 0.200 kg instead of 0.257 kg. The theoretical period would have been 0.90 s instead of 1.02 s. This represents a value that is about 12% less than the value which accounts for spring mass.

INSTRUCTOR NOTES 13 Archimedes' Principle

Process Skills

using numbers, observing, predicting, communicating, interpreting data, measuring, questioning

Teaching Suggestions

1. Be sure that the spring scales are functioning properly. If they stick, a large error is introduced into the results.
2. Each laboratory group could be given different masses, such as 200 g, 400 g, and 1000 g. To prevent damage to the equipment, be sure that the spring scale has the capacity to measure the larger masses.
3. Review with students the equation for buoyant force, $F_b = \rho Vg$. This will help them understand that the buoyant force is related to the weight of the volume of fluid displaced, not the weight of the submerged object.

Observations and Data

Table 1 (Sample data are given.)

Weight of 500-g mass in air	4.9 N
Weight of 500-g mass immersed in water	4.2 N
Volume of water in beaker	300 mL
Volume of water in beaker with 500-g mass immersed	375 mL

Table 2 (Sample data are given.)

Volume of water in beaker	300 mL
Volume of water with 100-g mass immersed	320 mL
Volume of water with 100-g mass in polystyrene cup	400 mL

Analysis

1. $F_{\text{buoyant}} = 4.9\text{ N} - 4.2\text{ N} = 0.70\text{ N}$
2. Volume displaced = 375 mL − 300 mL = 75 mL;
   75 mL of water is equivalent to 75 g of water.
   $$F = (0.075\text{ kg})(9.8\text{ m/s}^2) = 0.73\text{ N}.$$
   Student explanations will vary, but may include errors in measuring volume and force. Students might also note the effect of air bubbles that adhere to the surface of the mass.
3. It rose. The 100-g mass in the boat has an average density less than that of water, and the boat (with mass) floats. But the weight of the fluid it displaces is now greater than the weight of the water displaced by the mass alone. Whereas the volume of water displaced by the weight of the mass alone was 20 mL, now the 100-g mass displaces 100 g of water when it is placed in the boat. Since 100 g of water is equivalent to 100 mL of water, this is the difference between the observed volumes.

Application

The water level in the pool drops because Tim and Sally are heavier than the weight of the water they displace while submerged. When they fall into the water, they displace a volume of water that is less than their weight; the volume of water displaced is equal to the buoyant force acting on them. Since they displace less water while submerged than when floating, the pool water level drops when they fall off the raft.

INSTRUCTOR NOTES 14 Specific Heat

Process Skills

observing, communicating, interpreting data, measuring, using numbers, questioning

Teaching Suggestions

1. Mercury thermometers are dangerous and should be removed from school laboratory supply stock. Use only alcohol thermometers to avoid the risk of a mercury spill.
2. The old-style calorimetry cups (typically aluminum) can be used. However, if this type is used, then the heat lost by the hot metal equals the heat gained by the water, plus the heat gained by the calorimeter.
3. If lead is used, the mass must be large enough (300–400 g) to cause a measurable temperature change.
4. Review with students the values for specific heat of common substances found in Appendix B. They may note that the value for water is very high. Explain that this property of water makes it a particularly good coolant for car engines.

Observations and Data

Table 1 (Sample data are given.)

	Trial 1	Trial 2
Type of metal	brass	aluminum
Mass of calorimeter cup (kg)	0.0016	0.0016
Mass of calorimeter cup and water (kg)	0.1203	0.1251
Mass of metal (kg)	0.2741	0.0905
Initial temperature of room temperature water (°C)	22	23
Temperature of hot metal (°C)	100	100
Final temperature of metal and water (°C)	35	33.5

Table 2 (Sample data are given.)

	Trial 1	Trial 2
Mass of room temperature water (kg)	0.1187	0.1235
ΔT metal (°C)	65	66.5
ΔT room temperature water (°C)	13	10.5

Analysis

1. See Table 2.
2. Trial 1

   $Q_{\text{gained by water}} = (0.1187 \text{ kg})(13°\text{C})(4180 \text{ J/kg}\cdot°\text{C}) = 6450 \text{ J}$

   Trial 2

   $Q_{\text{gained by water}} = (0.1235 \text{ kg})(10.5°\text{C})(4180 \text{ J/kg}\cdot°\text{C}) = 5420 \text{ J}$
3. Trial 1

   $C_{\text{brass}} = 6450 \text{ J}/(0.2741 \text{ kg})(65°\text{C}) = 362 \text{ J/kg}\cdot°\text{C} = 362 \text{ J/kg}\cdot\text{K}$

   Trial 2

   $C_{\text{aluminum}} = 5420 \text{ J}/(0.0905 \text{ kg})(66.5°\text{C}) = 901 \text{ J/kg}\cdot°\text{C} = 901 \text{ J/kg}\cdot\text{K}$
4. Trial 1

   relative error $= [(376 - 362) \times 100\%]/376 = 4\%$

   Trial 2

   relative error $= [(903 - 901) \times 100\%]/903 = 0.2\%$

   Student errors should be less than 15%. If samples are of lead or of very small mass, errors will be larger because the temperature changes in these situations will not be great enough to measure.
5. The thermometer may not be reading accurately (however, the difference in temperature should be accurate). Heat may have been lost to the environment from radiation out of the top of the cup. Some hot water from the sample may have dripped into the calorimeter.

Application

$$C_{\text{substance}} = \frac{(m_{\text{water}})(\Delta T_{\text{water}})(4180 \text{ J/kg}\cdot\text{K})}{(m_{\text{substance}})(\Delta T_{\text{substance}})} = 656 \text{ J/kg}\cdot\text{K}$$

From Appendix B, this value for specific heat is closest to that of glass.

Extension

As demonstrated in the application, students should be able to identify the substance by its specific heat. Be sure that the unknown has a large enough mass or the temperature change will be insignificant, and a large error will result.

INSTRUCTOR NOTES 15

Standing Waves in a Vibrating String

Process Skills

Observing, inferring, communicating, interpreting data, and questioning.

Teaching Suggestions

1. The electromagnetic vibrator exhibits a frequency of 120 Hz rather than the actual ac line frequency of 60 Hz. This is due to the fact that the metal vibrating strip is not magnetized, and it is attracted to the magnetic pole no matter which way the current flows. The strip is lifted as the current rises in either positive or negative direction and it springs back as the current falls. This results in twice the frequency that might be expected.
2. Once again the use of consistent units is of paramount importance. Common errors result from improper conversions. The mass must be in *kilograms,* the length in *meters,* and the force in *newtons.*
3. If desired, you can obtain slightly greater accuracy by having the students measure the internodal distances directly. The procedure chosen here is to divide the entire length of the string by the number of loops. However, the hole in the vibrating strip is obviously not a true nodal point. Thus, the first loop is not truly a half-wavelength. The error is small enough that it shouldn't affect the results very much.
4. Because the tension required to reach a single or a double loop is so great, you may wish to have students record data for 7, 6, 5, 4, and 3 loops. It will make for a better graph and probably a more accurate slope calculation.

Observations and Data

Mass of string m = 0.136 g = 0.000136 kg

Length of string L = 100 cm = 1.00 m

Linear density of string μ = 0.00014 kg/m

Number of loops	5	4	3	2	1
Length of vibrating string in meters (m)	1.00 m	1.00 m	1.00 m	1.00 m	1.00 m
Average length of one loop (m)	0.200 m	0.250 m	0.333 m	0.500 m	1.00 m
Wavelength λ (m)	0.400 m	0.500 m	0.666 m	1.00 m	2.00 m
Wavelength squared λ^2 (m^2)	0.160 m^2	0.250 m^2	0.444 m^2	1.00 m^2	4.00 m^2
Mass suspended from string (kg)	0.0330 kg	0.0510 kg	0.0910 kg	0.220 kg	0.840 kg
Tension in string T (N)	0.323 N	0.500 N	0.892 N	2.16 N	8.23 N

Slope of your graph T/λ^2 (include units) 2.07 N/m^2

Calculated frequency of the vibrator 122 Hz

Relative error 1.7%

INSTRUCTOR NOTES 16

Investigating Static Electricity

Process Skills

observing, classifying, communicating, interpreting data, inferring, hypothesizing, questioning

Troubleshooting

On a humid day, it may not be possible to produce a positive charge with the glass rods. In these weather conditions, you will find that many of the lucite or acrylic materials produce adequate positive charges. The strength of the positive charge produced by these materials can be verified by comparison with the negative charge produced by a hard rubber rod.

Alternative Materials

Nylon or cotton scraps can also be used for rubbing pads.

Teaching Suggestions

1. Encourage students to make detailed observations. Often students rush through this experiment and are unsure of what they saw.
2. On a dry day, the vane type of electroscope should perform well. This type requires more charge to cause a deflection than does the leaf electroscope. On more humid days, it is better to use a leaf electroscope; it responds better with a smaller charge.

Observations and Data

Table 1

A. Negatively Charging a Pith Ball

Observations of pith ball with nearby charged rod: The pith ball is attracted toward the charged rod.
Observations of pith ball after it has been touched with a charged rod: The pith ball is attracted toward the rod but, after it has been touched, it is repelled.

Table 2

B. Positively Charging a Pith Ball

Observations of pith ball with nearby charged rod: The pith ball is attracted toward the charged rod.
Observations of pith ball after it has been touched with a charged rod: The pith ball is attracted toward the rod but, after it has been touched, it is repelled.

Table 3

C. Charging an Electroscope by Conduction

Observations of uncharged electroscope when negatively-charged rod touches it: The vane deflects (or the leaves separate).
Observations of negatively-charged electroscope when negatively-charged rod is brought near: The electroscope vane is (or leaves are) further deflected while the rod is nearby; the original charged position is assumed when the rod is removed.
Observations of negatively-charged electroscope when a positively-charged rod is brought near: The vane moves back toward zero (or the leaves collapse). When the rod is removed, the electroscope again indicates the presence of charge.
Observations of deflection of leaves or vane when plastic material charges the electroscope and a negatively-charged rod is brought near: The rubber rod causes the electroscope to move back toward zero, indicating that it has a charge opposite that of the rod. The electroscope is positively charged.

Table 4

D. Charging an Electroscope by Induction

Observations of electroscope when charged rod is brought near: The electroscope vane or leaves move, indicating the presence of charge, but when the rod is removed, the vane returns to zero or the leaves fall.
Observations of electroscope after touching with finger: The electroscope indicates the presence of charge when the charged rod is brought near, but drops to zero when it is touched by a finger. After the finger and then the charged rod are removed from the electroscope top, the electroscope again indicates the presence of charge.
Observations to determine the type of charge: The electroscope has a charge opposite that of the charged rod that was originally brought near. The leaves converge or the vane returns to zero, indicating that the original charged rod is attracting the charge of the electroscope.

Table 5

E. Charging a Leyden Jar

Observations of charging a Leyden jar-electroscope combination: The electroscope charges easily by itself, but does not (apparently) charge when the Leyden jar is attached. The charge travels through the wire to the Leyden jar, which stores charge.

Analysis

1. The ball touches the charged rod, becomes charged, and then is repelled.
2. The ball touches the charged rod, becomes charged, and then is repelled.
3. The process is the same for either type of charge.
4. When the charged rod touches the electroscope ball, the vane deflects (leaves diverge). The vane or leaves return to normal when the electroscope ball is touched by a finger.
5. Electrons were transferred to the electroscope, the vane (leaves) became negatively charged and deflected (repelled each other).
6. The leaves were still negatively charged.
7. The charge was positive. Student results may vary depending on the type of material available. The charge type can be confirmed by testing it with a known negatively-charged rod.
8. The finger provided a path to ground for the charge that was the same type as that of the charged rod brought near the electroscope. The net charge remaining on the electroscope, after the finger and rod were removed from the electroscope top, was opposite that of the charged rod.
9. It was the charge opposite that of the rod.
10. It acted as a ground, removing some of the charges.

11. Conduction produces the same charge; induction produces the opposite charge.
12. The charge was transferred to the Leyden jar (it stores static charges) from the electroscope. The electroscope does not retain the charge, as shown by the action of the leaves (they come together) or the vane (it returns to zero).

Application

When the record is slid out of its plastic cover, static electricity is produced as a result of the rubbing together of these two materials. These static charges can damage the needle if, when it comes down onto the record, a discharge (electrical spark) occurs. Record cleaners serve two purposes—to remove dust and to eliminate static electricity. Dust may accumulate on or be attracted to a record, which is easily charged with static electricity. The fluid or water causes static charge to dissipate quickly.

INSTRUCTOR NOTES

17 The Capacitor

Process Skills

observing, measuring, communicating, predicting, hypothesizing, questioning, controlling variables

Alternative Materials

Larger capacitors may be substituted for the 1000 μF value; however, if smaller capacitors are used, the time constant, *RC,* will be small. The capacitor will charge too quickly, making measurements difficult.

Teaching Suggestions

1. Discuss polarity for meters, batteries, and capacitors prior to the experiment. This preparation will minimize the chances that students will wire the circuit incorrectly. Before they close the switch, have students trace the circuit path with a finger while looking at the circuit diagram. Review with students the “Rules for Using Meters” in Appendix C.
2. The initial value of the current will rise very quickly, and then begin dropping off. In analog meters, there will be a slight delay while the meter reaches the initial reading, so students probably will not have an accurate recorded value for time = 0. At time = 0, the capacitor acts like a short, so the actual value of current is $I = V/R$, where V is the potential difference of the power source and R is the value of the circuit resistor. When the graph is plotted, the initial reading will not make a significant difference in the curve.
3. Show students how the unit of *RC* (seconds) can be traced from the derived SI units of resistance (ohms) and capacitance (farads).

Observations and Data

Table 1 (Sample data are given.)

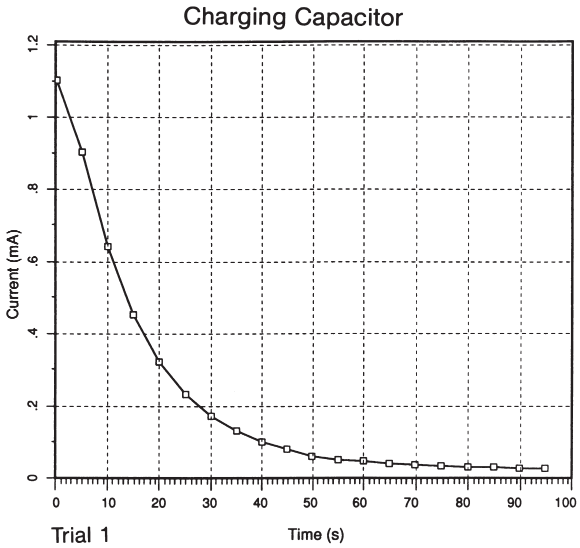
Battery voltage	15.0 VDC
Capacitance	1000 μF

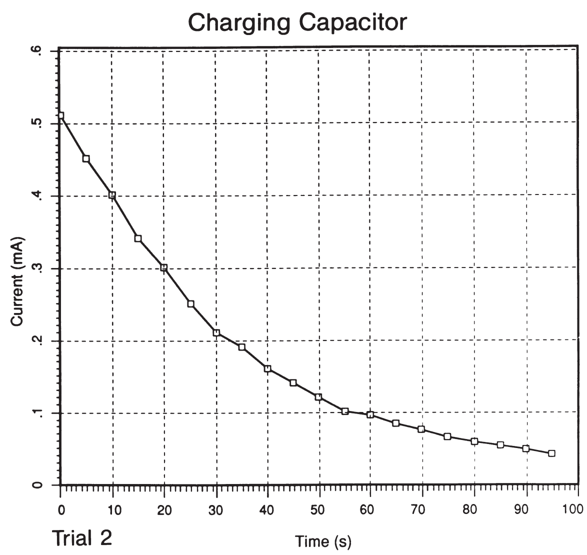
Table 2 (Sample data are given.)

Time (s)	**27 kΩ** Current (mA)	**10 kΩ** Current (mA)
0	1.100	0.510
5	0.900	0.450
10	0.640	0.400
15	0.450	0.340
20	0.320	0.300
25	0.230	0.250
30	0.170	0.210
35	0.130	0.190
40	0.100	0.160
45	0.080	0.140
50	0.060	0.120
55	0.050	0.100
60	0.046	0.095
65	0.039	0.083
70	0.035	0.075
75	0.032	0.064
80	0.030	0.058
85	0.028	0.052
90	0.025	0.048

Analysis

1. With no current on the capacitor plates, the current begins as a maximum. As the capacitor becomes charged, the current flow gradually becomes smaller until it approaches zero as the capacitor becomes fully charged.
2. The resistor controls the amount of current flowing to the capacitor; thus, it regulates the charging rate. The larger the value of resistance, the longer it will take to charge the capacitor.
3.





These graphs of current versus time for a charging capacitor were produced using the Lab Partner™ graphing program.

4. Charge = $\text{Area}_{27\ \text{k}\Omega} = \frac{1}{2}bh$
   $= \frac{1}{2}(35\ \text{s})(1.1 \times 10^{-3}\ \text{A})$
   $= 1.9 \times 10^{-2}\ \text{C}$
   Charge = $\text{Area}_{10\ \text{k}\Omega} = \frac{1}{2}bh$
   $= \frac{1}{2}(90\ \text{s})(0.4 \times 10^{-3}\ \text{A})$
   $= 1.8 \times 10^{-2}\ \text{C}$
5. Trial 1: $C = q/V = (1.9 \times 10^{-2}\ \text{C})/15.0\ \text{V} = 1.3 \times 10^{-3}\ \text{F} = 1300\ \mu\text{F}$
   Trial 2: $C = q/V = (1.8 \times 10^{-2}\ \text{C})/15.0\ \text{V} = 1.2 \times 10^{-3}\ \text{F} = 1200\ \mu\text{F}$
6. Trial 1: relative error = (1300 − 1000)(100%)/1000 = 30%
   Trial 2: relative error = (1200 − 1000)(100%)/1000 = 20%
7. Without a resistor, the capacitor would become charged almost instantly; the current would as quickly drop to zero.
8. The capacitor value and the power source voltage remained constant while the resistance was manipulated. The current in the circuit varies inversely with time.

Application

Since a capacitor requires a specific time to charge through a resistor, the *RC* combination can be used for timing applications, such as for a burglar alarm or a timer to turn on or off a light. For a short time of charging or discharging, the *RC* circuit can be used to produce musical notes for an electronic instrument or keyboard.

Extension

Answers will vary depending on the capacitor used. The exponential decay of current shown on the graph will drop more slowly as the capacitance increases.

INSTRUCTOR NOTES 18

Ohm's Law

Process Skills

observing, measuring, using numbers, interpreting data, communicating, predicting, inferring, questioning, controlling variables, defining operationally

Alternative Materials

An excellent source for an inexpensive, high quality voltmeter is Radio Shack. The versatile multitester unit provides several voltage ranges and current ranges from the same meter. The multitester can measure resistance if it is powered by a battery which, of course, you would not include if students are expected to find the values of unknown resistors.

Teaching Suggestions

1. Variable power supplies work well for this experiment. Remind students not to exceed the values each meter is designed to measure.
2. The recommended resistors are readily available and inexpensive, particularly if they are purchased from an electrical supply house or ordered from Radio Shack. Use of milliammeters and these resistors reduces the circuit currents; however, the resistors can still become warm. Caution students not to touch resistors when current flows in the circuit.
3. Unknown resistors can be made by covering other known resistors with heat-shrink tubing. To prevent current readings from being small and difficult to measure, try not to exceed values of more than about 470 Ω for unknowns. A couple of resistors can be placed in parallel or in series to create various resistance values. When resistors are sealed in heat-shrink tubing, the color bands are not visible. The use of unknowns encourages students to do their own work.
4. Tell students to open the switch immediately if the meter “pegs” or travels all the way to the far side of the meter.

Observations and Data

Table 1 (Sample data are given.)

Resistor	Printed value of resistor (Ω)	Tolerance range (+/− %)	Voltage (V)	Current (mA)	Current (A)	Resistance (Ω)
R_1	100	20	1.5	14	0.014	110
	100	20	5.0	49	0.049	100
R_2	150	20	1.5	10	0.010	150
	150	20	5.0	30	0.030	170
R_3	220	20	1.5	7.0	0.0070	210
	220	20	5.0	24	0.024	210

Analysis

1. See Resistance column of Table 1.
2. R_1 error: (105 − 100)(100%)/100 = 5%
   R_2 error: (160 − 150)(100%)/150 = 7%
   R_3 error: (220 − 210)(100%)/220 = 5%
   These sample values agree fairly well; however, student answers (values) may be more divergent.
3. The resistors may have overheated, causing the values to change. The voltmeter may introduce some error in the circuit, since it requires some current to cause deflection of the needle.
4. The ammeter must be placed in series with the circuit element.
5. The voltmeter must be placed in parallel with the circuit element to be measured.
6. The current in a circuit is equal to the voltage divided by the resistance.

Application

$$R = \frac{V}{I} = \frac{120\ \text{V}}{0.5\ \text{A}} = 240\ \Omega$$

Extension

Student answers will vary. Graphs of voltage versus current should be linear and should have a positive slope.

INSTRUCTOR NOTES

19 Series Resistance

Process Skills

observing, measuring, using numbers, communicating, interpreting data, predicting, questioning

Alternative Materials

Resistors of 5, 10, or 15 Ω can be used, but they are more expensive and difficult to obtain and must have 10-W ratings to prevent overheating in Part A (use of a single resistor). In this case, an ammeter with a range of 0–1 A must be used instead of the smaller milliammeter.

Teaching Suggestions

1. Caution students that, even though the resistors are small, they can still become hot if too large a voltage is applied. Do not exceed the recommended voltage and do not handle the resistors while the current is flowing through the circuit.
2. Remind students to check the polarity of their meters before activating the circuit to prevent damage to the meters.
3. Remind students to convert milliamps to amps before applying Ohm’s law.

Observations and Data

Table 1 (Sample data are given.)

	R_1 (Ω)	Ammeter reading (mA)	Voltmeter reading (V)
	100	50	5.0
Tolerance (%)	10		

Table 2 (Sample data are given.)

	R_1 (Ω)	R_2 (Ω)	Ammeter reading (mA)	Voltmeter reading (V)
	100	82	28	5.0
Tolerance (%)	10	10		

Table 3 (Sample data are given.)

	R_1 (Ω)	R_2 (Ω)	R_3 (Ω)	Ammeter reading (mA)	Voltmeter reading (V)			
					$V_{1,2,3}$	V_1	V_2	V_3
	100	82	68	20.0	5.0	2.0	1.6	1.4
Tolerance (%)	10	10	5					

Analysis

1. Measured value of resistance $= \frac{V}{I}$
$= \frac{(5.0\text{ V})}{(0.05\text{ A})} = 100\ \Omega$. The two values agree.
2. Measured value of the equivalent resistance $= \frac{V}{I} = \frac{(5.0\text{ V})}{(0.028\text{ A})} = 180\ \Omega$. The equivalent resistance $= 100\ \Omega + 82\ \Omega = 182\ \Omega$. 180 Ω is within the 20% tolerance range. Student answers will vary, but should be within the tolerance range.
3. Measured equivalent resistance $= \frac{V}{I}$
$= \frac{(5.0\text{ V})}{(0.02\text{ A})} = 250\ \Omega$. The calculated equivalent resistance $= R_1 + R_2 + R_3 = 100 + 82 + 68 = 250\ \Omega$. The two values agree. Student answers should fall within the sum of the tolerances for the resistors.
4. The equivalent resistance is determined by adding the individual resistances together.
5. The sum of the individual voltages = 2.0 V + 1.6 V + 1.4 V = 5.0 V. The sum of the voltage drops across individual resistances is equal to the total voltage drop around the circuit.
6. The amount of (equivalent) resistance determines the current in the circuit as long as the voltage remains constant.

Application

The equivalent resistance is found by

$$R = \frac{V}{I} = \frac{120\text{ V}}{1.0\text{ A}} = 120\ \Omega.$$

Since there are 50 lights of equal resistance, the resistance of an individual light is 120 Ω/50 = 2.4 Ω. The voltage drop per light is $V = IR = (1.0\text{ A})(2.4\ \Omega) = 2.4$ V.

INSTRUCTOR NOTES

20 Parallel Resistance

Process Skills

observing, predicting, measuring, using numbers, interpreting data, communicating, inferring

Teaching Suggestions

1. Remind students to convert milliamps to amps before applying Ohm's law.
2. Caution students to use care when touching the resistors and to leave switches closed no more than a few seconds at a time.
3. Depending on the internal resistance of the ammeters, student data may not match perfectly. Remind them to take careful measurements.
4. Be sure to allow sufficient time for students to complete this experiment. It takes time to move the meters about and obtain circuit measurements.

Observations and Data

Table 1 (Sample data are given.)

	R_1 (Ω)	Ammeter reading (mA)	Voltmeter reading (V)
	180	17	3.0
Tolerance (%)	10		

Table 2 (Sample data are given.)

	R_1 (Ω)	R_2 (Ω)	Ammeter reading (mA)			Voltmeter reading (V)		
			I	I_1	I_2	V	V_1	V_2
	180	220	30	17	14	3	3	3
Tolerance (%)	10	10						

Table 3 (Sample data are given.)

	R_1 (Ω)	R_2 (Ω)	R_3 (Ω)	Ammeter reading (mA)				Voltmeter reading (V)			
				I	I_1	I_2	I_3	V	V_1	V_2	V_3
	180	220	330	39	17	14	10	3	3	3	3
Tolerance (%)	10	10	10								

Analysis

1. $R_1 = \dfrac{3.0\text{ V}}{0.017\text{ A}} = 176\ \Omega.$
   Student answers will vary; the sample data yield a result within the tolerance range.
2. a. $R = \dfrac{V}{I} = \dfrac{3.0\text{ V}}{0.03\text{ A}} = 100\ \Omega$
   b. $I = 17\text{ mA} + 14\text{ mA} = 31\text{ mA}$
   c. $R_1 = \dfrac{3.0\text{ V}}{0.017\text{ A}} = 176\ \Omega$
   d. $R_2 = \dfrac{3.0\text{ V}}{0.014\text{ A}} = 214\ \Omega$
   e. $R = 99\ \Omega$
3. Student values may have a greater difference, depending on the quality of the ammeters used.
   a. The measured current should equal the sum of the currents (or very nearly).
   b. Using the sample readings, the calculated equivalent resistance (99 Ω) equals the measured equivalent resistance (97 Ω) within the tolerance of the resistors.
4. a. $R = \dfrac{3.0\text{ V}}{0.039\text{ A}} = 77\ \Omega$
   b. $I = 17\text{ mA} + 14\text{ mA} + 10\text{ mA} = 41\text{ mA}$
   c. $R_1 = \dfrac{3.0\text{ V}}{0.017\text{ A}} = 176\ \Omega$
   d. $R_2 = \dfrac{3.0\text{ V}}{0.014\text{ A}} = 214\ \Omega$
   e. $R_3 = \dfrac{3.0\text{ V}}{0.010\text{ A}} = 300\ \Omega$
   f. $R = 76\ \Omega$
5. Student values may have a greater difference, depending on the quality of the ammeters used.
   a. The two currents are very nearly equal (they should be equal).
   b. Using the sample readings, the calculated equivalent resistance (76 Ω) equals the measured equivalent resistance (73 Ω) within the tolerance of the resistors.
6. The sum of the current in the branches of a parallel circuit equals the total current in the circuit.
7. The voltage drop across each branch of a parallel circuit is the same as the voltage drop across the entire circuit.
8. The total current increases.

Application

Since the equivalent resistance is 0.5000 Ω and the meter resistance is 500.0 Ω, the shunt resistance is found from

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}, \text{ or } \frac{1}{0.5000\ \Omega} = \frac{1}{500.0\ \Omega} + \frac{1}{R_s}.$$

Solving for $\dfrac{1}{R_s}$,

$$\frac{1}{R_s} = 2.0\ \Omega - 0.002\ \Omega = 1.998\ \Omega.$$

Therefore, $R_s = \dfrac{1}{1.998} = 0.5005\ \Omega.$

Extension

There are many ways to solve this problem. In one solution, the circuit can be reduced to two parallel sets, each having four 100-Ω resistors in parallel connected in series with a pair of 100-Ω resistors in parallel. This reduces to two 75-Ω resistors in parallel, which is equivalent to one 37.5-Ω resistor in series with the 1.0-V battery.

The current $= I = \dfrac{V}{R} = \dfrac{1.0\text{ V}}{37.5\ \Omega} = 27\text{ mA}.$

INSTRUCTOR NOTES 21

Principles of Electromagnetism

Process Skills

observing, communicating, formulating models, classifying, interpreting data, predicting, questioning

Teaching Suggestions

1. Review the right-hand rule with students before beginning the lab.
2. Remind students to leave the switches closed only long enough to make observations.

Observations and Data

A. The Field Around a Long, Straight Wire

With current flowing upward, the north pole points counter-clockwise about the wire.

With current flowing downward, the north pole points clockwise about the wire.

B. Strength of the Field

The filings are oriented in circular patterns about the wire. The smaller the current, the less distinct the patterns. With 0.5 A of current, almost no pattern is observed.

C. The Field Around a Coil

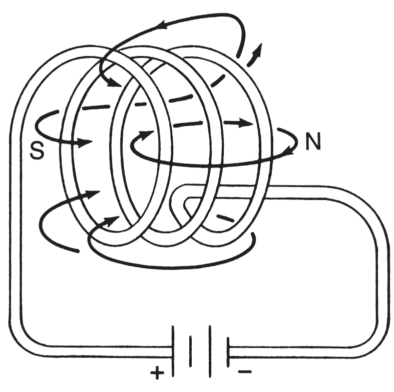
The compass needle lines up as indicated by the labels in the figure.

D. An Electromagnet

1. Sample electromagnet picks up six clips.
2. Sample electromagnet picks up ten clips; increasing the number of loops increases the magnet's strength.
3. Sample electromagnet picks up 16 clips; increasing the current increases the magnet's strength.

Analysis

1. The direction of the magnetic field follows the direction of the fingers of the right hand when the right thumb points in the direction of the conventional current (from positive to negative).
2. It increases electromagnetic strength.
3.



4. The number of turns, the current strength, and the type of core determine the strength of an electromagnet.
5. A bar magnet maintains its magnetism for a long time, while an electromagnet is a temporary magnet, which loses its magnetism as soon as the current flow is stopped.

Application

Continuously applied current: strong electromagnets—such as in junk yards, magnetic-resonance-imaging equipment

Intermittently applied current: telephone ringers, door bells, buzzers, door locks, electric switches (relays)

INSTRUCTOR NOTES

22 Electromagnetic Induction

Process Skills

observing, communicating, interpreting data, measuring, hypothesizing, predicting, questioning

Alternative Materials

Students can wind the coils around cardboard tubes, such as toilet-paper tubes or paper-towel tubes, using 20- or 22-gauge copper wire. A few pieces of masking or electrical tape keep the coils together. Commercially made coils are available or use a galvanoscope block with wound coils.

Teaching Suggestions

1. Help students understand that while the conversion of electrical energy to mechanical energy in a magnetic field is the principle of the electric motor, the conversion of mechanical energy to electrical energy in a magnetic field is the principle of the electric generator. Emphasize that this correspondence of opposites prevails in many areas of science and provides guidance and structure to researchers and students alike.
2. Remind students to keep magnets away from their wrist watches.

Observations and Data

1. The galvanometer just barely moves. Student answers will vary, depending on the strength of the magnet and the sensitivity of the galvanometer.

2. Students should see movement of the galvanometer needle, indicating that a current was produced.
3. Students should find that a much stronger current is produced, compared to that produced by the 25-turn coil.
4. The galvanometer needle deflects in one direction when the magnet is thrust into the coil and in the opposite direction when the magnet is pulled out. The needle deflects in opposite directions when the north or south pole is thrust into the coil, due to the different directions of the magnetic fields.
5. The stronger magnet produces the stronger current. The greater the speed of the magnets' motion, the stronger the current.
6. No current is induced when the magnets are stationary. A current is produced when the coil moves over the magnets.

Analysis

1. The end of the coil into which the north pole of the magnet is thrust becomes a south pole, and then reverses when the magnet is pulled out. An induced current acts in such a direction that its magnetic properties oppose the change by which the current is induced.
2. The *EMF,* measured in volts, depends on the strength of the magnetic field, the number of loops in the coil, and the speed at which the wire cuts through the magnetic flux. If the moving wire is part of a closed circuit, the induced current is equal to the voltage divided by the resistance of the circuit.
3. From Ohm's law, $V = IR$. If resistance is constant, the voltage *(EMF)* is proportional to the current. This experiment showed that the strength of the magnetic field, B, affected the magnitude of the current; the number of turns, l, affected the current; and the rate of movement, v, of the wire through the magnetic field affected the current. Therefore $EMF \propto B$, $EMF \propto l$, and $EMF \propto v$, and the equation, $EMF = Blv$, is substantiated.
4. No current flows in the wire. An electric current is produced only when the wire cuts the magnetic field lines.
5. No matter what its source, each field exerts a force, $q'E$, on a test charge, q'.

Application

A changing magnetic field appears in the iron core due to the alternating current in the primary coil. Through the iron core, the field moves over the loops of the secondary coil, causing an induced current, and an induced *EMF,* to appear in that coil. The transformer does not work with direct current since no changing magnetic field is produced; thus, no current can be induced.

Extension

1. $EMF = Blv \sin \theta$
   $= (0.75 \times 10^{-2}\ \text{T})(0.40\ \text{m})(5.0\ \text{m/s})(\sin 45°)$
   $= 1.1 \times 10^{-2}\ \text{V}$
2. EMF is greatest when $\theta = 90°$ and diminishes to zero as θ approaches 0°.
3. The output is an alternating current that varies sinusoidally over a period of time; the amplitude of the current changes with the sine of the angle between v and B. In the U.S., the frequency of alternating current is 60 cycles per second; the current changes direction (alternates) 120 times per second.

INSTRUCTOR NOTES 23 Planck's Constant

Process Skills

observing, measuring, using numbers, communicating, interpreting data, predicting, questioning

Alternative Materials

A variable power supply can be used instead of the battery; however, it should provide well-filtered, clean DC power. Most new variable power supplies meet these criteria. Using a variable power supply permits elimination of the battery and potentiometer.

Teaching Suggestions

1. The packing material of many LEDs displays the wavelength of their emitted radiation. However, if you have some LEDs that are not identified, the following table will help in approximating the wavelengths of light for typical LEDs.

Color	Wavelength (nm)
red	635, 650, 660, 675, 690 (standard red is 650 or 660)
yellow	590, 610
green	550, 563, 570

2. The purpose of the 22-Ω resistor is to limit current to the LED, thus preventing instantaneous destruction of the LED if students accidentally apply too large a voltage. Resistance could be increased to as much as 33 Ω, if desired, or eliminated. If it is eliminated and a potential difference of 3 V is applied to the LED, excess current will flow through the junction and destroy it.

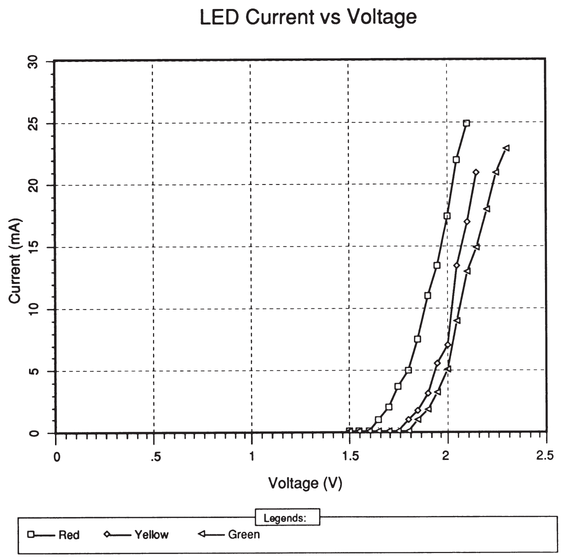
Observations and Data

Table 1

LED	LED Color	Wavelength (nm)
1	red	650
2	yellow	590
3	green	563

Table 2 (Sample data are given.)

LED 1		LED 2		LED 3	
Voltage (V)	Current (mA)	Voltage (V)	Current (mA)	Voltage (V)	Current (mA)
1.50	0	1.50	0	1.50	0
1.55	0	1.55	0	1.55	0
1.60	0	1.60	0	1.60	0
1.65	1	1.65	0	1.65	0
1.70	2	1.70	0	1.70	0
1.75	3.7	1.75	0	1.75	0
1.80	5.0	1.80	1	1.80	0
1.85	7.5	1.85	1.7	1.85	1
1.90	11.0	1.90	3.1	1.90	1.8
1.95	13.5	1.95	5.5	1.95	3.2
2.00	17.5	2.00	7.0	2.00	5.1
2.05	22.0	2.05	13.5	2.05	9.0
2.10	25.0	2.10	17.0	2.10	13.0
2.15		2.15	21.0	2.15	15.0
2.20		2.20		2.20	18.0
2.25		2.25		2.25	21.0
2.30		2.30		2.30	23.0
2.35		2.35		2.35	



This graph of LED current versus voltage was produced with the Lab Partner™ graphing program.

Analysis

1. a. red voltage: 1.75 V
   b. yellow voltage: 1.95 V
   c. green voltage: 2.05 V
2. red LED, $h = qV\lambda/c = (1.6 \times 10^{-19}\ \text{C})(1.75\ \text{V})(650\ \text{nm})/(3.0 \times 10^{8}\ \text{m/s}) = 6.1 \times 10^{-34}\ \text{J} \cdot \text{s}$
   yellow LED, $h = qV\lambda/c = (1.6 \times 10^{-19}\ \text{C})(1.95\ \text{V})(590\ \text{nm})/(3.0 \times 10^{8}\ \text{m/s}) = 6.14 \times 10^{-34}\ \text{J} \cdot \text{s}$
   green LED, $h = qV\lambda/c = (1.6 \times 10^{-19}\ \text{C})(2.05\ \text{V})(563\ \text{nm})/(3.0 \times 10^{8}\ \text{m/s}) = 6.2 \times 10^{-34}\ \text{J} \cdot \text{s}$
3. red error $= (6.6 \times 10^{-34} - 6.1 \times 10^{-34})(100\%)/6.6 \times 10^{-34} = 8\%$
   yellow error = 7%
   green error = 6%
   Student answers will vary but should be within 10–15% of *h*.
4. A blue LED should have a voltage greater than that of the green LED, which may be approximately 2.4–2.6 V. The infrared LED will have a voltage less than that of the red LED, or less than 1.6 V, possibly 1.2–1.4 V.

Application

The light-emitting diode is more durable because it has no fragile filament. Light from an incandescent light bulb comprises the entire visible spectrum, while light from the LED has only one wavelength (monochromatic light). The wavelength of an LED is a very narrow band around its computed value, with a band width of about 25–30 nm. When wavelength is closely controlled and the light is produced in a cavity at the junction, a laser diode results.

INSTRUCTOR NOTES

24 Reflection of Light

Process Skills

observing, measuring, using numbers, interpreting data, inferring, predicting, hypothesizing, defining operationally

Teaching Suggestions

1. If students have difficulty constructing their triangles in Part B, tell them to repeat the procedure, but emphasize that they must sight very carefully along the lines to the image of the pin in the mirror.
2. One set-up for Part C can be used for all students. As they work on Parts A and B, each lab group can take a turn with the laser. In this way, the laser remains in a separate, protected area of the room.

Observations and Data

Table 1 (Sample data are given.)

Object distance	4.1 cm
Image distance	3.8 cm
Angle of incidence, i_1, **PXN**	13°
Angle of reflection, r_1, **AXN**	13.5°
Angle of incidence, i_2, **PYN′**	24°
Angle of reflection, r_2, **BYN′**	25°

Table 2 (Sample data are given.)

Points	Distance to mirror line (cm)
A	1.7
B	5.4
C	1.8
A′	1.8
B′	5.2
C′	1.9

Table 3

Drawing of reflected laser light from a thin plane mirror:
A single large spot should appear.

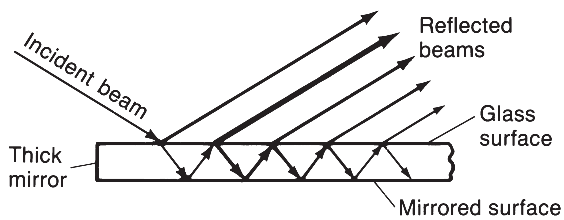
Drawing of reflected laser light from a thick plane mirror:

The second spot is brightest; this is the reflection from the mirrored surface.

Observation of reflected laser beams:
Students should note a series of reflected beams, becoming progressively narrower as they are more distant from the incident beam.

Analysis

1. They are equal (or should be nearly so).
2. The image is the same distance behind the mirror as the object is in front of the mirror.
3. The image should be the same size as the object. Students may have some small errors due to sighting inaccuracies.
4. Images formed by plane mirrors are as far behind the mirror as the object is in front of the mirror. The image is reversed right to left and is the same size as the object.
5. The image appears where the light rays apparently cross, not where they actually cross. This image does not exist behind the mirror, where it appears to be.
6. The second spot is brightest, because this beam is the reflection from the mirrored surface. The first spot is the reflection from the glass.
7. The thin mirror reflects light from the glass and mirrored surface, but the reflected spots are nearly in the same location. The thick mirror has multiple reflections, spaced farther apart, from the glass at the top and the silver at the bottom of the mirror, as shown below.



Partial reflection occurs at the mirror-air interface.

Application

Students should state that some of the light is transmitted while most light is reflected. One-way mirrors generally reflect a large portion of the incident light, such as 50%–60%, while allowing a smaller portion, such as 5%–15%, to pass through. Since a smaller portion of the light is transmitted, the viewing area is usually darker than the observed area.

Extension

The distances should be equal.

INSTRUCTOR NOTES

25 Concave and Convex Mirrors

Process Skills

observing, measuring, interpreting data, communicating, questioning, designing experiments

Troubleshooting

If students have difficulty locating sharp images, check the mirror. The mirror must be clean and of good quality to produce clear, sharp images. To check the quality of the mirrors, take clean mirrors and focus sunlight onto a screen. Those mirrors that are of good quality will produce a small image of the sun while those of poorer quality will not focus the sunlight.

Alternative Materials

1. Object markers may be used with the light sources. However, students usually have no trouble identifying the orientations of the images. Light bulbs generally have flat bases or glowing filaments, which indicate upright or inverted positions.
2. Candles can be substituted for light sources. If candles are used, caution should be observed around the flames.

Teaching Suggestions

1. Allow ample time to complete this investigation. A prelab discussion of the types of images formed by mirrors and a demonstration of how to find focal lengths may be helpful.
2. Use a concave mirror to project an outdoor scene from outside a window onto a screen. This demonstration will familiarize students with mirrors and real images. They should also be fascinated by the color image.

Observations and Data

Table 1 (Sample data are given.)

Focal length of mirror, f	33 cm
Center of curvature of mirror, **C**	66 cm
Height of light source, h_o	1 cm

Table 2 (Sample data are given.)

Position of object	Beyond C	At C	Between C and F	At F	Between F and A
d_o	1.0 m	66 cm	48 cm	33 cm	16 cm
d_i	49 cm	66 cm	98 cm	—	—
h_i	0.8 cm	1.0 cm	6 cm	—	larger than object
Type of image: real, none or virtual	real	real	real	none	virtual
Direction of image: inverted or erect	inverted	inverted	inverted	no image	erect

Table 3 (Sample data are given.)

Trial	Position of object	Position of image	Type of image: real or virtual	Image size compared to object size	Direction of image: inverted or erect
1	for all positions	behind mirror	virtual	smaller	erect
2					
3					

Analysis

1. a. The image is between **C** and **F,** inverted, real, and smaller than the object.
   b. The image is at **C,** real, inverted, and the same size as the object.
   c. The image is beyond **C,** inverted, real, and larger than the object.
   d. No image is formed.
   e. The image is behind the mirror, erect, and larger than the object.

2. The images are virtual, smaller and erect, and located behind the mirror.
3. For beyond **C,** $f = 33$ cm; at **C,** $f = 33$ cm; between **C** and **F,** $f = 32$ cm. Student values should be in good agreement.
4. The average is 33 cm, relative error = 0%. Students should have an error of no more than 10%–15% if they have made careful observations and have reasonably good mirrors.

Application

The top edge of the box should be along the principal axis, while the light bulb socket should be located at **C** to produce an image equal in size to the object and inverted.

INSTRUCTOR NOTES 26 Snell's Law

Process Skills

observing, using numbers, measuring, inferring, interpreting data, questioning, communicating

Teaching Suggestions

1. This activity should be easy to understand and complete, even for students who have not studied trigonometry. However, review the relationships of triangles prior to the lab and introduce Snell's law as a relationship between the opposite side and the hypotenuse of a triangle. The results should be apparent, even if the math is not.
2. A dish of water or oil could be substituted for the glass plate to provide a different index of refraction. The activity is conducted in the same manner. However, the oil is messy if it is spilled.

Observations and Data

Table 1 (Sample data are given.)

θ_i	θ_r	sin θ_i	sin θ_r	$\theta_{r'}$	Index of refraction, n
30°	19°	0.5	0.326	30°	1.53
45°					

Analysis

1. They should be equal or nearly equal. Students might have as much as 10% error if they are not careful while sighting along their rulers.
2. As the light rays pass at an angle from a less dense to a more dense medium, they bend toward the normal.
3. As the light rays pass at an angle from a more dense to a less dense medium, they bend away from the normal.
4. The two angles are equal. According to Snell's law, as the light ray passes back to the optically less dense medium, it should resume its original speed and bend away from the normal.
5. $v_s = c/n_s = (3.00 \times 10^8 \text{ m/s})/1.53$
   $= 1.96 \times 10^8$ m/s
   Light travels 3.00×10^8 m/s $- 1.96 \times 10^8$ m/s $= 1.04 \times 10^8$ m/s faster in a vacuum.
   % increase $= 1.04 \times 10^8/1.96 \times 10^8 = 53\%$ faster in a vacuum.

Application

Light will bend more traveling from air into water than from water into glass. Using the general form of Snell's law, $n_i \sin \theta_i = n_r \sin \theta_r$, light traveling from air into water yields an effective $n = 1.34$, while light traveling from water into glass yields an effective $n = 1.14$, determined from $(1.34)(\sin \theta_i) = (1.53)(\sin \theta_r)$. The greater the index of refraction, the greater the amount of refraction.

Extension

The sample materials should be easy to identify. The samples will take on a ghostlike appearance and be just barely visible in the liquid with nearly the same index of refraction. Glass normally has an index of refraction of about 1.5. You probably will not have any glass with $n = 1.7$.

INSTRUCTOR NOTES 27 Convex and Concave Lenses

Process Skills

observing, measuring, interpreting data, communicating, questioning, predicting, designing experiments

Troubleshooting

When using sunlight to determine the focal length of the concave lens, the contrast between the circle of light projected on the screen and the ambient light can be increased by placing a piece of paper around the lens so that sunlight is blocked from falling directly on the screen.

Teaching Suggestion

To find the focal length of the convex lens, arrange your lens, meter stick, and screen, as shown in Figure 3. When sunlight is used, the focal length can be determined by projecting a focused image of the sun onto a screen and measuring the distance from the lens to the focused spot on the screen. Measure the distance quickly, since a focused spot can become hot and cause the screen to burn. Supervise students and be sure to caution them to avoid looking directly at the sun.

Observations and Data

Table 1 (Sample data are given.)

Focal length	18 cm
$2F$	36 cm
Height of light source, h_o	1.2 cm

Table 2 (Sample data are given.)

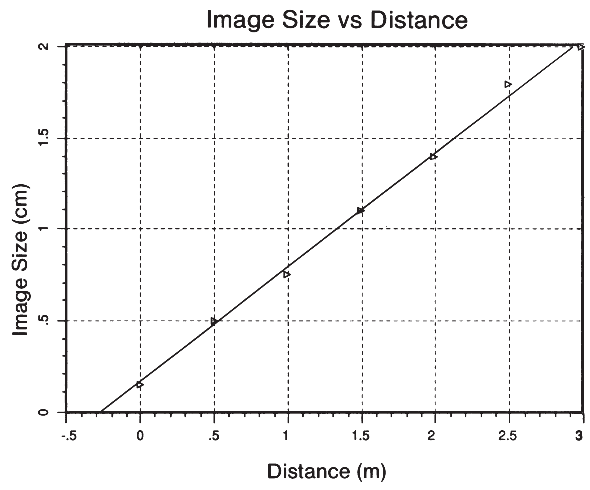
Position of object	Beyond $2F$ (cm)	At $2F$ (cm)	Between $2F$ and F (cm)	At F (cm)	Between F and lens (cm)
d_o	50	37	25	17.5	10
d_i	29.2	37.2	66.5	—	—
h_i	1.0	1.2	1.8	—	appears larger as viewed through lens
Type of image: real, none, or virtual	real	real	real	none	none
Direction of image: inverted or erect	inverted	inverted	inverted	—	erect

Table 3

Distance from lens (m)	Diameter of screen image (cm)
0.0	0.15
0.5	0.5
1.0	0.75
1.5	1.1
2.0	1.4
2.5	1.8
3.0	2.0

Analysis

1. a. The image is between F and $2F$, real, about the same size, and inverted.
   b. The image is at $2F$, the same size as the object, real, and inverted.
   c. The image is beyond $2F$, larger, real, and inverted.
   d. No image was readily apparent.
   e. The image is virtual, larger, erect, and on the same side of the lens as the object.
2. a. $f = 18.4$ cm; b. $f = 18.5$ cm; c. $f = 18.2$ cm. There should be good agreement for all measurements.
3. Average $f = 18.4$ cm; relative error = (18.4 − 18)(100%)/18 = 2%. Students should have a relative error of less than 10%.
4. The intersection provides a focal length of −0.25 m. The accepted value is −0.20 m, therefore the relative error = (0.25 − 0.20)(100%)/0.20 = 25%. Student error may vary greatly, since the observed diameters are usually not clearly defined at the edges.



This graph of image size versus distance from the lens was produced using the Lab Partner™ graphing program. The *x*-intercept is −0.26 m.

Application

If the direction of the reflected laser pattern is opposite to that of the observer's head, then this person is nearsighted. If the direction of the reflected laser pattern is the same as that of the observer's head, then this person is farsighted. If the observer does not perceive any relative motion, then his or her eyesight is normal. To simulate near- or farsightedness, students could hold various lenses in front of their eyes and observe the laser light spot.

Extension

The object appears about normal when viewed through a convex or a concave air lens in air. However, the object appears smaller when viewed through the convex air lens immersed in water and larger when viewed through the concave air lens immersed in water. Note the reversal of the usual effects of glass lenses on these shapes. In water, light rays are traveling from the object through a more dense medium (water) to a less dense medium (air in the lenses). This reversal of media accounts for the opposite effects of the lenses.

INSTRUCTOR NOTES 28 Double-Slit Interference

Process Skills

observing, communicating, interpreting data, measuring, predicting, questioning

Troubleshooting

If students have difficulty measuring x for the violet filter, suggest that they move farther away (increase L). This color is the most difficult to observe and measure, especially if the room lights are on.

Alternative Materials

Double slits can be purchased or constructed. If you wish to have students construct their own double slits, tape a pair of razor blades together and lightly pull the unit across a microscope slide covered with dried graphite emulsion. An alternative to graphite emulsion is aluminum foil, placed over a microscope slide and cut with the razor-blades unit.

Teaching Suggestions

1. Suggest that students use the red filter material first, since it provides the best observations of diffraction and interference.
2. If students have difficulty when the filter material is placed on the light bulbs, they can try holding the filter material in front of their slits.
3. If a variety of color filter material is available, give each lab partnership a red piece and two other colors, so that the variety of other colors is different for different lab partners. This individualizes the lab, and partners are less inclined to copy data.

Observations and Data

Table 1 (Sample data are given.)

	Observations of Light
Close	The bright bands of red are close together.
Far away	The bright bands of red move farther apart and are easier to see.

Table 2 (Sample data are given.)

Color	***d*** **(mm)**	***x*** **(m)**	***L*** **(m)**
Red	0.15	0.017	4.0
Yellow	0.15	0.015	4.0
Violet	0.15	0.012	4.0

Analysis

1. The pattern spreads out, so the first-order, second-order, etc., lines are farther apart.
2. $\lambda_{red} = xd/L$
$= (0.017 \text{ m})(0.15 \times 10^{-3} \text{ m})/4.0 \text{ m}$
$= 640 \text{ nm}$
$\lambda_{yellow} = xd/L$
$= (0.015 \text{ m})(0.15 \times 10^{-3} \text{ m})/4.0 \text{ m}$
$= 560 \text{ nm}$
$\lambda_{violet} = xd/L$
$= (0.012 \text{ m})(0.15 \times 10^{-3} \text{ m})/4.0 \text{ m}$
$= 450 \text{ nm}$
Student answers will vary and will be dependent on how carefully they measure x. Answers should be within the visible spectrum (in the range of 400–700 nm).

3. Red light is diffracted most. Using the same values for L and d, the angle will be larger, since x is greater for the larger wavelength, $x = \lambda L/d$.
4. Student answers will vary. However, the distance should be greater than the measured distance of x for the red light. The infrared light will be diffracted more than visible red light, since it has a larger wavelength.
5. Student answers will vary. However, the distance should be less than the measured distance for x for the violet light. The ultraviolet light will be diffracted less than visible violet light, since it has a smaller wavelength.

Applications

1. Since $\tan\theta = x/L$ and $\theta = 0.8°$, $\lambda = xd/L = d(\tan\theta) = (0.05 \times 10^{-3}\ \text{m})(\tan 0.8) = 700$ nm, which is the wavelength of red light.
2. $L = xd/\lambda$

$$= \frac{(14.7 \times 10^{-3}\ \text{m})(1.50 \times 10^{-5}\ \text{m})}{5.00 \times 10^{-7}\ \text{m}}$$

$$= 0.441\ \text{m}$$

3. $x = L\lambda/d$

$$= \frac{(4.41 \times 10^{-1}\ \text{m})(5.89 \times 10^{-7}\ \text{m})}{1.5 \times 10^{-5}}$$

$$= 0.0173\ \text{mm}$$

Extension

The solutions will vary, depending on the values for L and x. However, when students substitute their values into $d = \lambda L/x$, the resulting value for d should be very close to the actual value.

INSTRUCTOR NOTES 29 Semiconductor Properties

Process Skills

observing, measuring, using numbers, communicating, interpreting data, predicting, questioning

Alternative Materials

Any diode or rectifier can be substituted for the 1N4004 series diode as long as the diode working voltage is greater than the voltage you are using.

Teaching Suggestions

1. The 10-Ω resistor serves as a current-limiting device to prevent damage to the ammeter in case students accidentally turn the potentiometer control and apply the full battery or power-supply voltage to the meter. If the power-supply voltage is over 3 V, such as 6 V, the resistance can be increased to 33–47 Ω.
2. You can use any of the laboratory power supplies with an AC power output. The small transformer adapters with an AC output can be substituted. Use only a low-voltage AC power supply, not the 120-VAC line current.

Observations and Data

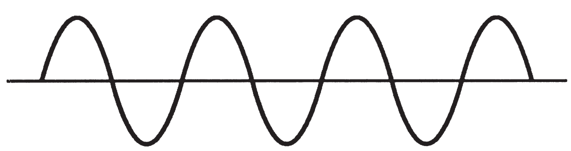
Table 1 (Sample data are given.)

Forward-Biased Diode									
Voltage (V)	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80
Current (mA)	0	0	0	0	0	0	2	17.5	180

Table 2 (Sample data are given.)

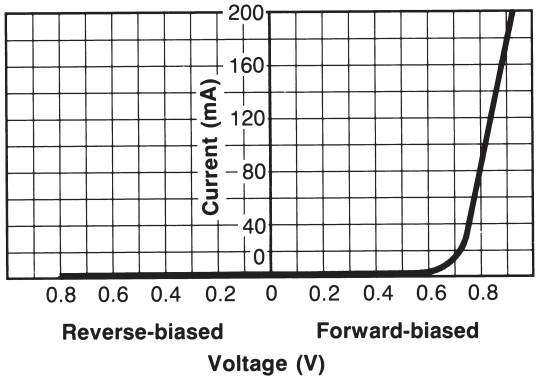
Reverse-Biased Diode									
Voltage (V)	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80
Current (mA)	0	0	0	0	0	0	0	0	0

Table 3

Diode with AC Power
AC wave shape

AC wave shape through a diode


Analysis

1. Current versus Voltage for Forward and Reverse Biasing of a Diode



2. With a resistor in the circuit, a linear relationship between current and voltage exists for both negative and positive values of voltage. With a diode in the circuit, no current flows when it is reverse biased (for negative voltages), but the current increases exponentially when the diode is forward biased and the voltage is increased.
3. The diode conducts current in only one direction.
4. The diode is made of silicon because it begins to conduct current with a forward bias at a voltage of about 0.6 V.
5. An alternating current source has a sinusoidal wave shape. The wave shape of a current across the resistor that passes through the diode is only the positive portion of the alternating current. The negative portion of the alternating current is blocked.
6. The shape is the opposite half (negative portion) of the AC wave shape that was drawn in Table 3 (AC wave shape through a diode).

Application

The figure shows full-wave rectification. Each diode alternately conducts current for one-half of the time.

Extension

The wave shape observed should be the same as the one predicted in the application.