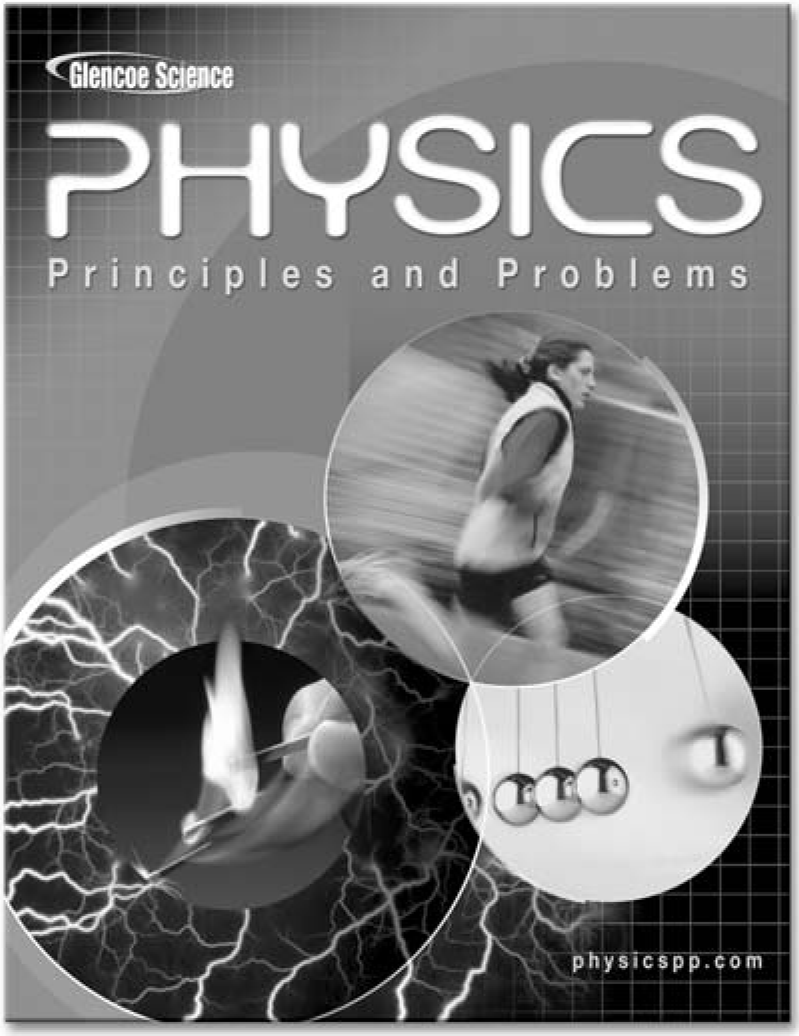

Forensics Laboratory Manual

Glencoe

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Send all inquiries to:
Glencoe/McGraw-Hill
8787 Orion Place
Columbus, Ohio 43240

ISBN 0-07-866559-0

Printed in the United States of America

1 2 3 4 5 6 7 8 9 045 09 08 07 06 05 04

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To the Student

In the real world, physics often is used to solve problems—sometimes even to solve mysteries. Physicists may examine problems in order to improve human life, such as: "How can supercomputers be used to model blood flow in veins and arteries?" and "How can wind energy be used to reduce use of fossil fuels?" Physics also can be used to solve mysteries by answering questions like: "How fast was the car moving when the driver slammed on the brakes?" and "From what direction did the projectile come?" Physicists work in the fields of forensics and technology to find the answers to these and many other questions.

In the ***Forensics Laboratory Manual,*** you will be presented with in-depth investigations that deal with the path of a projectile, collecting and analyzing data, or interpreting evidence found at a crime or accident scene. You will use your knowledge of scientific inquiry and your problem-solving skills as you learn physics and forensic procedures. You then will apply these techniques and procedures to real-world scenarios.

Each lab begins by stating a problem that needs to be solved by applying physics. Information presented in *Background* will help you understand the science involved in the problem or case. The *Procedure* section provides step-by-step instructions for learning a technique or procedure or for solving the problem presented. Finally, the *Analyze and Conclude* section allows you to interpret your data and demonstrate your problem-solving skills and understanding of the scientific processes involved.

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Laboratory and Safety Guidelines

Emergencies

- Inform the teacher immediately of any mishap—fire, injury, glassware breakage, chemical spills, etc.
- Know the location of the fire extinguisher, safety shower, eyewash, fire blanket, and first aid kit. Know how to use this equipment.
- If chemicals come into contact with your eyes or skin, flush with large quantities of water and notify your teacher immediately.

Preventing Accidents

- Do not wear clothing that is loose enough to catch on anything. Do not wear sandals or open-toed shoes. Remove loose jewelry—chains or bracelets—while doing lab work.
- Wear protective safety gloves, goggles, and aprons as instructed.
- Always wear safety goggles (not glasses) in the laboratory.
- Wear goggles throughout the entire activity, cleanup, and handwashing.
- Keep your hands away from your face while working in the laboratory.
- Remove synthetic fingernails before working in the lab (these are highly flammable).
- Do not use hair spray, mousse, or other flammable hair products just before or during laboratory work where an open flame is used (they can ignite easily).
- Tie back long hair and loose clothing to keep them away from flames and equipment.
- Eating, drinking, chewing gum, applying makeup, and smoking are prohibited in the laboratory.
- Do not inhale vapors or taste, touch, or smell any chemical substance unless instructed to do so by your teacher.

Working in the Laboratory

- Study all instructions before you begin a laboratory or field activity. Ask questions if you do not understand any part of the activity.
- Work only on activities assigned by your teacher. Never work alone in the laboratory.
- Do not substitute other chemicals or substances for those listed in your activity.
- Do not begin any activity until directed to do so by your teacher.
- Do not handle any equipment without specific permission.
- Remain in your own work area unless given permission by your teacher to leave it.
- Do not point heated containers—test tubes, flasks, and so forth—at yourself or anyone else.
- Do not take any materials or chemicals out of the classroom.
- Stay out of storage areas unless you are instructed to be there and are supervised by your teacher.

Laboratory Cleanup

- Keep work, lab, and balance areas clean, limiting the amount of easily ignitable materials.
- Turn off all burners, water faucets, probeware, and calculators before leaving the lab.
- Carefully dispose of waste materials as instructed by your teacher.
- With your goggles on, wash your hands thoroughly with soap and warm water after each activity.

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Safety Symbols

SAFETY SYMBOLS	HAZARD	EXAMPLES	PRECAUTION	REMEDY
DISPOSAL	Special disposal procedures need to be followed.	Certain chemicals, living organisms	Do not dispose of these materials in the sink or trash can.	Dispose of wastes as directed by your teacher.
BIOLOGICAL	Organisms or other biological materials that might be harmful to humans	Bacteria, fungi, blood, unpreserved tissues, plant materials	Avoid skin contact with these materials. Wear mask or gloves.	Notify your teacher if you suspect contact with material. Wash hands thoroughly.
EXTREME TEMPERATURE	Objects that can burn skin by being too cold or too hot	Boiling liquids, hot plates, dry ice, liquid nitrogen	Use proper protection when handling.	Go to your teacher for first aid.
SHARP OBJECT	Use of tools or glassware that can easily puncture or slice skin	Razor blades, pins, scalpels, pointed tools, dissecting probes, broken glass	Practice common-sense behavior and follow guidelines for use of the tool.	Go to your teacher for first aid.
FUME	Possible danger to respiratory tract from fumes	Ammonia, acetone, nail polish remover, heated sulfur, moth balls	Make sure there is good ventilation. Never smell fumes directly. Wear a mask.	Leave foul area and notify your teacher immediately.
ELECTRICAL	Possible danger from electrical shock or burn	Improper grounding, liquid spills, short circuits, exposed wires	Double-check setup with teacher. Check condition of wires and apparatus.	Do not attempt to fix electrical problems. Notify your teacher immediately.
IRRITANT	Substances that can irritate the skin or mucous membranes of the respiratory tract	Pollen, moth balls, steel wool, fiberglass, potassium permanganate	Wear dust mask and gloves. Practice extra care when handling these materials.	Go to your teacher for first aid.
CHEMICAL	Chemicals that can react with and destroy tissue and other materials	Bleaches such as hydrogen peroxide; acids such as sulfuric acid, hydrochloric acid; bases such as ammonia, sodium hydroxide	Wear goggles, gloves, and an apron.	Immediately flush the affected area with water and notify your teacher.
TOXIC	Substance may be poisonous if touched, inhaled, or swallowed.	Mercury, many metal compounds, iodine, poinsettia plant parts	Follow your teacher's instructions.	Always wash hands thoroughly after use. Go to your teacher for first aid.
FLAMMABLE	Flammable chemicals may be ignited by open flame, spark, or exposed heat.	Alcohol, kerosene, potassium permanganate	Avoid open flames and heat when using flammable chemicals.	Notify your teacher immediately. Use fire safety equipment if applicable.
OPEN FLAME	Open flame in use, may cause fire.	Hair, clothing, paper, synthetic materials	Tie back hair and loose clothing. Follow teacher's instruction on lighting and extinguishing flames.	Notify your teacher immediately. Use fire safety equipment if applicable.

Eye Safety
Proper eye protection should be worn at all times by anyone performing or observing science activities.

Clothing Protection
This symbol appears when substances could stain or burn clothing.

Radioactivity
This symbol appears when radioactive materials are used.

Handwashing
After the lab, wash hands with soap and water before removing goggles.

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Date ____________ Period ____________ Name ____________________

1 Forensics Lab 1

Safety Precautions

Caution: Fake blood may stain clothing.

Materials

- fake blood
- small beaker
- dropper with 0.5 mL graduation
- graph paper (smooth texture, if possible)
- ruler
- meterstick
- unknown droplet splatter

It's in the blood.

Problem

How does the distance that a drop of blood falls affect the shape and size of the splash when it lands?

Objectives

- **Observe** the effect of the distance and direction of fall on the shape or size of a droplet of fake blood.
- **Understand** the relationship between height of fall and velocity at impact.
- **Determine** earlier events using this relationship.
- **Analyze** and review graphical concepts.

Background

Blood splatter gives forensic scientists many clues as to what occurred in a crime. Blood can be washed away, but it leaves trace evidence that is very difficult for a criminal to eliminate. It will adhere to clothing and surfaces, and although it may not be detectable with the naked eye, blood can be easily found by luminescence and chemical tests. By analyzing the shape and size of blood droplets, investigators can begin to reconstruct the events that caused the spilling of blood. This is called *bloodstain pattern interpretation*.

In this experiment, you will investigate the effect of height and direction on the size and shape of a droplet of blood. You will determine the pattern that emerges and use this pattern to interpolate information about a drop that you did not make.

Procedure

1. Formulate a hypothesis about the relationship between the distance a drop of blood falls and the size of the splash it makes. Be as specific as possible. For example, do you think that the relationship is a linear one? Record your hypothesis on the lines provided under **Data and Observations.**
2. Obtain a small beaker with artificial blood.
3. Fill dropper with 0.5 mL of fake blood.
4. Hold dropper with open tip 10 cm above the graph paper and release one drop onto a clean spot.
5. Measure the diameter of the spot and record it in **Table 1.**
6. Repeat this process on a clean spot for heights from 20–100 cm, in 10-cm increments.

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7. Repeat steps 2–6 with a clean sheet of graph paper and record the results in **Table 2.**
8. Place a clean sheet of paper in your work area. (Any type of paper will work.)
9. Lightly squeeze the dropper bulb until a droplet forms but remains attached to the mouth of the dropper.
10. At an angle, gently fling the droplet from the dropper onto the paper. Observe the shape and size, and record your observations in the space provided below.
11. Obtain an unknown splatter sample from your teacher and measure the diameter of the drop to the nearest half millimeter.
12. Record this value in the space provided under Table 2 below.

Cleanup and Disposal

Wash the beaker and dropper thoroughly. Clean up your lab area, wiping up any droplets of fake blood from the table, chairs, and floor.

Data and Observations

Hypothesis

____

____

Table 1

Dropper Height (cm)	10	20	30	40	50	60	70	80	90	100
Droplet Diameter (mm)										

Table 2

Dropper Height (cm)	10	20	30	40	50	60	70	80	90	100
Droplet Diameter (mm)										

Effect of angle on shape (step 10): ____________

Unknown droplet diameter (mm): ____________

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Conclude and Apply

1. Average the Table 1 and Table 2 diameter data for each height and enter the values in **Table 3**.

Table 3

Dropper Height (cm)	10	20	30	40	50	60	70	80	90	100
Droplet Diameter (mm)										

2. Make a graph of droplet diameter versus height, using appropriate scaling techniques. Make a best-fit curve for these data points.

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3. What information about height and droplet diameter can you determine from your graph? Does the graph support your original hypothesis?

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4. Using this curve, determine the approximate height from which the unknown droplet was released. Do you think this is a good guess? Why or why not?

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5. What did you notice about the shape of droplets when dropped from directly above as compared to being dropped from an angle?

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Analyze and Conclude

1. **Error Analysis** Obtain the height data for the unknown droplet from your teacher. How accurate was your value? List any errors that may have occurred that would produce a largely inaccurate result.

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2. **Observe and Infer** How can this type of investigation help forensic scientists reconstruct events; that is, what is the importance of this technique?

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Date ____________ Period ____________ Name ____________________

2 Forensics Lab 2

Safety Precautions

Materials

- projectile launcher with projectiles
- carbon paper
- two sheets of clean paper
- tape
- meterstick
- digital timer or stopwatch

Mrs. McIntosh goes ballistic.

Problem

How can physics be used to reconstruct the events of a projectile being fired?

Objectives

- **Observe** the trajectory (path) of a projectile.
- **Examine** the relationship of angle and muzzle velocity on projectile motion.
- **Calculate** muzzle velocity based on data gathered.
- **Solve** a real-world crime using these techniques.

Background

Mrs. McIntosh called the police to report a case of vandalism. She claims that while she was at work, the Johnson boys next door deliberately launched a baseball through her living room window with their automatic pitching machine. An officer took their statement.

"It was an accident, officer," said 12-year-old Jimmy. "I was setting up the machine for my brother Chris to bat. When I tried to walk away, my shoestring got caught on this bolt. I tripped and knocked the machine sideways just as the ball launched."

He went on to state that they knocked on Mrs. McIntosh's door so that they could explain, but when they discovered she wasn't home, they just waited to hear from her later. Instead, she called the police. She insists the boys are a rambunctious pair headed for trouble. She believes their behavior needs to be stopped and wants to press charges.

The police began an investigation. Upon initial examination of the scene, the officers found the following:

The neighborhood was flat and level. The pitching machine had been put away in the Johnson's garage. There were no indentations from the feet of the machine or dragging tracks in either yard or driveway. The location of the baseball in Mrs. McIntosh's living room showed roughly the horizontal angle at which the ball was launched, which corresponded with the boys' story. The hole in the window was measured to be 2.43 m above the ground.

According to the account given by the Johnson boys, the ball launcher was approximately 15.24 m from Mrs. McIntosh's window (at the end of their driveway). Further examination of the machine showed that there is only one setting for the pitch. The angle of launch is 30° and the ball exit is 1.21 m above the ground. The exit velocity of the machine is given as

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64 km/h. The investigators (you) must determine whether the boys' story could be plausible or if the machine had to be moved closer to (or further from) her window in order to break it.

Ballistics is defined in varying degrees. It is the study of the dynamics of projectiles. It is also the study of the functioning of firearms and the firing, flight, and effects of ammunition. To study projectiles, we must explore the basic equations of projectiles, given by

$$y = v_{yi}t - \frac{1}{2}gt^2 \qquad (1)$$

and

$$x = v_{xi}t, \qquad (2)$$

where y is the height relative to the muzzle opening, x is the distance from the muzzle to the place of impact, t is the time it takes from firing to impact, g is the acceleration due to gravity (given as 9.80 m/s), and v_i represents muzzle velocity. v_{yi} is the component of muzzle velocity in the y direction, while v_{xi} is the component of muzzle velocity in the x direction. From trigonometry and an understanding of vectors, we can find the muzzle velocity using the Pythagorean theorem, given by

$$v_i = \sqrt{{v_{xi}}^2 + {v_{yi}}^2} \qquad (3)$$

Procedure

1. Tape a clean sheet of paper to the wall or an approved target area.
2. Set up the launcher on the lab table at an appropriate distance from the paper target and adjust the speed (if variable) to the slowest setting.
3. Set the launcher angle at 30°. Record this value in the appropriate column in **Table 3.**
4. Check to make sure the projectile will hit the paper somewhere above the center. Make speed and distance adjustments as necessary so this can be achieved.
5. Have one person prepare to launch the projectile, while another stands close to the wall with a stopwatch (away from the path of the projectile).
6. Working together, record the time from launch to impact. This may take a few practice trials.
7. Tape carbon paper over the clean sheet, with the ink side facing the clean sheet.
8. Measure the distance from the ground to the muzzle opening of the launcher. Record this value as your "zero" height.
9. Measure the distance from the muzzle opening to the wall. Record this value as x in **Table 1.**
10. Launch the projectile five times in a row, timing its flight each time. Redo a launch if the projectile doesn't hit the paper.
11. Remove the carbon paper, leaving the other sheet on the wall.
12. Measure the height from the ground of each of the five marks made on the paper, and record each of these in Table 1.
13. Move the projectile launcher either toward or away from the target so that the projectile, when launched, will hit the paper below the center.
14. Measure and record this new distance as x in **Table 2.**
15. Repeat the experiment at this new distance and record your results in Table 2.

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Cleanup and Disposal

Remove paper, carbon paper, and tape from the walls. Return carbon paper to the teacher, and dispose of the white paper target and tape in the wastebasket.

Data and Observations

Zero height: ________ cm

Initial distance from wall: x = ________ cm

Table 1					
Shot Number	**1**	**2**	**3**	**4**	**5**
Time, *t* (s)					
Height from Ground (cm)					

Initial distance from wall: x = ________ cm

Table 2					
Shot Number	**1**	**2**	**3**	**4**	**5**
Time, *t* (s)					
Height from Ground (cm)					

What effect does distance from the target, x, have on the height of the impact?

____

What effect does muzzle velocity have on the trajectory of the projectile?

____

Conclude and Apply

1. Average the height of the five shots in Table 1 and record this result.

   Average height: ________ cm

2. Subtract the zero height from this average (do not neglect negative values). This is the value assigned to the variable, y. Record this result.

   y = ________ cm

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3. Repeat these calculations for Table 2.

Average height: ________ cm

y = ________ cm

4. Record the values of all known variables in **Table 3** for both trials.

Table 3				
	x (cm)	y (cm)	Launch Angle (°)	t (s)
Table 1				
Table 2				

5. Given the acceleration due to gravity, g, is 9.80 m/s^2, use equation **(1)** to determine the value of v_{yi}. Do this separately for each trial and record the values in the results table.
6. Calculate the value of v_{xi} using equation **(2)** and record the results.
7. Finally, use equation **(3)** to determine the value of v_i for both trials and record the results in the table below.

Results			
	v_{yi} (cm/s)	v_{xi} (cm/s)	v_i (cm/s)
Table 1			
Table 2			

Analyze and Conclude

1. **Collect and Interpret Data** How close were the results in each column in the results table? Should they be the same? What is the reason for your answer?

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2. **Error Analysis** What types of experimental errors could occur that would give unexpected results? Be specific.

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3. **Draw a Conclusion** Using these concepts, determine whether the Johnson boys could be telling the truth, or if they are lying about how Mrs. McIntosh's window was broken. Show your calculations and explain your answer. (Remember, the acceleration due to gravity is 9.80 m/s.)

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3 Forensics Lab 3

Safety Precautions

Caution: The cutting edge of the plastic wrap box is sharp.

Materials

- clear tape
- wool cloth or wool fleece
- various materials, such as fur, wool, plastic comb, glass rod, metal
- plastic wrap
- smooth, clean surface, such as a 30-cm × 30-cm slab of metal or tray
- dark surface (such as lab tabletop)

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I'm not positive, but I think you're being negative.

Problem

Can neutral objects be attracted by a static charge? How can static electricity help forensic investigators gather clues?

Objectives

- **Examine** the nature of static charge and how opposite and like charges behave with one another, as well as with other, possibly neutral, objects.
- **Demonstrate** how static electricity can be useful in gathering seemingly invisible footprints on a crime scene.

Background

Forensic scientists discovered that static electricity could be used to pick up dust particles (and hair and fibers) that may be useful evidence in a crime scene. The most useful application of this method of collection is where the particles are concentrated in a pattern, such as dust left by footprints. Modern forensics uses very high voltage static sources in order to pin the particles firmly in place. You will use the older, cruder (and safer) version that was in use when this technique was first discovered. But first, you will try to understand the nature of static charge in an attempt to explain why this works.

Procedure

Part 1:

1. Tear off a strip of tape about 15 cm long.
2. Fold over a small amount of one end of tape so that it sticks to itself to make a handle.
3. Firmly attach tape to the top of the lab table.
4. Tear off another strip about 15 cm long and make a handle.
5. Carefully lay the second strip over the first. Mark the handle area with the number *1*. Rub along the length of the tape in order to neutralize it (remove any static electricity).
6. Using the handle, swiftly pull up the top tape.
7. Attach the tape (using the end opposite the handle) to the side of the table so it is hanging off the edge. Use caution not to touch the tape except on the ends.

8. Choose three different objects or materials. (Do not charge these objects.) One at a time, slowly move each object close to the suspended tape. Record your observations in **Table 1** (e.g. did the object attract or repel the tape, or neither?).
9. Tear off another strip of tape, make a handle, attach it to the tape on the tabletop, and neutralize it with your finger.
10. Mark the handle with the letter *B* for "bottom tape".
11. Again, tear off another strip, prepare it as above, placing it on top of Tape B, neutralize it, and mark the handle with the letter *T* for "top tape".
12. Swiftly pull both Tape B and Tape T together, as if they were a single strip.
13. Run your finger over the length of the smooth side to ground the tapes.
14. Swiftly pull Tape B and Tape T apart and suspend each one in the same manner as strip 1 (leave plenty of distance between all three strips).
15. Using the same materials from step 8, perform the same tests on Tape B and Tape T. Record your observations in Table 1.
16. Using the handle, detach Tape T from the table, being careful not to neutralize it.
17. Move Tape T close to Tape B. Record your observations in **Table 2.**
18. Move Tape T close to Tape 1. Record your observations in Table 2.
19. Move Tape B close to Tape 1. Record your observations in Table 2.

Part 2:

1. Have someone step firmly on a clean, smooth surface.
2. Carefully remove a piece of plastic wrap ~35–40 cm long and keep it from sticking together (have one person hold two corners while another holds the other two). Remember that the cutting edge of the package is very sharp.
3. Have a third person neutralize the plastic wrap by rubbing his or her hand across one side of it.
4. Gently lower the flat film of plastic wrap onto the smooth surface, and hold it as tight and smoothly as possible.
5. Have a third person carefully, yet completely, rub the surface of the film with wool.
6. Lift the plastic sheet and turn it over and place it on a dark surface.
7. Record your observations in the space provided below Table 2. If nothing happened, try this again with a different person or shoe.

Cleanup and Disposal

Return plastic wrap to teacher. Pick up any items left on the floor. Detach and throw away all used pieces of tape and plastic wrap.

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Data and Observations

Table 1

Object or Material	Tape 1 Interaction	Tape B Interaction	Tape T Interaction

Table 2

T–B Interaction	T–1 Interaction	B–1 Interaction

Record your observations of part 2 here.

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____

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Conclude and Apply

1. From step 8 of the procedure, can you conclude that Tape 1 is statically charged? If yes, can you tell if it is a positive or negative charge? Explain your answers.

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2. From the observations made in step 15, can you determine whether Tape T and Tape B have like charges or opposite charges? Explain.

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3. At what point could you positively determine that you had oppositely charged strips of tape?

4. Is Tape 1 charged like Tape T or Tape B? How do you know?

Analyze and Conclude

1. Error Analysis What kinds of experimental errors would give unexpected results?

2. Observe and Infer From what you know about static charge, are dust particles positively charged, negatively charged, neutral, or can you tell? Explain the reason for your answer.

3. Think Critically Give an example of a situation where forensic scientists would use static electricity to collect evidence.

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Date ______________ Period ______________ Name ________________________

4 Forensics Lab 4

Safety Precautions

Materials

- graduated beaker or cylinder
- three-beam mass balance
- metal sphere
- pure, metal, odd-shaped object
- alloy, metal, odd-shaped object
- ruler or calipers
- paper towels

Archimedes: The first forensic scientist?

Problem

How can investigators determine whether a material is a pure substance, or if it is an alloy or a mixture of substances?

Objectives

- **Relate** the concepts of mass, volume, and density.
- **Determine** the composition of substances using this relationship.
- **Analyze** the quality of the experimental method and data.

Background

In the first century B.C. the Roman architect Vitruvius related a story of how Archimedes uncovered a fraud in the manufacture of a golden crown commissioned by Hiero II. Suspecting that the goldsmith might have replaced some of the gold given to him by an equal weight of silver, Hiero asked Archimedes to determine whether the crown was pure gold. Because the crown was a holy object dedicated to the gods, Archimedes could not disturb it in any way. Vitruvius wrote that while taking a bath in a tub filled with water, Archimedes observed that the water ran out over the tub as his body entered the water. The more he sank, more water ran out. Archimedes reasoned that if the goldsmith had replaced part of Hiero's crown gold with a less-dense alloy of silver, the volume of the crown would increase and therefore displace more water than the pure gold crown when introduced into a bowl filled to the brim.

Density, D, is simply an object's mass, m, divided by its volume, V. In standard SI units, it is measured in kg/m^3 or, quite commonly, in g/cm^3 (g/mL). That is,

$$D = \frac{m}{V}$$

It is an intrinsic property of a substance, meaning no matter how much of it or what shape of it, a material's density, at normal temperatures, is constant. Once density is found, one can refer to a table of standards and match the density of the object to the known density of a particular material, and make a guess as to what the material is. However, this is not so simple for irregularly shaped objects, since measuring volume can be difficult. So what was it that Archimedes found?

Archimedes made two masses of the same weight as the crown, one of gold and the other of silver. He filled a large vessel with water to the very brim, and dropped the mass of silver into it. The amount of water that

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overflowed was equal in volume to that of the silver mass sunk in the vessel. Archimedes refilled the vessel and dropped the mass of gold into the full vessel. Not as much water overflowed because gold is more dense than silver, so the same weight takes up less volume. Finally, Archimedes filled the vessel again and dropped the crown itself into the water. He found that more water overflowed for the crown than for the mass of gold of the same weight. From this, he reasoned that silver had been mixed with gold, and thus made the theft of the contractor perfectly clear.

You will use a similar experiment to determine the composition of objects. You also will assess your experimental methods and data by means of discrepancy calculations.

When there is a known, standard value to compare against an experimentally obtained value, a *percent discrepancy* can be calculated. This is found by the following equation:

$$\textit{Percent discrepancy} = \frac{|St - Ex|}{St} \times 100$$

where *St* is the standard value, and *Ex* is the experimental value. The ratio is multiplied by 100 and is represented as a percentage. If there is no known standard, or if you wish to compare the closeness of results using two different experimental measures, then a *relative discrepancy* is appropriate. This is given by:

$$\textit{Relative discrepancy} = \frac{|Ex - Av|}{Av} \times 100$$

where *Av* is the average of the experimental data and *Ex* is any one of the experimental data.

Results within 10 percent are generally considered good. If a percent discrepancy yields a value within 10 percent, you can assume the object is made of the material you are comparing it to. Relative discrepancies within 10 percent imply that the different methods of experiment were equally reasonable and yielded nearly the same result.

Procedure

1. Measure and record the mass of all three objects—one sphere and two irregularly shaped objects—in **Data Table 1** on the next page.
2. Measure and record the diameter of the sphere in Data Table 1 on the next page.
3. Fill the beaker with enough water to fully submerge objects.
4. Record the volume of water in the beaker in Data Table 1.
5. Carefully place one of the objects in the beaker.
6. Measure and record the new volume of water.
7. Remove the object and dry it off.
8. Repeat steps 4–7 for the remaining two objects. (Note: you must repeat step four, as some water may be lost when you remove the objects)

Cleanup and Disposal

Dry off all objects. Pour water into sink. Wipe any spilled water off the table. Dispose of paper towels.

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Data and Observations

Data Table 1			
Object	**Mass (g)**	**Initial Water Volume (mL)**	**Submerged Water Volume (mL)**
Metal sphere			
Irregular object 1			
Irregular object 2			

Diameter of sphere: __________ cm

Conclude and Apply

Record your calculations and place your results in the chart.

1. Find the volume of each of the three objects by subtracting the initial water volume from the submerged water volume. Record this in **Data Table 2** as the volume of the object.

2. Calculate the density of all three objects using their measured mass and calculated volume and record these values in Data Table 2.

3. The formula for the volume of a sphere is $V = \frac{4}{3}\pi r^3$. Use this formula and the diameter of the sphere that you recorded above to determine the volume of the sphere. Using this value for volume, recalculate the density of the sphere and record this value in Data Table 2.

Data Table 2			
Object	**Volume from Step 1 (mL)**	**Density (g/mL) from Step 2**	**Density (g/mL) from Step 3**
Metal sphere			
Irregular object 1			
Irregular object 2			

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Analyze and Conclude

1. **Draw a Conclusion** In **Data Table 3** below, identify the composition of your three objects by referring to a table of known standard values for the density of metals. Use the closest value of density found and compare it to the calculated density in the first column of Data Table 3 using a percent discrepancy. If you cannot find a value that gives a percent discrepancy within 10 percent, then the object can be assumed to be an alloy. You do not need to try to determine the makeup of the alloy.

Data Table 3		
Object	**Composition**	**Percent Discrepancy**
Metal sphere		%
Irregular object 1		%
Irregular object 2		%

2. **Measure and Use Numbers** Using values for density of the sphere from two different methods, perform a relative discrepancy calculation. Show your calculations in the space below.

3. **Apply Concepts** Can you think of any situations where modern-day forensic investigators would need to determine the composition of materials?

____
____
____

4. **Error Analysis** List sources of experimental error that would cause the percent discrepancies you found. Comment on the results of your relative discrepancy calculation.

____
____
____
____

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Date ____________ Period ____________ Name ____________________

5 Forensics Lab 5

Safety Precautions

Materials

- wood block with hook on smallest end
- sliding surface
- pulley with C clamp
- string
- mass hanger and masses (ranging from 1 g to 200 g)
- 500-g mass
- 1000-g mass
- 1500-g mass

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You aren't going to slide out of this one!

Problem

How can a skid mark left on the pavement help police reconstruct the events of an accident?

Objectives

- **Study** accelerated motion.
- **Demonstrate** how friction creates negative acceleration (deceleration).
- **Practice skills** needed to manipulate standard physics equations.
- **Recognize cause and effect** from elements at the scene of a crime.
- **Review** unit conversion methods so that numbers become meaningful.

Background

A body was found on the roadside, having apparently been struck by a vehicle. Coroners can determine the time of death, so that the police may look for witnesses to the accident. Meanwhile, investigators will attempt to reconstruct the events that led to the pedestrian's death. Aside from the body, the only evidence was a skid mark. With this, they can at least determine the speed of the vehicle that hit the victim.

The skid mark was 71.4 m long. Tests on this stretch of concrete showed that for an average tire, the coefficient of kinetic friction is about 0.7.

When a car has some initial velocity, v_i, and the driver slams on the brakes until they are at a complete stop, inertia carries them forward, while there is a backward acceleration due to friction between the tires and the road. (This does not apply to cars with antilock brakes.) The only force acting, then, is the force of kinetic (moving) friction, F_k. We will define this force as

$$F_k = \mu_k N$$

where N is the normal force, the force that the ground exerts upward to oppose the weight of the vehicle. So

$$N = Mg$$

with M being the mass of the car, and g, the standard value for acceleration due to gravity. So finally,

$$F_k = \mu_k Mg$$

where μ_k is the coefficient of kinetic friction. The coefficient of friction is a unitless number that describes the interaction between the two surfaces in contact and is distinct for that interaction. The term *kinetic* implies motion. This number is descriptive for objects that are sliding against each other.

From Newton's second law of motion, the sum of the forces acting on an object is its mass, m, times its acceleration, a. In the horizontal direction, the only force acting is the force of friction, which leads us to the following relationship.

$$\Sigma F = ma = \mu_k mg, \text{ which leads to}$$

$$a = \mu_k g \qquad (1)$$

This is where the derivation may get a little bit tricky. First, we recall that the displacement, x, is given by

$$x = v_i t + \frac{1}{2}at^2 \qquad (2)$$

and

$$a = \frac{v_f - v_i}{t}. \qquad (3)$$

In these equations, t is the time over which the skidding (acceleration) occurred, and v_f represents the final velocity. In our case, $v_f = 0$, so equation **(3)** becomes

$$a = -\frac{v_i}{t}. \qquad (4)$$

Since we know acceleration and are interested in finding the initial velocity (how fast the car was going before it slammed on the brakes), we can eliminate t from equation **(2)**. Rearranging equation **(3)** for t, we get

$$t = -\frac{v_i}{t}$$

Substituting this into **(2)** and combining like terms gives

$$x = \left(\frac{1}{2}\right)\left(\frac{v_i^2}{a}\right)$$

Finally, rearranging for v_i gives

$$v_i = \sqrt{2ax}$$

And substituting **(1)** for a, we find the initial velocity of the car to be:

$$v_i = \sqrt{2\mu_k gx}. \qquad (5)$$

We will use the ideas presented above to determine the force and coefficient of kinetic friction for a block sliding on a surface.

Procedure

1. Measure the mass of the block and record it in **Data Table 1** on the next page.
2. Clamp the pulley to the edge of the table.
3. Attach a string to the hook on the block and place it over the pulley.
4. Hang the mass hanger from the string.
5. Add just enough mass so that when the block is lightly shoved toward the pulley, it will keep moving (this may be so slow that it is nearly undetectable).
6. Record the mass needed.
7. Add 500 g to the mass of the block and record the total mass in Table 1.

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8. Repeat steps 5 and 6.
9. Add another 500 g, for a total of 1000 g, to the mass of the block.
10. Repeat steps 5 and 6.
11. Add another 500 g, for a total of 1500 g, and repeat steps 5 and 6.

Cleanup and Disposal

Detach the C clamp and pulley from the edge of the table. Return the masses to their appropriate storage containers. Detach the string and set it aside for future use. Tidy up your table.

Data and Observations

Data Table 1

Mass of Block (kg)	Mass Needed (kg)
Block ________	
Block + 0.5 kg ________	
Block + 1 kg ________	
Block + 1.5 kg ________	

Discuss any pattern that you notice about the increased mass of the block and the mass needed to keep it moving.

____

____

Conclude and Apply

1. On the next page, graph the data you collected with the mass of the block on the *x*-axis, and the mass needed to keep it moving on the *y*-axis and produce a best-fit line. Be sure to label the graph's axes. What can be said about the relationship shown on the graph?
2. Using the mass needed, calculate the force needed to just overcome the force of kinetic friction, for each value, knowing that this is simply the force due to gravity ($F = mg$). Assume that this is nearly equal to the force of kinetic friction, so from here on out, call this value F_k, the force of kinetic friction. Show the calculations below and record the results in **Data Table 2.**

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3. From the values of F_k, calculate the coefficient of kinetic friction, μ_k, from each of the trials and record your results below.

Data Table 2			
Mass Needed (kg)	**$F = mg$**	**F_k (N)**	**μ_k**

4. Determine the average value of the coefficient of kinetic friction. μ_k = ____________

5. Finally, using the ideas presented, determine the speed the vehicle in our scenario was moving before the driver hit the brakes. v_i = ____________ m/s

How fast was it going in kilometers per hour? ____________ km/h

Analyze and Conclude

1. Think Critically Comment on the results for the values of μ_k. Should the calculations give the same results for the coefficient of kinetic friction? Explain.

____

____

____

2. Error Analysis If the values of μ_k are not exactly the same, give are some of the reasons that would cause the data to yield different values.

____

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Date ____________ Period ____________ Name ____________________

6 Forensics Lab 6

Safety Precautions

CAUTION: The ends of connecting wires may be sharp and could puncture skin. Double-check setup with the teacher. Check condition of wires and apparatus.

Materials

- 12-V variable DC power supply
- three lightbulbs in fixtures
- six connecting wires
- 12 alligator clips (if needed)

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Resistance is futile—in time, you will see the light.

Problem

How do different circuit configurations affect the voltages across and currents through the resistors (lightbulbs) in the circuit?

Objectives

- **Develop** the ability to read a circuit diagram.
- **Create** real circuits based on circuit diagrams.
- **Understand** the difference between series and parallel circuit configurations.
- **Predict** the behavior of lightbulbs in different parts of a circuit.

Background

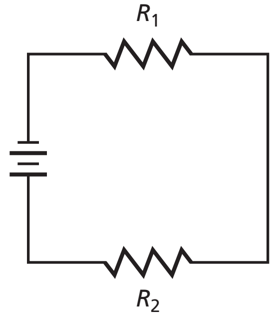
Jasmine called the police because she had seen a man standing outside near her kitchen window. She had no idea how long he had been there, but had felt he was watching her. She was very scared. Upon arrival, the police looked for evidence around the outside of her house. It was dark, but they used flashlights. No window screens had been cut, and the ground was frozen hard with no snow, so there were no footprints to be found. Officer Martin, the policeman who usually patrols Jasmine's neighborhood, suggested that, since it was Christmas time, she might increase her personal security by plugging in her Christmas lights each night. Surprised that she hadn't noticed before, Jasmine said she had plugged them in. So the police inspected to see if the cord had been cut, but it was not. Officer Martin decided they needed to have the crime lab take a look at each individual bulb, because he believed they might get fingerprints from a bulb that was unscrewed. The crime lab did find a loose bulb, lifted prints, and upon investigation of the individual, found he was a wanted criminal. The key to this investigation was Officer Martin's knowledge of the behavior of circuits.

When resistors are placed in a circuit, there is a voltage drop across that resistor as charges flow through it. The total amount of voltage drop per resistor will depend on how the circuit is put together along with the placement of a particular resistor. There is also interdependence between the current through a resistor or branch of the circuit, the voltage drop across the resistor, and the size of the resistance. This interdependence is determined, again, by the configuration. The relationship is shown by Ohm's law, which is

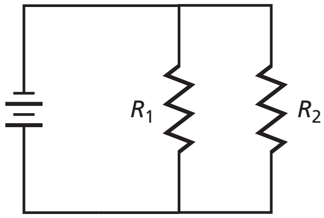
$$V = IR$$

where V is voltage in volts, V, I is current in amps, A, and R is resistance in ohms, Ω.

When two resistors are placed in series, the current through them is equal, while the voltage drop differs with the size of each resistor. The individual voltage drops within the circuit add to account for the voltage across the circuit. Removing one resistor will break the circuit and stop the current.



If two resistors are placed in parallel, the voltage drop across the resistors is equal, and is the full amount of the voltage across the circuit. However, the current splits across the branches, according to the size of the resistors, as indicated by Ohm's law. Removal of one of the resistors does not stop the current through the other, since each resistor has its own complete circuit with the power supply.



Lightbulbs are resistors in a circuit. The brightness of a bulb gives a visual indicator of how current is being distributed in different circuit configurations. Keep in mind, however, that brightness is proportional to the power dissipated by the bulb, but with the resistors being equal, brightness provides a good qualitative indication of current.

Procedure

1. With the power supply off, connect a circuit through a single lightbulb.
2. Turn on the power supply and increase voltage to 10 V.
3. Briefly observe the brightness of the bulb.
4. Turn off the power supply.
5. Connect two lightbulbs in series to the power supply.
6. In the space provided, write your prediction as to the brightness each bulb will display.
7. Turn on the power supply (10 V).
8. Record your observations about the brightness.
9. Connect two lightbulbs in parallel and repeat steps 6–8.
10. Diagram the four different configurations possible for three lightbulbs in a circuit.

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11. For each configuration, predict the brightness of each bulb by labeling the diagram with numbers, where 1 represents the brightest a bulb will be, and 2 will be the next brightest, and so on. Record your predictions in the space provided.

12. Connect each of the circuits, one at a time, and have the teacher check each configuration.

13. Turn on the power supply. If any of the bulbs appear not to be lit, you may need to increase the voltage by small amounts.

14. Record your observations using the same numbering system.

Cleanup and Disposal

Unplug the power supply. Disconnect all wires.

Data and Observations

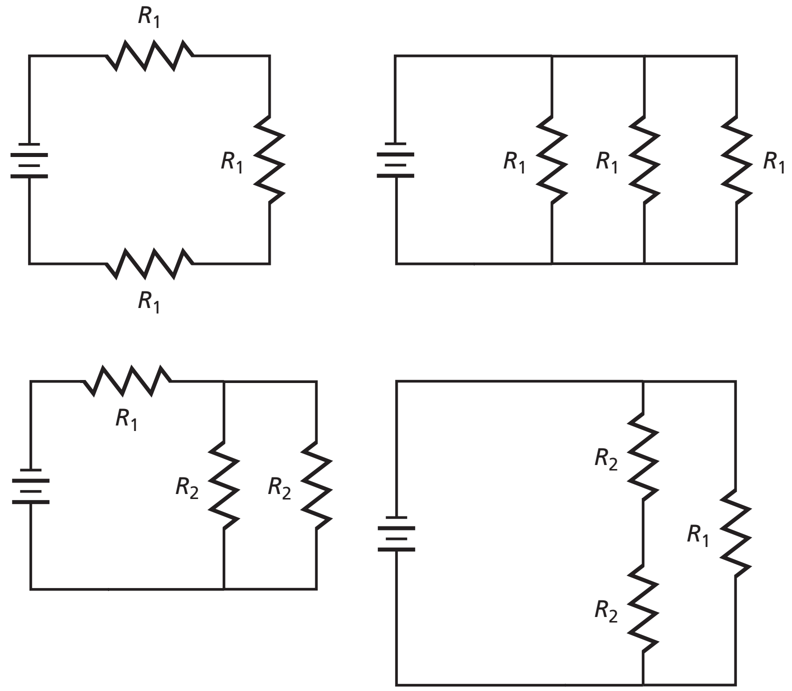
1. Prediction ______________________________

2. Observation ______________________________

3. Prediction ______________________________

4. Observation ______________________________

5. Three bulb circuits diagrams (with prediction labels) ______________________________



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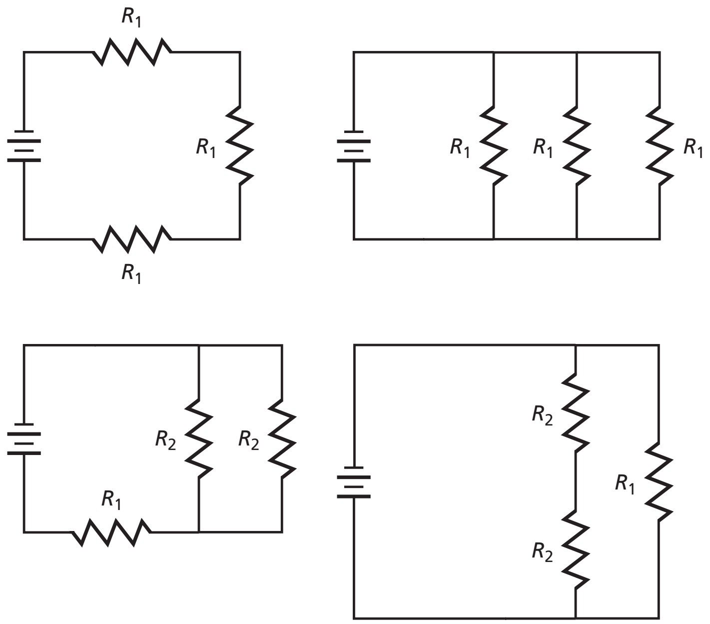
6. Three bulb circuit observations



Conclude and Apply

1. From your observations, what can be said about the equivalent resistance of the two resistors in parallel in circuit 3 for three bulbs, compared to the resistance of a single lightbulb (resistor)? Explain your answer.

____

____

____

2. From your observations, what can be said about the equivalent resistance of the two resistors in series in circuit 4 for three bulbs compared to the resistance of a single lightbulb (resistor)? Explain your answer.

____

____

____

Analyze and Conclude

1. Draw a Conclusion How did Officer Martin know to look for a loose lightbulb?

____

____

2. Error Analysis Other than the fact that lightbulbs do not follow Ohm's law, what sources of resistance may be present but unaccounted for?

____

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7 Forensics Lab 7

Safety Precautions

CAUTION: Be careful not to break thermometers or stirring rods.

Let your teacher handle the hot metal samples.

Materials

- mass balance
- calorimeter
- stirring rod
- thermometer
- pure water
- hot metal samples (from teacher)
- timer

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How many calories are there?

Problem

How can conservation of energy be used to help determine the content or purity of a substance?

Objectives

- **Observe** the transfer of thermal energy.
- **Separate and control variables** to observe conservation of energy.
- **Calculate** the specific heat of a material.
- **Identify** the nature of a material based on its specific heat.
- **Compare** experimental results to well-known standards.
- **Determine** whether the crime of counterfeiting has occurred.

Background

A new international coin collector had just returned from overseas, where he had purchased his first set of ancient silver coins. After he returned, he showed the coins to several other collectors who were not convinced that these were authentic. He began to suspect that he was a victim of fraud. Since this was an international counterfeit coin case, he contacted the FBI.

The federal agents obtained several coins from the dealer and ran a simple experiment to help determine whether the coins were made of pure silver. The experiment they used was as follows:

After heating up each 28.4-g coin to 120°C, they placed each one in 300.0 g of water that was initially 25.0°C. They measured the temperature of the system until it reached an equilibrium temperature of 25.5°C.

The experiment they used is called calorimetry. It is based on the transfer of thermal energy from one substance to another. It relies on the fact that energy is conserved in the system, and that some substances, more readily than others, change temperature, T, with a transfer of energy. The capacity for a substance to change temperature from a transfer of thermal energy is called the specific heat, and is denoted by the letter C. The specific heat of a substance is a constant for that material and is not affected by the amount, or mass, m.

Heat transfer is defined by $Q = mC\Delta T$. When a transfer of heat occurs, the amount of thermal energy gained by one substance is equal to the amount of thermal energy lost by the other. In an isolated system, such as a calorimeter the change in thermal energy is equal to the heat transferred. This leads us to

$$m_1C_1\Delta T_1 = -m_2C_2\Delta T_2$$

In this experiment, our substance gaining heat is pure water, which has a specific heat of 4186 J/kg·°C. This means that it takes 4184 J of energy to raise the temperature of 1 kg of water by 1°C.

We wish to identify the makeup of the unknown pure substance by finding its specific heat. Simple rearrangement of our equation of conservation of energy for heat transfer yields this result:

$$C_2 = -\frac{m_1 C_1 \Delta T_1}{m_2 \Delta T_2}$$

When there is a known, standard value to compare against an experimentally obtained value, a percent discrepancy can be calculated. This is found by the following equation:

$$Percent\ discrepancy = \frac{|St - Ex|}{St} \times 100$$

where *St* is the standard value and *Ex* is the experimental value. The ratio is multiplied by 100 and is represented as a percentage. Results within 10 percent generally are considered good. If a percent discrepancy yields a value within 10 percent, you can assume the object is made of the material you are comparing it to.

Procedure

1. Measure and record the mass of the calorimeter, the stirring rod, and the thermometer together.
2. Fill the calorimeter approximately two-thirds full of pure, room-temperature water.
3. Measure and record the mass of the calorimeter, the stirring rod, thermometer, and the water together.
4. Record the initial temperature of the water.
5. Have your teacher place a heated metal sample into the calorimeter, and quickly close the lid. Record the initial temperature of the metal.
6. Constantly but gently stir the water in the system.
7. Every 30 s, measure and record the temperature of the system.
8. When you observe the temperature is unchanged for three readings, you can assume the system has reached equilibrium, so this will be the final temperature. (Note: If the temperature begins to decrease, then you are losing heat from the system to the environment, and you should use the maximum temperature recorded for that trial.)
9. Measure and record the mass of the entire system with the metal still in it.
10. Return the metal sample to the teacher, and repeat steps 2–9 for a different metal.

Cleanup and Disposal

Return the second metal sample to the teacher. Pour out the water and dry out the calorimeter. Clean up any spills. Replace the stirring rod and thermometer in their proper holders.

Data and Observations

A. **1.** Mass of calorimeter, stirring rod, and thermometer: ____________ kg

2. Mass of calorimeter, stirring rod, thermometer, and water: ____________ kg

3. Initial temperature of water: ____________ °C

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4. Initial temperature of metal: __________ °C

First Metal Sample	
Time (s)	Temperature (°C)
30	
60	
90	
120	
150	

5. Mass of entire system with metal: __________ kg

B. 1. Mass of calorimeter, stirring rod, and thermometer: __________ kg

2. Mass of calorimeter, stirring rod, thermometer, and water: __________ kg

3. Initial temperature of water: __________ °C

4. Initial temperature of metal: __________ °C

Second Metal Sample	
Time (s)	Temperature (°C)
30	
60	
90	
120	
150	

5. Mass of entire system with metal: __________ kg

Conclude and Apply

1. For both metal samples, subtract the mass you recorded in Data and Observations 1 from that recorded in Data and Observations 2 to determine the mass of the water. Record these values in the **Compare Data** table on the next page.

2. Subtract the mass recorded in Data and Observations 2 from that in Data and Observations 5 to determine the mass of the metal. Record this value for both metal samples in the Compare Data table on the next page.

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3. Determine ΔT for the water and for the metal (these should be very different) for each of the two samples. Recall that this notation simply means $\Delta T = T_{final} - T_{initial}$. Record these values in the Compare Data table below.

4. Calculate the specific heat of each metal sample and record these values in the Compare Data table below.

5. Refer to a table of specific heats (making sure the unit convention is the same) to try to determine the makeup of the metal. Use a percent discrepancy for each to indicate whether or not your guess is correct.

Compare Data

Sample	Mass of Water (kg)	Mass of Metal (kg)	ΔT of Water (°C)	ΔT of Metal (°C)	Specific Heat (J/kg·°C)	Material and Percent Discrepancy
A						
B						

6. Using the method shown in this lab, determine whether the novice coin collector was taken advantage of. A percent discrepancy should be used to assure yourself of your conclusion. Include your result for the specific heat.

____

____

Analyze and Conclude

1. Acquiring and Analyzing Information Explain what conservation of energy means.

____

____

2. Error Analysis What factors could cause the total energy of the calorimeter system to change? How did this impact your data? Are there any other reasons for the values of specific heat to be inaccurate?

____

____

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Date ____________ Period ____________ Name ____________________

8 Forensics Lab 8

Safety Precautions

Materials

- flat, vertically positioned mirror
- several straight pins with spherical head
- corkboard
- ruler or straightedge
- protractor

A Little Time to Reflect

Problem

How can we determine the path of light rays incident on a reflective surface, such as glass or a mirror?

Objectives

- **Determine** the path that reflected light takes.
- **Understand** the relationship between incident and reflected light.
- **Observe** a mirror image and find its location inside the mirror.

Background

A woman came home to her fifth-floor, west-facing apartment and found it ransacked, her safe open, and the contents of the safe missing. A police canvas of her building and the five-story building 15.24 m to the west produced one witness. The witness claimed that he happened to be looking directly across the way, out of his fifth-floor east-facing window, at about 7:25 P.M. He said he remembered the time because his favorite show was just about to come on the television. At that time he noticed three men, including one man with blond hair, running hurriedly through the apartment. According to the witness, the blond man was wearing a light brown jacket with a car-racing patch on the back. He said he saw one of the men toss objects off of the dresser, and the two other men seemed to be yelling at each other. The witness claimed that he had seen the blond man in the apartment before and, therefore, didn't think it necessary to call the police. He also commented that the woman had many visitors in and out of her apartment and that he had never seen the other two men before. The next day, police took him in for questioning as the primary suspect. They indicated that with the sixth story window being 4.57 m feet above the woman's apartment, and with the Sun being at approximately a 17° angle in the western sky, there is no way he could have seen the details he described.

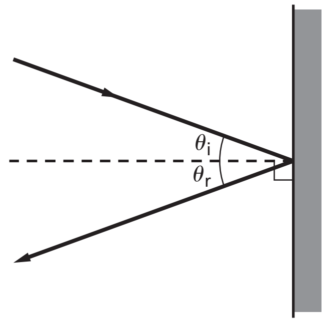

Figure A

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Procedure

A. 1. Pin Diagram 1 on page 38 onto the corkboard.

2. Place the mirror on the indicated spot on Diagram 1.

3. Place a pin in spots A and B on the diagram.

4. Look along the line the pins fall on and into the mirror. With a third pin in your hand, find a spot in region C where the reflection of the pin appears to fall directly in line with the other two, and push it into the corkboard at this location.

5. Remove all three pins from the diagram.

6. Using a straightedge, connect a line between points A and B and a line between B and C.

7. With a protractor, measure and record the angle of incidence and the angle of reflection.

B. 1. Remove Diagram 1 from the corkboard and pin Diagram 2, also on page 38, into place. Place a pin in location A.

2. Place a ruler somewhere in the indicated region to the left (about 2–3 cm away from the pin).

3. Using line of sight, adjust the ruler so that when you extend an imaginary line along the straightedge and into the mirror, it will pass through the reflection location of the pin.

4. Carefully trace this straight line, remove the mirror from its location, and extend this line well behind the mirror's location.

5. Replace the mirror and repeat this with your ruler in the indicated region on the right side of the diagram.

6. Mark the location where these two lines intersect (behind the mirror) as *A′*.

7. Move the pin from location A to location B and repeat steps 2–6 marking the intersection as *B′*.

8. Repeat steps 2–6 for location C, marking the intersection as *C′*.

9. Connect points A′, B′, and C′ with a straightedge.

Cleanup and Disposal

Account for all straight pins and place them in designated location. Write all lab partners' names on the diagrams.

Data and Observations

Angle of incidence: θ_i = ____________°

Angle of reflection: θ_r = ____________°

Conclude and Apply

1. Comment on the result of procedure **A**.

____

____

____

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2. Describe the result of connecting A′, B′, and C′ in Diagram 2 (Note: "mirror image" is not an appropriate response here). Compare the distance of the reflection from the mirror to the distance from the mirror of the original triangle ABC.

Analyze and Conclude

1. **Collect and Interpret Data** Draw a small-scale diagram of the scenario that caused the police to suspect the witness.

2. **Draw a Conclusion** What justifies the conclusion that the suspect couldn't have seen what he claimed to see?

3. **Error Analysis** What could cause the angle of reflection to appear to be a different size than the angle of incidence in Diagram 1? State the best reason for possibly not being able to produce an exact mirror image of the triangle in Diagram 2.

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Diagram 1

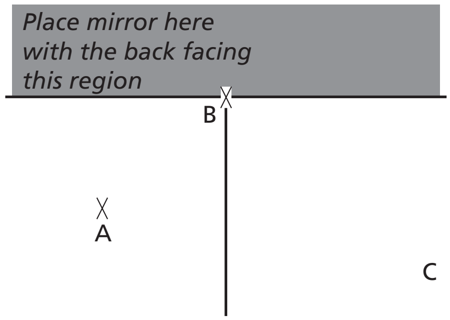
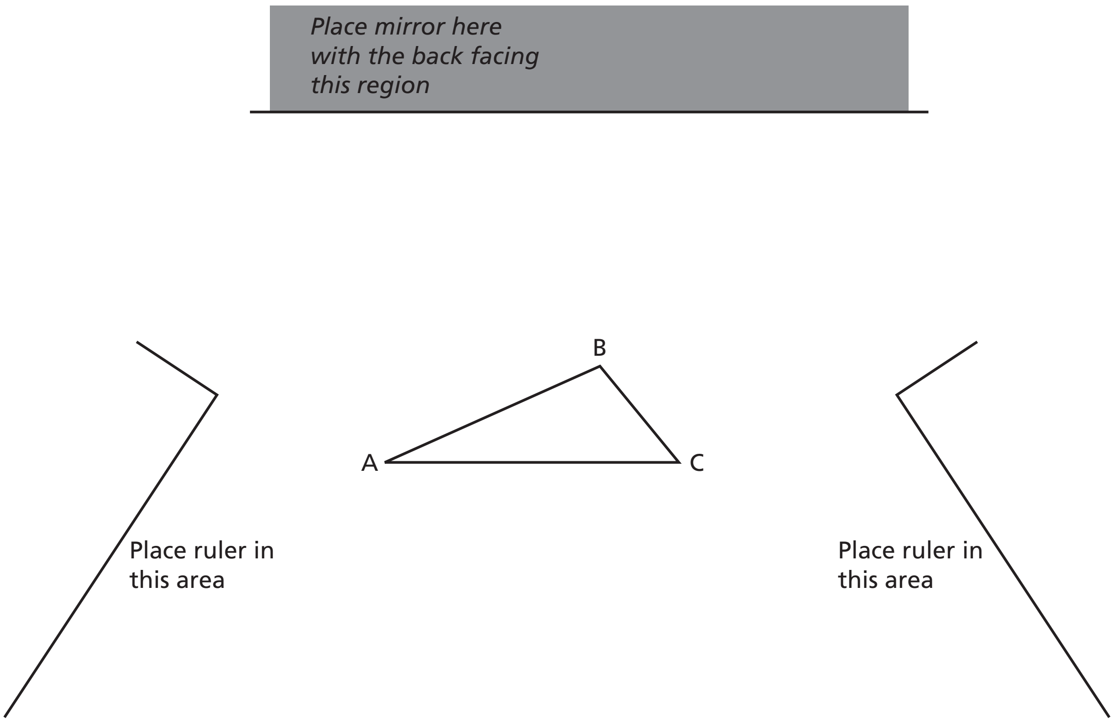


Diagram 2



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9 Forensics Lab 9

Safety Precautions

Materials

- strip of wood with evenly spaced holes (one at the midpoint of the length)
- string
- two support rods
- long rod
- hook collar
- two cross-clamps
- hanging masses
- mass balance

All I need is a little leverage.

Problem

Can a person use a simple lever to create thousands of pounds of force?

Objectives

- **Study** the concept of torque.
- **Demonstrate** how a lever can reduce the effort needed to create large forces.

Background

The safe at Art's Garage was found one morning to have been pried open with all of the week's profits gone. The amount missing was enough for a case of grand theft—a felony. The head mechanic, Bob, had stayed late the night before and admits he may have forgotten to lock the back door. There was no sign of forced entry, so Art assumed that the perpetrator must have entered through an unlocked door. But when the police began to question Bob, they immediately began to suspect him. The paperwork on the safe said that the door lock could hold under a 2250 kg outward force. Art asked if some kind of complicated device was necessary to break this lock open. An officer noticed the high-quality titanium crowbar in Bob's toolbox, which was locked and undisturbed before the investigation, and suspected that it was used as a simple lever to create the large torque necessary. Inspection of the safe showed that whatever was used to pry the door had only wedged 64 mm into the doorframe. If the crowbar had been used, microscopic scratch analysis could be performed to prove this; but first, the officers wanted to find out if this could be eliminated as a possibility. Knowing the crowbar was a total of 30.48 cm long and that Bob was a muscular fellow of about 99 kg, they decided to bring the crowbar into the crime lab for scratch analysis because it seemed physically possible that Bob could have pried the lock.

Torque, τ, is the product of applying a perpendicular force, F, at a distance, d, from a pivot point or fulcrum. It is given by the equation

$$\tau = Fd.$$

A lever is a simple machine used to create a balance of torques on either side of a fulcrum or to reduce the effort needed on one side of the

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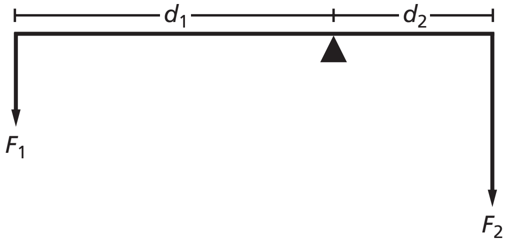
fulcrum in order to produce a larger force on the other side. The diagram below shows this balance of torque on a lever.



We define torque that works to produce counterclockwise rotation as positive and clockwise rotation as negative.

Now in a balanced situation, the sum of all the torques is equal to zero, so from above,

$$\tau_1 - \tau_2 = 0 \Rightarrow \tau_1 = \tau_2$$
$$F_1 d_1 = F_2 d_2$$

Procedure

1. Slide the hook collar onto the long rod.
2. Assemble the rods with the cross clamps so that the long rod with the hook can be used to suspend objects.
3. Thread the string through the center hole of the strip of wood (lever) and tie it into a loop.
4. Hang the lever from the hook collar. Check to be sure that the lever is pretty well balanced (lengthwise parallel to the ground).
5. Hang a 600-g mass two holes from the center.
6. Hang masses six holes from the center until the lever is again balanced. Record the amount of mass needed in the **Data Table** on the next page.
7. Remove both sets of masses.
8. Hang a mass of 200 g seven holes from the center.
9. Determine the amount of mass needed three holes from the center in order to balance the lever and record the amount in the Data Table.
10. Remove both sets of masses.
11. Take the lever down and remove the suspending string from the center and place it four holes from the center.
12. Hang the lever from the hook collar.
13. Hang masses two holes from the pivot point (the string)—or six holes from the center—until the lever is again horizontal. Record this value.
14. Remove the masses and take the lever off of the hook and determine its mass on the balance.
15. Record the mass of the lever.

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Cleanup and Disposal

Replace masses. Remove the string from the lever and discard the string. Disassemble rods and clamps.

Data and Observations

mass needed at six holes from center: __________g

mass needed at three holes from the center: __________g

mass needed from step 13: __________g

mass of the lever: __________g

Conclude and Apply

1. Calculate the theoretical values for steps 6–9 of the procedure. Record these values, along with the experimentally determined values in the table below.

2. Compare the experimental results against the theoretical results using a percent discrepancy calculation, given by

$$\textit{Percent discrepancy} = \frac{|\textit{Theoretical} - \textit{Experimental}|}{\textit{Theoretical}} \times 100$$

Data Table			
Step #	**Experimental Value (g)**	**Calculated Value (g)**	**% Discrepancy**
6			%
9			%

3. Using the data from step 13, calculate the mass of the lever, and compare this value to the directly measured value using a percent discrepancy, given by

$$\textit{Percent discrepancy} = \frac{|\textit{Measured} - \textit{Calculated}|}{\textit{Measured}} \times 100$$

Measured value: __________g

Calculated value: __________g

Percent Discrepancy: __________%

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Analysis and Conclusions

1. **Measure and Use Numbers** Explain why the data from step 13 should yield the mass of the lever.

2. **Acquire and Analyze Information** Were the police correct in determining that Bob could have possibly used his crowbar for leverage and broken into the safe, or should this scenario have been ruled out as a possibility? Explain clearly, using numbers to justify your answer.

3. **Error Analysis** Comment on the values of percent discrepancy. Were the experimental values close to the expected values? What types of errors in your system or setup could cause you to get unexpected numbers? Be specific.

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10 Forensics Lab 10

Safety Precautions

Materials

- spectrometer
- prism
- mercury or helium vapor lamp
- low-watt desk lamp

A Whole Spectrum of Possibilities

Problem

How can broken glass at an accident scene help to identify a suspect vehicle?

Objectives

- **Study** light dispersion through a prism.
- **Determine** the index of refraction of a glass prism.
- **Understand** the relationship between index of refraction and wavelength.
- **Produce** the normal dispersion curve for a glass prism.

Background

Accident scenes often have pieces of broken glass from windshields, headlights, and side windows. In cases where a vehicle leaves the scene of the accident, steps can be taken to match a suspect's vehicle to evidence on the scene. Classifying shards of glass is one of the steps that would be taken to do so.

When light encounters a transparent material at an angle, the material will bend the light according to its index of refraction, *n*. The angle at which the light bends depends on the index of refraction, and the index of refraction depends on both the material and the particular wavelength, λ, that is being bent. This means that, for a particular material, there is a continuum of *n* values for every wavelength of light. For example, white light is composed of all of the visible wavelengths of light, and when passed through a prism, the colors separate. This occurs because for that prism, each color has a different index, *n*, which causes it to be bent at a unique angle. When a graph of index of refraction versus wavelength is produced, the resulting curve is called a *normal dispersion curve.*

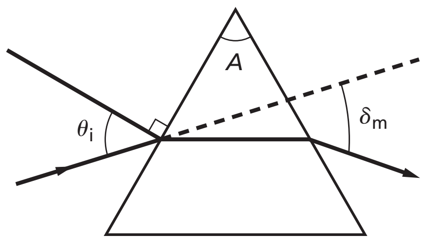

Figure A

In **Figure A** above, *A* represents the apex angle of the prism (usually 60°), θ_i is the incident angle of the light ray, and δ_m is the minimum angle of

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deviation. Using the spectrometer, you will be able to measure the angle of deviation. The index of refraction, n, for that wavelength will be given by

$$n = \frac{\sin 0.5(A + \delta_m)}{\sin(0.5A)}$$

Procedure

1. Turn on the vapor lamp and line it up with the collimator (slit) of the spectrometer.
2. Line the telescope until the light coming through the slit is focused and aligned with the crosshair of the scope. The slit width may need to be adjusted to get an appropriately thin image.
3. Record the angle (should be approximately 180°) as the central angle.
4. Place the prism on the spectrometer stage so the incident light hits one side at an angle.
5. Move the telescope to the left until a solid line of color appears.
6. Slowly rotate the prism stage until you have achieved the minimum angle.
7. Adjust the telescope so the crosshair is on the color line closest to the central angle (should be red).
8. Record the angle.
9. Move the telescope further to the left and align the crosshair with the next color line.
10. Record the angle.
11. Repeat this process for every line of color through the violet part. (If you come back to a red line, do not go any further).
12. Next, go back to the central angle location and move the telescope to the right to find the first red line.
13. Repeat the procedure steps 6–11 for the right-side angles.

Cleanup and Disposal

Turn off lamps and unplug them. Return prism to appropriate container.

Data and Observations

Central angle: ____________

Use the appropriate data table for your vapor lamp (mercury or helium).

Mercury			
Color	**Left Angle**	**Right Angle**	λ_{std}
Orange			578
Yellow green			546
Dim green			491.6
Bright blue			435.8
Violet			404.7

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Helium			
Color	**Left Angle**	**Right Angle**	λ_{std}
Dim red			706.5
Bright red			667.8
Bright yellow			587.6
Pale green			501.6
Green blue			492.2
Blue			471.3
Blue violet			447.1
Dim blue violet			438.8
Faint violet			414.4
Dim violet			402.6
Violet			388.9

Conclude and Apply

1. Find and record the minimum angle of deviation on both the left and the right, using one of the following equations:

$$|C - \text{Left angle}| = \delta_m$$
$$|C - \text{Right angle}| = \delta_m$$

2. Determine and record the average minimum angle of deviation.

3. Using the average minimum angle of deviation, determine the refractive index for each wavelength and record these values.

Mercury				
Color	δ_m **Left**	δ_m **Right**	n	λ_{std}
Orange				578
Yellow green				546
Dim green				491.6
Bright blue				435.8
Violet				404.7

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Helium				
Color	**δ_m Left**	**δ_m Right**	***n***	**λ_{std}**
Dim red				706.5
Bright red				667.8
Bright yellow				587.6
Pale green				501.6
Green blue				492.2
Blue				471.3
Blue violet				447.1
Dim blue violet				438.8
Faint violet				414.4
Dim violet				402.6
Violet				388.9

4. On a separate sheet of paper, graph the index of refraction versus the wavelength for your lamp to produce the normal dispersion curve for your prism.

Analyze and Conclude

1. **Apply Concepts** Explain how you think a normal dispersion curve may help police to match glass particles.

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2. **Error Analysis** What is the primary source of error in the setup that could cause inaccurate angle readings?

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