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The Laboratory Manual contains 40 experiments for
the beginning study of physics. The experiments
illustrate the concepts found in this introductory
course. Both qualitative and quantitative experi-
ments are included, requiring manipulation of
apparatus, observation, and collection of data. The
experiments are designed to help you utilize the
processes of science to interpret data and draw
conclusions.

The laboratory report is an important part of the
laboratory experience. It helps you learn to com-
municate observations and conclusions to others.
Special laboratory report pages are included with
each experiment to allow the most efficient use of
lab-report time. Graph paper is necessary for most
labs requiring construction of graphs.

While accuracy is always desirable, other goals
are of equal importance in laboratory work that
accompanies early courses in science. A high prior-
ity is given to how well laboratory experiments
introduce, develop, or make the physics theories
learned in the classroom realistic and understand-
able and to how well laboratory investigations
illustrate the methods used by scientists. The
investigations in the Laboratory Manual place more
emphasis on the implications of laboratory work
and its relationship to general physics principles,
rather than to how closely results compare with
accepted quantitative values.

Processes of Science

The scientifically literate person uses the processes
of science in making decisions, solving problems,
and expanding an understanding of nature. The
Laboratory Manual utilizes many processes of sci-
ence in all of the lab activities. Throughout this
manual, you are asked to collect and record data,
plot graphs, make and identify assumptions, per-
form experiments, and draw conclusions. In addi-
tion, the following processes of science are includ-
ed in the Laboratory Manual.

Observe: Use the senses to obtain information
about the physical world.

Classify: Impose order on a collection of items or
events.

Communicate: Transfer information from one
person to another.

Measure: Use an instrument to find a value, such
as length or mass, that quantifies an object of
event.

Use Numbers: Use numbers to express ideas,
observations, and relationships.

Control Variables: Identify and manage various
factors that may influence a situation or an event,
so that the effect of any given factor may be
learned.

Design Experiments: Perform a series of data-
gathering operations that provide a basis for test-
ing a hypothesis or answering a specific question.

Define Operationally: Produce definitions of an
object, a concept, or an event in terms that give it a
physical description.

Formulate Models: Devise a mechanism or struc-
ture that describes, acts, or performs as if it were a
real object or event.

Infer: Explain an observation in terms of previous
experience.
Interpret Data: Find a pattern or meaning inherent in a collection of data, which leads to a generalization.

Predict: Make a projection of future observation based on previous information.

Question: Express uncertainty or doubt that is based on the perception of a discrepancy between what is known and what is observed.

Hypothesize: Explain a relatively large number of events by making a tentative generalization, which is subject to testing, either immediately or eventually, with one or more experiments.

The Experiment

Experiments are organized into several sections. Most of the experiments are traditional in nature. They open with a review or an introduction of relevant physics concepts and background information. Objectives listed in the margin help focus your inquiry.

The Materials section lists the equipment used in the experiment and allows you to assemble the required materials quickly and efficiently. All of the equipment listed is either common to the average high school physics lab or can be readily obtained from local sources or a science supply company. Slight variations of equipment can be made and will not affect the basic integrity of the experiments in the Laboratory Manual. Safety symbols alert you to potential dangers in the laboratory investigation.

The Procedure section contains step-by-step instructions to perform the experiment. This format helps you take advantage of limited laboratory time. Caution statements are provided where appropriate.

The Data and Observations section helps organize the lab report. All tables are outlined and properly labeled. In more qualitative experiments, questions are provided to guide your observations.

In the Analysis and Conclusions section, you relate observations and data to the general principles outlined in the objectives of the experiment. Graphs are drawn and interpreted and conclusions concerning data are made. Questions relate laboratory observations and conclusions to basic physics principles studied in the text and in classroom discussions.

The Extension and Application section allows you to extend and apply some aspect of the physics concept investigated. This section may include supplemental procedures or problems that expand the scope of the experiment. They are designed to further the investigation and to challenge the more interested student. Often this section illustrates a current application of the concept.

Some of the experiments are called Design Your Own. Their format is similar to the Design Your Own labs in your textbook. As with the traditional labs, they begin with introductory information and objectives. A statement of the problem focuses the challenge for the experiment. The Hypothesis section reminds you to use what you know to develop a possible explanation of the problem. You then have the opportunity to develop your own procedure to test your hypothesis. The Plan the Experiment section provides overall guidance for this process. The list of materials includes items that could be used for the experiment, depending on your procedure. You may choose to use all, some, or none of these items. Your teacher will help you determine the safe use of materials when he or she checks your procedure. In more cases, a table is
provided in which you can record your data. *Analyze* and *Conclude* questions help you make sense of your data and determine whether or not they support your hypothesis. Finally, *Apply* questions give you the opportunity to apply what you’ve learned to new situations.

**Introduction**

**Purpose of Laboratory Experiments**

The laboratory work in physics is designed to help you better understand basic principles of physics. You will, at the same time, gain a familiarity with the scientific methods and techniques employed in the laboratory. In each experiment, you will be seeking a definite goal, investigating a specific principle, or solving a definite problem. To find the answer to your problem, you will make measurements, list your measurements as data, and then interpret the data to find the results of your measurements.

The values you obtain may not always agree with accepted values. Frequently, this result is to be expected because your laboratory equipment is usually not sophisticated enough for precision work, and the time allowed for each experiment is not extensive. The relationships between your observations and the broad general laws of physics are of much more importance than strict numerical accuracy.

**Preparation of Your Lab Report**

One very important aspect of laboratory work is the communication of your results obtained during the investigation. This laboratory manual is designed so that laboratory report writing is as efficient as possible. In most of the laboratory experiments in this book, you will write your report on the report sheets placed immediately following each experimental procedure. All tables are outlined and properly labeled for ease in recording data and calculations. Adequate space is provided for necessary calculations, discussion of results, conclusions, and interpretations. For instructions on writing a formal laboratory report, see page xix.

**Using Significant Digits**

When making observations and calculations, you should stay within the limitations imposed upon you by your equipment and measurements. Each time you make a measurement, you will read the scale to the smallest calibrated unit and then obtain one smaller unit by estimating. The doubtful or estimated figure is significant because it is better than no estimate at all and should be included in your written values.

It is easy, when making calculations using measured quantities, to indicate a precision greater than your measurements actually allow. To avoid this error, use the following guidelines:

- When adding or subtracting measured quantities, round all values to the same number of significant decimal places as the quantity having the least number of decimal places.
- When multiplying or dividing measured quantities, retain in the product or quotient the same number of significant digits as in the least precise quantity.

**Accuracy and Precisions**

Whenever you measure a physical quantity, there is some degree of uncertainty in the measurement. Error may come from a number of sources, including the type of measuring device, how the measurement is made, and how the measuring device is read. How close your measurement is to the accepted value refers to the accuracy of a measurement. In several of these laboratory activities, experimental results will be compared to accepted values.
When you make several measurements, the agreement, or closeness, of those measurements refers to the precision of the measurement. The closer the measurements are to each other, the more precise the measurement is. It is possible to have excellent precision but to have inaccurate results. Likewise, it is possible to have poor precision but to have accurate results when the average of the data is close to the accepted value. Ideally, the goal is to have good precision and good accuracy.

Relative Error

While absolute error is the absolute value of the difference between your experimental value and the accepted value, relative error is the percentage deviation from an accepted value. The relative error is calculated according to the following relationship:

\[
\text{relative error} = \frac{|\text{accepted value} - \text{experimental value}|}{\text{accepted value}} \times 100\%
\]

Graphs

Frequently an experiment involves finding out how one quantity is related to another. The relationship is found by keeping constant all quantities except the two in question. One quantity is the varied, and the corresponding change in the other is measured. The quantity that is deliberately varied is called the independent variable. The quantity that changes due to the variation in the independent variable is called the dependent variable. Both quantities are then listed in a table. It is customary to list the values of the independent variable in the first column of the table and the corresponding values of the dependent variable in the second column.

More often than not, the relationship between the dependent and the independent variables cannot be ascertained simply by looking at the written out data. But if one quantity is plotted against the other, the resulting graph gives evidence of what sort of relationship, if any, exists between the two variables. When plotting a graph, use the following guidelines:

- Plot the independent variable on the horizontal x-axis (abscissa).
- Plot the dependent variable on the vertical y-axis (ordinate).
- Draw the smooth line that best fits the most plotted points.

Chapter 1 and the Math Handbook of the textbook provide information about linear, quadratic, and inverse relationships between variables.
First Aid in the Laboratory

Report all accidents, injuries, and spills to your teacher immediately.

**You Must Know**
- safe laboratory techniques.
- where and how to report an accident, injury, or spill.
- the location of first-aid equipment, fire alarm, telephone, and school nurse’s office.

<table>
<thead>
<tr>
<th>Situation</th>
<th>Safe Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burns</td>
<td>Flush with cold water.</td>
</tr>
<tr>
<td>Cuts and bruises</td>
<td>Treat as directed by instructions included in your first aid kit.</td>
</tr>
<tr>
<td>Electric shock</td>
<td>Provide person with fresh air; have person recline in a position such that the head is lower than the body; if necessary, provide artificial respiration.</td>
</tr>
<tr>
<td>Fainting or collapse</td>
<td>See Electric shock.</td>
</tr>
<tr>
<td>Fire</td>
<td>Turn off all flames and gas jets; wrap person in fire blanket; use fire extinguisher to put out fire. Do not use water to extinguish fire, as water may react with the burning substance and intensify the fire.</td>
</tr>
<tr>
<td>Foreign matter in eyes</td>
<td>Flush with plenty of water; use eye bath.</td>
</tr>
<tr>
<td>Poisoning</td>
<td>Note the suspected poisoning agent; contact your teacher for antidote; if necessary, call poison control center.</td>
</tr>
<tr>
<td>Severe bleeding</td>
<td>Apply pressure or a compress directly to the wound and get medical attention immediately.</td>
</tr>
<tr>
<td>Spills, general hydrogen acid burns</td>
<td>Wash area with plenty of water; use safety shower; use sodium carbonate, NaHCO₃ (baking soda).</td>
</tr>
<tr>
<td>Base burns</td>
<td>Use boric acid, H₃BO₃.</td>
</tr>
</tbody>
</table>
If you follow instructions exactly and understand the potential hazards of the equipment and the procedure used in an experiment, the physics laboratory is a safe place for learning and applying your knowledge. You must assume responsibility for the safety of yourself, your fellow students, and your teacher. Here are some rules to guide you in protecting yourself and others from injury and in maintaining a safe environment for learning.

1. The physics laboratory is to be used for serious work.
2. Never bring food, beverages, or make-up into the laboratory. Never taste anything in the laboratory. Never remove lab glassware from the laboratory, and never use this glassware for eating or drinking.
3. Do not perform experiments that are unauthorized. Always obtain your teacher’s permission before beginning an activity.
4. Study your laboratory assignment before you come to the lab. If you are in doubt about any procedure, ask your teacher.
5. Keep work areas and the floor around you clean, dry, and free of clutter.
6. Use the safety equipment provided for you. Know the location of the fire extinguisher, safety shower, fire blanket, eyewash station, and first-aid kit.
7. Report any accident, injury, or incorrect procedure to your teacher at once.
8. Keep all materials away from open flames. When using any heating element, tie back long hair and loose clothing. If a fire should break out in the lab, or if your clothing should catch fire, smother it with a blanket or coat or use a fire extinguisher. NEVER RUN.
9. Handle toxic, combustible, or radioactive substance only under the direction of your teacher. If you spill acid or another corrosive chemical, wash it off with water immediately.
10. Place broken glass and solid substances in designated containers. Keep insoluble water material out of the sink.
11. Use electrical equipment only under the supervision of your teacher. Be sure your teacher checks electric circuits before you activate them. Do not handle electric equipment with wet hands or when you are standing in damp areas.
12. When your investigation is completed, be sure to turn off the water and gas and disconnect electrical connections. Clean your work area. Return all materials and apparatus to their proper places. Wash your hands thoroughly after working in the laboratory.

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

**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.
**Common Physical Constants**

Absolute zero \( T = -273.15^\circ \text{C} = 0 \text{ K} \)

Acceleration due to gravity at sea level (Washington, D.C.): \( g = 9.80 \text{ m/s}^2 \)

Atmospheric pressure (standard): 1 atm = \( 1.013 \times 10^5 \) Pa = 760 mm Hg

Avogadro’s number: \( N_A = 6.02 \times 10^{23} \text{ mol}^{-1} \)

Charge of one electron (elementary charge): \( e = -1.602 \times 10^{-19} \text{ C} \)

Coulomb’s law constant: \( K = 9.0 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2 \)

Gas constant: \( R = 8.31 \text{ J/mol} \cdot \text{K} \)

Gravitational Constant: \( G = 6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2 \)

Heat of fusion of ice: \( 3.34 \times 10^5 \text{ J/kg} \)

Heat of vaporization of water: \( 2.26 \times 10^6 \text{ J/kg} \)

Mass of electron: \( m_e = 9.1 \times 10^{-31} \text{ kg} = 5.5 \times 10^{-4} \text{ u} \)

Mass of neutron: \( m_n = 1.675 \times 10^{-27} \text{ kg} = 1.00867 \text{ u} \)

Mass of proton: \( m_p = 1.673 \times 10^{-27} \text{ kg} = 1.00728 \text{ u} \)

Planck’s constant: \( h = 6.625 \times 10^{-34} \text{ J/Hz} \text{ (J} \cdot \text{s)} \)

Velocity of light in a vacuum: \( c = 2.99892458 \times 10^8 \text{ m/s} \)

**Conversion Factors**

**Mass:**
- \( 1000 \text{ g} = 1 \text{ kg} \)
- \( 1000 \text{ mg} = 1 \text{ g} \)

**Volume:**
- \( 1000 \text{ mL} = 1 \text{ L} \)
- \( 1 \text{ mL} = 1 \text{ cm}^3 \)

**Length:**
- \( 100 \text{ cm} = 1 \text{ m} \)
- \( 1000 \text{ m} = 1 \text{ km} \)

1 atomic mass unit (u) = \( 1.66 \times 10^{-27} \text{ kg} = 931 \text{ MeV/c}^2 \)

1 electron volt (eV) = \( 1.602 \times 10^{-19} \text{ J} \)

1 joule (J) = 1 N \cdot m = 1 \text{ V} \cdot \text{C}

1 coulomb = \( 6.242 \times 10^{18} \) elementary charge units
Color Response of Eye to Various Wavelengths of Light

<table>
<thead>
<tr>
<th>Color</th>
<th>in nm</th>
<th>in m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultraviolet</td>
<td>less than 380</td>
<td>less than $3.8 \times 10^{-7}$</td>
</tr>
<tr>
<td>Violet</td>
<td>400–420</td>
<td>$4.0–4.2 \times 10^{-7}$</td>
</tr>
<tr>
<td>Blue</td>
<td>440–480</td>
<td>$4.4–4.8 \times 10^{-7}$</td>
</tr>
<tr>
<td>Green</td>
<td>500–560</td>
<td>$5.0–5.6 \times 10^{-7}$</td>
</tr>
<tr>
<td>Yellow</td>
<td>580–600</td>
<td>$5.8–6.0 \times 10^{-7}$</td>
</tr>
<tr>
<td>Red</td>
<td>620–700</td>
<td>$6.2–7.0 \times 10^{-7}$</td>
</tr>
<tr>
<td>Infrared</td>
<td>above 760</td>
<td>above $7.6 \times 10^{-7}$</td>
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</table>

Prefixes Used with SI Units

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Symbol</th>
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<th>Prefix</th>
<th>Symbol</th>
<th>Multiplier</th>
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<tr>
<td>Pico</td>
<td>p</td>
<td>$10^{-12}$</td>
<td>Tera</td>
<td>T</td>
<td>$10^{12}$</td>
</tr>
<tr>
<td>Nano</td>
<td>n</td>
<td>$10^{-9}$</td>
<td>Giga</td>
<td>G</td>
<td>$10^{9}$</td>
</tr>
<tr>
<td>Micro</td>
<td>μ</td>
<td>$10^{-6}$</td>
<td>Mega</td>
<td>M</td>
<td>$10^{6}$</td>
</tr>
<tr>
<td>Milli</td>
<td>m</td>
<td>$10^{-5}$</td>
<td>Kilo</td>
<td>k</td>
<td>$10^{3}$</td>
</tr>
<tr>
<td>Centi</td>
<td>c</td>
<td>$10^{-2}$</td>
<td>Hecto</td>
<td>h</td>
<td>$10^{2}$</td>
</tr>
<tr>
<td>Deci</td>
<td>d</td>
<td>$10^{-1}$</td>
<td>Deka</td>
<td>da</td>
<td>$10^{1}$</td>
</tr>
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</table>
## Properties of Common Substances
### Specific Heat and Density

<table>
<thead>
<tr>
<th>Substance</th>
<th>Specific Heat (J/kg·K)</th>
<th>Density</th>
</tr>
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<tbody>
<tr>
<td>Alcohol</td>
<td>2450</td>
<td>0.8</td>
</tr>
<tr>
<td>Aluminum</td>
<td>903</td>
<td>2.7</td>
</tr>
<tr>
<td>Brass</td>
<td>376</td>
<td>8.5 varies by content</td>
</tr>
<tr>
<td>Carbon</td>
<td>710</td>
<td>1.7–3.5</td>
</tr>
<tr>
<td>Copper</td>
<td>385</td>
<td>8.9</td>
</tr>
<tr>
<td>Glass</td>
<td>664</td>
<td>2.2–2.6</td>
</tr>
<tr>
<td>Gold</td>
<td>129</td>
<td>19.3</td>
</tr>
<tr>
<td>Ice</td>
<td>2060</td>
<td>0.92</td>
</tr>
<tr>
<td>Iron (steel)</td>
<td>450</td>
<td>7.1–7.8</td>
</tr>
<tr>
<td>Lead</td>
<td>130</td>
<td>11.3</td>
</tr>
<tr>
<td>Mercury</td>
<td>138</td>
<td>13.6</td>
</tr>
<tr>
<td>Nickel</td>
<td>444</td>
<td>8.8</td>
</tr>
<tr>
<td>Platinum</td>
<td>433</td>
<td>21.4</td>
</tr>
<tr>
<td>Silver</td>
<td>235</td>
<td>10.5</td>
</tr>
<tr>
<td>Steam</td>
<td>2020</td>
<td>–</td>
</tr>
<tr>
<td>Tungsten</td>
<td>133</td>
<td>19.3</td>
</tr>
<tr>
<td>Water</td>
<td>4180</td>
<td>1.0 at 4°C, 0.99 at 0°C</td>
</tr>
<tr>
<td>Zinc</td>
<td>388</td>
<td>7.1</td>
</tr>
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## Index of Refraction

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Air</td>
<td>1.000029</td>
</tr>
<tr>
<td>Alcohol</td>
<td>1.36</td>
</tr>
<tr>
<td>Benzene</td>
<td>1.50</td>
</tr>
<tr>
<td>Beryl</td>
<td>1.58</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>1.00045</td>
</tr>
<tr>
<td>Cinnamon oil</td>
<td>1.6026</td>
</tr>
<tr>
<td>Clove oil</td>
<td>1.544</td>
</tr>
<tr>
<td>Diamond</td>
<td>2.42</td>
</tr>
<tr>
<td>Garnet</td>
<td>1.75</td>
</tr>
<tr>
<td>Glass, crown</td>
<td>1.52</td>
</tr>
<tr>
<td>Glass, flint</td>
<td>1.61</td>
</tr>
<tr>
<td>Mineral oil</td>
<td>1.48</td>
</tr>
<tr>
<td>Oil of wintergreen</td>
<td>1.48</td>
</tr>
<tr>
<td>Olive oil</td>
<td>1.47</td>
</tr>
<tr>
<td>Quartz, fused</td>
<td>1.46</td>
</tr>
<tr>
<td>Quartz, mineral</td>
<td>1.54</td>
</tr>
<tr>
<td>Topaz</td>
<td>1.62</td>
</tr>
<tr>
<td>Tourmaline</td>
<td>1.63</td>
</tr>
<tr>
<td>Turpentine</td>
<td>1.4721</td>
</tr>
<tr>
<td>Water</td>
<td>1.33</td>
</tr>
<tr>
<td>Water vapor</td>
<td>1.00025</td>
</tr>
<tr>
<td>Ziron</td>
<td>1.87</td>
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</table>
### Spectral Lines of Elements

<table>
<thead>
<tr>
<th>Element</th>
<th>Wavelength (nanometers)</th>
<th>Color</th>
</tr>
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<tbody>
<tr>
<td>Argon</td>
<td>many close lines</td>
<td></td>
</tr>
<tr>
<td></td>
<td>706.7</td>
<td>red (strong)</td>
</tr>
<tr>
<td></td>
<td>696.5</td>
<td>red (strong)</td>
</tr>
<tr>
<td></td>
<td>603.2</td>
<td>orange</td>
</tr>
<tr>
<td></td>
<td>591.2</td>
<td>orange</td>
</tr>
<tr>
<td></td>
<td>588.8</td>
<td>orange</td>
</tr>
<tr>
<td></td>
<td>550.6</td>
<td>yellow</td>
</tr>
<tr>
<td></td>
<td>545.4</td>
<td>green</td>
</tr>
<tr>
<td></td>
<td>525.2</td>
<td>green</td>
</tr>
<tr>
<td></td>
<td>522.1</td>
<td>green</td>
</tr>
<tr>
<td></td>
<td>518.7</td>
<td>green</td>
</tr>
<tr>
<td></td>
<td>451.0</td>
<td>purple</td>
</tr>
<tr>
<td></td>
<td>433.3</td>
<td>purple</td>
</tr>
<tr>
<td></td>
<td>430.0</td>
<td>purple</td>
</tr>
<tr>
<td></td>
<td>427.2</td>
<td>purple</td>
</tr>
<tr>
<td></td>
<td>420.0</td>
<td>purple</td>
</tr>
<tr>
<td>Barium</td>
<td>659.5</td>
<td>red</td>
</tr>
<tr>
<td></td>
<td>614.1</td>
<td>orange</td>
</tr>
<tr>
<td></td>
<td>585.4</td>
<td>yellow</td>
</tr>
<tr>
<td></td>
<td>577.7</td>
<td>yellow</td>
</tr>
<tr>
<td></td>
<td>553.5</td>
<td>green (strong)</td>
</tr>
<tr>
<td></td>
<td>455.4</td>
<td>blue (strong)</td>
</tr>
<tr>
<td>Bromine</td>
<td>many green lines</td>
<td></td>
</tr>
<tr>
<td></td>
<td>481.7</td>
<td>green</td>
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<td></td>
<td>478.6</td>
<td>blue</td>
</tr>
<tr>
<td></td>
<td>470.5</td>
<td>blue</td>
</tr>
<tr>
<td></td>
<td>many purple lines</td>
<td></td>
</tr>
<tr>
<td>Calcium</td>
<td>445.4</td>
<td>blue</td>
</tr>
<tr>
<td></td>
<td>443.4</td>
<td>blue-violet</td>
</tr>
<tr>
<td></td>
<td>552.6</td>
<td>violet (strong)</td>
</tr>
<tr>
<td></td>
<td>396.8</td>
<td>violet (strong)</td>
</tr>
<tr>
<td></td>
<td>393.3</td>
<td>violet (strong)</td>
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<tr>
<td>Chromium</td>
<td>520.8</td>
<td>green</td>
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<tr>
<td></td>
<td>520.6</td>
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<tr>
<td></td>
<td>520.4</td>
<td>green</td>
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<tr>
<td></td>
<td>428.9</td>
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<tr>
<td></td>
<td>427.4</td>
<td>violet (strong)</td>
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<tr>
<td></td>
<td>425.4</td>
<td>violet (strong)</td>
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<tr>
<td>Copper</td>
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<tr>
<td></td>
<td>515.3</td>
<td>green</td>
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<td></td>
<td>510.5</td>
<td>green</td>
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<td>Hydrogen</td>
<td>656.2</td>
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<tr>
<td></td>
<td>486.1</td>
<td>green</td>
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<tr>
<td></td>
<td>434.0</td>
<td>blue-violet</td>
</tr>
<tr>
<td></td>
<td>410.1</td>
<td>violet</td>
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<td>Helium</td>
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</tr>
<tr>
<td></td>
<td>667.8</td>
<td>red</td>
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<tr>
<td></td>
<td>587.5</td>
<td>orange (strong)</td>
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<tr>
<td></td>
<td>501.5</td>
<td>green</td>
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<tr>
<td></td>
<td>471.3</td>
<td>blue</td>
</tr>
<tr>
<td></td>
<td>388.8</td>
<td>violet (strong)</td>
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<tr>
<td>Iodine</td>
<td>many lines</td>
<td></td>
</tr>
<tr>
<td></td>
<td>546.4</td>
<td>green (strong)</td>
</tr>
<tr>
<td></td>
<td>516.1</td>
<td>green (strong)</td>
</tr>
<tr>
<td>Krypton</td>
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<td></td>
</tr>
<tr>
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<td>587.0</td>
<td>orange (strong)</td>
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<tr>
<td></td>
<td>557.0</td>
<td>yellow (strong)</td>
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<tr>
<td></td>
<td>455.0</td>
<td>blue</td>
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<tr>
<td></td>
<td>442.5</td>
<td>blue</td>
</tr>
<tr>
<td></td>
<td>441.0</td>
<td>blue</td>
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<tr>
<td></td>
<td>430.2</td>
<td>blue-violet</td>
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<td></td>
<td>579.0</td>
<td>yellow (strong)</td>
</tr>
<tr>
<td></td>
<td>576.9</td>
<td>yellow (strong)</td>
</tr>
<tr>
<td></td>
<td>546.0</td>
<td>green (strong)</td>
</tr>
<tr>
<td></td>
<td>435.8</td>
<td>blue-violet</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>567.6</td>
<td>green (strong)</td>
</tr>
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<td>566.6</td>
<td>green</td>
</tr>
<tr>
<td></td>
<td>410.9</td>
<td>violet (strong)</td>
</tr>
<tr>
<td></td>
<td>409.9</td>
<td>violet</td>
</tr>
<tr>
<td>Potassium</td>
<td>404.7</td>
<td>violet (strong)</td>
</tr>
<tr>
<td></td>
<td>404.4</td>
<td>violet (strong)</td>
</tr>
<tr>
<td>Lithium</td>
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<td>red (strong)</td>
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<td></td>
<td>610.3</td>
<td>orange</td>
</tr>
<tr>
<td></td>
<td>460.3</td>
<td>violet</td>
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<tr>
<td>Sodium</td>
<td>589.5</td>
<td>yellow (strong)</td>
</tr>
<tr>
<td></td>
<td>588.9</td>
<td>yellow (strong)</td>
</tr>
<tr>
<td></td>
<td>568.8</td>
<td>green</td>
</tr>
<tr>
<td></td>
<td>568.2</td>
<td>green</td>
</tr>
<tr>
<td>Neon</td>
<td>many lines in the red</td>
<td></td>
</tr>
<tr>
<td></td>
<td>640.2</td>
<td>orange (strong)</td>
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<tr>
<td></td>
<td>585.5</td>
<td>yellow (strong)</td>
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<tr>
<td></td>
<td>583.2</td>
<td>yellow (strong)</td>
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<tr>
<td></td>
<td>540.0</td>
<td>green (strong)</td>
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<tr>
<td>Strontium</td>
<td>496.2</td>
<td>blue-green</td>
</tr>
<tr>
<td></td>
<td>487.2</td>
<td>blue</td>
</tr>
<tr>
<td></td>
<td>483.2</td>
<td>blue</td>
</tr>
<tr>
<td></td>
<td>460.7</td>
<td>blue (strong)</td>
</tr>
<tr>
<td></td>
<td>430.5</td>
<td>blue-violet</td>
</tr>
<tr>
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<td>421.5</td>
<td>violet</td>
</tr>
<tr>
<td></td>
<td>407.7</td>
<td>violet</td>
</tr>
<tr>
<td>Xenon</td>
<td>492.3</td>
<td>blue-green</td>
</tr>
<tr>
<td></td>
<td>484.4</td>
<td>blue</td>
</tr>
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<td></td>
<td>480.7</td>
<td>blue</td>
</tr>
<tr>
<td></td>
<td>469.7</td>
<td>blue</td>
</tr>
<tr>
<td></td>
<td>467.1</td>
<td>blue (strong)</td>
</tr>
<tr>
<td></td>
<td>462.4</td>
<td>blue (strong)</td>
</tr>
<tr>
<td></td>
<td>460.3</td>
<td>blue</td>
</tr>
<tr>
<td></td>
<td>458.3</td>
<td>blue</td>
</tr>
<tr>
<td></td>
<td>452.4</td>
<td>blue</td>
</tr>
<tr>
<td></td>
<td>450.0</td>
<td>blue (strong)</td>
</tr>
</tbody>
</table>
Rules for Using Meters

Introduction

Electric meters are precision instruments and must be handled with great care. They are easily damaged physically or electrically and are expensive to replace or repair. Meters are damaged physically by bumping or dropping and electrically by allowing excess current to flow through the meter. The heating effect in a circuit increases with the square of the current. The wires inside the meter actually burn through if too much current flows through the meter. When possible, use a switch in the circuit to prevent having the circuit closed for extended periods of time. Note that meters are generally designed for use in either AC or DC circuits and not interchangeable. In DC circuits, the polarity of the meter with respect to the power source in the circuit is critical. Be sure to use the proper meter for the type of circuit you are investigating. Always have your teacher check the circuit to be sure you have assembled it correctly.

The Voltmeter

A voltmeter is used to determine the potential difference between two points in a circuit. It is always connected in parallel, never in series, with the element to be measured. If you can remove the voltmeter from the circuit without interrupting the circuit, you have connected it correctly.

On a DC voltmeter, the terminals are marked + or −. The positive terminal should be connected either directly or through components to the positive side of the power supply. The negative terminal must be connected either directly or through circuit components to the negative side of the power supply. After you have connected the voltmeter, close the switch for a moment to see if the polarity is correct.

Some meters have several ranges from which to choose. You may have a meter with ranges from 0-3 V, 0-15 V, or 0-300 V. If you do not know the potential difference across the circuit on which the voltmeter is to be used, choose the highest range initially, and then adjust to a range that gives readings in the middle of the scale (when possible).

The Ammeter

An ammeter is used to measure the current in a circuit and must always be connected in series. Since the internal resistance of an ammeter is very small, the meter will be destroyed if it is connected in parallel. When you connect or disconnect the ammeter, the circuit must be interrupted. If the ammeter can be included or removed without breaking the circuit, the ammeter is incorrectly connected.

Like a voltmeter, an ammeter may have different ranges. Always protect the instrument by connecting it first to the highest range and the proceeding to a smaller scale until you obtain a reading in the middle of the scale (when possible).

On a DC ammeter, the polarity of the terminals is marked + or −. The positive terminal should be connected either directly or through components to the positive side of the power supply. The negative terminal must be connected either directly or through circuit components to the negative side of the power supply. After you have connected the ammeter, close the switch for a moment to see if the polarity is correct.
The Galvanometer

A galvanometer is a very low resistance instrument used to measure very small currents in microamperes. Thus, it must be connected in a series in a circuit. The zero point on some galvanometers is in the center of the scale, and the divisions are not calibrated. This type of galvanometer measures the presence of a very small current, its direction, and its relative magnitude. A low resistance wire, called a shunt, may be connected across the terminals of the galvanometer to protect it. If the meter does not register a current, the shunt is then removed.

Potentiometer (variable resistors)

A potentiometer is a precision instrument that contains an adjustable resistance element. When placed in a circuit, a potentiometer allows gradual changing of the resistance, which, in turn, causes the current and voltage to vary. Some power resistors are called rheostats.

Resistor Color Code

Suppose that a resistor has the following color bands:

<table>
<thead>
<tr>
<th>1st band</th>
<th>2nd band</th>
<th>3rd band</th>
<th>4th band</th>
</tr>
</thead>
<tbody>
<tr>
<td>brown</td>
<td>black</td>
<td>yellow</td>
<td>gold</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>4</td>
<td>±5%</td>
</tr>
</tbody>
</table>

The value of this resistor is $10 \times 10,000 \pm 5\%$ or it has a range of 80,000 $\Omega$ to 120,000 $\Omega$.

Resistance Color Codes (resistance given in ohms)

<table>
<thead>
<tr>
<th>Color</th>
<th>Digit</th>
<th>Multiplier</th>
<th>Tolerance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Brown</td>
<td>1</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Red</td>
<td>2</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Orange</td>
<td>3</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>Yellow</td>
<td>4</td>
<td>10,000</td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td>5</td>
<td>100,000</td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td>6</td>
<td>1,000,000</td>
<td></td>
</tr>
<tr>
<td>Violet</td>
<td>7</td>
<td>10,000,000</td>
<td></td>
</tr>
<tr>
<td>Gray</td>
<td>8</td>
<td>10,000,000</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>9</td>
<td>10,000,000</td>
<td></td>
</tr>
<tr>
<td>Gold</td>
<td>0.1</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Silver</td>
<td>0.01</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>No color</td>
<td></td>
<td>20</td>
<td></td>
</tr>
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</table>
Preparing Laboratory Reports

Ordinarily, the reports you write for the experiments in this manual will be simple summaries of your work. Laboratory data sheets are provided in the manual for this purpose. In the future, you may be called upon to write more formal reports for other science courses. There is an accepted procedure for writing these reports. The procedure is outlined below. Your teacher may require that you write a number of reports in accordance with this outline so that you learn how to prepare reports properly.

Sections to be included in a formal laboratory report include the following: Introduction, Data, Results/Analysis, Graphs, Sample Calculations, Discussion, Conclusions.

I. Introduction
   A. Heading
      This includes the experiment number and title, date, name, and your partner’s name if you do a joint experiment. When two students work together using the same apparatus, they are partners for data collection purposes, yet each must write a separate report.

   B. Diagrams
      1. Make sketches of mechanical apparatus (if called for).
      2. Draw complete electric circuit diagrams showing all electrical components.
         Label the polarity of all DC meters and power sources.
   
   C. Provide a brief explanation or title for each diagram.
   
   D. Include an elaboration or a summary of the concept, purpose, procedure, theory, or the history of the experiment.

II. Data
   
   A. Use only the original record of the measurements made during the experiment. Never jot the data down on scrap paper for future use. Prepare a data sheet and use it.

III. Results/Analysis
   A. The result section consists of a tabulation of all intermediate calculated values and final results.
   B. Whenever there are several results, the numerical values should be recorded in a table.
   C. Tables must have titles. Headings and extra notes may be required to make the analysis or significance of the results clear to the reader.

IV. Graphs
   A. Use adequate labels (title, legend, names of quantities and units)
   B. Draw the best, smooth curve possible; do not draw curves dot-to-dot.
V. Sample Calculations

A. Each sample calculation should include the following items:
   1. an equation in a familiar form
   2. an algebraic solution of the equation for the desired quantity
   3. substitution of known values with units
   4. numerical answer with units

For example, if \( d = 10 \text{ m} \) and \( t = 2 \text{ s} \), to solve for \( a \):

Using \( d = v_i t + \frac{1}{2} a t^2 \), where \( v_i = 0 \),

\[
a = 2d/t^2 = (2)(10 \text{ m})/(2 \text{ s})^2 = 5 \text{ m/s}^2.
\]

VI. Discussion

In some cases, the conclusions of an experiment are so obvious that the discussion section may be omitted. However, in these instances a short statement is appropriately included. More often, some discussion of the results will be required to make their significance clear. You may also wish to comment upon possible sources of error and to suggest improvements in the procedure or apparatus.

VII. Conclusions

The conclusion is an important part of every report. The conclusion must be the individual work of the student who writes the report and should be completed without the assistance of anyone, unless it is the teacher.

The conclusions consists of one or more well-written paragraphs summarizing and drawing together only the main results and indicating their significance in relationship to the observed data.

A. Conclusions must cover each point of the subject.
B. Conclusions must be based upon the results of the experiment and the data.
C. If conclusions are based upon graphs, reference must be made to the graph by its full title.
D. Clarity and conciseness are particularly important in conclusions. The personal form should be avoided except, perhaps, in the discussion. Therefore, do not use the words \( I \) or \( we \) unless there is a special reason for doing so.
How does mass depend on volume?

With the skills of making observations, using measuring equipment, and calculating using significant figures, you are ready to investigate one aspect of physics: the constant. A constant is a property that has been scientifically determined to remain the same for a given set of conditions. For example, if through a number of experiments you observed that water always freezes at 0°C, then you might conclude that the freezing temperature of water is a constant. Using this fact, you can extend your scientific research to discover more things about water or about the physical process of freezing.

In this lab you will investigate density. Density is an intrinsic property of matter. Density is the amount of mass in a unit volume. Density is used by physicists to understand phenomena such as buoyancy. Engineers use density to help determine whether a particular design for a ship will float or sink.

You will measure the mass of several objects made from the same material. You will then take measurements of the objects and calculate the volume of the objects. You will graph your data and determine whether the density of a particular material is a constant.

Objectives

■ Measure the dimensions and masses of several objects, using SI units.
■ Graph the mass of an object versus its volume.
■ Explain how to determine the volume of an object without measuring its dimensions.

Procedure

1. Obtain a block, a cylinder, and a sphere made from the same type of wood.
2. Record the type of wood in Table 1.
3. Use a balance to determine the mass of each object to the nearest gram and record the mass of each object in Table 1.
4. Use the Vernier caliper to measure the length, width, and height of the block to the nearest millimeter. Measure each dimension of the block four times and record your measurements in Table 1.
5. Use the Vernier caliper to measure the diameter and height of the cylinder to the nearest millimeter. Measure each dimension of the cylinder four times and record your measurements in Table 1.
6. Use the Vernier caliper to measure the diameter of the sphere to the nearest millimeter. Measure the diameter of the sphere four times and record your measurements in Table 1.

7. Obtain a block, a cylinder, and a sphere made from the same type of metal.

8. Record the type of metal in Table 2.

9. Repeat steps 3 through 6 for the metal objects. Record the data in Table 2.

Data and Observations

<table>
<thead>
<tr>
<th>Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of wood ____________________________</td>
</tr>
<tr>
<td>Block</td>
</tr>
<tr>
<td>Cylinder</td>
</tr>
<tr>
<td>Sphere</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of metal ____________________________</td>
</tr>
<tr>
<td>Block</td>
</tr>
<tr>
<td>Cylinder</td>
</tr>
<tr>
<td>Sphere</td>
</tr>
</tbody>
</table>
Analysis and Conclusions

1. For each object, calculate the average of each dimension’s measurement and record the averages in Table 3.

<table>
<thead>
<tr>
<th>Object</th>
<th>Average Dimensions (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wooden block</td>
<td>Length</td>
</tr>
<tr>
<td>Wooden cylinder</td>
<td>Diameter</td>
</tr>
<tr>
<td>Wooden sphere</td>
<td>Diameter</td>
</tr>
<tr>
<td>Metal block</td>
<td>Length</td>
</tr>
<tr>
<td>Metal cylinder</td>
<td>Diameter</td>
</tr>
<tr>
<td>Metal sphere</td>
<td>Diameter</td>
</tr>
</tbody>
</table>

2. Calculate the volume of each measured object using the averages calculated in Table 3. Convert each calculated volume to m³ and record the result in Table 4.

<table>
<thead>
<tr>
<th>Shape</th>
<th>Equation for Volume</th>
<th>Volume of Wooden Object V (m³)</th>
<th>Volume of Metal Object V (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block</td>
<td>( V = lwh )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cylinder</td>
<td>( V = \pi \left( \frac{d}{2} \right)^2 h )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sphere</td>
<td>( V = \frac{4}{3} \pi \left( \frac{d}{2} \right)^3 )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Use the grids on the next page to plot your data. Use one grid for all of the wood objects and the other grid for all of the metal objects. Plot the measured mass of each object on the y-axis and its calculated volume on the x-axis.
4. Analyze the two plots. Is there a pattern to the plot for each material? If so, what is it? Is there a relationship between mass and volume? Explain.

5. Draw a best-fit straight line through the points associated with each material. What is the value of the slope of each line? What does the slope represent? What are the units of the slope?

6. Analyze the fit of the straight lines you have drawn to the points in the plots. Are all of the points on or close to the line? Does your data indicate the presence of a constant? What are some possible reasons for some data points lying off the line?

Extension and Application

1. Formulate an equation for each line in your graphs and record the equation below with units. What is the name of the constant in the equation?

2. Suppose you have an irregularly shaped object made of a known material. Because the object has an irregular shape, it is not possible to determine its volume by measurements and calculations. How could you determine the volume of the object?
Where will the vehicle be?

When studying motion, only two quantities can be easily measured: Position, \( d \), and time, \( t \). All other quantities related to motion are calculated using position and time measurements. One such quantity is called speed. Speed is the rate of change of position over time. It is a tool that scientists can use to make predictions about the motion of an object, such as the time required to travel a given distance, or the distance of travel that can be achieved in a given amount of time.

To determine the average speed of an object, measure the change in position (displacement), \( \Delta d \), for a time interval, \( \Delta t \), and divide the displacement by the time interval.

\[
\bar{v} = \frac{\Delta d}{\Delta t}
\]

If an object has a uniform displacement over equal time intervals, the value of average speed is constant. The slope of the plot of position versus time is a straight line. The slope of a line is the ratio of rise to run. In this case, the rise is equal to the difference between final position and initial position, \( (d_f - d_i) \). The run is the difference between the final time and the initial time, \( (t_f - t_i) \).

\[
\bar{v} = \frac{(d_f - d_i)}{(t_f - t_i)}
\]

This equation is similar in form to the theoretical equation that defines average speed. For an object with a constant speed, \( \bar{v} \), that starts at \( d_i = 0 \) when \( t_i = 0 \), the relationship between the object’s final position and the elapsed time is the following:

\[
t_f = \frac{d_f}{\bar{v}}
\]

In this lab, you will study an object moving at a constant speed. You will make predictions on the time required for the object to reach selected positions. You then will design and perform an experiment to see if your predictions are correct.

Objectives

- **Predict** the time required for a constant speed vehicle to travel selected distances.
- **Measure** time intervals associated with distance traveled at constant speed
- **Evaluate** your experiment.
Problem
How are time and distance related for an object moving at a constant speed?

Hypothesis
Formulate a hypothesis about the relationship between distance traveled and elapsed time for a vehicle moving at a constant speed. Based on your hypothesis, predict the amount of time required for your vehicle to travel the distances identified in Table 1 at a constant speed. Use a speed provided by your teacher.

<table>
<thead>
<tr>
<th></th>
<th>Given:</th>
<th>Prediction:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance Traveled (cm)</td>
<td></td>
<td>Time Required (s)</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
<td></td>
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<td>40</td>
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<td>80</td>
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<tr>
<td>90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Plan the Experiment
1. Work with a partner or in small groups. Select what you need from the suggested materials (or others of your choosing) to design an experiment that will help you test your hypothesis.
2. Select the measuring instruments you will use to measure the time of travel based upon the distances in Table 1. Make sure that you know how to operate your selected measuring instruments, and be sure you understand the limits of their precision.
3. Decide on a procedure that uses the materials and measuring methods that you have selected. Write your procedure on another sheet of paper or in your notebook. In the space on the next page, draw a diagram of your experimental setup. Also create a table to record your data and calculated results.
4. Check the Plan Have your teacher approve your plan before you proceed with your experiment. Make sure that you understand how to operate all of the equipment.

5. Perform the experiment using Table 2 to record your data.

Setup

Data and Observations

<table>
<thead>
<tr>
<th>Data Run</th>
<th>Use these columns to record data based upon your experimental setup.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (10 cm)</td>
<td></td>
</tr>
<tr>
<td>2 (20 cm)</td>
<td></td>
</tr>
<tr>
<td>3 (30 cm)</td>
<td></td>
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<tr>
<td>4 (40 cm)</td>
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<tr>
<td>5 (50 cm)</td>
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<td>6 (60 cm)</td>
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<tr>
<td>7 (70 cm)</td>
<td></td>
</tr>
<tr>
<td>8 (80 cm)</td>
<td></td>
</tr>
<tr>
<td>9 (90 cm)</td>
<td></td>
</tr>
<tr>
<td>10 (100 cm)</td>
<td></td>
</tr>
</tbody>
</table>
Analyze and Conclude

1. Examine Data  How do your experimental results compare with your predictions?

2. Analyze Data  Break down each time measurement that you made into increments of time to travel 10 cm. Can you detect a pattern? Explain.

3. Interpret Information  Imagine that the distances used in the experiment had the same numerical value but were in meters rather than centimeters. How would this affect your time measurements?

4. Draw Conclusions  Compose a conclusion statement for your experiment regarding how distance relates to time for a constant speed.

5. Evaluate Methods  Critique your experiment. What worked well? Is there something you would do differently?

Apply

1. What if you performed your experiment with a constant-speed object that moves in a circle. Would you expect your hypothesis to still hold true? Explain.
How does a ball roll?

The concept of acceleration was not understood by the scientists of Galileo’s time. An object that traveled farther in a given time was believed simply to have more speed. Galileo recognized that some objects increase in speed, but he initially thought that this increase in speed was proportional to distance. After performing experiments with balls rolling down ramps, Galileo realized that the increase in speed is proportional to time, and that the distance traveled is proportional to time squared.

\[ d \propto t^2 \]

Galileo established this law of falling objects by using an experimental setup similar to the one shown in Figure A. He used a ramp with a very small slope, such that the rolling ball would accelerate slowly. Galileo had difficulty finding a clock that measured time consistently. The advantage that you have over Galileo is that you will use a photogate timer to measure time. In this lab, you will perform the ball rolling experiment to establish that distance traveled is proportional to time squared when an object is accelerating.

Objectives

- **Demonstrate** the relationship between distance and time for an accelerating, rolling ball.
- **Compute** the acceleration of a rolling ball.
- **Discover** a relationship between increasing speed and time using distance and time data.

Procedure

1. Obtain a ball from your teacher.
2. Using a flat board as a ramp, set up the apparatus shown in Figure A. Adjust the slope of the ramp so it is nearly horizontal and is the same as the slope of the ramps of other lab groups. The ball should accelerate steadily but slowly. Make sure the timer is in stopwatch mode.
mode so that time starts when the start button is pressed and stops when the ball passes through
the photogate. Adjust the photogate so that the ball has enough room to pass through it but still
blocks the light to the sensor.

3. Place the ball at the top of the ramp and hold it against the starting block. Using the meterstick,
place the photogate so that the distance along the slope of the ramp from the front of the ball to
the photogate is 10 cm.

4. Release the ball and start the timer at the same instant. After the ball passes through the photogate,
record the time for 10 cm of travel in the Time 1 column of Table 1.

5. Repeat step 4 three more times and record time measurements for Time 2 and Time 3 in Table 1.

6. Repeat steps 3 and 5 for Data Sets 2–10 identified in Table 1. Each subsequent data set adds 10 cm
to the distance of roll.

**Data and Observations**

<table>
<thead>
<tr>
<th>Data Set</th>
<th>Distance d (cm)</th>
<th>Time 1 ( t_1 ) (s)</th>
<th>Time 2 ( t_2 ) (s)</th>
<th>Time 3 ( t_3 ) (s)</th>
<th>Average Time ( \bar{t} ) (s)</th>
<th>Average Time Squared ( \bar{t}^2 ) (s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
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</tbody>
</table>
Analysis and Conclusions

1. Calculate the average time and the square of the average time for each data set and record the value in Table 1.

2. Use the grid below and plot the data from the table. Plot distance on the y-axis and the square of the time on the x-axis.

3. Analyze your graph. Can you detect a pattern to the points? Explain.

4. Draw a best-fit straight line through the points in the graph and compute the slope of the line. What does the slope represent? What are the units of the slope?
5. Assess the fit of the straight line you have drawn based on the points in the graph. Did the rolling ball experience constant acceleration? Are all of the points on or close to the line? What are some possible reasons for some data points lying away from the line?


Extension and Application

1. Compare the value of the slope of your line to the values determined by other lab groups. Considering that all lab groups used the same angle of slope, what factor seems to be common among the lab groups with similar data?


2. Imagine that you are an assistant to Galileo, and you have been directed to make marks on the ramp such that the ball passes over them in equal time intervals. Using the data from your twenty-first century version of the experiment, at what distances from the starting point would you place the next two marks, if your first mark is placed at the 10-cm point?


3. Using the starting point and your three marks, do you see a pattern in the separation distances of adjacent marks? Explain the meaning of this pattern.
What are the forces in a train?

You have learned that when you apply a force to a system that is free to move, the system accelerates. This is known as Newton’s second law.

\[ a = \frac{F_{\text{net}}}{m} \]

When testing this law within a single-body system, like a car, you can measure the net force causing acceleration. What happens, though, when the system is not just a single car, but a series of cars that are coupled together, such as the cars of a train? Treating the train as a single body does not allow you to investigate the forces across the coupling between each pair of cars in the train. Figure A shows the interaction of forces between two coupled cars in a train. Forces in Figure A are indicated by vector lines. Vectors \( F_{A \text{ on } B} \) and \( F_{B \text{ on } A} \) indicate the force that each car exerts on the other. Each system under consideration is outlined by dotted lines.

When you treat each car as a separate system, the interaction between the two systems can be explained using Newton’s third law.

\[ F_{A \text{ on } B} = -F_{B \text{ on } A} \]

Newton’s third law reveals that when you treat an accelerating train of cars as a single system, there are still forces between the cars. These forces are internal to the system. Do these internal forces contribute to the motion of the train? According to Newton’s second law, the only forces that contribute to the motion of a system are forces that are external to the system. These forces occur only when the train is accelerating. As the car in front accelerates, it pulls on the car behind it, causing it to accelerate. Newton’s third law indicates that the rear car pulls on the front car with equal and opposite force. The forces would seem to cancel each other. However, it is important to remember that you must consider all of the external forces on a system to determine how it moves. You must add up all of the forces and use Newton’s second law to determine acceleration.
In a train system like this one, the locomotive in the front applies the external force to the train of cars as an entire system, causing the entire train to accelerate uniformly. The coupling between each pair of cars acts to transmit the force from the part of the train in front of the couple to the part of the train behind the couple. Figure B shows forces acting on a three car train. Locomotive A exerts the external pulling force over cars B and C. At the same time also cars B and C exert forces. Thus, this train of three cars can be analyzed as if it is three separate systems that are all moving with the same acceleration. System 1 is made of cars A, B, and C; System 2 is made of cars B and C; and car C makes system 3. Figure B shows where forces are exerted throughout the system.

**Objectives**

- **Prepare** an experiment to test the forces between cars in a train.
- **Relate** the forces between cars in a train with the force pulling the train.
- **Distinguish** between Newton’s second law and Newton’s third law.

**Problem**

How does the force that is accelerating a train compare with the forces that transmit the pull?

**Hypothesis**

Formulate a hypothesis on how the force between a pair of cars in a train undergoing constant acceleration compares to the forces between other cars in the same train.

**Plan the Experiment**

1. Work with a partner or in small groups. Select from the suggested materials (or others of your choosing) to design an experiment that will help you confirm your hypothesis.
2. Select the measuring instruments you will use to measure forces. Make sure that you understand the limits of precision of your selected measuring instruments. Decide how you will determine the force that is applied to each part of the train.
3. Decide on a procedure that uses the materials and measuring methods that you have selected. Write your procedure on another sheet of paper or in your notebook. In the space on the next page, draw a diagram of your experimental setup.
4. Check the Plan Have your teacher approve your plan before you proceed with your experiment. Make sure that you understand how to operate all of the equipment.
5. Perform the experiment using Table 1 to record your data.

Setup

Data and Observations

<table>
<thead>
<tr>
<th>Trial</th>
<th>Force on System 1 (N)</th>
<th>Force on System 2 (N)</th>
<th>Force on System 3 (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
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<tr>
<td>4</td>
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</tbody>
</table>

Analyze and Conclude

1. Examine Data  Compare the magnitudes of the forces on the three systems in the train.
2. **Recognize Patterns** Look for a pattern in your force data. Explain the pattern that you see.

3. **Analyze Data** Identify the cause-and-effect relationship that produces the pattern in the force data. Consider the total mass of system 1, the total mass of system 2, and the total mass of system 3.

4. **Draw Conclusions** Imagine a train of many cars. What does the relationship of the forces between cars in the train suggest about the forces in the couplings at the front of a train to the forces at the rear of a train.

---

**Apply**

1. **Apply Conclusions** Imagine that you are the chief engineer of a locomotive connected to a long train of cars. You know that the locomotive cannot exert the huge force needed to start all of the cars in motion at once. Instead, the wheels of the locomotive only spin against the track. What strategy might you use to get the train in motion? *HINT: Each coupling has several centimeters of free movement forward and backward before it exerts a force on the next car.*

2. **Design Experiments** Construct a setup to compare the acceleration of a three-car train with a one-car train where both trains have the same total mass, and the same total force is applied to each train. How do the accelerations compare? What does this tell you about the difference between Newton’s second law and Newton’s third law?
How does an object move when two forces act on it?

You have learned that a system can accelerate when a single force is applied to it. What would happen if two forces are applied to a system, and the forces are perpendicular to each other? Assuming that the forces are not in equilibrium, you would expect the system to accelerate. However, is it possible to predict the amount of acceleration and the direction? The acceleration of a system that results when two or more forces are applied to it is equal to the vector sum of the accelerations that would be caused by each force individually.

Look at Figure A. Suppose forces $F_I$ and $F_{II}$ act simultaneously on an object. The forces are at right angles to each other. The resultant force, $F_{I+II}$, on the object is the sum of the vectors $F_I$ and $F_{II}$, and is found by applying the Pythagorean theorem to the right triangle. However, the acceleration of an object is proportional to the applied force, $a \propto F$, so the same vector diagram can represent the accelerations, $a_I$ and $a_{II}$, caused by forces $F_I$ and $F_{II}$. Thus, the resultant acceleration, $a_{I+II}$, can be found in the same way as $F_{I+II}$:

$$F_{I+II} = \sqrt{F_I^2 + F_{II}^2}$$

$$a_{I+II} = \sqrt{a_I^2 + a_{II}^2}$$

Figure A

In this lab, you will measure the acceleration of a system when two forces are applied to it. You will do this by measuring the accelerations caused by two individual forces, calculating the vector sum of the two forces, and then measuring the acceleration caused by the vector sum of the forces. You will then compare this measured acceleration to that predicted by the addition of vectors.

Objectives

- Adapt a one-dimensional acceleration experiment to experiment with adding forces in two dimensions.
- Depict the superposition of forces using vector diagrams.
- Evaluate the results of your experiment.

Materials

- air track with glider and accessories
- mass hanger
- slotted masses
- meterstick
- string
- photogate
- photogate timer
Procedure

1. Set up the air track so that it is horizontal, level and more than 1 m above the floor. Attach the pulley accessory on one end of the air track. Measure the mass of the glider and record it in Table 1.

2. Cut a string that is equal in length to the air track. Tie one end of the string to the end of the glider. Tie the other end of the string to the mass hanger. Place the glider against the stop on the air track at the end opposite the pulley. Hang the string over the pulley.

3. Place a photogate at a distance of 1.00 m from the front end of the glider. This will allow the glider to accelerate the entire distance to the photogate before the mass hanger hits the floor. Record this distance in Table 1. Connect the photogate to the timer.

4. Have one team member hold the glider against the back stop of the air track, while a second team member turns on the air. Place slotted masses on the mass hanger and test the acceleration of the glider. You should place enough mass on the glider and on the mass hanger to cause the glider to travel 1.00 m to the photogate timer in approximately 2–4 s. The mass hanger should have at least 10 g of mass. Perform a few test runs to establish the hanging mass needed. Record this mass in Table 1 in the row for Force I.

5. Hold the glider against the back stop of the air track. Release the glider and start the timer at the same instant. Once the timer stops after the glider passes through the photogate, record the time of travel in Table 1 in the row for Force I.

6. Repeat steps 4 and 5 with an additional 5 g of hanging mass. Record the time of travel in Table 1 in the row for Force II.

7. Calculate the accelerating forces using the following equations.

\[ F_1 = \left[ \frac{m_{\text{glid}} m_{\text{hangI}}}{m_{\text{glid}} + m_{\text{hangI}}} \right] \times g \]

\[ F_{\text{II}} = \left[ \frac{m_{\text{glid}} m_{\text{hangII}}}{m_{\text{glid}} + m_{\text{hangII}}} \right] \times g \]

Record the calculated forces in Table 1.

8. Calculate the resultant of the two forces as if they were acting on the glider perpendicular to each other, using the following equation:

\[ F_{1+\text{II}} = \sqrt{F_1^2 + F_{\text{II}}^2} \]

Record this force value in Table 1 in the row for Force I + II.

9. Calculate the amount of hanging mass required to achieve an accelerating force of \( F_{1+\text{II}} \) using the following equation

\[ m_{\text{hangI+II}} = m_{\text{glid}} \frac{F_{1+\text{II}}}{(m_{\text{glid}} g + F_{1+\text{II}})} \]

Record this hanging mass value in Table 1 in the row for Force I + II.

10. Place slotted masses on the mass hanger until the total hanging mass is equal to the amount required to produce an accelerating force of \( F_{1+\text{II}} \) on the glider. Hold the glider against the backstop of the air track. Turn on the air. Release the glider and start the timer at the same instant. Once the timer stops after the glider passes through the photogate, record the time of travel in Table 1 in the row for Force I + II.
Data and Observations

<table>
<thead>
<tr>
<th>Data Run</th>
<th>Hanging Mass $m_{\text{hang}}$ (kg)</th>
<th>Force $F$ (N)</th>
<th>Time $t$ (s)</th>
<th>Acceleration $a$ (m/s$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force I</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Force II</td>
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<tr>
<td>Force I + II</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Analysis and Conclusions

1. Calculate the acceleration caused by each force using the following equation:

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

Show calculations in the space below, and record the calculated acceleration for each data run in Table 1.

2. Calculate the resultant vector of the accelerations caused by Force I and Force II as if they are perpendicular to each other using the following equation:

$$a_{I+II} = \sqrt{a_I^2 + a_{II}^2}$$

Show calculations in the space below, and record this acceleration on the line below.
3. Compare the calculated value in problem 2 with the experimental value of $a_{I+II}$ in Table 1.

4. Model the data in Table 1 by drawing vector diagrams similar to Figure A of the force and acceleration values in the space below.

5. Did the method of calculating resultant vectors succeed in predicting the acceleration you observed with the experimental determination of $a_{I+II}$? Explain.

**Extension and Application**

1. Predict what would happen if three forces, $F_I$, $F_{II}$, and $F_{III}$, each perpendicular to the other two, act on the same object and the object is free to move in three dimensions. Draw a sample vector diagram for this system, and write the equations for the magnitudes of the vector sums of the force vectors and acceleration vectors.
How does a glider slide down a slope?

If you have been on a roller coaster, you experienced a large, downhill acceleration after reaching the top of the first hill. Compare this acceleration to the acceleration you might experience if you coast on a bike down a slightly sloped roadway. The acceleration on the sloped roadway is probably less than the acceleration on the roller coaster. What causes objects to experience different accelerations down different slopes?

You have already learned that the force of gravity causes things to roll or slide down a slope. Figure A shows a motion diagram of a box that is sliding down a hill. From the diagram, you can see that there is simultaneous acceleration in both the positive x- (horizontal) and negative y- (downward) directions.

By turning the coordinate system so that the x-axis is parallel to the slope, it is easy to resolve the downward force due to gravity into a force perpendicular to the board and a force parallel to the slope. This parallel force causes the block to accelerate down the slope. The free-body diagram in Figure B shows the forces that are acting on the block. Notice that the coordinate system is angled with the x-axis in the direction along the slope. The component of \( F_g \) the weight of the box, lying perpendicular to the plane can be shown to be in equilibrium with the normal force of the surface on the box, \( F_N \), because there is no acceleration in the y-direction. If \( \theta \) is the angle of the slope, then Newton’s second law for the y-direction shows that

\[
F_N - F_g \cos \theta = 0
\]
The motion diagram in Figure A shows that there is acceleration in the \(x\)-direction of Figure B. So, Newton's second law in the \(x\)-direction along the slope shows that

\[ F_g \sin \theta = m_{\text{block}} a \]

This equation can be solved for \(a\) to provide a way to determine the acceleration of the block. Since \(F_g = m_{\text{block}} g\), you can substitute into the equation above to get \((m_{\text{block}} g) \sin \theta = m_{\text{block}} a\), which reduces to

\[ a = g \sin \theta. \]

In this lab, you will calculate accelerations based on this relationship between the acceleration of an object sliding without friction at various angles along a slope. Then you will compare the calculated accelerations to actual experimental results.

**Objectives**
- Adapt the traditional vertical and horizontal axes to a coordinate system aligned with a slope.
- Compare experimental and expected values of acceleration.
- Show that the acceleration of a glider down a slope is dependent on the angle of the slope.

**Procedure**

1. Set up an air track with a single glider. Place the glider on the track against the back-stop at one end.
2. Place a photogate on the air track at the opposite end of the air track from the glider. Position it as far away from the glider as possible, while still leaving a space equal to at least the length of the glider between the photogate and the end of the air track. Connect the photogate to the photogate timer and turn it on.
3. Measure the distance between the front end of the glider and the photogate. Record this distance in Table 1.
4. Raise the glider-end of the air track until the air track has a slope of about 5°. This is the Data Set 1 slope angle. Record the slope angle in Table 1.
5. Have one lab team member hold the glider against the back-stop of the air track, while a second team member turns on the air. Release the glider and start the timer at the same instant. When timing stops after the glider passes through the photogate, record the time of travel in Table 1. Reset the photogate timer.
6. Repeat step 5 four more times, so that you have a total of five time measurements for Data Set 1. Record the time measurements in Table 1 in the columns for Time 1, Time 2, Time 3, Time 4, and Time 5.
7. Raise the glider end of the air track until the air track has a slope of about 10°. This is the slope for Data Set 2. Record this angle in Table 1.
8. Perform step 5 a total of five times to obtain five time measurements for Data Set 2. Record the times in Table 1 in the columns for Time 1, Time 2, Time 3, Time 4, and Time 5.
9. Raise the glider end of the air track until the air track has a slope of about 15°. This is the slope for Data Set 3. Record this angle in Table 1.
10. Perform step 5 a total of five times to obtain five time measurements for Data Set 3. Record the time measurements in Table 1 in the columns for Time 1, Time 2, Time 3, Time 4, and Time 5.
Data and Observations

<table>
<thead>
<tr>
<th>Distance $d$ (m): ____________</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Data Set</td>
</tr>
<tr>
<td>------</td>
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<td>2</td>
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<td>3</td>
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</tbody>
</table>

Analysis and Conclusions

1. Calculate the average time and the square of the average time for each data set and record the values in Table 2. Show calculations in the space below.

<table>
<thead>
<tr>
<th>Data Set</th>
<th>Average Time $\bar{t}$ (s)</th>
<th>Average Time Squared $\bar{t}^2$ (s)$^2$</th>
<th>Experimental Acceleration $a$ (m/s$^2$)</th>
<th>Expected Acceleration $a$ (m/s$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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</tbody>
</table>

2. Calculate the acceleration for each slope angle using your experimental data and record the values in Table 2. Show calculations in the space below. Use the following equation to calculate experimental acceleration.

$$a = \frac{2d}{\bar{t}^2}$$
3. Use your experimental results to make an association between the slope of the air track and the acceleration of the glider.

4. Calculate the acceleration that you would expect for each slope using Newton’s second law in two dimensions.

\[ a = g \sin \theta. \]

Record these values as the expected acceleration for each data set in Table 2. Show calculations in the space below.

5. Compare the values of experimental acceleration and expected acceleration for each data set. Do your experimental data support the predictions based on Newton’s second law?

Extension and Application

1. Imagine that you conduct this same experiment with a block sliding on a non-frictionless surface. What results would you expect and why?

2. Construct a setup that uses a rolling cylinder to perform this same experiment. Use the same slope angles as you did with the air-track experiment. Compare and contrast the time required at each slope angle for the cylinder to roll the same distance as the glider to the time that was required by the glider. What are some possible reasons for the similarities or differences?
Centripetal force causes a moving object to follow a curved path. When an object is in uniform circular motion, a constant centripetal force is being applied to the object. The relationship between the speed of the object and the centripetal acceleration caused by the centripetal force is

$$a_c = \frac{v^2}{r}$$

In this lab, you will use the setup shown in Figure A to test the relationships between the speed of a stopper in uniform circular motion, the radius of the stopper's circular path, and centripetal force. In order to study the cause-and-effect relationships between these three variables, you must hold one variable constant while controlling the change of a second variable to determine the effect on the third variable. At first, you will perform one experiment with a constant radius while varying the speed. The final experiment will test how speed varies when centripetal force is constant and radius is increased.

**Objectives**

- **Relate** the variables involved in uniform circular motion.
- **Operate** a lab setup with three variables that requires active involvement to maintain one variable constant.
- **Justify** the method of using many revolutions in a centripetal force experiment to reduce the effect of random error.
Procedure

A. Setup

1. Measure the mass of the stopper and washer, \( m \), and record in the Data and Observations section. Then, prepare the experimental apparatus as shown in Figure A.

2. Throughout this experiment, you need to maintain a constant radius of uniform circular motion while ensuring that all of the centripetal force is provided by the clamp and measured on the spring scale. Practice whirling the stopper in a horizontal plane until you can keep the paper clip a short distance just below the bottom of the tube while the stopper whirls. If the paper clip touches the bottom of the tube, then the clamp is no longer supplying the centripetal force. If the paper clip rises or falls appreciably as the stopper whirls, then the radius of the circle is changing.

B. Constant Radius and Variable Speed

1. With the paper clip against the bottom of the tube and the string pulled taut, measure the length of the string from the top of the tube to the stopper. Record this as the radius, \( r \), for all three data runs in Table 1.

2. Whirl the stopper while maintaining a constant force reading on the scale. The force can vary slightly. The value of the force is the scale reading at the middle of the variation. Once you obtain a constant force, start the stopwatch and continue the whirling while monitoring the force. Stop the stopwatch after 30 rev.

3. Record your force and time data in Table 1, data run 1.

4. Increase the rate of whirling while maintaining the clip just below the bottom of the tube, and observe what happens to the tension measured by the spring scale. It should increase. Repeat step B2 at this higher spring force.

5. Record your force and time data in Table 1, data run 2.

6. Repeat step B4 and record the data in Table 1, data run 3.

C. Constant Force and Variable Radius

1. Change the position of the paper clip to decrease the radius of uniform circular motion for the stopper. Try to get as small a radius as you can and still be able to maintain a constant force.

2. Whirl the stopper while maintaining a constant force on the scale. Start the stopwatch and continue the whirling while monitoring the force. Stop the stopwatch after 30 rev.

3. Record your force and time data in Table 2, data run 1. With the paper clip against the bottom of the tube and the string pulled taut, measure the length of the string from the top of the tube to the stopper. Record this as the radius, \( r \), in Table 2, data run 1.

4. Change the position of the paper clip to increase the radius of uniform circular motion for the stopper. Repeat step C2 at the same spring force value as data run 1.

5. Record your force and time data in Table 2, data run 2. With the paper clip against the bottom of the tube and the string pulled taut, measure the length of the string from the top of the tube to the stopper. Record this as radius in Table 2, data run 2.

6. Repeat step C4, measure the length of the string from the top of the tube to the stopper, and record the data in Table 2, data run 3.
Data and Observations

\[ m = \text{__________} \]

### Table 1

<table>
<thead>
<tr>
<th>Data Run</th>
<th>Spring Force ( F ) (N)</th>
<th>Number of Revs ( n )</th>
<th>Time ( t ) (s)</th>
<th>Radius ( r ) (m)</th>
<th>Stopper Speed ( v ) (m/s)</th>
<th>Centripetal Acceleration ( a_c ) (m/s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>30</td>
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<td></td>
<td>30</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>Data Run</th>
<th>Spring Force ( F ) (N)</th>
<th>Number of Revs ( n )</th>
<th>Time ( t ) (s)</th>
<th>Radius ( r ) (m)</th>
<th>Stopper Speed ( v ) (m/s)</th>
<th>Centripetal Acceleration ( a_c ) (m/s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>30</td>
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<td>30</td>
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</tbody>
</table>

### Analysis and Conclusions

1. Calculate the stopper speed for each data run in Table 1 and Table 2 using the following equation.

\[ v = \frac{n2\pi r}{t} \]

Record the calculated speed for each data run in Table 1 and Table 2. Show calculations in the space below.
2. Calculate the centripetal acceleration for each data run in Table 1 and Table 2. Record the calculated centripetal acceleration for each data run in Table 1 and Table 2. Show calculations in the space below.

3. What do your data show about the relationship between centripetal force and change in speed at a constant radius of circular motion?

4. What do your data show about the relationship between radius of circular motion and change in speed at a constant centripetal force?

5. Use a piece of graph paper to plot spring force versus centripetal acceleration using all of the data runs of Table 1 and Table 2.

6. Analyze the resulting plot. Is there a pattern? If so, what does the pattern mean?

7. Formulate an equation for the relationship between the spring force and the centripetal acceleration of the stopper. What does this equation tell you about the spring force?

Extension and Application

1. Justify the method of recording time for 30 rev to minimize the error associated with calculating the speed of the stopper. In other labs, you have used multiple data runs and averaged the data to minimize the random error associated with measuring. Why did you not have to do that in this lab?
How fast is that cart moving?

So far, you have studied the motion of objects in nonmoving reference frames. For example, when you are standing on a sidewalk, you could determine the average speed of a car by measuring the amount of time it takes for the car to move a known distance. How would you determine the speed of a car moving past you if you are in a different car moving in the opposite direction? One way would be to measure the speed of the first car with respect to you and then subtract the speed shown on the speedometer of your own car, i.e. the speed of your car with respect to the street. Using this method, the equation for the speed of the first car is

\[
 v_{\text{car 1/street}} = v_{\text{car 1/car 2}} - v_{\text{car 2/street}}
\]

In this lab, you will study this relative motion effect using a cart track, two constant speed carts, and a tape timer. With the tape timer, you will be able to measure the position of one cart with respect to the other cart at fixed time intervals as the first cart moves away from the second cart. You will use these position and time measurements to determine the speed of the first cart with respect to the second cart.

Objectives

- Gather relative speed data on two vehicles.
- Graph relative motion on a position-time graph.
- Predict the effect that an accelerating reference frame would have on the motion of a constant velocity object.

Procedure

A. Preparation

1. Set the tape timer at its lowest frequency. Record the frequency in the Data and Observations section.
2. Securely fasten the tape timer to the second cart.
3. Adjust the speed of each of the two carts so that each cart will travel the length of the track (up to 2 m) in 2–10 s.

B. Speed of the Cart in the Lab Reference Frame

1. Arrange the cart track and two constant-speed carts in the configuration shown in Figure A. Secure the second cart to the cart track.
2. Cut a section of data tape equal to the length of the cart track. Secure the data tape to the first cart. Place the first cart so that it starts next to the second cart and will move away from the second cart when it is turned on. Feed the tape through the tape timer on the second cart until the section of the tape between the cart and the tape timer is taut. Allow the rest of the data tape to remain loose, but make sure it cannot become snagged or tangled as it is pulled through the tape timer.

3. Start the first cart and the tape timer at the same time. When the first cart reaches the end of the track, turn off the tape timer and the first cart.

4. Circle each hole on the data tape that you will use for a data point. If the holes are very close together on the timing tape, you can decide to circle every second, third, or fourth hole as a data point. Record the number of holes you will use as the Part B data point hole count, \( N \), above Table 1.

5. Starting with the hole in the timing tape closest to the first cart (data point 0), measure the distance to the next data point. Record this as the displacement increment for data point 1 in Table 1.

6. Next, measure from data point 1 to data point 2 and record this value as the displacement increment for data point 2. Repeat this step, measuring from data point 2 to data point 3 and so on until you have a total of nine increments measured and recorded.

C. Speed of the Cart in a Moving Reference Frame

1. Arrange the two carts on the cart track in the configuration shown in Figure B.

2. Cut a section of data tape equal to the length of the cart track. Secure the data tape to the first cart. Arrange the carts back to back in the middle of the track so that they will move away from each other. Feed the data tape through the tape timer as in step B2.

3. Start the carts and the tape timer at the same time. When one of the carts reaches the end of the track, turn off the tape timer and both carts.

4. On a separate piece of paper, copy the Data and Observations information and table, label it Table 2, and use this for data gathered in part C.

5. As in step B4, determine the hole count between data points that you will use. Record this as the Part C data point hole count, \( N \), above Table 2.

6. Starting with the hole in the timing tape closest to the first cart (data point 0), measure the distance to the next data point. Record this as the displacement increment for data point 1 in Table 2.

7. Repeat the measurements as in step B6 for nine more data points.
**Data and Observations**

Tape timer frequency, \( f \) (Hz): __________

Part B data point hole count, \( N \): __________

<table>
<thead>
<tr>
<th>Data Point</th>
<th>Displacement Increment (cm)</th>
<th>Displacement Subtotal ( d ) (cm)</th>
<th>Time Increment ( T ) (s)</th>
<th>Time Subtotal ( t ) (s)</th>
</tr>
</thead>
<tbody>
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</tbody>
</table>

**Analysis and Conclusions**

1. Calculate the displacement subtotal for each data point in Table 1 and Table 2 by adding the displacement increment for the data point to the displacement subtotal for the previous data point. Record the results of your calculations in Table 1 and Table 2. Show calculations in the space below.
2. Calculate the time increment as the number of time intervals between data points divided by the frequency, \( \frac{T}{N/f} \). Record this value as the time increment for every data point in Tables 1 and 2. Then, calculate the time subtotal for each data point in Tables 1 and 2 by adding the time increment for the data point to the time subtotal for the previous data point. Record the results of your calculations in Table 1 and Table 2. Show calculations in the space below.

3. Use graph paper and a colored pencil to plot \( d \) versus \( t \) for the lab reference frame data (Table 1). On the same graph paper, use a different color of pencil to plot \( d \) versus \( t \) for the moving reference frame data (Table 2).

4. Use these two plots to determine the speed of the first cart in each reference frame.
   - Lab Reference Frame: \( v = \) __________
   - Moving Reference Frame: \( v = \) __________

5. Compare the relative speed of the first cart to the second in each reference frame.

6. Draw a conclusion about the effect that the motion of the second cart had on the measurements made by the tape timer.

**Extension and Application**

1. If the situation in part C of the experiment was duplicated with real cars, and an observer was sitting in the second car and was unaware of the motion of the second car, what would the observer see?

2. Imagine that you perform the cart experiment with the first cart maintaining a constant velocity and the second cart (the one with the tape timer) accelerating away from the first cart. What would the data look like as recorded by the tape timer? What interpretation could be made by someone looking only at the tape?
Is inertial mass equal to gravitational mass?

A pendulum consists of an object that is suspended from a fixed support so that it swings freely under the influence of gravity. When you observe a pendulum, you notice that its swing has a constant period, which is the time it takes to swing back and forth once. Unlike projectile motion, a pendulum involves vertical motion and horizontal motion that are coupled together. In order for the pendulum to fall a certain distance, it has to move horizontally a certain distance. According to Newton's second law, an equation can be developed for the period of a pendulum with a small angle of swing made up of a string of length $l$, with an object on the end of gravitational mass, $m_G$, inertial mass, $m_I$.

$$T = 2\pi \sqrt{\frac{m_I l}{m_G g}}$$

Isaac Newton referred to inertial mass as quantity of matter. In his scientific pursuit to understand the force of gravity, Newton performed experiments with pendulums. Newton mentioned one such series of experiments in his work, *Principia Mathematica*, published in 1687. In these experiments, Newton observed that different materials of the same gravitational mass have the same inertial mass (quantity of matter), and, therefore, cause the pendulums with the different materials to have the same period.

It can further be shown that, for a given material, inertial mass is equal to gravitational mass, which means that the ratio of the two is equal to one.

$$\frac{m_I}{m_G} = 1$$

If this is true, then the equation for the period of a pendulum is entirely independent of mass, and is

$$T = 2\pi \sqrt{\frac{l}{g}}$$

In this lab, you will perform an experiment similar to one performed by Isaac Newton to show that materials with the same gravitational mass have the same inertial mass. You then will measure the period of a pendulum of fixed length with different gravitational masses of the same material to determine the relationship between gravitational mass and inertial mass.
Objectives

■ Explain the equal periods of pendulums with equal gravitational masses but different materials.
■ Show that inertial mass and gravitational mass are equal.
■ Integrate your observations and knowledge into the design of a pendulum clock.

Procedure

A. Pendulum Setup

1. With another lab team, construct two pendulum assemblies of equal pendulum length at adjacent lab tables. For each pendulum, use two support rods, one right-angle support clamp, and one rod with a hook collar to form the support for the pendulum, as shown in Figure A.

2. For each pendulum, tie a hook to the end of a length of string, hang the string over the hook on the collar, and wrap the excess string several times around a thumbscrew of the support clamp, as shown in Figure B.

3. Adjust the pendulums of both lab teams until their lengths are equal and at least ten times the height of the sample cup.

B. Comparing Inertial Mass in Different Materials

1. Place different materials in each of the two sample cups, and determine their gravitational masses with a pan balance. Adjust the contents of one of the cups until the masses of the two cups are equal, as measured with the balance.

2. Hang each sample cup from a separate string. Use the string to adjust the lengths of the pendulums so that they are equal. Pull both pendulums back to equal angles of swing as read on the protractors. Release them at the same time. Write your observations in the Data and Observations section.

3. Replace the material in one of the sample cups with a different material. Use a balance to make sure the cup is equal in gravitational mass to the material that is still in the other sample cup. Repeat step B2 and write your observations in the Data and Observations section.

4. Repeat this process for several other materials.
C. Comparing Gravitational Mass to Inertial Mass

1. Select one material to use for this portion of the lab and perform the remainder of the lab without the other lab team.

2. Measure the length, \( l \), of your pendulum from the bottom of the hook on the collar to the bottom of the sample cup and record this value in the Data and Observations section.

3. Fill your sample cup with your selected material and measure the gravitational mass. Record the gravitational mass for data run 1 in Table 1.

4. Hang the sample cup on the end of your pendulum. Pull the cup back to give the pendulum an angle of swing of less than 10° using the protractor. Record the angle in the Data and Observations section.

5. You are now going to record the amount of time it takes for the pendulum to swing back and forth 30 times. Release the pendulum so that it starts swinging. At the top of a swing start the stopwatch. Stop the stopwatch when the pendulum has returned to that same point on the thirtieth swing. Record the time in data run 1 in Table 1.

6. Repeat steps C3 through C5 two more times at the same angle of swing but with different gravitational masses of the same material. Record the data in Table 1.

Data and Observations

Observations of Procedure B:

Observations of Procedure C: \( l = \) _______________  angle = _______________

<table>
<thead>
<tr>
<th>Data Run</th>
<th>Gravitational Mass ( m_G ) (g)</th>
<th>Time for 30 Swings ( t ) (s)</th>
<th>Measured Pendulum Period ( T ) (s)</th>
<th>Expected Pendulum Period ( T ) (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
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<td>3</td>
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</tbody>
</table>
Analysis and Conclusions

1. Explain the observations you made in part B of your experiment.

2. Determine the experimental pendulum period for each data run in Table 1 by dividing the time for 30 swings by 30. Record the result as the measured pendulum period, \( T \), for each data run in Table 1. Show calculations in the space below.

3. Calculate the expected pendulum period using

\[
T = 2\pi \sqrt{\frac{l}{g}}
\]

Record the result as the calculated pendulum period, \( T \), for each data run in Table 1. Show calculations in the space below.

4. Compare the experimental pendulum periods with each other and with the expected pendulum period.

5. Draw a conclusion about the relationship of inertial mass and gravitational mass.

Extension and Application

1. On a separate piece of paper, research and design a pendulum that you could use in a clock. Specifically, what properties would your pendulum have, considering your observations as well as other forces that will act on a pendulum in addition to gravity? Explain.
How can you measure mass?

Mass is a measure of the quantity of matter in an object. There are several ways to measure mass. A triple-beam balance uses gravity to balance an unknown mass and a known mass against each other. Thus, the triple-beam balance is used to measure gravitational mass.

Mass is also a measure of the resistance to any effort made to change the velocity of an object. So, you should be able to measure the mass of an object by making an effort to change its velocity. You would then record the response of the object to your effort, and use this response as a relative measure of the inertial mass. An inertial balance is a device that measures mass in this way. It uses two strips of spring steel to apply the effort of forcing an object to vibrate, moving horizontally back and forth, speeding up, slowing down, and changing direction in a repetitive manner. If the object vibrates at a fast rate, it is not as resistant to the effort made by the springs compared to an object that vibrates at a lower rate. So the object vibrating at a lower rate would have a larger inertial mass than the quickly vibrating object.

By measuring how fast known gravitational masses vibrate on the inertial balance, you can construct a graph that calibrates the inertial balance. You can use the graph to relate the period of vibration of an unknown mass directly to the gravitational mass of the object. In this lab, you will calibrate an inertial balance and use it to measure some samples that have unknown gravitational masses.

Objectives

- Prepare a calibration graph for an inertial balance.
- Use an inertial balance to predict the values of unknown masses.
- Judge how you would use the inertial balance.

Procedure

A. Collect Calibration Data
1. As shown in Figure A, clamp one end of the inertial balance to the table so that the other end is free to vibrate freely beside the table.

2. Place a 500-g standard mass in the inertial balance pan, as shown in Figure A. Displace the free end of the inertial balance to one side and release it. The balance should start vibrating back and forth. Practice until you can get a steady vibration without vertical flexing and without hitting any supports.

3. Replace the 500-g mass in the inertial balance with the mass identified for data run 1 in Table 1.

4. You now are going to record the amount of time it takes for the inertial balance to vibrate back and forth 30 times. Pull the free end of the inertial balance to one side and release it. At one side of the vibration, start the stopwatch. Stop the stopwatch when the inertial balance has returned to that same point on the thirtieth vibration. Record the time for 30 swings in data run 1 in Table 1.

5. Repeat steps A3 through A4 for data runs 2 through 10. Record the data in Table 1.

**B. Collect Data on Unknown Masses**

1. Obtain three unknown mass samples from your teacher.

2. Place one unknown mass in the inertial balance. Pull the free end of the inertial balance to one side and release it. At one side of the vibration, start the stopwatch. Stop the stopwatch when the inertial balance has returned to that same point on the thirtieth vibration. Record the time for 30 swings in data run 11 in Table 2.

3. Repeat step B2 for data runs 12 and 13 using the remaining unknown mass samples. Record the data in Table 2.

**Data and Observations**

<table>
<thead>
<tr>
<th>Data Run</th>
<th>Standard Mass ( m ) (kg)</th>
<th>Time for 30 Swings ( t ) (s)</th>
<th>Inertial Balance Period ( T ) (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>7</td>
<td>0.350</td>
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<td>8</td>
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<tr>
<td>9</td>
<td>0.450</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.500</td>
<td></td>
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</tbody>
</table>
Analysis and Conclusions

1. Use the following grid to plot inertial balance period, $T$, versus standard mass, $m$, for the standard mass data in Table 1.

2. Analyze the plot. Is there a pattern that would suggest a relationship between $T$ and $m$? Explain.
3. Draw a smooth best-fit line through the points in the plot. You may decide whether to draw a straight line or a smooth curve. Note that the line will not pass through the origin (0, 0).

4. Use your graph to determine the mass of the unknown mass samples based upon the periods you observed and recorded in Table 2. Record this value of the mass from the graph, $m_{\text{graph}}$, that you obtain for each unknown mass sample in Table 2.

5. Use a pan balance to measure the mass of each unknown sample mass. Record the value of the mass from the balance, $m_{\text{balance}}$, that you obtain for each unknown mass sample in Table 2.

6. Identify the cause-and-effect relationship between $T$ and $m$ for the inertial balance.

7. Assess the accuracy and precision of using the inertial balance to measure mass.

---

**Extension and Application**

1. You are a member of a scientific team that is to conduct experiments in orbit, and you need to select a method for measuring mass. Would you select the inertial balance or the mass balance scale? Explain your selection.

2. Identify what else you would need to know to use the inertial balance to prove that inertial mass is equal to gravitational mass. Does the graph of period versus mass give you enough information to make this claim? Explain.
Torques

There is a good reason for attaching a doorknob as far as possible from the hinges of the door. When you open a door, you must apply a force. Where you apply that force and in what direction you push or pull determine how easily the door will swing open. Not only do forces produce motion in a straight line, but they also produce rotation in a rigid body that has an axis. How effectively a force acting on a body that is free to rotate causes it to rotate is known as torque, \( \tau \). The magnitude of torque is the product of the vector quantity force, \( F \), and the lever arm, \( L \), or \( \tau = FL \), and the units of torque are newton-meters (N\( \cdot \)m). The lever arm, \( L \), is equal to \( r \sin \theta \), where \( r \) is the perpendicular distance from the axis of rotation to the point where the force acts, and \( \theta \) is the angle at which the force acts with respect to \( r \). Thus, the farther away from the axis the force acts, the more effective is the force that causes rotation. If the force acts at an angle of 90° to \( r \), as in this lab, then \( \sin \theta = \sin(90°) = 1 \), and the lever arm is given as \( L = r \).

In this experiment, two parallel forces—the two spring scales—will balance the downward force of the hanging mass, as shown in Figure A. The two parallel forces will tend to cause rotation because each is exerted over a specific distance, the lever arm, from the third force, the weight of the hanging mass. The weight force is at the pivot, point B in the figure. This fixed point, B, is the axis of rotation. The force at point A acts over a distance, AB, and produces a clockwise torque (a negative value). The force at point C acts over a distance, BC, and produces a counterclockwise torque (a positive value). The sum of the two torques may cause the meterstick to rotate in either a clockwise or a counterclockwise direction about the axis. If the sum of all the clockwise torques about the axis and the sum of all the counterclockwise torques about the same axis equal zero, the meterstick will not rotate. In this experiment, when the two par-
Parallel forces are balanced by the third force, the sum of all torques will equal zero, and the system will be in rotational equilibrium.

**Objectives**

- **Measure** forces that produce torque.
- **Calculate** clockwise and counterclockwise torque on a rotating body.
- **Determine** the relationship between torque and a lever arm.

**Procedure**

1. Set up the apparatus, as shown in Figure A, without the hanging mass. Hang the two spring scales from supports on the laboratory table or tape them with masking tape so they hang over the edge of the table. Be sure that the spring scale mechanisms can move freely.

2. For the first trial, place one clamp at the 5-cm mark on the meterstick (point A) and place the other clamp at the 95-cm mark (point C), as shown in Figure A.

3. Observe the force readings on the spring scales. Record these values in Table 1 as the original readings.

4. Hang a 500-g mass (4.9 N) from the clamp at point B, at the center of the meterstick. Observe the scale readings at points A and C when the apparatus is in equilibrium. Record these values in Table 1 as the final readings.

5. The real reading of each spring scale is the difference between the final reading and the original reading. The real reading is the force due to the hanging mass at point B. Calculate the real reading for each scale and record these values in Table 1.

6. Measure and record the distances AB and BC in Table 2.

7. The clockwise torque is equal to the product of the real reading for spring scale A and the distance AB. The counterclockwise torque is equal to the product of the real reading for spring scale C and the distance BC. Calculate the clockwise and counterclockwise torques and record these values in Table 2.

8. Repeat steps 2–7 for trials 2 and 3, moving the clamp at point A to two different positions on the meterstick.

**Data and Observations**

<table>
<thead>
<tr>
<th><strong>Table 1</strong></th>
<th>Balance A</th>
<th>Balance C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Trial</strong></td>
<td><strong>Original Reading (N)</strong></td>
<td><strong>Final Reading (N)</strong></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
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<td>2</td>
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<td>3</td>
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</tbody>
</table>
Analysis and Conclusions

1. Because the system in each trial was in equilibrium, what conditions had been met?

2. What is the relationship between the magnitudes of the forces exerted (real reading) and the lever-arm distances over which the forces were exerted?

3. Compare the absolute values of the clockwise and counterclockwise torques for each trial by finding the relative percentage difference between the two values.

\[
\% \text{ difference} = \frac{|\text{counterclockwise torque}| - |\text{clockwise torque}|}{|\text{counterclockwise torque}|} \times 100
\]

4. What is the relationship between the counterclockwise torque and the clockwise torque when the system is in equilibrium?

5. Why is it necessary that the meterstick remain level at each position of the hanging mass? How would your calculations change if the meterstick became tilted?
Extension and Application

1. The technique for measuring forces in this lab can be used to determine the forces exerted by the piers of a bridge. In this case, the forces are reversed. The two pier supports (replacing the two spring scales) exert an upward force, and a person standing on the bridge (replacing the hanging mass) exerts a downward force on the bridge. Calculate the force exerted by each pier, $F_1$ and $F_2$, of a 5.0-m footbridge with a mass of 100.0 kg, evenly distributed, when a 55-kg person stands 2.0 m from one end of the bridge.
Newton’s second law applies to rotational motion as well as to linear motion. The rotational analog of $F_{\text{net}}/m$ is $\tau_{\text{net}}/I$, where $\alpha$ is the angular acceleration; $\tau$ is the net torque, the force applied to an object rotating about a fixed axis; and $I$ is the moment of inertia of the object.

The moment of inertia of an object is its resistance to changes in its angular velocity and involves both the mass of a rotating object and the distribution of its mass, or its shape.

Like other linear values, linear momentum has an angular equivalent. In linear motion, momentum is equal to $mv$. Substituting the rotational equivalents of $m$ and $v$, the angular momentum, $L$, is

$$L = I\omega$$

where $\omega$ is the angular velocity. If we look at the change in angular momentum over a period of time, the equation can be written as follows:

$$\frac{\Delta L}{\Delta t} = I(\Delta\omega/\Delta t).$$

Since $\alpha = \Delta\omega/\Delta t$, $\tau = I\alpha = I(\Delta\omega/\Delta t)$, substituting $\Delta L/\Delta t$ for $I(\Delta\omega/\Delta t)$ yields

$$\tau = \Delta L/\Delta t = \text{change in angular momentum/time interval}.$$ 

Note that if the torque is zero, then $\Delta L$ must also be zero. If there is no change in the angular momentum over a period of time, it must be conserved. If there are no net external torques acting on an object, the angular momentum, $I\omega$, is a constant. While $I$ and $\omega$ can change, their product must remain constant. This relationship can be written as follows:

$$I_1\omega_1 = I_2\omega_2$$

For example, if an object is rotating at a given velocity about a fixed axis, its angular velocity must increase if its moment of inertia decreases and vice versa. Angular momentum is a vector quantity, and its direction is along the axis of rotation perpendicular to the plane formed by $\omega$ and $r$, where $r$ is the object’s radius of rotation.

**Objectives**

- Observe the torque produced by the moment of inertia.
- Apply the law of conservation of momentum.
- Predict the effects of moment of inertia.

**Procedure**

Use caution while performing the following activities. If you become dizzy or feel nauseous, you may lose your balance and fall off the stool or platform.
1. Sit on a rotating stool, or stand on a rotating platform, and hold a large mass in each hand. Extend your arms to each side and have your lab partner give you a gentle spin. Observe what happens as you pull your arms in. Record your observations in item 1 of Data and Observations.

2. Hold one side of the bicycle wheel shaft. Without the wheel rotating, slowly tilt the wheel upward. What happens? Record your observations in item 2 of Data and Observations. Hold the gyroscopic bicycle wheel by the shaft with both hands. Have your lab partner give the wheel a strong spin. Let go of one side of the shaft, as shown in Figure A. Slowly tilt the shaft upward. What happens? Record your observations in item 3 of Data and Observations. Quickly tilt the shaft upward or downward. What happens? Record your observations in item 3.

3. While sitting on the rotating stool or standing on the rotating platform, hold the gyroscopic bicycle wheel shaft with both hands, as shown in Figure B. Have your lab partner spin the wheel. Slowly rotate the wheel to the right by raising your left hand and lowering your right hand. Observe what happens. Record your observations in item 4.

4. Change positions with your lab partner so that each student has a set of observations.

**Data and Observations**

1. Observations of student holding masses on spinning stool or platform:

   ____________________________________________________________

   ____________________________________________________________

   ____________________________________________________________

2. Observations of effects of tilting the shaft of a stationary wheel upward:

   ____________________________________________________________

   ____________________________________________________________

   ____________________________________________________________
3. Observations of effects of tilting the shaft of a rotating wheel upward:

   _____________________________________________________________

   _____________________________________________________________

   _____________________________________________________________

4. Observations of effects of rotating the spinning wheel:

   _____________________________________________________________

   _____________________________________________________________

   _____________________________________________________________

Analysis and Conclusions

1. According to the observations you recorded in item 1, is your angular momentum conserved? Explain, using the law of conservation of momentum.

   _____________________________________________________________

   _____________________________________________________________

   _____________________________________________________________

2. Under what conditions could the angular momentum of the closed system of isolated student, stool, and masses change? Describe one such condition.

   _____________________________________________________________

   _____________________________________________________________

   _____________________________________________________________

3. Compare the effects of tilting the shaft of a stationary wheel and of a rotating wheel. Using your observations in items 2 and 3 and the relationship between torque and angular momentum, explain the result of your attempt to change the angular momentum of the rotating wheel.

   _____________________________________________________________

   _____________________________________________________________

   _____________________________________________________________
4. Using your observations in item 4, explain what happened in terms of the law of conservation of momentum.

Extension and Application

1. If a uniformly filled cylinder, such as a solid wood cylinder, and a hollow cylinder or hoop, such as a can with clay pressed on the inside edge, roll down an inclined plane, would you expect them to reach the bottom at the same time? Try it. Explain your observations in terms of rotational inertia.

2. Describe in detail the changes in rotational inertia and the rate of rotation of a diver performing a one-and-a-half forward-somersault dive after leaving the springboard. Is the diver’s angular momentum conserved throughout the dive?

3. A child sits on a swing and pumps it, setting the swing in motion. Explain why the child and the swing do not represent a closed, isolated system.
How can pulleys help you lift?

Pulleys are simple machines that can be used to change the direction of a force, to reduce the force needed to move a load through a distance, or to increase the speed at which the load is moving. Like other simple machines, pulleys do not change the amount of work done. However, if the distance the load moves is decreased in proportion to the distance the force moves, the required effort force is reduced. Pulley systems may contain a single pulley or a combination of fixed and movable pulleys.

Objectives

■ Assemble and manipulate fixed and moveable pulley systems.
■ Calculate the efficiencies of different pulley systems.
■ Infer how the arrangement of a pulley system affects the ideal mechanical advantage and efficiency of the system.

Procedure

1. Set up the single fixed pulley system, as shown in pulley arrangement 1 of Figure A below.

2. Select a mass that can be measured on your spring scale. Record the value of the mass in Table 1. In this lab the resistance force, \( F_r \), of the mass that is lifted is the weight of the mass. So, \( F_r = F_g = mg \). Determine the weight, in newtons, of the mass to be raised by multiplying its mass in kilograms by the acceleration due to gravity.
3. Carefully raise the mass by pulling on the spring scale. Measure the distance the mass is raised, \( d_r \), in meters. Record this value in Table 1. Calculate the work output, \( W_o \), of the pulley system by multiplying the weight of the mass by the distance it was raised, \( F_r d_r \). Record this value in Table 2.

4. Using the spring scale, raise the mass to the same height it was raised in step 3. Ask your lab partner to read, directly from the spring scale, the force, in newtons, required to lift the mass. (If your spring scale is calibrated in grams, rather than newtons, calculate the force by multiplying the reading expressed in kilograms by the acceleration due to gravity.) Record this value in Table 1 as the effort force, \( F_e \), of the spring scale. As you are lifting the load with the spring scale, pull at a slow, steady rate, using the minimum amount of force necessary to move the load. Any excess force will accelerate the mass and cause an error in your calculations.

5. Measure the distance, in meters, through which the force acted to lift the mass to the height it was raised. Record this value in Table 1 as the distance, \( d_e \), through which the effort force acts. Determine the work input, \( W_i \), in raising the mass by multiplying the force reading from the spring scale by the distance through which the force acted, \( F_e d_e \). Record the value for the work input in Table 2.

6. Repeat steps 2 through 5 for a different load.

7. Repeat steps 2 through 6 for each of the remaining pulley arrangements in Figure A. Be sure to include the mass of the lower pulley(s) as part of the mass raised.

8. Count the number of lifting strands of string used to support the weight or load for each arrangement, 1 through 4. Record these values in Table 2.

**Data and Observations**

<table>
<thead>
<tr>
<th>Pulley Arrangement</th>
<th>Mass Raised (kg)</th>
<th>Weight ((F_r)) of Mass (N)</th>
<th>Height ((d_r)) Mass is Raised (m)</th>
<th>Force ((F_e)) of Spring Scale (N)</th>
<th>Distance ((d_e)) Through Which Force Acts (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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</table>
Analysis and Conclusions

1. Find the efficiency of each system. Enter the results in Table 2. What are some possible reasons that the efficiency is never 100%?

2. Calculate the ideal mechanical advantage, \( IMA \), for each arrangement by dividing \( d_e \) by \( d_r \). Enter the results in Table 2. What happens to the effort force, \( F_e \), as the mechanical advantage gets larger?

3. How does increasing the load affect the ideal mechanical advantage and efficiency of a pulley system?

4. How does increasing the number of pulleys affect the ideal mechanical advantage and efficiency of a pulley system?

5. The ideal mechanical advantage also may be determined from the number of strands of string supporting the weight or load. How does the calculated \( IMA \) from problem 2 compare with the number of strands of string you counted for each pulley arrangement?

<table>
<thead>
<tr>
<th>Pulley Arrangement</th>
<th>Work Output ((W_o = F_r d_r) ) (J)</th>
<th>Work Input ((W_i = F_e d_e) ) (J)</th>
<th>( IMA ) ((d_e / d_r))</th>
<th>Number of Lifting Strands</th>
<th>Efficiency %</th>
</tr>
</thead>
<tbody>
<tr>
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</tbody>
</table>
6. Explain why the following statement is false: A machine reduces the amount of work you have to do.
What does a machine actually do?

Extension and Application

1. In the space provided below, sketch a pulley system that can be used to lift a boat from its trailer to the rafters of a garage, such that the effort force would move a distance of 30 m while the load will move 5 m.
Is energy conserved?

When you lift a block straight up, you do work on the block by the force you use to lift it. For a slow lift, this force is in equilibrium with the weight of the block. There is no acceleration, so there is no change in kinetic energy. Thus, according to the work-energy theorem, \( W_{\text{you}} + W_{\text{g}} = 0 \). The work done by the force you applied is not conserved, \( W_{\text{nc}} = W_{\text{you}} \). It can’t be stored and used later by the block for acceleration. However, the work done by gravity is conserved as gravitational potential energy, \( PE = mgh \), where \( h \) is measured from the original vertical level of the object. Gravitational potential energy can be used later by the block for acceleration. Thus, for this problem, the work-energy theorem takes on the form

\[ W_{\text{nc}} = PE \]

When you lift this same block by pulling it up a frictionless inclined plane to the same vertical height, the amount of force that you apply will be smaller, because it will be in equilibrium with the component of the block’s weight parallel to the surface. This lower force is applied over a longer distance to achieve the same vertical height; thus, you do the same amount of work on the block, and the block has the same increase in gravitational potential energy. The need for less force is why ramps are so useful when moving heavy objects to a higher level.

When you pull the block up an inclined plane that has friction, you have to pull the block against the friction, which also does work that is not conserved. The force of your pull is higher than what is required on the frictionless plane, because friction is now pulling in the opposite direction. Your pull is now in equilibrium with the sum of the component of the block’s weight parallel to the surface and friction.

\[ F_{\text{pull}} = F_{g||} + F_f \]

When you pull the block up the incline, the force of your pull, minus the drag of friction, is equal to the force that you apply when there is no friction. Thus, the same amount of work is done on the block in this situation as the situation without friction, and is equal to the increase in gravitational potential energy. When you lower the block down the incline, the friction that the slope applies to the block is the same, but in opposite directions.

\[ F_{\text{lower}} = F_{g||} - F_f \]

In this lab, you will be using a force spring scale to measure the force required to pull a block up an incline and lower it down an incline. You will use these measured forces to determine the friction force of the inclined surface on the block. Finally, you will calculate the net
nonconserved work done on the block when it is pulled by your force against friction up the slope, and compare this to the expected gravitational potential energy that the block gains.

**Objectives**
- **Measure** the forces on an object on an inclined plane.
- **Calculate** the nonconserved work of pulling and friction.
- **Demonstrate** the work-energy theorem.
- **Compare** the experimental results with the law of conservation of energy and conservation of mechanical energy.

**Procedure**

1. Measure the mass of the block of wood using a mass balance scale and record this value on the line above Table 1.
2. Set up the adjustable inclined plane, and clean and spray its surface with silicone. Clean and spray the surfaces of the block with silicone, also.
3. Adjust the plane to an angle such that the block will just slide down without being pushed. Measure the angle of slope, $\theta$, and record this value for trial 1 of Table 1.
4. Have one lab team member hook the spring scale to the block and pull the block up the plane at a slow, constant speed, as shown in Figure A. While the block is moving at constant speed, have another team member read the value on the force spring scale. Record this value as pulling force for trial 1 in Table 1.
5. Repeat step 4 using the configuration in Figure B, lowering the block down the incline from the top. Record the value from the force spring scale as the lowering force for trial 1 in Table 1.
6. Repeat steps 3 and 4 at two higher angles and record data for trials 2 and 3 in Table 1.
Data and Observations

Mass of the block, \( m \) (kg): ______________

<table>
<thead>
<tr>
<th>Trial</th>
<th>Angle of Slope ( \theta ) (degrees)</th>
<th>Pulling Force ( F_{\text{pull}} ) (N)</th>
<th>Lowering Force ( F_{\text{lower}} ) (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
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<tr>
<td>2</td>
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<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial</th>
<th>Friction Force ( F_f ) (N)</th>
<th>Net Force of Pulling and Friction ( F_{\text{nc}} = F_{\text{pull}} - F_f ) (N)</th>
<th>Nonconserved Work ( W_{\text{nc}} = F_{\text{nc}}d ) (J)</th>
<th>Gravitational Potential Energy ( mgd \sin \theta ) (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
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<td>3</td>
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</tbody>
</table>

Analysis and Conclusions

1. Solve the system of equations of pulling and lowering forces for the friction force.

2. Calculate the value of the friction force for each trial and record the values in Table 2.

3. Calculate the net force of pulling and friction for each trial and record the values in Table 2.
4. Calculate the nonconserved work done that would be done if the block were pulled for 1 m in each trial. Record the values in Table 2.

5. Calculate the gravitational potential energy that the block would gain for each trial based upon the 1.00-m distance of pull up the incline \( (g = 9.80 \text{ m/s}^2) \). Record the values in Table 2.

6. Compare the nonconserved work in pulling the block up the incline to the gravitational potential energy gained by the block.

---

**Extension and Application**

1. Prepare an explanation of the nonconserved work of pulling and friction forces. Observe what happens when you rub your hands together quickly. Also, observe what happens when you hold a heavy book out to your side for as long as you can. What form do you think the friction and muscle work take? Define the system for each situation in which energy is conserved.

2. Apply conservation of mechanical energy to a 60.0-kg student who starts from rest and skis down an icy, frictionless hill with a vertical drop of 10.0 m. Is all of the skier’s potential energy converted to kinetic energy? Explain. What is different about this situation compared to the block experiment that you just performed?
How much energy does it take to melt ice?

An ice cube held in your hand will slowly melt. This is an endothermic process. Thermal energy from your hand is absorbed by the ice. In order to melt, the ice must change from a solid state to a liquid. First the temperature of the ice will increase to the melting point from its initial temperature. As thermal energy is absorbed, the ice changes state to water, and as more thermal energy is added the temperature of the water increases. The amount of energy needed to melt 1 kg of a specific substance is called the heat of fusion. If 1.00 kg of ice at its melting point of 0°C, 273 K, absorbs \(3.34 \times 10^5\) J of energy, then the ice will become 1.0 kg of water at 0°C, 273 K. The absorbed energy causes a change in state but not in the temperature.

An ice cube placed into warm water also will melt. The heat energy, \(Q\), necessary to melt a solid is equal to the mass, \(m\), of the solid times the heat of fusion, \(H_f\), of the solid. Thus \(Q_{\text{ice to water}} = mH_f\). While the ice cube is melting, the warm water will be transferring energy to the ice. The amount of energy lost by the water, \(Q_{\text{water}}\), is given by \(Q_{\text{water}} = m_wC_w\Delta T\), where \(C_w\) is 4.18 J/g°C, \(m_w\) is the mass of the water, and \(\Delta T\) is the difference between the initial and final temperature of the water, \(T_{\text{final}} - T_{\text{initial}}\).

In this lab you are to design a procedure to measure the amount of thermal energy needed to melt ice. In the process you will need to measure the temperature changes that occur as ice melts in a beaker of warm water.

**Objectives**

- **Apply** the law of conservation of energy as a method to measure the heat of fusion of water.
- **Calculate** energy transfer and the heat of fusion for water.
- **Understand** principles of calorimetry.

**Problem**

How can the thermal energy lost by warm water and absorbed by ice—causing it to melt, and then increasing its temperature as water—be used to calculate the heat of fusion of ice?
Hypothesis
Formulate a hypothesis describing how energy is conserved and transferred from the warm water to ice.

Plan the Experiment
1. Work in a small group. Decide on a procedure that uses the suggested materials, or others of your choosing, to gather data on ice melting in water.

2. Decide what kind of data to collect and how to analyze it. You can record your data in the table on the next page. Label the columns appropriately.

3. Write your procedure on another sheet of paper or in your notebook. In the space below, draw the setup you plan to use.

4. Check the Plan Have your teacher approve your plan before you proceed with your experiment.

Setup
Data and Observations

Analyze and Conclude

1. Summarize How was the cooling of the water affected by placing ice cubes in it?

2. Use Numbers a. Determine the thermal energy lost by the water. b. Calculate the thermal energy gained by the melted ice. Show calculations in the space below.

3. Analyze Data What is the thermal energy gained by the ice? Show calculations in the space below.

4. Interpret Data Calculate the heat of fusion of ice (water). Show calculations in the space below.
5. **Analyze Results** Determine the percent error between your calculated value and the accepted value. Show calculations in the space below.

6. **Infer** In addition to the thermal energy transferred from the water to the ice, what are other possible places to which thermal energy can transfer?

7. **Check Your Hypothesis** How much thermal energy is needed to change 100 g of ice at 0°C to water at 50°C? Show calculations in the space below.

**Apply**

1. The heat of fusion does not result in a temperature change in the ice; therefore, where does the energy go?

2. What advantage is there in using warm water for this experiment rather than cold water or room temperature water?
Why does a rock feel lighter in water?

Archimedes’ principle states that an object that is wholly or partially immersed in a fluid has an upward force on it that is equal to the weight of the fluid displaced by the object. Recall that \( F_{\text{buoyant}} = \rho_{\text{fluid}} V g \), where \( \rho \) is the density of the fluid, \( V \) is the volume of fluid displaced, and \( g \) is the acceleration due to gravity. When an object is less dense than the fluid it is submerged in, it sinks only until it displaces a volume of fluid with a weight equal to the weight of the object. At this time, the object is floating partially submerged, equilibrium exists, and \( \rho_{\text{fluid}} V_{\text{fluid displaced}} = \rho_{\text{object}} V_{\text{object}} \).

If an object is more dense than the fluid, an upward buoyant force from the pressure of the fluid will act on the object, but the buoyant force will be too small to balance the downward weight of the denser object. While the object will sink, its apparent weight decreases by an amount equivalent to the buoyant force.

In this experiment you will investigate the buoyant force of water acting on an object. Recall that 1 mL of water has a mass of 1 g and a weight of 0.01 N. The buoyant force acting on the object is the difference between the weight of the object in air and the apparent weight of the object when it is immersed in water:

\[
F_{\text{buoyant}} = F_{\text{weight}} - F_{\text{apparent}}
\]

Objectives

- Demonstrate the relationship between the buoyant force and the weight of an object in air and its apparent weight in water.
- Apply Archimedes’ principle to buoyancy.
- Infer the effect of surface area and density on the amount of water displaced by a known mass.

Procedure

1. Pour cool tap water into the 500-mL beaker to the 300-mL mark. Carefully read the volume from the graduation on the beaker and record this value in Table 1.

2. Hang the 500-g mass from the spring scale. Measure the weight of the mass in air and record this value in Table 1.
3. Immerse the 500-g mass, suspended from the spring scale, in the water, as shown in Figure A. Do not let the mass rest on the bottom or touch the sides of the beaker. Measure the apparent weight of the immersed mass and record this value in Table 1.

4. Measure the volume of the water with the mass immersed. Record the new volume in Table 1. Remove the 500-g mass from the beaker and set it aside.

5. Measure and record in Table 2 the volume of water in the beaker. Place the 100-g mass in the beaker of water. Measure and record in Table 2 the volume of the water in the beaker with the mass immersed.

6. The plastic foam cup will serve as a boat for the next step. Remove the mass from the water, dry it with a paper towel, and place it in the plastic foam cup. Float the cup as best you are able to in the beaker of water. Measure the new volume of water and record this value in Table 2.

Data and Observations

<table>
<thead>
<tr>
<th>Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of 500-g mass in air</td>
</tr>
<tr>
<td>Apparent weight of 500-g mass immersed in water</td>
</tr>
<tr>
<td>Volume of water in beaker</td>
</tr>
<tr>
<td>Volume of water in beaker with 500-g mass immersed</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume of water in beaker</td>
</tr>
<tr>
<td>Volume of water with 100-g mass immersed</td>
</tr>
<tr>
<td>Volume of water with 100-g mass in plastic foam cup</td>
</tr>
</tbody>
</table>

Analysis and Conclusions

1. Calculate the buoyant force of water acting on the 500-g mass. Show calculations in the space below.
2. Using the data from Table 1, calculate the volume of water displaced by the 500-g mass. Calculate the weight of the water displaced. Show calculations in the space below. Compare the weight of the volume of water displaced with the buoyant force acting on the immersed object that you calculated in question 1. If the values are different, describe sources of error to account for this difference.

3. What happened to the water level in the beaker when the 100-g mass was placed in the boat (plastic foam cup)? Suggest an explanation, which includes density, for any difference in volume you found in steps 5 and 6.

Extension and Application

1. Juan and Sally are floating on an inflatable raft in a swimming pool. What happens to the water level in the pool if both fall off of the raft and into the water?

2. Icebergs are huge floating masses of ice that have broken from glaciers or polar ice sheets. Only the tip of the iceberg is visible. The density of ice is 0.92 g/cm³ and the density of seawater is 1.03 g/cm³. What percentage of an iceberg’s total volume will be above the surface of the ocean?

3. Cargo freighters, carrying everything from food to electronic merchandise, travel between ports on different continents and each is able to haul hundreds of tractor trailer-size containers. While traveling through the Central American canal system locks, if several dozen containers break loose and fall into the canal, what happens to the water level?
4. Imagine a beaker of water sitting on a scale. Does the weight of the beaker increase, decrease, or remain unchanged as a suspended weight is lowered into the beaker?

5. Use the concept of buoyant force to explain why a rock feels lighter in water than it does in the air.
Why do your ears hurt under water?

Blaise Pascal, a French scientist, helped to pioneer the foundations of hydrostatics—the study of fluids at rest. He found that pressure in an enclosed fluid is transmitted undiminished to each portion of the fluid and the walls of the containing vessel. The pressure exerted by the fluid depends only upon the depth of the fluid at the point where it is measured.

What happens when you dive into the deep end of a swimming pool and go to the bottom? You feel the pressure increase the deeper you swim. Water, as is the case for all liquids, is virtually incompressible. A small change in pressure applied to one portion of a liquid will propagate throughout the liquid at the speed of sound in the liquid.

The pressure exerted by the water in the swimming pool is a result of gravity acting on the water column above you. Pressure is force per unit area, so the pressure, \( P \), of the water is given by

\[
P = \frac{F_g}{A}
\]

where \( F_g \) is the force exerted by gravity on the mass of water above you and \( A \) is the area of the column of water above you. Furthermore, the weight of the mass of water above you is given by

\[
F_g = mg = \rho Vg
\]

where \( m \) is the mass of the water, \( g \) is the acceleration due to gravity, \( \rho \) is the density of water, and \( V \) is the volume of the water. The volume can be expressed as simply the area times the height of the water column. Therefore, the pressure of the water can be written as

\[
P = \frac{F_g}{A} = \frac{mg}{A} = \frac{\rho Vg}{A} = \frac{\rho gAh}{A} \text{ or simplifying,}
\]

\[
P = \rho gh
\]

Objectives

- Analyze forces acting on a fluid.
- Develop an understanding of Pascal’s principle.
- Observe the effect of force in a fluid.
Procedure

A. Mariotte’s Bottle
1. Take a clean 2-L bottle and mark three dots on the bottle. Place the dots so that one is one-fourth, one is one-half, and one is three-fourths of the way between the bottom and top. Use an ice pick or a compass to punch a hole in the bottle where each mark is located.

2. While holding your fingers over the three holes, fill the bottle with water. Carefully sit the bottle in your pan and remove your fingers. Observe the flow of water from the holes. Record and sketch your observations in Table 1.

3. Pour the overflow water into the sink and repeat step 2.

B. Open and Closed Tubes
1. Measure the barometric pressure and record this value in Table 2.

2. Fill the graduated cylinder with water. Insert the straw.

3. Place your thumb, or a finger, over the end that is out of the water, to seal it.

4. Withdraw the straw vertically from the graduated cylinder. Record your observations in Table 2.

5. While holding the straw over the graduated cylinder, release your thumb. Record your observations in Table 2.

6. Replace the straw in the graduated cylinder. Without covering the end of the straw, lift the straw out of the water. Record your observations in Table 2.

C. Inverted Glasses
1. Measure the diameter and the height of your glass. Record these values in Table 3.

2. Fill the glass with water all the way to the top. Place the index card over the top, as shown in Figure A.

3. While holding the jar over a sink, hold the card in place with your hand and carefully turn the glass upside down, as shown in Figure B. Remove your hand. Were you able to keep the water in the glass? Record your observations in Table 3.
Data and Observations

Table 1

Observations and sketch of the Mariotte’s bottle:

Table 2

Barometric pressure = ______ kPa

Observations of the straw lifted from the water (with thumb sealing the end):

Observations of the straw and water when thumb was removed:

Observations of the straw when lifted from water (thumb not sealing):

Table 3

Diameter of glass:

Height of glass:

Observations of upside-down glass with index card:

Analysis and Conclusions

1. Gravity is pulling on all of the water molecules in the 2-L container in part A. Describe the pressure throughout the bottle.

__________________________________________________________________________________

__________________________________________________________________________________

__________________________________________________________________________________
2. Summarize the results of lifting the straw from the water-filled cylinder.

3. Draw a diagram of the pressure and the forces acting on the water-filled straws.

4. Using the data from Table 3, calculate the pressure exerted on the index card by the water in the glass. The density of water is $1.00 \times 10^3 \text{ kg/m}^3$. Show calculations in the space below.

5. Using the data from Table 3 and your result for pressure in problem 4, calculate the amount of force the water exerts on the note card. Show calculations in the space below.

6. The column of air from Earth's surface to the upper reaches of the atmosphere comprises the barometric pressure. The air in the room behaves as a fluid and exerts this pressure to all surfaces throughout the room. Compare the pressure exerted by the air on the index card to the pressure due to the weight of water on the index card. Which is larger?

7. Why is it possible for the index card to stay on the glass while the glass is inverted?

**Extension and Application**

1. If there is more than a small difference in pressure between the outside of your body and an air space within your body, a squeeze can result. Squeezes can be painful. While swimming, the eardrum acts as a wall between water and air. If you dive 3 m to the bottom of a swimming pool, what increase in pressure is transmitted from the water to your eardrum? If this pressure is not equalized what will result?
Safety Precautions

Materials
• dowel
• eyedropper
• glass plate
• large sheet of plain white paper
• level tool
• light source
• parabolic ripple-tank barrier
• protractor
• ripple tank
• straight ripple-tank barrier
• washers

What do wave reflection and refraction look like?

Reflection occurs when a wave bounces off a barrier. The law of reflection states that the angle of incidence of a wave relative to a barrier is equal to the angle of reflection of the wave relative to the barrier. In other words, this bouncing effect causes the wave to change direction, but it does not cause the wave to change speed. When waves pass through a boundary from one medium into another, the waves undergo a change in speed, because wave speed is a property of the medium. This change in speed causes the wave to also change direction. This phenomenon is called refraction.

In this lab, you will investigate the wave phenomena that involve a changing of the direction of travel of waves, known as reflection and refraction. To do this, you will use a ripple tank. A ripple tank is an ideal medium for observing the behavior of waves. It projects images of waves in the water onto a paper screen below the tank. Light shining through water waves is seen as a pattern of bright lines and dark lines separated by gray areas. You will use these shadows of waves to observe reflection and refraction.

Objectives
■ Observe wave reflection and wave refraction in a ripple tank.
■ Analyze wave patterns in water.
■ Predict the behavior of surface waves in water.

Procedure
A. Setup
1. Set up the ripple tank as shown in Figure A. Before adding water, place a level tool in the bottom of the tank and check the level. Check the level in the direction of the width of the tank and in the direction of the length of the tank. Adjust the level of the tank as necessary so that it is level in both directions. Add water to a depth of 5–8 mm.
2. Turn on the light source. While creating small waves with a pencil, adjust the light source so that clear images of waves appear on the picture screen made of paper.

B. Reflection
1. Place the dowel in the water against one side of the ripple tank. Test the use of the dowel by rolling it back and forth gently to generate plane wave pulses.
2. Place a straight barrier at the opposite end of the tank such that it is parallel with the edge of the tank. Using the dowel, send plane wave pulses toward the straight barrier so that they strike the barrier head-on (angle of incidence $\theta_i = 0^\circ$). Using the paper screen, observe what happens to the pulses as they strike the barrier. Record a description of your observations in the item 1 space of Table 1.

3. Shift the position of the straight barrier such that it is at an angle relative to the end of the tank. Using the dowel, send plane-wave pulses toward the straight barrier. Using the paper screen, observe what happens to the pulses as they strike the barrier. Record a description of your observations in the item 1 space of Table 1. Sketch a picture of your observations in the item 2 space of Table 1. Remember that the behavior of pulses is the same as the behavior of waves.

4. Use your protractor to measure the angle of incidence and the angle of reflection of the waves. The angle of incidence, $\theta_i$, is the acute angle between the line along the incoming plane wave front and the line along the straight barrier, so it is always less than or equal to $90^\circ$. The angle of reflection, $\theta_r$, is the acute angle between the line along the reflected plane wave front and the line along the straight barrier, so it also is always less than or equal to $90^\circ$. Record these angle measurements in the item 3 space of Table 1.

5. Replace the straight barrier with a parabolic barrier, arranged such that the open side of the curve is toward the dowel. Using the dowel, send plane-wave pulses toward the parabolic barrier. Using the paper screen, observe what happens to the pulses as they strike the barrier. Record a description of your observations in the item 4 space of Table 1. Using the paper screen, locate the point where the reflected waves come together. Using a pencil, mark this point on the paper. This point is called the focus.

6. Stop making wave pulses with the dowel. Using an eyedropper, drip small drops of water on the focus point, or tap the water gently at this point with a pencil. Observe what happens to the waves that move from the point in a direction away from the parabolic barrier. Observe what happens to the waves that are reflected off the parabolic barrier. Record a description of your observations in the item 5 space of Table 1.

7. Remove the parabolic barrier from the ripple tank.

C. Refraction

1. Place a rectangular glass plate in the center of the tank and to one side, as shown in Figure B1. If necessary, support the plate with washers in order to produce an area of shallow water.

2. Using the dowel, generate plane-wave pulses in the tank. Carefully observe what happens to the waves at the glass plate boundary. In Figure B1, sketch the patterns you observe as waves move from the deep water of the tank into the shallow water above the glass plate.

3. Rotate the glass plate such that one corner is pointed toward the end of the tank with the dowel, as shown in Figure B2. Using the dowel, generate plane-wave pulses in the tank. In Figure B2, sketch the patterns you observe as the waves move from the deep water of the ripple tank into the shallow water above the glass plate.
## Data and Observations

<table>
<thead>
<tr>
<th>Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. <strong>Description of plane-wave pulses striking a straight barrier at 0° and at another angle</strong></td>
</tr>
<tr>
<td>2. <strong>Sketch of incoming pulses and reflected pulses</strong></td>
</tr>
<tr>
<td>3. $\theta_i = ____$  $\theta_r = ____$</td>
</tr>
<tr>
<td>4. <strong>Description of waves that are reflected from a parabolic barrier</strong></td>
</tr>
<tr>
<td>5. <strong>Description of waves that are generated at the focus of a parabolic barrier</strong></td>
</tr>
</tbody>
</table>

### Figure B

- **Glass plate**
- **Straight wave generator**
Analysis and Conclusions

1. Recall your observations of reflecting waves in the ripple tank. Did the waves change speed or keep the same speed? Did the distance between waves (the wavelength) change?

2. Compare the angle of incidence and the angle of reflection that you recorded in Table 1.

3. Make an association between the law of reflection and your observations of the waves that reflected off the parabolic barrier. Does the law of reflection still apply in this case?

4. Compare and contrast your observations in item 4 of Table 1 with your observations in item 5 of Table 1.

5. Compare and contrast your observations of reflection with your observations of refraction.

6. Identify a cause-and-effect relationship of refraction. What caused the changes to the waves as they crossed into the shallow water?

Extension and Application

1. Relate the refraction model of the ripple tank to how an explorer could locate underwater reefs or sandbars.

2. Relate the reflection model of the ripple tank to sports like tennis, racquetball, and pool.
What do wave diffraction and interference look like?

In this lab, you will explore phenomena associated with wave superposition. One such phenomenon is known as diffraction. A wave front is the result of the superposition of Huygens' wavelets all along the wave front. This type of superposition occurs with all waves and results in a traveling wave front that can maintain its size, like a plane wave, or spread and grow, like a circular wave. When a plane wave front passes by an edge, the edge cuts the wave front, causing the Huygens’ wavelets where the wave front is cut to start propagating as circular waves. The result is a wave front that appears to bend around the edge, when, in actuality, the wave is spreading as a circular wave.

Interference is the phenomenon that occurs when two or more separately traveling waves pass through each other. When the peaks or troughs of waves are in the same place at the same time, they build on each other. This is called constructive interference. When a peak and a trough from two different waves are in the same place at the same time, they cancel each other such that the resulting wave has a smaller peak or trough than either of the original two waves. This is called destructive interference.

You will use a ripple tank to observe the phenomena of diffraction and interference. Rather than using barriers to reflect waves, you will use barriers to cut waves and observe the resulting diffraction. Then, you will use a two-point-source wave generator to observe the result of two waves interfering.

Objectives

■ Operate a ripple tank to observe diffraction and interference wave phenomena.

■ Analyze wave behavior associated with diffraction and interference.

■ Predict the behavior of diffraction with two openings.

Procedure
A. Setup

1. Set up the ripple tank as shown in Figure A. Do not install the wave generator until part C.

2. Before adding water, place a level tool in the bottom of the tank and check the level. Check the level in the direction of the width of the tank and in the direction of the length of the tank. Adjust the level of the tank as necessary so that it is level in both directions.

3. Add water to a depth of 5–8 mm.

4. Turn on the light source. While creating small waves with a pencil, adjust the light source and water depth so that clear images of waves appear on the picture screen made of paper.

B. Diffraction

1. Place the dowel in the water against one side of the ripple tank. Test the use of the dowel by rolling it back and forth gently to generate plane-wave pulses.

2. Arrange two wood or paraffin blocks, as shown in Figure B. Using the dowel, send plane-wave pulses toward the opening between the blocks. Observe the diffraction of the waves. Make a sketch of the diffraction of the waves for a wide opening in the item 1 space of Table 1.

3. While one lab team member continues to generate plane waves at a regular rate, have another lab team member slowly narrow the opening. Make a sketch of the diffraction of the waves for a narrow opening in the item 1 space of Table 1.

4. Increase the wave-generator frequency. Observe the resulting wave diffraction for the narrow opening. Make a sketch of the diffraction of the waves in the item 2 space of Table 1.

5. Remove the dowel and the blocks from the ripple tank.

C. Interference

1. Place the two-point-source wave generator in the tank near one end. Attach the variable power supply to the generator. Turn the power supply to a low voltage setting so that the point sources produce a continuous series of circular waves of long wavelength. The superposition of the waves from the two sources should produce an interference pattern in the tank. Nodal lines should be visible. They are lines of calm water. Antinodal regions will be between the nodal lines. They are regions of water with visible waves. Make a sketch of the interference pattern of the waves in the item 1 space of Table 2.

2. Increase the wave-generator frequency and observe the resulting interference pattern. Make a sketch of the interference pattern of the waves in the item 2 space of Table 2.
Data and Observations

<table>
<thead>
<tr>
<th>Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1</strong> Sketches of Diffraction of Waves</td>
</tr>
<tr>
<td><strong>Wide Opening</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>2</strong> Sketch of Diffraction of Waves with Higher Wave Generator Frequency</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1</strong> Interference Pattern</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Analysis and Conclusions

1. Identify the wave parameter that is controlled by the wave generator.
2. Explain the effect that increasing wave frequency has on the waves produced by the generator.

3. Summarize the superposition that occurs with diffraction.

4. Describe the superposition of waves that occurred on nodal lines in the interference experiment. Describe the superposition of waves that occurred in antinodal regions in the interference experiment.

5. Compare the diffraction patterns of the wide and the narrow openings.

6. Analyze the effect of increasing wave-generator frequency on diffraction.

7. Analyze the effect of increasing wave-generator frequency on two-source interference.

**Extension and Application**

1. Integrate your observations of diffraction and interference to predict the pattern of waves that would be produced by a barrier with two narrow openings.
What is a decibel?

The human ear can sense a wide range of sound intensities. The intensity of a sound at the threshold of pain is $1 \times 10^{12}$ times greater than that of the faintest detectible sound. However, the ear does not perceive sounds at the threshold of pain as $1 \times 10^{12}$ times louder than a barely audible tone. Loudness, as measured by the human ear, is not directly proportional to the intensity of a sound wave. Instead, a sound with ten times the intensity of another sound is perceived as twice as loud.

The human ear senses pressure variations as sound and the intensity of the pressure as the relative intensity of the sound. The pressure produced by a sound wave is not easily measured. A more practical unit for measuring the relative intensity of a sound level, $\beta$, is the decibel, dB.

$$\beta = (10 \text{ dB}) \log \frac{I}{I_0}$$

where $I$ is the intensity at sound level $\beta$ and $I_0$ is a standard reference intensity near the lower limit of human hearing, which corresponds to a sound level of 0 dB. A sound at the threshold of pain corresponds to a sound level of 120 dB.

Table 1 compares intensity ratios and their sound-level equivalents in decibels. Note that when the intensity ratio doubles, the sound level increases by only 3 dB. If the intensity ratio of a sound is multiplied by 10, the sound level increases by 10 dB, but if the intensity ratio is multiplied by 100, the sound level increases by 20 dB.

<table>
<thead>
<tr>
<th>$\frac{I}{I_0}$</th>
<th>dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
</tr>
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<td>10</td>
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<td>20</td>
</tr>
<tr>
<td>1000</td>
<td>30</td>
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</tbody>
</table>

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<table>
<thead>
<tr>
<th>Sound Level (dB)</th>
<th>Exposure per Day (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>8</td>
</tr>
<tr>
<td>92</td>
<td>6</td>
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<td>95</td>
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<td>97</td>
<td>3</td>
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<td>1.5</td>
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<td>105</td>
<td>1</td>
</tr>
<tr>
<td>110</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Prolonged exposure to loud sounds can damage your hearing; the longer the exposure, the greater is the damage. Federal regulations state that workers cannot be continuously exposed to sound levels of more than 90 dB during an 8-h day. Table 2 compares sound levels and the limit of continuous exposure per day to avoid permanent damage to hearing.

In this lab, you will use a sound-level meter, like the one shown in Figure A, to measure the sound level of a radio or CD player.

**Objectives**
- Measure the sound level of a radio or CD player.
- Determine the relationship between sound level and volume settings.
- Recognize sound levels that may damage hearing.
- Analyze sound levels in various situations.

**Procedure**
1. Check the volume control of your radio or CD player for numerical settings. If it doesn’t have them, use white correction fluid to make 8-10 equally spaced marks on the control dial, beginning at the off position.
2. Tune the radio to a station that is playing music or insert a CD of your choice into the CD player.
3. Be sure you understand how to use and take readings from the sound-level meter. If you do not, ask your teacher for instructions.
4. Use masking tape to attach the headphones to the sound-level meter, placing the meter microphone against one earpiece.
5. Turn on the radio or CD player and the sound-level meter. Measure the sound level at each increment on the volume control. Record the sound levels in Table 3. Repeat the procedure for other radios or CD players. In Table 3, record these data as additional trials.
6. Turn the volume control to a low setting. Remove the headphones from the sound meter and put them on your head. Play some music you enjoy and adjust the volume setting until you have reached the amplitude that you prefer. Record this volume setting in Table 4. Estimate the number of hours, in a given day, that you listen to music at this level. Record this value in Table 4.

**Data and Observations**

<table>
<thead>
<tr>
<th>Setting</th>
<th>Sound Level (db)</th>
<th>Setting</th>
<th>Sound Level (db)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trial 1</td>
<td>Trial 2</td>
<td>Trial 3</td>
</tr>
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<td>5</td>
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</tbody>
</table>
Analysis and Conclusions

1. Graph sound level (y-axis) versus volume setting (x-axis). Is there any recognizable relationship between the measured sound level and the corresponding volume setting? Give a reason for your answer.

2. Use your graph to determine which sound level corresponds to your preferred listening volume setting.

3. Refer to Table 2 to determine the maximum time you should be listening to music at your preferred volume level. What is this value?

4. Could your radio or CD player be damaging your hearing? Give a reason for your answer.
Extension and Application

1. Jack’s hearing test revealed that he needs a sound level of 20 dB to detect sounds at 2000 Hz. Caroline’s hearing test revealed that she needs a sound level of 40 dB to detect sounds at the same frequency. If the normal sound level for testing is 15 dB, how much greater than normal were the sound intensities that Jack and Caroline need to detect sound?

2. The sound level of a rock group at 1 m is 110 dB, while that of normal conversation at 1 m is 60 dB. Find the ratio of their intensities. Show all your calculations.

3. In open space, the intensity of sound varies inversely with the square of the distance from the source, \( I \propto \frac{1}{r^2} \). Predict what happens to sound levels in an enclosed room. Give a reason for your answer.

4. A student is considering a new stereo system for her room and thinks she needs an 800-W amplifier to produce 80.0 W of sound power from her speakers at her listening position. She has asked you if this is a good choice. To help this student, you must find (a) the possible intensity of the sound from this system at a distance \( r = 2.25 \) m from the speakers and (b) the corresponding sound level. Use the equation

\[
I = \frac{P}{4\pi r^2}
\]

where \( P \) is the power in watts and \( I \) is the intensity measured in watts per square meter. \( I_0 = 10^{-12} \) W/m\(^2\). Show all your calculations. Is this a wise choice for the student? If the student does buy the amplifier, what can she do to prevent hearing damage? Give a reason for your answers.

5. If the student in question 4 has one speaker producing 100 dB of sound at 1 m and she places a second speaker of the same capacity next to it, what is the new sound level at 1 m from the speakers?
How fast does sound travel?

You have learned that the wavelength of a sound wave is dependent on the frequency of the wave as generated by the source and the speed of sound in the medium.

\[ \lambda = \frac{v}{f} \]

Using this relationship, standing waves can be used to make an indirect measurement of the speed of sound in air. Standing longitudinal waves form in air columns in open tubes as well as in closed ones. When a tuning fork vibrates, it disturbs the molecules of air in the tube, so that the air rushes into and out of the tube. A wave reflected at the end of a tube can interfere with an incident wave. Destructive interference occurs at the nodes. Constructive interference occurs at the antinodes and creates resonance, an increase in the vibrations' amplitudes. You can sense this increase in amplitude as a significant increase in the volume of the tone.

At the fundamental harmonic of an open tube, there is a pressure node at each end, with one pressure antinode between. The length, \( L \), of the tube is about one half of the wavelength, \( \lambda \), of the sound wave. The effective length of the air column, \( L_{\text{eff}} \), in a resonating open tube is larger by a factor that relates to the diameter, \( D \), of the tube. This correction is needed to account for the air that is vibrating back in and out of the ends of the tube. A 0.8 coefficient comes from the need to make two end corrections for an open tube. Using \( L_{\text{eff}} = L + 0.8D \) and \( L_{\text{eff}} = \lambda / 2 \),

\[ \lambda = 2(L + 0.8D) \]

In this lab, you will apply the phenomena of standing waves and resonance to determine the speed of sound in air at six different frequencies. You will generate the tones using tuning forks of known frequency, \( f \). By holding a vibrating tuning fork to the end of an adjustable length open tube, you will find the length at which the air column resonates for each frequency. Then you will use \( \lambda = v/f \) to calculate the speed of sound in air, \( v \).

Objectives

- **Relate** the wavelength of sound waves in an open tube to the speed of sound.
- **Evaluate** the precision and accuracy of using open tubes and resonance to indirectly measure the speed of sound.
- **Predict** if resonance occurs at longer tube lengths and test your prediction.
Procedure

1. Select an assortment of open tubes such that you have a 1-m range of tube lengths. Using a meterstick, measure the minimum length of your shortest tube and the maximum length of your longest tube.

2. Figure A graphs the approximate relationship between the length and the resonant frequency of an open tube. Using the information in Figure A, select six tuning forks that correspond to the range of length of your tube. Record the frequency of each tuning fork as a separate trail in Table 1.

3. Select an adjustable tube that has a length range that would work with the trail 1 tuning fork per Figure A. Measure the diameter of the adjustable tube. Record the diameter in trial 1 of Table 1.

4. Strike the tuning fork for trial 1 with the tuning fork-hammer. While one lab team member holds the tuning fork close to, but not touching the tube, as shown in Figure B, have another lab team member slowly adjust the length of the tube to obtain the loudest sound.

5. Measure the tube length that produces the loudest resonant sound. Record the tube length in trial 1 of Table 1.

6. Repeat steps 3 through 5 for the remaining five tuning forks. Switch tubes as necessary to obtain resonance with the different tuning forks. Record the tube diameter and tube length for each trial in Table 1.
## Data and Observations

### Table 1

<table>
<thead>
<tr>
<th>Trial</th>
<th>Frequency $f$ (Hz)</th>
<th>Tube Diameter $D$ (m)</th>
<th>Tube Length $L$ (m)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
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</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>Trial</th>
<th>Correction Factor $0.8D$ (Hz)</th>
<th>Effective Tube Length $L_{\text{eff}}$ (m)</th>
<th>Wavelength $\lambda$ (m)</th>
<th>Wave Speed $v$ (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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</table>

### Analysis and Conclusions

1. Calculate the correction factor for each trial. Record the values for each trial in Table 2.
2. Calculate the effective length of the tube for each trial. Record the values for each trial in Table 2.

3. Calculate the wavelength of the sound for each trial. Record the values for each trial in Table 2.

4. Calculate the wave speed for each trial. Record the values for each trial in Table 2.

5. Compare the values for wave speed in Table 2 with each other and with the accepted value for the speed of sound in air at room temperature provided in your textbook.

6. Assess the precision and accuracy of the method used in this lab to determine the speed of sound. Are the calculated values of wave speed clustered or spread out. How close is the average of your calculated values of wave speed to the accepted value of the speed of sound in air?

Extension and Application
1. What if you continued to extend the length of an open tube beyond the length where it produced resonance? Would the sound resonate at another length? Record your hypothesis below, then test it and record your observations.

2. Imagine that an open organ pipe that is 3.0 m long and 0.15 m in diameter, resonates when air at 20.0°C is blown against its opening. What is the frequency of the note that is produced?
How can you reduce glare?

While at the beach or swimming pool you probably have noticed the bright reflection of light from the water. Light reflected from the water’s surface is partially polarized by the reflection effect.

Only transverse waves can be polarized, or made to vibrate in one plane. Since light travels in transverse waves, it can be polarized by absorption, reflection, or scattering from shiny objects or materials. Light is also polarized when it passes through certain materials. If you rotate a polarizing filter while observing a light beam, the light intensity may vary from dark to light. Light waves affected in this manner are polarized. If light observed through the rotating filter does not change in intensity, it is unpolarized.

**Objectives**
- **Observe** light through polarizing filters.
- **Determine** a light’s polarity.
- **Describe** applications for polarizing filters.

**Procedure**

1. Hold one polarizing filter between a light source and your eyes. Rotate the polarizing filter through 360°. Observe the intensity of light as you rotate the filter. Record your observations in **Table 1**.

2. Repeat step 1, adding a second filter. Observe what happens to the intensity of light as you rotate the filter closer to the light source. Record your observations in **Table 1**.
3. Repeat step 2 and this time rotate the polarizing filter closer to your eye. Record your observations in Table 1.

4. Using only one polarizing filter, rotate the filter while observing light reflected from a plane mirror. Record your observations of light intensity in Table 2.

5. Using only one polarizing filter, rotate the filter while observing light reflected from a glass plate. Then observe light reflected from a shiny tabletop. Record your observations of light intensity in Table 2.

Data and Observations

<table>
<thead>
<tr>
<th>Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observations of light source with one polarizing filter</td>
</tr>
<tr>
<td>Observations of light source with two polarizing filters, rotating the filter closer to the light</td>
</tr>
<tr>
<td>Observations of light source with two polarizing filters, rotating the filter closer to your eye</td>
</tr>
</tbody>
</table>
Analysis and Conclusions

1. Is light from a lightbulb polarized? Give a reason for your answer.

2. What happens to the intensity of light viewed through two polarizing filters as one filter rotates? Does it matter which filter rotates? How far must one filter rotate for transmitted light to go from maximum to minimum brightness?

3. Malus’s law states that the intensity of light coming out of a second polarizing filter is equal to the intensity of light coming out of the first multiplied by the cosine, squared, of the angle between the polarizing axes of the two filters. Do your results appear to confirm Malus’s law? Explain why or why not.
4. Is light reflected from a plane mirror polarized? Give a reason for your answer.

5. Is light reflected from a glass plate or shiny laboratory surface polarized? Give a reason for your answer.

Extension and Applications

1. Describe an orientation of polarizing material on cars that would enable drivers to use their high-beam lights at all times.

2. Use a single polarizing filter to observe light reflected from a glass plate. Examine various angles of reflection until the reflected light is entirely eliminated, as shown in Figure B. With your protractor, measure this angle, \( \theta_p \). When unpolarized light strikes a smooth surface and is partially reflected, the light is partially, completely, or not polarized, depending on the angle of incidence. The angle of incidence at which the reflected light is completely polarized is the polarizing angle. The law of reflection states that the angle of incidence and the angle of reflection are equal. An expression relating the polarizing angle, \( \theta_p \), to the index of refraction, \( n \), of the reflecting surface is \( n = \tan \theta_p \), which is Brewster’s law.

![Figure B](image)

Using the measured angle of reflection, calculate the index of refraction for the glass plate. Substitute a beaker of water and measure the angle of incidence at which reflected light is completely polarized. Calculate the index of refraction of water.
Where is your reflection in a mirror?

When a reflecting surface is very smooth, it causes specular reflection. At the point where a ray of light reflects from the surface, the angle of reflection equals the angle of incidence, $\theta_r = \theta_i$. Both angles are measured from the normal, which is an imaginary line that is perpendicular to the surface at the point where the beam is reflected. When a beam of light strikes the surface, the entire beam is at the same angle of incidence to the smooth surface, so the entire beam is reflected at an equal angle. Specular reflection makes it possible for you to see your reflection in a plane mirror, a perfect image of yourself behind the surface of the mirror.

In this lab, you will investigate the location of images that are formed by a plane mirror. By using the ray model of light, you can construct a ray diagram that locates the virtual image formed by a plane mirror. You also will use a partially reflecting surface to physically determine the location of a virtual image and some properties of the image.

Objectives

- Describe the images produced by different plane-reflecting surfaces.
- Compare objects with their associated images produced by plane-reflecting surfaces.
- Compose a list of properties of images produced by plane-reflecting surfaces.

Procedure

A. Image Point Location

1. Attach a sheet of paper to the corkboard with thumb tacks. Use the edge of a ruler to draw a line, M, across the width of the paper.

2. Attach a small block of wood to the back of a plane silvered mirror with a rubber band. Place the block and mirror on the paper so that the surface of the mirror runs along line M, as shown in Figure A. Center the mirror on the paper. Be sure the mirror stands perpendicular to the surface of the paper.

Figure A
3. Using a pencil, make a dot on the paper about 4 cm in front of the mirror and label it \( O \). This is the location of the object. Stick a pin through the paper at point \( O \) and into the corkboard so that it stands erect.

4. Place the ruler on the paper about 5 cm to the left of the pin. Look along the edge of the ruler at the image of the pin in the mirror, as shown in Figure B. When the edge of the ruler is lined up on the image, draw a line segment along the ruler toward the mirror. Do not draw the line all the way to the mirror at this time. Label this line \( K \).

5. Move the ruler another 3 to 4 cm to the left and sight. Look along the edge of the ruler at the image of the pin in the mirror. When the edge of the ruler is lined up on the image, draw a line segment along the ruler toward the mirror. Do not draw the line all the way to the mirror at this time. Label this line \( L \).

6. Remove the pin and the block and mirror from the paper.

7. Extend lines \( K \) and \( L \) to line \( M \). Using dotted lines, extend lines \( K \) and \( L \) beyond line \( M \) until they intersect, as shown in Figure B. Label the point of intersection \( I \). This is the location of the image.

8. Line up the straight edge of the ruler so that it connects points \( O \) and \( I \). Using the ruler, draw a solid line from point \( O \) to line \( M \) and a dashed line from \( M \) to point \( I \). Measure the distance of point \( O \) from line \( M \) along the solid portion of the line and measure the distance of point \( I \) from line \( M \) along the dashed portion of the line. Record these distances in Part A of the Data and Observations section.

**B. Image Formation**

1. Repeat step A1 with a clean sheet of paper.

2. Use a support rod and one or two rod-mounted, 3-prong extension clamps to hold a tinted acrylic plate in a vertical position. Position the cork board with the paper under the acrylic so that the front surface of the acrylic runs along the line \( M \) as shown in Figure C.

3. Lay a plastic plumbing tee in front of the acrylic with the open ends on the top of the tee pointing toward and away from the acrylic, respectively. The bottom opening of the tee should be pointing to the left or right. Using a pencil, trace the outline of the tee, and make a dot on the outline at the edge and center of each opening of the plastic plumbing tee. Label the point nearest the acrylic as \( O_1 \). Label the point farthest away from the acrylic as \( O_2 \). Label the point at the bottom opening of the tee as \( O_3 \). Stick a pin through the paper into the corkboard at each point such that the three pins stand erect.
4. Remove the plastic plumbing tee from the paper. Perform steps A4 and A5 for each of the three pins using the reflection of the pins in the tinted acrylic. Use the labels K1 and L1 for the two lines associated with pin O1. Use the labels K2 and L2 for the two lines associated with pin O2. Use the labels K3 and L3 for the two lines associated with pin O3.

5. Place the plastic plumbing tee back on the paper in its original position. Remove the three pins. While looking through the acrylic at the image of the plastic plumbing tee, place a second, identical plastic plumbing tee behind the acrylic so that it is exactly superimposed on the image of the first tee. Look through the acrylic in the reverse direction. Record your observations in Part B of the Data and Observations section.

6. Using a pencil, trace the outline of the second plastic plumbing tee on the paper. Then remove both plastic plumbing tees and the acrylic plate from the paper.

7. Perform step A7 for line sets \{K1, L1\}, \{K2, L2\}, and \{K3, L3\}. Label the points of intersection I1, I2, and I3, respectively.

8. Perform step A8 for point sets \{O1, I1\}, \{O2, I2\}, and \{O3, I3\}. Record the distances of the object points and image points in Part B of the Data and Observations section.

**Data and Observations**

**Part A**

Distance of point O from mirror: ________  Distance of point I from mirror: ________

**Part B**

Observations of looking through the acrylic in both directions:

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

Distance of point O1 from mirror: ________  Distance of point I1 from mirror: ________

Distance of point O2 from mirror: ________  Distance of point I2 from mirror: ________

Distance of point O3 from mirror: ________  Distance of point I3 from mirror: ________

**Analysis and Conclusions**

1. Describe the images produced by a silvered mirror and the images produced by tinted acrylic. Compare the two images.

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________
2. Compare the distances of the object points from the reflecting surfaces with the distances of the associated image points.

3. Compare the outline and image points of the second plastic plumbing tee with the outline and object points of the first plastic plumbing tee.

4. Compare the orientation of image points I1, I2, and I3 with the orientation of object points O1, O2, and O3.

5. Describe the properties of an image created by a plane reflecting surface using your observations in this lab.

**Extension and Application**

1. Demonstrate the image created by a double reflection. Line up two plane, silvered mirrors edge-to-edge at a 90° angle. Write your name at the top of a 2-in × 3-in index card and place the card so that the bottom edge of the card is against the mirror on the left. Your name now should look upside down to you. Look into the mirror on the right at about a 45° angle. Observe the image of your name in the mirror on the right and record the orientation. Finally, observe the image of the left mirror in the mirror on the right and record the orientation of your name. What is different about the second image of your name compared to the normal plane mirror image?
**Convex and concave lenses**

A convex, or converging, lens is thicker in the middle than at the edges. The principal axis of the lens is an imaginary line perpendicular to the plane that passes through the lens’s midpoint. It extends from both sides of the lens. At some distance from the lens along the principal axis is the focal point, F, of the lens. Light rays that strike a convex lens parallel to the principal axis come together or converge at this point. The focal length of the lens depends on both the shape and the index of refraction of the lens material. As with mirrors, an important point is located at a distance twice the focal length. The points F and 2F are the same distance on both sides of the lens, as shown in Figure A.

Focal length, object distance, and image distance are measured from the lens along the principal axis.

The distance from the center of the lens to the object is \( d_o \), and the distance from the center of the lens to the image is \( d_i \). The lens/mirror equation is

\[
\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}
\]

In this activity, you will measure the focal length, \( f \), of a convex lens and place an object at various distances from the lens to observe the location, size, and orientation of the images. Recall that real images can be projected onto a screen; virtual images cannot.

**Objectives**
- **Demonstrate** the formation of images from a convex lens.
- **Define** the characteristics of the images formed by a convex lens.
Procedure

A. Focal Length of a Convex Lens

To find the focal length of the convex lens, arrange your lens, meterstick, and screen as shown in Figure B. Point the lens at a distant object and move the screen back and forth until you obtain a clear, sharp image of the object on the screen. A darkened room makes the image easier to see. Record in Table 1 your measurement of the focal length. Compute the distance 2F and record this value in Table 1.

B. Images Formed by a Convex Lens

1. Arrange the apparatus, as shown in Figure C. Place the light source somewhere beyond 2F on one side of the lens and place the screen on the opposite side of the lens. Move the screen back and forth until a clear, sharp image forms on the screen. Record in Table 1 the height of the light source (object), \( h_o \). Record in Table 2 your measurements of \( d_o, d_i, \) and \( h_i \) and your observations of the image.

2. Move the light source to 2F. Move the screen back and forth until a clear, sharp image forms on the screen. Record in Table 2 your measurements of \( d_o, d_i, \) and \( h_i \) and your observations of the image.

3. Move the light source to a location between F and 2F. Move the screen back and forth until a clear, sharp image forms on the screen. Record in Table 2 your measurements of \( d_o, d_i, \) and \( h_i \) and your observations of the image.

4. Repeat step 3 at a different position between F and 2F.

5. Move the light source to a distance F from the lens. Try to locate an image on the screen. Record your observations in Table 2.
6. Move the light source to a position between F and the lens. Try to locate an image on the screen. Look through the lens at the light source and observe the image. Record your observations in Table 2.

**Data and Observations**

<table>
<thead>
<tr>
<th>Name</th>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Table 1</th>
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<tbody>
<tr>
<td>Focal length, $f$</td>
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<td>2F</td>
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<td>Height of light source, $h_0$</td>
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</table>

<table>
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<th>Table 2</th>
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</thead>
<tbody>
<tr>
<td>Position of Object</td>
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<tr>
<td>-----------</td>
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<tr>
<td>$d_0$</td>
</tr>
<tr>
<td>$d_i$</td>
</tr>
<tr>
<td>$h_i$</td>
</tr>
<tr>
<td>Type of image: real, none, or virtual</td>
</tr>
<tr>
<td>Direction of image: inverted or erect</td>
</tr>
</tbody>
</table>

**Analysis and Conclusions**

1. Use the data from Table 2 to summarize the characteristics of images formed by convex lenses in each situation.

   a. The object is beyond 2F:

   

   b. The object is at 2F:

   

   c. The object is between 2F and F:

   


**Physics Lab 18-1**

**d.** The object is at F.

**e.** The object is between F and the lens.

2. For each of the real images you observed, calculate the focal length of the lens, using the lens/mirror equation. Do your values agree with each other?

3. Average the values for $f$ found in question 2 and calculate the relative error between this average and the value for $f$ from Table 1.

**Extension and Application**

1. Use two identical, clear watch glasses and a small fish aquarium to investigate an air lens. Carefully glue the edges of the watch glasses together with epoxy cement or a silicone sealant so that the unit is watertight. Attach the air lens to the bottom of an empty fish aquarium with a lump of clay and place an object nearby, as shown in **Figure D**. Observe the object through the lens and record your observations. Predict what will happen when the aquarium is filled with water and light passes from a more dense medium to a less dense one as it passes through the air lens. Fill the aquarium with water and repeat your observations. Compare the two sets of observations. Explain your results. What would you expect if you used a concave air lens? Design and construct a concave air lens to test your hypothesis.

2. The movement of reflected laser light relative to an observer’s moving head can be used to determine nearsightedness or farsightedness. Observers should remove their glasses or contact lenses. In a darkened room, use a concave lens to expand the beam diameter of a laser to project a large spot on a screen. Observers should move their heads from side to side while looking at the spot. Each student should record the direction in which the reflected speckles of laser light appear to move and the direction in which his or her head is moving. Then observers should replace their glasses or contact lenses and repeat their observations.
How does light bend?

Light travels at different speeds in different media. As light passes at an angle from one medium to another, it changes direction at the boundary between the two media. The index of refraction of a medium, \( n \), is the ratio of the speed of light in a vacuum, \( c \), to its speed in the substance, \( v \).

\[
    n = \frac{c}{v}
\]

When light enters a medium with a higher index of refraction than the medium it is leaving, it bends toward the normal. When light enters a medium with a lower index of refraction than the medium it is leaving, it bends away from the normal. This change of direction of light at the boundary of two media is called refraction.

For any light that is traveling from one medium of index of refraction \( n_1 \), at angle of incidence \( \theta_1 \), to another medium of index of refraction \( n_2 \), Snell’s law of refraction describes the angle of refraction, \( \theta_2 \), experienced by the light.

\[
    n_1 \sin \theta_1 = n_2 \sin \theta_2
\]

For air, the index of refraction is equal to 1, because the speed of light in air is nearly equal to the speed of light in a vacuum. Whenever air is the medium of incidence of the light, Snell’s law can be simplified.

\[
    n_2 = \frac{\sin \theta_1}{\sin \theta_2}
\]

In this lab, you will measure the angle of refraction of light in a glass slab for a number of different angles of incidence. You then will calculate the index of refraction of the glass. Finally, you will compare the index of refraction for each angle of incidence to verify that it is a constant.

Objectives

- **Draw** ray diagrams to model the refraction of light from air into glass.
- **Deduce** whether the index of refraction for a material is a constant.
- **Infer** from experimental data whether refraction is reversible.

Procedure

**A. Setup**

1. Place a glass slab in the center of a sheet of paper. Using a pencil, trace the outline of the slab. Then remove the glass slab from the paper.
2. Using a protractor and a pencil, mark a dot at a point that is 90° from the long side of the outline on the left of the upper side of the outline, as shown in Figure A. Label the dot as \( N_1 \). Label the point on the side of the outline at the center of the protractor as \( B \). Using a ruler and a pencil, draw a dashed line from point \( N_1 \) to point \( B \). This is the normal to the surface of the glass slab. Continue drawing the dashed normal across to the other side of the outline. Label the point where the normal connects with the other side of the outline as \( N_2 \).

![Figure A](image)

3. Using a protractor and a pencil, mark a dot at a point that is 30° from the normal that you drew in step 2. Label the dot as \( A \).

4. Using a ruler and a pencil, draw a straight line segment between points \( A \) and \( B \).

5. Label the angle \( ABN_1 \) as \( \theta_1 \).

6. Attach the sheet of paper to the corkboard with thumb tacks. Stick two pins through the paper at points \( A \) and \( B \) and into the corkboard, as shown in Figure B.

B. Measure Refraction

1. Replace the glass slab in the outline on the paper.

2. Hold the ruler on edge on the paper on side of the glass slab opposite the pins, and sight along the edge of the ruler at the images of the two pins through the glass slab, as shown in Figure B. When the images of the two pins and the edge of the ruler are lined up, draw a line segment along the ruler toward the glass slab. Remove the glass slab and continue the line until it meets with the outline of the glass slab. Label the point where the line meets the outline as \( C \). Label the farthest point along this line from the outline as \( D \).
3. Using the ruler and a pencil, draw a line segment that connects points B and C. Label the angle \( \angle CBN_2 \) as \( \theta_2 \).

4. Using a protractor, measure the angle \( \theta_2 \). Record this angle in Table 1 for the 30° angle of incidence.

5. Using the same process as in step A3 and placing the center of the protractor at point C, draw a dashed line that is normal to the outline, labeling the point on the normal as \( N_2 \). Label the angle \( \angle DCN_2 \) as \( \theta'_2 \).

6. Using a protractor, measure the angle \( \theta'_2 \). Record this angle in Table 1 for the 30° angle of incidence.

C. Repeat for Various Angles

1. Repeat parts A and B of this lab for five more angles of incidence of your own choosing. Use a different sheet of paper for each trial. Record the results in Table 1.

Data and Observations

<table>
<thead>
<tr>
<th>Trial</th>
<th>( \theta_1 ) (degrees)</th>
<th>( \theta_2 ) (degrees)</th>
<th>( \theta'_2 ) (degrees)</th>
<th>sin ( \theta_1 )</th>
<th>sin ( \theta_2 )</th>
<th>( n_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td></td>
<td></td>
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<td>5</td>
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<td>6</td>
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</tbody>
</table>

Analysis and Conclusions

1. Classify the bending of light as exhibited by the ray diagrams that you drew for each trial. According to your diagrams, is light refracted away from or toward the normal as it passes at an angle into a medium with a higher index of refraction? Is light refracted away from or toward the normal as it passes at an angle into a medium with a lower index of refraction?

2. Calculate \( \sin \theta_1 \) and \( \sin \theta_2 \) for each trial. Record the results in Table 1.
3. Calculate $n_2$ for each trial. Record the results in Table 1.

4. Compare the values for index of refraction of glass for each trial. Is there good agreement between them? Would you conclude that index of refraction is a constant for a given medium?

---

**Extension and Application**

1. Compare the values of $\theta_1$ and $\theta_2$, for each trial. Is there a relationship between the two? If so, what does this indicate?

2. Substitute the average value of the index of refraction that you measured in this lab into the equation for index of refraction and calculate the speed of light in the glass.

3. What if you conducted this experiment under water. Compare and contrast the results you get in such a situation to the results you have from this lab.

4. When people read the word *bend*, many visualize a bend or a curve in a road. How would you explain to another the meaning of the word *bend* when used to describe the refraction of light?
Materials

- clear lightbulb with vertical filament
- double-slit slide
- meterstick
- narrow-slit slide
- pencil
- red, yellow, and violet filters
- metric tape measure
- low-power laser

Safety Precautions

What is the wavelength?

In 1801, Thomas Young demonstrated that light falling on two closely spaced slits passes through the slits and is diffracted. The spreading coherent light from the two slits overlaps and produces an interference pattern on a screen: a number of dark and bright bands in an alternating sequence. The bright bands are of about equal width and are approximately evenly spaced. Bright bands appear where constructive interference occurs, and dark bands appear where destructive interference occurs.

When the positions of the bright bands are related to the positions of the slits, it is evident that there is one bright band lined up with the slits, and equal numbers of bright bands on either side of this central bright band. The first bright band on each side of the central bright band is known as the first-order band. This band is bright because the path lengths of light waves arriving from each slit differ by one wavelength. The next bright bands out from the first-order bands are known as the second-order bands. Several bright bands are visible on either side of the central bright band. The number of bright bands will vary depending upon slit width and slit separation.

The distance between bright bands, $x$, depends on the wavelength of light, $\lambda$, the slit separation, $d$, and the distance from the slits to the screen, $L$. This relationship often is written in a form that can be used to determine the wavelength of a light source by experiment with a double slit.

$$\lambda = \frac{xd}{L}$$

In this lab, you will use a double slit to determine the wavelengths of various colors of light. Because double slits that produce good experimental results are too close together to measure with the necessary precision, you will use a laser of known wavelength to determine the slit separation distance. Finally, you will shine light of different colors through the double slit, measure the distance between the bright lines, and use these data to calculate the wavelength of the light.

Objectives

- Use a laser to determine the slit separation distance of a double slit.
- Adapt the double-slit experiment to use a lightbulb as the source of light.
- Relate double-slit interference pattern spreads to diffraction and wavelength.
Procedure

A. Gather Data for Slit Separation Distance

CAUTION: Avoid staring directly into a laser beam. Always wear ANSI-approved laser protective eyewear when working with lasers.

1. Set up a He-Ne laser or a laser pointer to shine light through a double slit onto a white screen. Position the double slit far enough away from the screen to obtain a measurable distance between bright bands in the interference pattern. The value of wavelength for He-Ne laser light is \(6.328 \times 10^{-7}\) m. The value of wavelength for a laser-pointer light is \(6.70 \times 10^{-7}\) m. Record the applicable value in Table 1 in the “Known Wavelength” column.

2. Count the number of bright bands that are visible. Record this value as the Number of Bright Bands in Table 1.

3. Using a meterstick, measure the distance between the bright bands at either end of the pattern. Record this value as the Pattern Spread Distance in Table 1.

4. Use the tape measure to determine the distance from the double slit to the white screen. Record this value as the Screen Distance in Table 1.

B. Gather Data on Unknown Wavelengths

1. Set up a clear light with a vertical filament behind a narrow slit, as shown in Figure A. Place a red filter between the lightbulb and the narrow slit. Place a meterstick flat on the table in front of the single slit.

2. Turn on the lightbulb behind the single slit. Dim the classroom lights.

3. Have one lab team member stand 1 m from the light and look through the double slit you used in part a at the light shining through the narrow slit. Record your observations in Table 2.

4. Move several meters away from the light and look through the double slit at the light shining through the narrow slit. Record your observations in Table 2.

5. Move up to 4 m from the light while still being able to see a bright interference pattern through the double slit. Count the number of bright bands that are visible. Record this value as the Number of Bright Bands in Table 3.
6. Using a measuring tape, have a lab team member measure the distance from the single slit to the double slit. Record this value as Virtual Screen Distance in Table 3.

7. While the lab team member with the double slit observes the interference pattern through the double slit, have another lab team member stand behind the light and single slit setup. This team member should hold a pencil vertically just to the right of the single slit with the pencil tip on the meterstick. Have the lab team member with the double slit direct the lab team member with the pencil to slowly move the pencil away from the single slit along the meterstick until the pencil lines up with the last visible bright band on the right. Record the value on the meterstick that the pencil points to as the Rightmost Band Position in Table 3.

8. Repeat step 7 while moving the pencil to the left of the single slit and lining it up with the last visible bright band on the left. Record the value on the meterstick that the pencil points to as the Leftmost Band Position in Table 3.

9. Remove the red filter and repeat steps 5 through 8 with a yellow filter, and then with a violet filter. Record your data in Table 3.

Data and Observations

<table>
<thead>
<tr>
<th>Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wavelength, ( \lambda ) (m)</strong></td>
</tr>
<tr>
<td>---</td>
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<tr>
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</table>

<table>
<thead>
<tr>
<th>Table 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Close</strong></td>
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<tr>
<td>---</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Filter Color</strong></td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>Red</td>
</tr>
<tr>
<td>Yellow</td>
</tr>
<tr>
<td>Violet</td>
</tr>
</tbody>
</table>
Analysis and Conclusions

1. Describe how the double-slit pattern changes as you move farther from the light source.

2. Calculate the distance between bright bands, \( x \). Divide the pattern spread distance, \((N - 1)x\), by the number of bright bands minus 1, \(N - 1\). Record the results in Table 1.

3. Calculate the slit separation distance, \( d \), by using the equation for wavelength from double-slit experiment. Record the results in Table 1.

4. Calculate the distance between bright bands, \( x \), for each color and record the results in Table 3. Use the following equation:

\[
x = \frac{|P_n - P_{n+1}|}{N - 1}
\]

5. Calculate the wavelength, \( \lambda \), for each color, using the equation for wavelength from the double-slit experiment and the value for \( d \) in Table 1. Record the results in Table 3.

6. Compare your experimental values of wavelength with known values for these colors. Draw a conclusion on the usefulness of the double slit to determine light wavelength.

Extension and Application

1. Make an association between the pattern spread for each color and diffraction. Which color of light is diffracted the most as it passes through the double slit? Provide a reason for your answer.
What is a hologram?

One unique application of lasers is the production of holograms. Holograms are three-dimensional images or photographs produced by interference of coherent light. Two primary types of holograms are reflection and transmission. Transmission holograms have great depth and clarity. They are produced when a laser beam is split into two parts. One part of the beam reflects off the object being photographed and strikes the holographic film, while the other falls directly on the film. The two superimposed beams form an interference pattern, which is recorded on the film. The film picks up the varying intensity of the interference pattern. When the developed film is viewed, it is illuminated from behind by a coherent light beam of the same wavelength used to expose the film. The viewer looks at the light being transmitted through the film and sees a three-dimensional virtual image behind the film.

Most of you have seen a white-light reflection hologram, such as those on cereal boxes, on credit cards, and in magazines. Reflection holograms are created when laser light goes through a transparent photographic film and reflects off an object back onto the film. The transmitted light and the reflected light create an interference pattern on the film, which, when developed and viewed using reflected light, looks like a three-dimensional picture of the object. In this lab, you will make a reflection hologram.

Objectives

- Produce a hologram using the interference of coherent light.
- Describe how a color reflection hologram results when using black-and-white film.
- Compare reflection holograms, transmission holograms, and color photographs.

Procedure

A. Setup

1. Place the foam packing material, or other material designed to dampen vibration, on the lab table in a rectangular pattern. Place a concrete paving piece on the foam.

2. Place a small concave mirror in the helping hand. Place the helping hand on the concrete paving piece, as shown in Figure A.
3. Place the following objects on the concrete paving piece: a stopwatch; a holographic film container; a piece of black paper; four small piles of disk magnets; a precut card; and some small metal objects, such as coins and keys. Do not worry about arranging them yet.

**CAUTION:** *Avoid staring directly into a laser beam. Always wear laser protective eyewear approved by ANSI when working with lasers.*

4. Place the He-Ne laser on an adjacent table. Before turning on the laser, adjust the position of the concave mirror so that it will reflect the laser light down at the concrete paving piece. Turn on the green safelight and turn off the classroom lights. Turn on the laser and direct the beam onto the mirror. Adjust the mirror as necessary to ensure that the reflected, expanded beam from the laser is directed down onto the concrete paving piece. Move the small green light to a location so that it provides just enough light to see the concrete paving piece in the darkened room.

5. Position the small metal objects in the illumination of the laser light on the concrete paving piece. Arrange the four small piles of disk magnets around the metal objects with the precut card laid across the top of the piles, so that the four piles support the precut card at the four corners of the card. These will be supports for the holographic film. Adjust the height of the magnet supports so that the index card is just above the metal objects but not touching them. Remove the precut card.

**B. Make a Reflection Hologram**

1. Using the black paper, have one lab team member block the laser beam on the upstream side of the concave mirror. Have a second lab team member prepare the stopwatch for timing the exposure of the film. A third lab team member carefully opens the film container and removes one holographic film plate. Hold the plate by its edges. Do not touch the center of the film. A fourth lab team member closes and reseals the remaining plates in the light-tight container.

2. Place the holographic film plate on the magnet supports with the emulsion side facing down. Your teacher has marked the emulsion side of the plate.

3. During the exposure of the holographic film, all students in the room should not walk around or touch any tables. This will minimize vibrations. The lab team members that are blocking the laser light and holding the stopwatch will time the exposure of the film to the laser light. Start timing the exposure from the moment the black paper is pulled out of the path of the laser beam. After 20 s, or a time dictated by your teacher, use the black paper to block the laser light to stop the film exposure. Take the holographic film plate to your teacher for developing. Turn off the laser.
4. When all lab teams have completed the lab and your teacher has developed all of the film, turn on the classroom lights and turn off the green safelight. When your developed hologram is dry, hold it up to an overhead light and look through it. Record your observations in Table 1.

5. Place a black background against the glass. Look at your hologram in front of a bright white light, such as that of an overhead projector, so that the light reflects off the front of the hologram. Record your observations in Table 1.

6. Wash your hands with soap and water when you are done handling the hologram.

Data and Observations

<table>
<thead>
<tr>
<th>Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Looking through hologram</td>
</tr>
<tr>
<td>Looking at reflection</td>
</tr>
</tbody>
</table>

Analysis and Conclusions

1. Explain the purpose of using foam and a heavy concrete paving piece for the lab setup.

2. Compare your observations of the hologram in Table 1. How do you account for the different observations?

3. Compare your hologram with an ordinary photograph in your textbook.

4. Identify the cause-and-effect relationship associated with obtaining a color hologram using black-and-white film.
Extension and Application

1. Use the top view shown in Figure B to make a transmission hologram. Place the helping hand with the concave mirror low to the concrete paving piece such that the expanding laser light beam is directed along the surface of the concrete paving piece. Use some large binder clips to hold the plane silvered mirror and the holographic film plate perpendicular to the surface of the concrete paving piece. After your teacher develops the film, remove the object from the concrete paving piece, place the developed film in its original location, and look through the film, as shown in Figure B. CAUTION: Never look directly into the laser source or into an unexpanded beam. Always wear approved, laser protective eyewear.

Describe your transmission hologram and compare it to the white-light reflection hologram you made previously. Compare the usefulness of both types of holograms.
How can you charge it up?

Clothes removed from the clothes dryer usually cling to each other and spark and crackle with static electricity when you separate them. When two dissimilar materials rub together, they can become charged. Objects acquire a charge by either gaining or losing electrons. An object that gains electrons has a net negative charge. For example, a hard rubber rod rubbed with wool becomes negatively charged. An object that loses electrons has a net positive charge. For example, a glass or acrylic rod rubbed with silk becomes positively charged. Only those objects separated from being grounded to Earth by an insulator will retain their charge for any length of time. Objects that are grounded, or hooked to Earth by a conductor, remain uncharged since the charge travels into the ground and quickly dissipates.

Objectives

- **Demonstrate** that static charges can be separated by contact.
- **Demonstrate** that opposite charges attract and like charges repel.
- **Infer** the type of charge produced on various materials.
- **Compare** the type of charge produced on an object by induction and conduction.

Procedure

Perform each part of the experiment several times to be sure you have made proper observations of the phenomena. If you are using glass rods they must be rubbed vigorously and do not retain charge well in humid weather.

A. Negatively Charging a Pith Ball

1. Rub the hard nylon rod with the wool pad to charge it. Bring the rod close to, but not touching, a suspended pith ball, as shown in Figure A. Touch the pith ball with your finger, which is nearly the same as grounding it, to remove any charge it may have.

2. Charge the nylon rod again. Bring it close to the pith ball and allow it to touch the ball. Then bring the charged rod near the charged ball and observe the behavior of the ball. Record your observations in Table 1.

---

**Materials**

- hard nylon rod
- plastic (acrylic) or glass rod
- wool pad
- silk pad
- fur
- pith ball suspended from holder by silk thread
- leaf or vane electroscope
- electrophorus
- neon bulb (NE-1 or NE-2)
B. Positively Charging a Pith Ball

1. Rub the plastic rod with a piece of silk to charge it. Bring the rod close to, but not touching, a suspended pith ball. Observe the behavior of the pith ball and record your observations in Table 2. Touch the pith ball with your finger to remove any charge.

2. Charge the rod again. Bring it close to the pith ball and allow it to touch the ball. Then bring the charged rod near the charged ball and observe the behavior of the pith ball. Record your observations in Table 2.

C. Charging an Electroscope by Conduction

1. Charge the nylon rod with the wool. Slowly bring it in contact with the metal top of the vane electroscope shown in Figure B. The electroscope is now negatively charged. Observe what changes occur in the electroscope as the charged rod is brought nearer or moved farther away. Record your observations in Table 3.

2. Recharge the electroscope negatively if it has discharged. Charge the plastic rod and bring it near the top of the electroscope. Observe what changes occur as the positively charged rod is brought nearer or moved farther away. Record your observations in Table 3. Discharge the electroscope by momentarily touching the top plate with your finger.

D. Charging an Electroscope by Induction

1. Select one of the rods and charge it. Bring it within 1–2 cm of, but not touching the electroscope. Observe the vane. Record your observations in Table 4.

2. With the charged rod near the electroscope, momentarily touch the top of the electroscope with your finger. After your finger has moved away, remove the charged rod. Observe the electroscope vane. Record your observations in Table 4.

3. Following the procedure from part c, determine the type of charge on the electroscope. Record your observations in Table 4.

Data and Observations

<table>
<thead>
<tr>
<th>Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observations of pith ball with nearby charged object:</td>
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<tr>
<td>Observations of pith ball after it has been touched with a charged rod:</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2</th>
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<tbody>
<tr>
<td>Observations of pith ball with nearby charged rod:</td>
</tr>
<tr>
<td>Observations of pith ball after it has been touched with a charged rod:</td>
</tr>
</tbody>
</table>
Analysis and Conclusions

1. Summarize your observations of negatively charging a pith ball.

2. Summarize your observations of positively charging a pith ball.

3. Compare the negative and positive charging of a pith ball.

4. Summarize your observations of charging by conduction.
5. Using your observations from part c, explain why the vane remained apart when you removed the charged rod.

________________________________________________________________________

________________________________________________________________________

6. Why did the electroscope vane move in part d and what type of charge did the electroscope receive?

________________________________________________________________________

________________________________________________________________________

Extension and Application

1. An electrostatic air filter sometimes is used to filter the air in heating systems for buildings. In this device air passes between a number of thin metal plates or wires that are attached to a source of high voltage that generates a static charge on the plates. Dust, dirt, and pollen are attracted to the plates or wires, thus, being removed from the air. Explain why the particles are attracted to the plates or wires, and what advantage this type of filter might have over an ordinary mechanical filter.

________________________________________________________________________

________________________________________________________________________

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________________________________________________________________________
How can large amounts of charge be stored?

Capacitors store energy in an electric field. Charges are stored on each plate of the capacitor. As charge is stored on the plates, the potential difference between the plates increases. The ratio of the charge, \( q \), stored on the plates to the electric potential difference, \( \Delta V \), between the plates is a constant called the capacitance, \( C \). Thus,

\[
C = \frac{q}{\Delta V}
\]

The greater the capacitance, the larger the amount of charge that can be stored for a given potential difference moving the charge onto the capacitor. Capacitors are designed to have a specific capacitance. Each capacitor has two conductors separated by an insulator. Capacitors typically found in computers and electronic devices have capacitances measured in microfarads. However, the capacity of commercial capacitors ranges from picofarads to farads. The capacitors used in this experiment have a very large capacitance, 1 farad.

In this experiment you will be investigating the ability to store energy in capacitors wired in networks—wired in both parallel and series arrangements. Rather than use a battery or power supply as an energy source, you will be the energy source turning a hand-cranked generator.

Objectives

- **Demonstrate** the storage of electric charge in capacitor networks.
- **Observe** the discharge of capacitor networks through an LED.
- **Infer** the most effective capacitor network arrangement for electric charge storage.

Procedure

1. Wire the hand-operated generator in series with a switch, indicated by a tilted line; milliammeter, represented by a circle with mA inside; and a 1-F capacitor, represented by two parallel lines, as shown in Figure A. Leave the switch open at this time.
Close your switch and observe the milliammeter while you turn the generator handle just a partial turn. If the meter needle moves backward (to the left), reverse the connecting leads to the generator. If the meter needle moves to the right when the generator handle was turned, then the circuit is wired correctly. Open the switch.

2. Close the switch. Begin cranking the generator. Observe the current flowing onto the capacitor. Crank the generator for 30 s, open the switch, and stop cranking. When the switch was opened, did you notice a change in resistance necessary to turn the generator? Record the current in Table 1.

3. Disconnect the generator and milliammeter. As shown in Figure B, wire an LED to the switch and capacitor connecting one end to the switch and one end to the capacitor.

![Figure B](image)

Close the switch and observe the LED. Use your stopwatch to time how long it stays bright. If the LED does not light, open the switch and reverse the connections to the LED and repeat this step. Record the time in Table 1. Does the LED stay on or turn off? Record your observation in Table 1. Open the switch and disconnect the LED.

4. Reattach the milliammeter and hand-crank generator and add a second 1-F capacitor in parallel as shown in Figure C.

![Figure C](image)

Repeat the procedure used in step 2 and record the current in Table 2.

5. Disconnect the generator and milliammeter. Wire an LED to the switch and capacitors, as shown in Figure D.

![Figure D](image)

Use the procedure from step 3 to observe the LED. Record the time and your observations in Table 2. Open the switch and disconnect the LED.
6. Reattach the milliammeter and hand-crank generator and change the arrangement of the second capacitor such that the two capacitors are in series, as shown in Figure E.

![Figure E]

Repeat the procedure used in step 2 and record the current in Table 3.

7. Disconnect the generator and milliammeter. Wire an LED to the switch and capacitors, as shown in Figure F.

![Figure F]

Use the procedure from step 3 to observe the LED. Record the time and your observations in Table 3. Open the switch and disconnect the LED.

8. Disconnect the components and return the materials to the location specified by your teacher.

**Data and Observations**

<table>
<thead>
<tr>
<th>Table 1 – Single 1-F Capacitor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current onto capacitor (mA)</td>
</tr>
</tbody>
</table>

Observation of LED:

<table>
<thead>
<tr>
<th>Table 2 – Two 1-F Capacitors in Parallel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current onto capacitors (mA)</td>
</tr>
</tbody>
</table>

Observation of LED:
Analysis and Conclusions

1. Which circuit arrangement required the least work to charge?

2. Which circuit arrangement required the most work to charge?

3. Suggest an explanation for why the amount of work or effort needed to crank the generator, in order to charge the capacitor(s), changed.

4. Which circuit arrangement stores the most charge? Explain your reasoning.

Extension and Application

1. Some electronic devices, such as a computer memory board, have a large value capacitor wired to the circuit board power supply. What purpose would this capacitor serve?

2. Instantaneous power surges, such as those accompanied by a significant bass sound from a CD in a car stereo, can cause the lights to dim and momentary distortion on high-powered amplifiers. Typically, car audio installers recommend a minimum of one 1-F capacitor per 1000 W of music power to supply the necessary instantaneous power. In the space below, draw the circuit arrangement to be used if you wanted to install three 1-F capacitors in your car.

3. What quantity of charge is stored in a 3.0-F capacitor charged to 14.7 V?
Is energy conserved in heating water?

The law of conservation of energy states that energy changes from one form to another without loss or gain. This means that a given amount of energy in one form is exactly the same amount of energy in any other form. In the experiment that follows, electric energy flows from a source through a heating coil. The heating coil converts the electric energy into thermal energy. The thermal energy from the heating coil is transferred to a mass of water and the temperature of the water increases.

In this experiment, you will determine whether energy is conserved when it is converted from electric energy to thermal energy. You will measure the amount of electric energy converted into thermal energy by means of an electric heating coil (a resistor) immersed in water. You will also measure the amount of thermal energy absorbed by a known mass of water.

How do you measure the amount of energy delivered to the heating coil? The electric energy delivered to the heating coil is \( E = IVt \), where \( E \) is the energy in joules, \( I \) is the current in amperes, \( V \) is the potential difference in volts, and \( t \) is the time in seconds. How do you measure the energy transferred to the water? The energy transferred from the coil to the water is \( Q_w = m_wC_w\Delta T_w \), where \( Q \) is the thermal energy in joules, \( m_w \) is the mass of the water, \( C_w \) is the specific heat of water, and \( \Delta T_w \) is the temperature change of the water. The polystyrene foam cup, used as a calorimeter, has very little mass and a very low specific heat. It will not absorb enough thermal energy to have a significant effect on the experiment.

To minimize the effect of heat loss to the atmosphere, warm the water to as many degrees above room temperature as it was below room temperature before heating started. Thus, if you start with water at 10°C and room temperature is 20°C, the final temperature of the water should be 30°C. In this way, any heat gained from the surroundings while the temperature is below room temperature is likely to be offset by an equal heat loss while temperature is higher than room temperature.

Objectives
- **Demonstrate** the law of conservation of energy.
- **Measure** and compare quantities of electric energy and thermal energy.
- **Calculate** the experimental error.
Procedure

1. Measure the mass of a polystyrene foam cup and record this value in Table 1. Record the room temperature.

2. Fill the cup about two-thirds full of cold water. Measure the mass of the cup plus water. Record this value in Table 1. Calculate and record the mass of the water.

3. Set up the circuit, as shown in Figure A. If you have an adjustable power supply, the potentiometer is built in, rather than separate. If the coil is not immersed, add more water and repeat step 2. After the teacher has checked your circuit, close the switch. Quickly adjust the power supply or potentiometer until the current flow is 2–3 A. Open the switch at once.

4. Stir the water gently. Use the thermometer to read the initial temperature of the water. Record this value in Table 1.

5. Prepare to time your readings. Close the switch. At the end of each minute, read the ammeter and voltmeter readings and record these values in Table 2. Gently stir the water from time to time and, if necessary, make any adjustments to maintain a constant current flow.

6. Monitor the water temperature to determine when it is approximately as many degrees above room temperature as it was below room temperature at the beginning of the experiment. At the end of the next minute after this temperature is reached, open the switch.

7. Stir the water gently until it reaches a constant temperature. Record the final temperature of the water in Table 1. Compute and record the change in temperature of the water.

8. Determine the average current and the average voltage. Record these values in Table 1.

Figure A

(a) A commercial calorimeter is similar to the polystyrene cup calorimeter in your experiment. The heating coil changes electric energy to thermal energy that is transferred to the water.

(b) Circuit diagram of the apparatus.
Data and Observations

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Table 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of polystyrene foam cup</td>
<td>Time (min)</td>
</tr>
<tr>
<td>Mass of water and cup</td>
<td>Current (A)</td>
</tr>
<tr>
<td>Mass of cold water</td>
<td>Voltage (V)</td>
</tr>
<tr>
<td>Initial temperature of water</td>
<td>1</td>
</tr>
<tr>
<td>Room temperature</td>
<td>2</td>
</tr>
<tr>
<td>Final temperature of water</td>
<td>3</td>
</tr>
<tr>
<td>Change in temperature of water</td>
<td>4</td>
</tr>
<tr>
<td>Average current heater current</td>
<td>5</td>
</tr>
<tr>
<td>Average voltage heater voltage</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>7</td>
</tr>
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<td></td>
<td>8</td>
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<td>14</td>
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<td></td>
<td>15</td>
</tr>
</tbody>
</table>

Analysis and Conclusions

1. Determine the electric energy expended in the resistance, using \( E = IVt \).

2. Determine the heat absorbed by the water, using \( Q_w = m_wC_w\Delta T_w \) where \( C_w \) is 4.18 J/g°C.
3. Find the relative difference between the electric energy expended and the thermal energy absorbed by the water. Use \( \% \text{ difference} = \left( \frac{E - Q_w}{E} \right) \times 100 \).

4. Suggest reasons why the energy difference in question 3 is not zero. Take into account the parts of the apparatus you used and any other sources of energy loss.

5. Were your results close enough to indicate that, under ideal conditions, you would find exact agreement in the energy exchange? Give a reason for your answer.

6. What percentage of the electric energy was converted to thermal energy in the water?

**Extension and Application**

1. Think about using the conversion of gravitational potential energy to thermal energy in order to heat water for showers. Assume that 1.0 L of water (1.0 kg of water), initially at 12.7°C, falls over a 50.0-m waterfall. If all of the potential energy of the water is converted to kinetic energy as the water is falling, and the kinetic energy is converted into thermal energy when it reaches the bottom, what temperature difference exists between the bottom and the top of the waterfall? Will this be sufficient to produce a warm shower? Show your calculations.

2. An electric immersion heating coil is used to bring 180.0 mL of water to a boil for a cup of tea. If the immersion heater is rated at 200 W, find the time needed to bring this amount of water, initially at 21°C, to the boiling point. Show your calculations.

3. Of the electric energy used by a 100-W incandescent lightbulb, 16 percent is converted to light. How many joules of thermal energy dissipate each second?
How do parallel resistors work?

A parallel circuit has two or more devices connected so that all the devices are independently connected to a source of voltage. If all of the devices are resistors, then you have a parallel resistance circuit. When resistors are connected in parallel, each resistor provides a path for current and each element has the same applied potential difference.

In Figure B, three resistors are connected in parallel across the voltage source. The current can pass from junction a to junction b along three paths. More current will flow between these junctions than would flow if only one or two resistors connected them. For this circuit, the total current, $I$, is represented by the following equation.

$$I = I_1 + I_2 + I_3$$

Each time another resistance is connected in parallel with other resistors, the equivalent resistance changes. The equivalent resistance of resistors in parallel can be determined by the following equation.

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

In this experiment, you will measure current and voltage with resistors in parallel and apply the relationship $R = \frac{V}{I}$ to verify your results. Follow closely the circuit diagrams in Figures A and B, but because you probably have only one ammeter and one voltmeter, you must move the meters from position to position to get your readings. For example, take the total current ($A$) and total voltage ($V$) readings, then move the meters to positions $A_1$, and $V_1$, and so on. For your calculations, convert milliampere readings to amperes ($1 \text{ mA} = 0.001 \text{ A}$).

The resistors in these circuits are connected in parallel. Note the positions of the voltmeter and ammeter in relation to the resistors.
Objectives
- Measure the current in each resistor in a parallel circuit.
- Compare the total current in a parallel circuit to the current in each resistor.
- Calculate the equivalent resistance of a parallel resistance circuit.
- Infer the difference in the equivalent resistance of a circuit after adding resistors.

Procedure
A. Two Resistors
1. Set up the circuit, as shown in Figure A. Close the switch. Adjust the power supply to a set voltage on the voltmeter, such as 3.0 V. Read the current value on the ammeter. Open the switch. Record your readings in Table 1.
2. Move the meters to get the other readings. Record the readings in Table 1.

B. Three Resistors
1. Set up the circuit, as shown in Figure B. Close the switch, adjust the power supply to the same voltage as in part A, and read the meters. Open the switch. Record the readings in Table 2.
2. Move the meters to get the other readings. Record the readings in Table 2.

C. Four Resistors
1. Set up the circuit with the unknown resistor wired in parallel with the three resistors from step B. Place the meters to obtain the total current in the circuit and the voltage across the circuit. Close the switch, adjust the power supply to the same voltage as in step A, and read the meters. Open the switch. Record the readings in Table 3.
2. Move the meters to obtain the voltage across and the current in the unknown resistor. Close the switch, adjust the power supply to the same voltage as in step A, and read the meters. Open the switch. Record the readings in Table 3.

Data and Observations

<table>
<thead>
<tr>
<th>Table 1</th>
<th>$R_1$ (Ω)</th>
<th>$R_2$ (Ω)</th>
<th>Ammeter Reading (mA)</th>
<th>Voltmeter Reading (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>$I$</td>
<td>$I_1$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2</th>
<th>$R_1$ (Ω)</th>
<th>$R_2$ (Ω)</th>
<th>$R_3$ (Ω)</th>
<th>Ammeter Reading (mA)</th>
<th>Voltmeter Reading (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$I$</td>
<td>$I_1$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Ammeter Reading (mA)</th>
<th>Voltmeter Reading (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$I$</td>
<td>$I_U$</td>
</tr>
</tbody>
</table>
Analysis and Conclusions

1. Use data from Table 1 to calculate the following values:
   a. the measured equivalent resistance, $R$, of the circuit where $R = \frac{V}{I}$.
   b. the current, $I_1 + I_2$.
   c. the equivalent resistance, $R$, where $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$.

2. a. Compare the current sum, $I_1 + I_2$, to the measured current, $I$.

   b. Compare the calculated equivalent resistance to the measured equivalent resistance.
   Are they equal? If not, what factors might be responsible for any difference in the values?

3. Use data from Table 2 to calculate the following:
   a. the measured equivalent resistance, $R$, of the circuit where $R = \frac{V}{I}$.
   b. the equivalent resistance, $R$, where $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$.

4. a. Compare the value of $I$ to the measured current sum, $I_1 + I_2 + I_3$.

   b. Compare the calculated equivalent resistance to the measured equivalent resistance. Are they equal? If not, what factors might be responsible for any difference in the values?
5. As more resistors are added in parallel to an existing circuit, what happens to the total circuit current? To the equivalent resistance?

6. Use the data from Table 3 to test your predictions from question 5. How did the total circuit current change? How did the equivalent resistance change?

7. Use the data from Table 3 to calculate the value of the unknown resistor.

Extension and Application

1. Tom has a sensitive ammeter that needs only 1.000 mA to provide a full-scale reading. The resistance of the ammeter coil is 500.0 Ω. He wants to use the meter for a physics experiment that needs an ammeter that can read 1.000 A. He has calculated that an equivalent resistance of 0.5000 Ω will produce the necessary voltage drop of 0.5000 V \( (V = IR = 1.000 \times 10^{-3} \ A \times 500.0 \ \Omega) \), so that only 1.000 mA of current passes through the meter. What value of shunt resistor, a resistor placed in parallel with the meter, should he use?

2. A voltmeter has resistance and provides a path for current in the circuit being measured. It is often important to know the resistance of the voltmeter, especially when measuring the voltage across a resistor with very little current or a resistor with high resistance. Assume that the current in a circuit is constant and that you want to measure the voltage across a 1000-Ω resistor. Would a voltmeter with a resistance of 10,000 Ω be a good choice? What about a voltmeter with a resistance of 1,000,000 Ω? Give reasons for your answer.
How can a current produce a strong magnetic field?

While experimenting with electric currents in wires, Hans Christian Oersted discovered that a nearby compass needle is deflected when current passes through a wire. This deflection indicates a magnetic field around the wire. You have learned that a compass shows the direction of the magnetic field lines. Likewise, the first right-hand rule determines the direction of the magnetic field: when the right thumb points in the direction of the conventional current, the fingers point in the direction of the magnetic field.

When an electric current is carried through a loop of wire, a magnetic field appears around the loop. A wire that is looped several times forms a coil and a coil has a field like that of a permanent magnet. A coil consisting of many loops is a type of electromagnet called a solenoid. Another type of electromagnet is made by winding the coil around a soft iron core. The magnetic field produced by the current in the wire causes the iron in the core to become a temporary magnet. The magnetic field of the iron core adds to the magnetic field produced by the wire and creates a stronger magnet.

In this lab, you will investigate the magnetic field produced by current-carrying wires using a compass and iron filings. Iron filings show the shape of a magnetic field, but they also show the relative strength of the field. As field strength increases, the iron filing pattern becomes more distinct and the pattern becomes thicker as the filings bunch together.

Objectives

■ Observe the magnetic field around a wire that carries current.

■ Demonstrate the relationship between current and magnetic field strength.

■ Observe the relationship between magnetic field polarity and direction of current.

■ Relate the magnetic field strength of an iron-core coil to that of an air-core coil.

Procedure

A. The Field Around a Long, Straight Wire

1. Place the cardboard at the edge of the lab table. Arrange the wire so that it passes vertically through a hole in the center of the cardboard, as shown in Figure A. Position the ring stand and clamp so that the wire continues vertically from the hole to the clamp. Bring
the wire down the clamp and ring stand to the ammeter, and then to the positive terminal of the power supply.

2. The wire should pass vertically at least 10 cm below the cardboard before running along the table to the knife switch and then to the negative terminal of the power supply. Observe the proper polarity of the power supply and the ammeter as you connect the wires.

3. Close the switch and set the current to 2–3 A. Open the switch. Place the compass next to the wire. **CAUTION:** The wire may become hot. Close the switch long enough to make your observations. Move the compass about the wire to map the field. In Part A of Data and Observations, sketch the field around the wire.

4. Reverse the connections at the power supply and ammeter so that the current will be in the opposite direction. Close the switch and use the compass to map the field around the wire. Sketch the field around the wire.

**B. Strength of the Field**

1. Make a slit and a hole in a piece of paper and put it over the cardboard with the wire at the center. Sprinkle some iron filings on the paper around the wire.

2. Close the switch and set the current to about 4.0 A. Gently tap the cardboard several times with your finger. Turn off the current. In Part B of Data and Observations, record your observations.

3. Tap the cardboard to disarrange the filings. Turn on the current and reduce it to 2.5 A. Gently tap the cardboard several times with your finger. Record your observations.

4. Tap the cardboard to disarrange the filings. Turn on the current and reduce it to 0.5 A. Gently tap the cardboard several times with your finger. Record your observations. Return the iron filings to the container.

**C. The Field Around a Coil**

1. Remove the straight wire from the cardboard. At the center of the wire, make three loops of wire around your hand to form a coil of wire with a diameter of approximately 10 cm. Tape the three loops together at the top, bottom, and each neck of the loops.

2. Connect the coil to the power supply through the ammeter and knife switch. Close the switch and adjust the current to 2.5 A. Hold the wire coil in a vertical plane and bring the compass near the
coil, moving it through and around the coil of wire. In Part C of Data and Observations, sketch the magnetic field direction around the coil. Show the positive and negative connections of your coil.

D. An Electromagnet

1. Uncoil your large loops. Wind loops of wire around the nail or another iron core until about half of the core is covered. Connect the coil to the power supply, knife switch, and ammeter. Close the switch and adjust the current to 1.0 A. Bring the nail near the box of paper clips and see how many paper clips the electromagnet can pick up. Open the switch and record your observations in Part D of Data and Observations.

2. Wind more turns of wire on the iron core to double the number of turns from step 1. Close the switch and see how many paper clips the electromagnet can pick up. Open the switch and record your observations.

3. Increase the current to 2.0 A and see how many paper clips the electromagnet can pick up. Record your observations.

4. Turn the current on and, using the compass, determine the polarity of the electromagnet.

Data and Observations

A. The Field Around a Long, Straight Wire

Observations of direction of north pole:

B. Strength of the Field

Observations of magnetic field with different currents:

C. The Field Around a Coil

Observations of magnetic field around a coil of current-carrying wire:

D. An Electromagnet

1. Several loops of wire on nail:

2. Double the number of loops:

3. Double the number of loops and double the current:
Analysis and Conclusions

1. How does the right-hand rule apply to the current in a long, straight wire?

2. What is the effect of increasing the current in a wire?

3. In Figure B draw the magnetic field direction and the polarities for the current-carrying coil.

4. What three factors determine the strength of an electromagnet?

5. Explain the difference between a bar magnet and an electromagnet.

Extension and Application

1. List several solenoid applications that operate with either continuously applied or intermittently applied currents.
What causes the swinging?

Electromagnetic induction generates an electric current from the relative motion of a conductor in a magnetic field. The third right-hand rule indicates the direction of the induced current. Hold your right hand flat with your thumb pointing in the direction in which the wire is moving and your fingers pointing in the direction of the magnetic field. The palm of your hand points in the direction of the conventional (positive) current.

Michael Faraday invented the electric generator, which converts mechanical energy into electric energy. A generator has a large number of wire loops wound about an iron core, called the armature, which is in a strong magnetic field. As the armature turns, the wire cuts through the magnetic field and an EMF is induced. The \( \text{EMF} = BLv \), where \( B \) is magnetic induction, \( L \) is the length of wire rotating in the field, and \( v \) is the velocity with which the loops move through the magnetic field. An electric motor is the opposite of a generator. In an electric motor, the magnetic field of an electric current, applied to the coil, turns the armature in a magnetic field. Alternately attracted and repelled by fixed magnets, the armature spins, using a magnetic force to convert electric energy to mechanical energy.

Objectives

- Demonstrate the mechanical behavior of a coil of wire in a magnetic field.
- Observe the behavior of two connected coils of wire in magnetic fields.
- Explain the differences between a generator and a motor.
- Infer Lenz’s law from the observations.

Procedure

1. Wind two 120-turn coils of enameled magnet wire around a 100-mL beaker, a toilet-paper tube, or a paper-towel tube. Leave a 50-cm-long wire lead at each end of the coil, coming out about 4 cm apart on the same side of the coil, as shown in Figure A. After winding each coil, carefully slide it off the coil form and wrap several small pieces of tape around the coils so that they maintain their shape.
2. Carefully sand 1 cm of each end of the enameled wires to expose clean copper.

3. Set up a ring stand with a clamp approximately 45 cm above the bottom of the stand. Place the second clamp next to the first one, but pointing in the opposite direction. Hang the coils from the clamps, as shown in Figure B, using a piece of tape to secure the wire leads to the clamps. Position the horseshoe magnets as shown in the figure. Adjust the height of the clamps so that one bar of each horseshoe magnet is in the center of each coil and projects several centimeters through the coil.

4. Use wires to connect one set of coil leads to the leads of the other coil. Swing one of the coils on the horseshoe magnet. Record your observations in item 1 of Data and Observations.

5. Reverse the connections to one coil. Swing one of the coils and observe what happens. Record your observations in item 2 of Data and Observations.

6. Increase the amplitude of the swing of the coil. Record your observations in item 3 of Data and Observations.

7. Disconnect the wires between the coils. Swing one coil and observe what happens. Record your observations in item 4 of Data and Observations.

8. Use wires to connect a resistor to one coil. Start the coil swinging and observe its motion. Record your observations in item 5.
Data and Observations
1. Observations of swinging coil attached to other coil:

2. Observations of swinging coil attached to other coil with connections reversed:

3. Observations of swinging coil when swing amplitude is increased:

4. Observations of swinging coil system with coils disconnected:

5. Observations of swinging coil with resistor attached:

Analysis and Conclusions
1. Use your observations from item 1 to explain the motion of the coils. Which coil acts like a generator, and which coil acts like a motor?
2. Use your observations from item 2 to explain the motion of the coils.

3. Explain your observations from item 3 in terms of the strength of the induced current.

4. Compare the rates of swinging of the coil that you observed in steps 4 and 7. How can the difference be explained?

5. Explain your observations of the swinging coil from item 5 in terms of energy transfer.

Extension and Application

1. When a load is applied to or increased on a generator, why is it more difficult to keep the generator turning? (You may have felt this effect when you turned on bicycle lights powered by a pedal-driven generator.)
What’s the mass of an electron?

J.J. Thomson was the first to measure the ratio of charge to mass for an electron. He observed the deflection of a beam of electrons passing through combined electric and magnetic fields. In his experiment, the electric and magnetic fields exerted forces perpendicular to the direction of the electron’s motion. He applied a fixed electric field and adjusted the magnetic field until the electrons traveled in a straight path. By equating the forces due to the fields, Thomson could calculate the ratio of charge to mass.

In this experiment, you will follow a process like Thomson’s to balance the forces of electrons and to determine the ratio of charge to mass. You will be using a mass-of-the-electron apparatus—a 6E5-style tube. The cathode is in the center of the tube under a circular metal cap. Electrons emitted from the cathode accelerate horizontally toward the large conical-shaped anode that nearly fills the top of the tube. The anode is coated with a fluorescent material that glows green when electrons strike it.

In the absence of any external electric or magnetic fields, the electrons falling on the anode produce the pattern shown in Figure A1. If you put the tube in an air-core solenoid that has current flowing in it, the electrons are subjected to a constant magnetic field acting perpendicular to their direction of motion. Since the electrons are moving at a fairly uniform speed, the situation is that of a moving particle subjected to a constant force. As a result, the electrons move in an arc. The pattern observed on the anode of the tube will be like the one in Figure A2.

To find the radius of curvature of the electron path, you will compare the tube pattern with a rounded object such as a wooden dowel. You may have to adjust the coil current or the anode voltage to get a good match.

When an electron, having mass \( m \), is acted upon by a magnetic force in a direction perpendicular to its motion, it travels in an arc of a circle with radius \( r \). The centripetal force, \( F_c \), produces circular motion with an acceleration of \( v^2/r \), giving

\[
F = \frac{mv^2}{r}
\]
The force exerted by the magnetic field is equal to $Bqv$. When the two forces are equal,

$$Bqv = \frac{mv^2}{r}$$

Solving for $v$ yields

$$v = \frac{Bqr}{m}$$

and, by squaring both sides

$$v^2 = \frac{B^2q^2r^2}{m^2}$$

The electrons accelerate through a potential difference in the tube. The energy that each electron acquires as it accelerates through the potential difference is $qV$, where $q$ is the charge carried by an electron in coulombs, and $V$ is the potential difference in volts. Since $1 \text{ V} = 1 \text{ J/C}$, $qV$ is expressed in joules. The energy acquired by the electron is kinetic energy, $\frac{mv^2}{2}$. Thus,

$$qV = \frac{mv^2}{2}$$

where $v$ is the velocity the electron acquires as it moves through a potential difference, $V$. If the particle then passes perpendicularly through a magnetic field, $B$, the velocity is the same $v$ found from equating the electric and magnetic forces. Therefore, if we substitute for $v^2$ in the kinetic energy,

$$\text{Energy} = qV = \frac{mB^2q^2r^2}{2m^2}$$

and by rearranging terms, the charge-to-mass ratio can be determined as

$$\frac{q}{m} = \frac{2V}{B^2r^2}$$

An electron carrying a charge, $q$, accelerated by a known voltage, $V$, entering a magnetic field of magnitude $B$, will travel in a circular path of radius $r$, which can be measured to determine the charge-to-mass ratio. Since the charge, $q$, on an electron is known, $1.6 \times 10^{-19} \text{ C}$, you can determine the mass of an electron, $m$, from

$$m = \frac{q}{q/m}$$

where $q/m$ is the ratio you calculated earlier.

**Objectives**

- Observe the deflection of electrons moving through a magnetic field.
- Determine the charge-to-mass ratio for an electron.
- Determine the mass of an electron.
- Calculate the experimental error relative to the accepted value.

**Procedure**

1. Use a coil for which you have a graph of coil current versus magnetic field strength. If you do not have a graph, then measure the magnetic field strength for your coil and make a plot before continuing. This can be done by placing a CBL magnetic field sensor inside a coil, placing the probe
dot facing upward, and recording the magnetic field strength for various coil currents. Follow the instructions that accompany the magnetic field probe.

2. Wire the mass-of-the-electron apparatus, as shown in Figure B. The tube should be premounted and supplied with color-coded wires that match the figure. Connect the air-core solenoid to the power source, as shown in Figure C. Have your teacher check your wiring.

3. Turn on the low-voltage filament power supply. Wait about 30 s before applying the high-voltage plate supply. Set the plate voltage between 130 and 250 V. Inspect the resulting pattern. It should match the pattern shown in Figure A1.

4. Carefully place the coil over the tube. Turn on the power supply to the coil. Increase the current to 3 A. The tube pattern should now look like the pattern in Figure A2. Turn off the coil current.

5. Carefully insert one of the wooden dowels or another nonmetal object, such as a pencil, into the coil and rest the end of it on top of the tube. Apply power to the coil and adjust the coil current until the curvature of the tube pattern approximates the curvature of the dowel. The pattern will not match exactly.

6. Record in Table 1 the radius of the dowel, the accelerating voltage, and the coil current that causes the deflection.

7. Repeat steps 4–6, making two more trials with dowels of different sizes. If you want, change the accelerating voltage.

**Data and Observations**

Recall that $1 \text{T} = 1 \text{ N/A} \cdot \text{m}$

<table>
<thead>
<tr>
<th>Trial</th>
<th>Coi1 Current, $I$ (A)</th>
<th>Magnetic Field Strength, $B$ (T)</th>
<th>Potential Difference, $V$ (V)</th>
<th>Radius, $r$ (m)</th>
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</thead>
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</tbody>
</table>
Analyze and Conclude

1. Calculate $B^2$, $r^2$, $q/m$, and finally the mass of an electron. Enter the results in Table 2. Show calculations in the space below.

2. Determine the average mass for one electron. Show calculations in the space below.

3. Compare the average mass for one electron with the accepted value and find the relative error. Show calculations in the space below.

4. Despite the error in your measured values, what have you learned as a result of your experimental data?

Extension and Application

1. The magnetic field at the surface of Earth is about $5 \times 10^{-5}$ T. On a separate piece of paper, compare the field strength of your solenoid to Earth’s magnetic field strength. With your comparison in mind, propose a design to use Earth’s magnetic field to deflect a beam of electrons. Is there a limiting component in this experiment?
Safety Precautions

Materials

- ammeter, 0–50 mA DC
- connecting wires
- knife switch
- meterstick
- potentiometer, 1000–Ω
- two 1.5-V C-size batteries or 3-V power supply
- battery holder
- resistor, 22-Ω
- three various color LEDs
- voltmeter, 0–5 VDC
- diffraction grating

What is the relationship between color and voltage drop in an LED?

A diode is made from a semiconductor that has been doped with two types of impurities. When doped with impurities that have loosely bound electrons, a semiconductor donates those electrons and is designated as an n-type material. A semiconductor doped with acceptor impurities has holes that collect electrons and is designated as a p-type material. When a layer with n-type impurities and a layer with p-type impurities are joined, a pn-junction is formed that permits electric current to flow in one direction across the junction, but not in the other direction. If the n-side of the diode has a higher electric potential applied to it than the p-side, the diode is said to be reverse biased. In this case, it has a very high resistance, so it does not conduct electric current. When the diode is forward biased (higher electric potential applied to the p-side), the diode has a very low resistance, so electric current flows.

A light-emitting diode (LED) is a specific type of diode that emits light when current flows across the forward-biased pn-junction, as shown in Figure A. The frequency or frequencies of the emitted light depends on the types of impurities used in the LED.

When an electron moves from a higher energy level to a lower energy level, the energy is released as photons. The energy produced can be expressed as

\[ E_{\text{photon}} = E_{\text{high}} - E_{\text{low}} \]

The energy of the emitted photons also can be expressed as

\[ E_{\text{photon}} = hf = \frac{hc}{\lambda} \]

where \( E \) is the energy in joules, \( h \) is Planck’s constant, \( c \) is the speed of light, \( f \) is the frequency of the emitted light, and \( \lambda \) is the wavelength of the emitted light.

In this lab, you will be exploring the relationship between the voltage applied to an LED and the wavelength of the emitted light.

Figure A
Objectives

■ Explain the relationship between voltage supplied to an LED and the minimum energy required to emit light.

■ Discover the relationship between voltage and wavelength of light emitted by the LED.

■ Determine Planck’s constant using the results of your experiment.

Procedure

1. Select three different LEDs.

2. Wire the circuit shown in Figure B. CAUTION: Handle the LEDs carefully. The wire leads of LEDs are fragile. Be sure to hook up the meters with the correct polarity. Open the switch before you install it. Have your teacher inspect your circuit.

3. Place the circuit so that the LED will shine through a diffraction grating onto a white screen. Obtain the value for the slit separation distance of the diffraction grating from your teacher and record the value in Table 1. CAUTION: At no time during the experiment should the current to the LED exceed 25 mA.

4. Rotate the potentiometer control to its center position. Close the switch and observe the voltage on the voltmeter. Slowly adjust the potentiometer until the voltmeter displays approximately 2 V. If the LED is not glowing, open the switch, reverse the LED leads, and close the switch. If the LED is still not glowing, open the switch and replace the LED with a new one from your teacher.

5. Rotate the potentiometer until the voltmeter displays 1.50 V. Record this voltage and the current in the first row for LED 1 in Table 2.

6. Increase the voltage by increments of 0.05 V and record the voltage and current readings in Table 2 until the current is less than or equal to 20 mA.

7. While at the highest current reading for the LED, make measurements of the pattern produced by the diffraction grating. Devise a method for projecting the light onto a white surface as a screen. Position the screen far enough away from the diffraction grating to obtain a measurable distance between bright lines in the pattern, but close enough so that the bright lines are not too dim to see. Using a meterstick, measure the distance from the diffraction grating to the screen, L, and the distance between the central bright line and first-order bright line, x. Record the color of the light, L, and x in Table 1. Open the switch.

8. Repeat steps 4 through 7 for each of your remaining LEDs. Record the data in Tables 1 and 2 for each LED.

Figure B
### Physics Lab 27-1

**Data and Observations**

<table>
<thead>
<tr>
<th>Table 1</th>
</tr>
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<tr>
<td>Diffraction grating slit separation distance, ( d ): _______________</td>
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</table>

<table>
<thead>
<tr>
<th>LED</th>
<th>Color of Light</th>
<th>Screen Distance, ( L ) (m)</th>
<th>Distance to First-Order Bright Line, ( x ) (m)</th>
<th>Angle to First-Order Bright Line, ( \theta ) (degrees)</th>
<th>Wavelength, ( \lambda ) (m)</th>
</tr>
</thead>
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<table>
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<tr>
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<tr>
<td>LED 1 voltage, ( V ) (V)</td>
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Analysis and Conclusions

1. Describe what happened as you increased the voltage across the LED.

2. Explain your observations and how they relate to quantum theory.

3. Calculate the angle to the first-order bright line, \( \theta = \tan^{-1}\left(\frac{x}{L}\right) \) and the wavelength, \( \lambda = d \sin \theta \), in Table 1 for each LED. Record the results of your calculations in Table 1.

4. Calculate the energy values for each LED and enter them in Table 3. In an LED, energy is supplied from a battery or DC power supply. Electric energy supplied to an electron is \( E = qV \), where \( E \) is the energy in joules, \( q \) is the elementary charge \( (1.6\times10^{-19} \text{ C}) \), and \( V \) is the voltage drop across the LED in volts. This is the energy that goes into the changing of the energy state of an electron in an LED, causing it to give off a photon of energy \( E = hc/\lambda \), where \( h = 6.626\times10^{-34} \text{ J}\cdot\text{s} \).

| Table 3 |
|-----------------|-----------------|
| LED | Electric Energy, \( qV \) (J) | Energy of Photons, \( hc/\lambda \) (J) |
| 1   |                              |                                |
| 2   |                              |                                |
| 3   |                              |                                |

5. Compare the energy values in Table 3 for each LED. Is there a relationship? Explain any error(s) that you see in the data.

Extension and Application

1. Formulate a method to determine the value of Planck’s constant using the data from this experiment. Calculate Planck’s constant and compare it to the accepted value.
What can you learn from an emission spectrum?

When solids glow with heat, their atoms produce a continuous spectrum. A gaseous substance, however, emits a spectrum that consists of a series of lines of different colors. This emission spectrum is characteristic of the substance. For example, a solution of sodium chloride placed on a platinum wire and held in a flame emits a bright yellow light. Another way to produce a spectrum is to apply high voltage across a gaseous substance sealed in a glass tube. Atoms of a gaseous substance under low pressure are excited by the electric discharge and emit light consisting only of characteristic wavelengths. You can view these characteristic wavelengths as illustrated in Figure A. When the emitted light passes through a spectroscope, the emission spectrum becomes visible as lines of color, also known as a bright-line spectrum. The identity of a substance may be determined by examining this set of characteristic lines.

Since each element produces a unique bright-line spectrum, spectroscopy is valuable for detecting the presence of elements. Sodium, for example, gives off bright yellow light that appears in the spectroscope as a spectrum containing two adjacent bright lines of yellow. A gas is identified by comparing the wavelengths of its emission spectrum to the spectrum produced by a known gas.
Objectives

■ Observe the emission spectra of various elements in the gaseous state.
■ Compare the intensity of spectral lines for different elements.
■ Analyze a bright-line spectrum.
■ Recognize an element from its emission spectrum.

Procedure

CAUTION: The output of the power supply is several thousand volts. Do not touch the spectrum-tube power supply or spectrum tubes when power is applied. Use thermal mitts to handle the tubes.

1. Look through a spectroscope at an incandescent light bulb. The spectrum should appear when the slit in the spectroscope is pointed just off center of the glowing filament. Practice moving the spectroscope until you see a bright, clear image.

2. Verify that the power to the spectrum-tube power supply is turned off. Insert one of the spectrum tubes into the sockets. Helium or hydrogen is a good first choice.

3. Turn on the power supply. Darken the room but leave enough background lighting to illuminate the spectroscope scales. If an exposed window is the background lighting source, point the spectroscope away from the window, since daylight will affect the observed gas spectrum. Adjust the spectroscope until the brightest image is oriented on your scale. Some of the spectrum tubes produce light so dim that you must be very close to them to get good observations of the spectral lines. Record in Table 1 the bright lines of the observed spectrum. The width and darkness of your lines should reflect your observations. Turn off the power supply and, using a thermal mitt, carefully remove the hot spectrum tube. Your teacher will tell you where to put these hot tubes so that other students don’t accidentally touch them and get burned.

4. Repeat steps 2 and 3, using all of the other spectrum tubes. Record your observations in Table 1.

Data and Observations

| Table 1 |
|------------------|------------------|
| Location of spectral lines | Element |
| \( \lambda \times 10^{-7} \text{ m} \) | \( \lambda \times 10^{-7} \text{ m} \) | \( \lambda \times 10^{-7} \text{ m} \) |
| 4 | 5 | 6 | 7 | | 4 | 5 | 6 | 7 | | 4 | 5 | 6 | 7 |

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### Table 1 (Cont.)

<table>
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</tbody>
</table>
Analysis and Conclusions

1. Compare the color of light emitted by the spectrum tube to that observed through the spectroscope. Explain any differences.

2. Compare the intensities of the observed spectral lines for each element.

3. Observe a fluorescent lightbulb with the spectroscope. While a continuous spectrum will be visible, you also will see a bright-line spectrum. Compare this spectrum with those of the gases observed in this activity and identify the gas in a fluorescent lightbulb.

Extension and Application

1. A pulse of high-voltage electricity that is passed through a tube filled with xenon gas creates the electronic flash that is used for photography. Examine the spectrum of xenon and compare it with other gases. Why is xenon used rather than some other gas?

2. Describe the uses of a spectroscope in the study of astronomy.

3. How did Bohr’s model of the atom account for the discontinuous emission spectra of atoms.

4. Suggest a practical use for a spectroscope in the laboratory.
How can you measure the number of electron energy transitions?

When you heat a substance until it vaporizes, the elements in it emit light at characteristic wavelengths. Electrons absorb energy from the heat source and move to higher orbitals. When these electrons return to a lower orbital, they give off energy in the form of light. Because energy changes occur in fixed steps and each element has a unique electron structure, each element has a unique emission spectrum. By measuring the wavelengths of light that are emitted when a material is heated, you can identify the elements in the material.

In this lab, you will use a diffraction grating to observe the emission spectrum of various light sources. You will look at the spectrum emitted by various light sources when they are heated by electric current. You will match these spectra with spectra that are in your textbook to determine the elements that are emitting the light. Finally, you will relate the number of spectra you see to electron energy transitions.

Objectives

■ Recognize the relationship between emission spectra and elements.
■ Relate the number of spectral lines to the number of electron energy transitions made in an atom.
■ Differentiate between laboratory light sources and light sources used commercially.

Procedure

1. Fasten a meterstick to the table using modeling clay, as shown in Figure A. Use clay to mount a narrow slit on the edge of the meterstick at the 0.0-cm point on the end of the meterstick.
2. Position another meterstick perpendicular to the first meterstick in front of the narrow slit. Use clay to mount a diffraction grating on this meterstick at 1.00 m from the narrow slit.
3. Place one of the test light sources behind the narrow slit.
4. While one lab team member looks through the diffraction grating at the spectrum, have another lab team member stand behind the light and narrow slit setup and hold a pencil vertically next to the left side of the narrow slit with the pencil tip on the meterstick.

![Figure A](https://via.placeholder.com/150)

5. Have the lab team member who is looking through the diffraction grating direct the lab team member with the pencil to slowly move the pencil away from the single slit along the meterstick until the pencil lines up with the first bright line. Record the value on the meterstick that the pencil points to as the position of line 1 in Table 1. Record the color of the line in the same space. Continue this process to measure the positions and colors of each of the bright lines in the emission spectrum for the light source. Record up to seven lines.

6. Repeat steps 3–5 with a three more light sources. Record the positions and colors of the spectral lines in Table 1.

### Data and Observations

<table>
<thead>
<tr>
<th>Light Source</th>
<th>Position of Line 1 and Color</th>
<th>Position of Line 2 and Color</th>
<th>Position of Line 3 and Color</th>
<th>Position of Line 4 and Color</th>
<th>Position of Line 5 and Color</th>
<th>Position of Line 6 and Color</th>
<th>Position of Line 7 and Color</th>
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</tbody>
</table>
Analysis and Conclusions

1. Explain the order of the colors that appear in each of the spectra.

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

2. Illustrate the spectra of each of the light sources that you viewed through the diffraction grating by making scale drawings of each spectrum in Table 2.

<table>
<thead>
<tr>
<th>Table 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Source 1 Spectrum</td>
</tr>
<tr>
<td>Light Source 2 Spectrum</td>
</tr>
<tr>
<td>Light Source 3 Spectrum</td>
</tr>
<tr>
<td>Light Source 4 Spectrum</td>
</tr>
</tbody>
</table>

3. Compare your drawings of spectra with pictures of spectra in your book and in pictures provided by your teacher. Identify the element(s) that is (are) emitting light in the light sources.

Light Source 1 Element(s): ____________
Light Source 2 Element(s): ____________
Light Source 3 Element(s): ____________
Extension and Application

1. Relate the number of spectral lines to the number of electron energy transitions made in an atom. Draw arrows in Figure B showing all the transitions an electron could make between the four illustrated energy levels, which would result in the emission of a photon. How many emission lines could possibly be produced by this atom?

   4
   3
   2
   1

   Figure B

2. Make an association between the spectra in Figure C. What is the evidence for the claim that iron exists in a relatively cool outer layer of the Sun?

   Solar Spectrum
   Dark Fe (absorption)
   Bright Fe (emission) matches solar absorption

   Laboratory Spectrum of Iron

   Figure C

3. Differentiate between the neon light that appears orange to the eye and the neon lights that are used to make advertising signs by bending colorfully glowing tubes into words or pictures. How can a neon sign with colors other than orange in it be made? Explain.
How can my computer make decisions?

An integrated circuit, IC, may have dozens to millions of elements, such as transistors, resistors, diodes, and conductors, which together form one or more electronic circuits. The individual components are manufactured on an appropriately doped piece of semiconductor substrate, usually silicon. These components are built up layer by layer on the substrate, and integrated electrically to perform a specific function. After construction, small wires are attached to connecting pads on the IC and run to external metal leads or terminals. The IC then is packaged in a plastic or ceramic container to protect it from moisture and environmental pollutants.

Data entered into a microcomputer or a calculator are manipulated with binary mathematics. In the binary system, all numbers are represented by combinations of zeros and ones. This system can be interpreted by transistor circuitry in ICs. A transistor switch that is on represents a one, and a switch that is off represents a zero. An IC has one or more gates, the basic building blocks of electronic logic systems. A gate is an electronic switch that controls the current flowing between the terminals. The output of an IC can be monitored using a light-emitting diode (LED) as a logic probe. When a transistor circuit is turned on, the LED probe lights to indicate a logical 1 (a true condition). When the transistor circuit is turned off, the LED does not light, indicating a logical 0 (a false condition).

The binary operations are sometimes called logical operations or Boolean logic: for example, if \( a \) and \( b \) then \( c \). Adding large numbers or handling more complicated operations, such as multiplication or division, requires many logical operations.

Objectives

- Observe the properties and functions of integrated circuit logic devices.
- Obtain the truth table for several types of logic devices.
- Compare different logic functions.
- Construct a circuit to add two numbers.

Procedure

1. Study your breadboard. A center channel runs lengthwise across the middle of the board. An IC is placed on the board with the pins from one side fitting into the holes on one side of the channel, and the pins from the other side fitting into holes on the other side of the channel. Along the outer edges of the breadboard are two rows, or buses, or electrically-connected holes that run parallel to the center channel. Insert a lead from each side of the battery to a hole in each row, as shown in Figure A. This procedure creates a row of
positive connecting points and a row of negative connecting points. Between the center channel and each outer bus are columns of electric connecting points. All columns between the center channel and the positive or negative bus are electrically connected. Electric connections to the board are made by carefully inserting exposed wires into the holes of the breadboard.

2. Place the LED in the lower right-hand corner of the breadboard with one lead in one of the holes of the negative bus. Place the other lead in one of the column holes. Connect a 1000-Ω resistor between a hole in the column where the LED is and an adjacent column. Attach a long wire to the column where the 1000-Ω resistor terminates. This wire is your test probe. To check the LED, touch the test probe to a hole along the positive bus. If the LED does not light, unplug it and reverse the holes into which the two wires are inserted. The LED should now light. If it does not, ask your teacher for help.

3. Disconnect the 9-V battery. Handle the ICs carefully because they can be damaged by static electricity. Discharge any excess static electricity by touching a water faucet before handling an IC. Select the 4081 IC, which has four AND gates. An AND gate symbol is shown in Figure B and is represented mathematically by $Z = A \cdot B$, which means $Z$ equals $A$ AND $B$. The schematic representation of the four gates in the 4081 (quad 2-Input AND gate) is shown in Figure B.

Pin 14 is the positive-voltage input, and pin 7 is the negative-voltage input to power the IC. Look on top of the IC. The orientation of the IC usually is identified by a semicircular notch on the end near pins 1 and 14 and an index mark, such as a hole or dot, by pin 1. Carefully push the 4081 into your breadboard with pin 1 near the negative bus. Reversing the IC usually destroys it. One power lead of the IC must be connected to a positive bus and the other to a negative bus. Connect a wire to one of the holes in the column associated with pin 7 and attach the other end to the negative bus. Likewise, connect a wire from a hole associated with pin 14 to the positive bus. One of the AND gates is connected to pins 1, 2, and 3. Connect the free end of the test probe to the AND gate output, pin 3. Connect one long wire to a hole in the column that corresponds to pin 1 and another long wire to a hole in the column that corresponds to pin 2. These wires will be connected to the negative or positive bus to provide the logical 0 and 1.
4. Connect a 9-V battery. Let the wire connected to pin 1 be input $A$ and the wire connected to pin 2 be input $B$. Record your observations in Table 1 under the output column $Z$. Connect both inputs to the negative bus, producing a 0, 0 input to the AND gate. Observe the test probe LED. Move input $B$ to the positive bus, producing a 0, 1 input to the AND gate. Observe the test probe LED. Move input $A$ to the positive bus and input $B$ to the negative bus, producing a 1, 0 input to the AND gate. Observe the test probe LED. Finally, connect input $B$ to the positive bus, producing a 1, 1 input to the AND gate. Observe the test probe LED. Demonstrate the AND gate logic to your teacher before proceeding.

5. Disconnect your battery before switching IC’s. Replace the 4081 with a 4071 shown in Figure C. Figure C shows an OR gate symbol and is mathematically represented by $Z = A + B$, which means $Z$ equals $A$ OR $B$. The figure shows a schematic representation of a 4071 IC containing four OR gates (quad 2- Input OR gate). Repeat step 4 with the 4071 and record your results in Table 2.

6. Shown in Figure D is a 4070 Exclusive-OR (XOR) IC. Replace the 4071 with the 4070. This IC is mathematically represented by $Z = A \oplus B$, which means $Z$ equals $A$ XOR $B$. This logic configuration can be created by combining several other logic gates together. Repeat step 4 with the 4070 and record your results in Table 3.

7. Shown in Figure E is a 4011 NAND gate IC. Replace the 4070 IC with the 4011 IC. This IC is mathematically represented by $Z = \overline{A \cdot B}$ which means $Z$ equals NOT ($A$ AND $B$). Repeat step 4 with the 4011 and record your results in Table 4.
Data and Observations

<table>
<thead>
<tr>
<th>AND Gate Truth Table</th>
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<th>XOR Gate Truth Table</th>
<th>NAND Gate Truth Table</th>
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Analysis and Conclusions

1. Compare the AND and NAND logic functions.

2. Predict the result of hooking together the inputs of a NAND gate.

3. You need an AND function in a particular circuit, but you have only three NAND gates available. How would you connect the NAND gates to perform the AND function?

4. Study the truth table results for the OR and XOR. Compare the OR and XOR functions.

Extension and Application

1. Use the 4011 NAND gate IC to wire the circuit in Figure F. This circuit is useful in many applications and is called an Exclusive-OR (XOR). Write a truth table for the various input combinations.
How can I protect myself from radioactivity?

Alpha, beta, or gamma radiation is released when the nucleus of an atom changes in some way. Recall that an alpha particle is the nucleus of a helium atom, a beta particle is an electron emitted by the nucleus, and a gamma ray results from the redistribution of energy within the nucleus. The mechanics of radiation absorption vary with the type of radioactive source, the initial energy of the particle or ray, and the type of absorbing material present. While an alpha particle is quite heavy, it carries a double positive charge compared to an electron with a single negative charge. This ionization state makes an alpha particle very interactive. Alpha particles are quickly absorbed despite being heavy and can be stopped by a sheet of paper. Because electrons have the same mass as the electrons in the absorbing material, they are deflected when involved in a collision with other electrons. Therefore, electrons do not follow a well-defined path through the material.

Charged particles gradually lose their energy throughout collisions; however, photons lose all their energy in a single collision. The absorption of gamma rays is defined in terms of the absorption coefficient, with the reciprocal being the thickness of the absorber that reduces the number of photons in a beam by a certain percentage. Thus, the intensities of gamma rays decrease exponentially as they penetrate a given material.

Objectives

■ Demonstrate the ability of different types of radiation to penetrate materials.
■ Compare the shielding efficiencies of various materials.
■ Infer the relative shielding effectiveness of various materials.
■ Design a procedure for investigating radioactive shielding properties of materials.

Problem

How do different materials compare in their ability to shield radiation sources?

Hypothesis

Formulate a hypothesis about the relative shielding efficiency of different materials exposed to beta and gamma radiation.
Plan the Experiment

CAUTION: Do not bring any food, drink, or makeup into the laboratory. Handle the radioactive materials with tweezers, tongs, or gloves. Wash your hands with soap and water before you leave the laboratory.

1. Work in a small group. Decide on a procedure that uses the suggested materials (or others of your choosing) to gather data on how well beta and gamma radiation are shielded by materials such as paper, cardboard, aluminum, and lead.

2. Decide what kind of data to collect and how to analyze it. You can record your data in the table provided. Label the columns appropriately.

3. Write the procedure on another sheet of paper or in your notebook. In the space below, draw the setup you plan to use.

4. Check the Plan Have your teacher approve your plan before you proceed with your experiment. Make sure that you understand how to operate the Geiger counter or scaler. The thin window at the end of the Geiger-Mueller tube is fragile. Handle it carefully.

Setup

Data and Observations

<table>
<thead>
<tr>
<th>Type of Shielding</th>
<th>Number of Sheets</th>
<th>Alpha Count/10 s</th>
<th>Beta Count/10 s</th>
<th>Gamma Count/10 s</th>
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Analyze and Conclude

1. **Graph Data** Use the grid below to graph the measured activity of gamma radiation for lead versus the number of sheets of lead.

<table>
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<tr>
<th>Type of Shielding</th>
<th>Number of Sheets</th>
<th>Alpha Count/10 s</th>
<th>Beta Count/10 s</th>
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Compare the graph results to the expected trend for gamma radiation.
2. **Analyze Data** What type of radiation is most easily absorbed and which type is least easily absorbed?

3. **Analyze Data** How much and what type of material is required to reduce the various radiation sources to one-half of their activity?

4. **Analyze Data** Explain how to distinguish between beta and gamma radiation using shielding materials.

5. **Check Your Hypothesis** Suppose you were constructing a medical facility that has both gamma and beta sources. What type of shielding would you recommend using within the walls?

6. **Analyze Data** Was it possible in this experiment to eliminate all of the gamma radiation? Explain.

**Apply**

1. Based on the materials you have worked with, as a prospective astronaut participating on board the *International Space Station*, what recommendations would you make for safe areas during solar storms containing high intensity alpha, beta, and gamma radiation?
How can you find the half-life of a short-lived radioactive isotope?

One medical diagnostic tool involves the use of radioactive tracers that emit gamma radiation. They are administered in doses that contain small amounts of a specific isotope. The isotope is selected so that it will accumulate in or be absorbed by a specific organ of the human body. These radioactive tracers need to have a short half-life so that they will decay and be eliminated from the body quickly, thus minimizing radioactive exposure.

In this experiment, you will use a small isotope generator that is able to produce a short-lived radioisotope and determine its half-life. The $^{137}\text{Cs}/^{137}\text{Ba}$ isogenerator is a miniature eluting system containing a long-lived radioactive nuclide that decays into a short-lived radioactive nuclide. The chemical decay of $^{137}\text{Cs}$ is a two-step process. The miniature generator contains a small quantity of $^{137}\text{Cs}$, which has a half-life of approximately thirty years and decays by beta emission to $^{137}\text{Ba}$m. A neutron inside the $^{137}\text{Cs}$ nucleus undergoes a beta decay. This converts the neutron into a proton, a beta particle, and a neutrino. The $^{137}\text{Ba}$ is left in an excited or metastable state designated by $^{137}\text{Ba}$m. The $^{137}\text{Ba}$m quickly decays into stable $^{137}\text{Ba}$ by gamma emission. The half-life of $^{137}\text{Ba}$m is 2.6 m. By eluting the minigenerator, the $^{137}\text{Ba}$m may be extracted from the $^{137}\text{Cs}$. After eluting the minigenerator and extracting $^{137}\text{Ba}$m, you will use your Geiger counter or scaler/timer to collect activity data of the radioactive nuclide.

Objectives

- Demonstrate how to extract a radioactive decay product.
- Measure the radioactivity of decaying $^{137}\text{Ba}$.
- Determine the half-life of $^{137}\text{Ba}$.

Procedure

**CAUTION:** Do not bring any food, drink, or makeup into the laboratory. Handle the radioactive materials with tweezers, tongs, or gloves. Wash your hands with soap and water before you leave the laboratory.

1. Put on your safety goggles, gloves, and apron.
2. Set up your Geiger counter apparatus according to your teacher’s instructions. Turn on the Geiger counter and take a background reading. Record this value in Table 1.
3. Holding the isogenerator in one hand, carefully remove the large cap above the reservoir. To catch the eluant, attach the small collection vial to the bottom of the generator.
4. Fill the eluting syringe or vial with approximately 3 mL of the eluting solution or to the level specified in your kit. Place the tip securely into the larger opening of the minigenerator, as seen in Figure A.

5. Gently squeeze the syringe, or plastic bottle, to force the eluting solution through the minigenerator. Wipe up any spills immediately and report them to your teacher. Cap the vial and place it into the Geiger counter. The barium begins decaying immediately.

6. Begin measuring the activity in 1-min intervals. Count the activity for 1 min and then record it in counts per minute, cpm. Wait 1 min and then count for the next minute. Continue to record 1-min activity readings until the background radiation level is reached.

7. Return materials to the locations your teacher has designated. The isogenerator should be stored according to the manufacturer’s directions. Dispose of the radioactive waste according to your teacher’s directions. Wash your hands before leaving the laboratory.

Data and Observations

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Activity (cpm)</th>
<th>cpm Corrected for Background</th>
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Table 1

Background Activity = _______ cpm
Analysis and Conclusions

1. For each of the measurements in Table 1, subtract the background radiation from the activity of your sample and record these values as the cpm corrected for background. Show calculations in the space below.

2. Plot a graph of corrected activity (cpm) versus time, with the activity placed on the y-axis and the time on the x-axis.

3. What does your graph show about the decay of $^{137}_{56}$Ba m?
4. Determine the half-life of $^{137}_{56}$Ba m. The half-life is the time required for one-half of the material to decay. Select an activity measurement at the 1-min time. Find the activity amount that is one-half of this activity. Locate this value on your graph and draw a line to the x-axis. The half-life is the time difference between this time and 1 min.

5. What is the half-life of $^{137}_{55}$Cs?

6. Compute your percent error by comparing the value you obtained and by using the accepted value for the half-life of $^{137}_{56}$Ba m. Show calculations in the space below.

**Extension and Application**

1. Write the decay reaction for $^{137}_{55}$Cs.

2. If 1.0 g of $^{137}_{56}$Ba m were extracted from the minigenerator, after five half-lives how much remains?