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Introduction

Learning 😄

Temperament!

Laboratory Format

Accuracy & Precision (Tolerance)
To the Student

Purpose:
This laboratory manual is designed to assist the learner in mastering the concepts that are associated with the Next Generation Science Standards as well as the Common Core English Language Arts Standards for Science and the Common Core Mathematics Practices. The laboratory experiments and activities have learning objectives based upon the standards that direct the learning. The objectives are set up in four categories: knowledge, reasoning, skills and product. The knowledge objectives state the content that must be learned. The objectives for reasoning describe how the learner will refine their knowledge using processing techniques. Skill objectives are processes that the learner needs to master to be able to conduct the experimental procedures and analysis. These include techniques of data gathering and problem solving. Finally, through product objectives the learner will be creating formal or common laboratory report, and projects including water rockets, catapults, paper towers, etc. You will use the mathematical processes that are part of the Common Core Mathematics Standards as you work through the laboratories. These include:

CCSS Math Practice 1: Make sense of problems and persevere in solving them.
CCSS Math Practice 2: Reason abstractly and quantitatively.
CCSS Math Practice 3: Construct viable arguments and critique the reasoning of others.
CCSS Math Practice 4: Model with mathematics
CCSS Math Practice 5: Use appropriate tools strategically.
CCSS Math Practice 6: Attend to precision.
CCSS Math Practice 7: Look for and make use of structure.
CCSS Math Practice 8: Look for and express regularity in repeated reasoning

You will also be able to incorporate the Common Core English Language Arts Standards as you read through the laboratories and develop your Pre-Laboratories and as you write you laboratory reports. These standards include:

Key Ideas and Details:
CCSS.ELA-Literacy.RST.11-12.1 Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
CCSS.ELA-Literacy.RST.11-12.2 Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.
CCSS.ELA-Literacy.RST.11-12.3 Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.

Craft and Structure:
CCSS.ELA-Literacy.RST.11-12.4 Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.
CCSS.ELA-Literacy.RST.11-12.5 Analyze how the text structures information or ideas into categories or hierarchies, demonstrating understanding of the information or ideas.
CCSS.ELA-Literacy.RST.11-12.6 Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text, identifying important issues that remain unresolved.

Integration of Knowledge and Ideas:
CCSS.ELA-Literacy.RST.11-12.7 Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.
CCSS.ELA-Literacy.RST.11-12.8 Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.
CCSS.ELA-Literacy.RST.11-12.9 Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.
Range of Reading and Level of Text Complexity:
CCSS.ELA-Literacy.RST.11-12.10 By the end of grade 12, read and comprehend science/technical texts in the grades 11-CCR text complexity band independently and proficiently.

Laboratory Safety:
In the classroom laboratory it is imperative that you practice safety techniques. Most accidents can be avoided using laboratory safety. When in the laboratory use all precautions including:

- Paying strict attention to the teacher.
- Preparing for all experiments in advance by making a pre-laboratory.
- Always working with a laboratory partner.
- Keeping your work environment clear of clutter.
- Reporting all accidents to the teacher immediately.
- Using the apparatus according to the instruction given in the laboratory procedure.
- Never looking directly into a laser beam.
- Using goggles and aprons when working with chemicals.
- When using electricity make all connections prior to turning on the source.
Leaning Temperaments

**Standard:**
Student understanding is actively constructed through individual and social processes. In the same way that scientists develop their knowledge and understanding as they seek answers to questions about the natural world, students develop an understanding of the natural world when they are actively engaged in scientific inquiry—alone and with others.

**Knowledge Objective:**
- I will identify and describe vocabulary associated with my learning temperament.

**Reasoning Objective:**
- I will explore my personal learning strengths.

**Product Objectives:**
- I will illustrate my learning temperament using the color wheel.
- I will create an illustration representing my learning temperament.
- I will write two paragraphs describing my personality and learning temperament.

**Materials:** learning style inventory, learning temperament graph, summary of learning temperaments

**Instructions:**
You have the opportunity to self-evaluate your individual learning temperaments. This is done using a learning style inventory. Place a check mark next to each word that describes who you are. You will then tally up the marks for each column. Glue the inventory on the right side of your notebook. Next, use the Be Your Best Self page to graph your learning temperament. You start at the center circle and count out diagonally the number of dashed lines that correspond to the total marks from each column. Place a mark at each of these points and connect them forming a four sided kite. Next use colored pencils to color in each quadrant with the appropriate color. Use green for soul, blue for heart, yellow for mind and red for body. This page is glued in as a flip page on top of the inventory on the right side page. You may ink your thumb and make a finger print in the center circle to represent you as an individual.

![Learning Temperament Graph](image)

Read over the learning temperament summaries so that you are familiar with your learning strengths. Next draw an illustration that informs you and others who you are and what you’re learning temperament is.
- The centerpiece of the artwork is a slogan or phrase.
- The surrounding artwork (minimum of 4 colors) will illustrate your interest and learning strengths.
- The artwork must be suitable for all ages and appropriate for viewing in all social situations.

Finally, you will write 2-3 paragraphs explaining how the artwork represents you. This will be placed as a flip page on the left hand processing page of your interactive notebook. To assist you in better understanding your temperament see the Summary of Learning Temperaments page.

**Questions**
1. What are the benefits of working in cooperative groups created using students of different learning temperaments?
2. Predict how your learning will increase through the use of collaborative groups work.
3. Predict how your knowledge of your learning temperament will assist you in learning.
Temperament Inventory

Place a check next to each word that firmly describes you and then tally up the total number of marks for each column.

<table>
<thead>
<tr>
<th>Tidy</th>
<th>Affectionate</th>
<th>Visionary</th>
<th>Spontaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accurate</td>
<td>Cooperative</td>
<td>Critical</td>
<td>Adventurous</td>
</tr>
<tr>
<td>Consistent</td>
<td>Enthusiastic</td>
<td>Curious</td>
<td>Artistic</td>
</tr>
<tr>
<td>Honest</td>
<td>Friendly</td>
<td>Independent</td>
<td>Athletic</td>
</tr>
<tr>
<td>Logical</td>
<td>Gentle</td>
<td>Investigative</td>
<td>Charming</td>
</tr>
<tr>
<td>Loyal</td>
<td>Giving</td>
<td>Knowledgeable</td>
<td>Cheerful</td>
</tr>
<tr>
<td>On-time</td>
<td>Good listener</td>
<td>Laid-back</td>
<td>Competitive</td>
</tr>
<tr>
<td>Organized</td>
<td>Idealistic</td>
<td>Musical</td>
<td>Courageous</td>
</tr>
<tr>
<td>Prepared</td>
<td>Kind</td>
<td>Persevering</td>
<td>Creative</td>
</tr>
<tr>
<td>Respectful</td>
<td>Nature-lover</td>
<td>Problem solver</td>
<td>Hands-on</td>
</tr>
<tr>
<td>Responsible</td>
<td>Peacemaker</td>
<td>Rational</td>
<td>Inventive</td>
</tr>
<tr>
<td>Sensible</td>
<td>Persuasive</td>
<td>Self-directed</td>
<td>Lively</td>
</tr>
<tr>
<td>Service</td>
<td>Social</td>
<td>Spiritual</td>
<td>Mechanical</td>
</tr>
<tr>
<td>Thrifty</td>
<td>Tolerant</td>
<td>Strategic</td>
<td>Playful</td>
</tr>
<tr>
<td>Supportive</td>
<td>Understanding</td>
<td>Technical</td>
<td>Risk-Taker</td>
</tr>
</tbody>
</table>

Totals

Yellow   Blue   Green   Red
### Green: Key Questions

**Why?** Why things work or do not work? Why people think and act the way they do?

**Personality Strengths**

People with a strong **Soul** temperament are imaginative, intellectual, and skeptical. They thrive with independent thinking and are often uncompromising. They have clearer ideas and try to improve our world. They tend to have sharply defined interests, yet understand the overall goals of a project. Time alone to be reflective is important. Their natural desire to engineer ideas and things in order to improve lives is a strong asset. People with these strengths thrive in sciences, music, technology, theology, mathematics, literature, and problem solving.

**Key intelligences:**

- **Intrapersonal (self smart) & Musical (music smart)**
  - **Learns and works best with:** data, ideas, multiple resources, intellectual challenges, logical discussions or debates, problems to be solved, opportunities to explore new solutions, projects of personal interest, and time to work independently.
  - **Relates best with others when:** ideas are listened to, attune can be informal, questions are welcomed, praised for ingenuity, given time to think or make decisions, abstract thinking is valued, not forced to follow routines or traditional methods of doing things.
  - **Does not like:** small talk, routine tasks, predetermined procedures, emotional displays, time pressure, arbitrary rules, appearing foolish, and being inside the box.

### Yellow: Key Questions

**What & When?** What needs to be done? When is it due?

**Personality Strengths**

People with a strong **Mind** temperament are responsible, hard-working, and detailed. They provide stability to a project or group. Their willingness to learn, be on time, and keep a project organized is very helpful to a group or team. They thrive in environments that are traditional, efficient, predictable, and require accuracy. This temperament gains success through concentration and thoroughness. They do not seek popularity, but work carefully, steadily, and are dependable. People with these strengths thrive in language arts, mathematics, leadership, academic clubs, technical projects, and student government.

**Key intelligences**

- **Linguistic (word smart) and logical-mathematical (number smart)**
  - **Learns and works best with:** discipline, priority lists, time to practice, organization, practical assignments, schedules, systems, clear guidelines, traditional ways of doing things, and acknowledgement for accuracy & completeness.
  - **Relates best with others when:** they can be helpful, praised for their work, there is commitment, important dates are remembered, routines are respected, time is honored, and others realize their stress comes from disorganization.
  - **Does not like:** bending the rules, too much fun before the work is done, tardiness, unusable tasks, complicated directions, undisciplined behavior, abstract ideas, and open-ended activities.

### Blue: Key Questions

**Where & How?** Where will things take place? How will it be accomplished?

**Personality Strengths**

People with a strong **Heart** temperament are personable, compassionate and friendly. They have genuine concern for people, the environment and animals. Peace within a family and with friends is very important. They have strength in making others feel included, appreciated and comfortable. Building friendships and being part of a team are natural gifts. They are usually comfortable taking direction as part of a group, yet can also be highly motivating leaders. People with these strengths thrive in peer communications, social justice projects, school leadership, and social sciences.

**Key intelligences**

- **Interpersonal (people smart) & Naturalist (plant & animal smart)**
  - **Learns and works best with:** social sciences, leadership, cooperative groups, talking, storytelling, interactions with nature, encouragement, opportunities to present a project, acting out concepts, partner learning, connecting learning to people’s lives.
  - **Relates best with others by:** expressing feelings, personal conversations, being helpful and caring, sharing notes, giving and receiving praise, recognizing others’ strengths, physical contact, and understanding how they contribute to a team or family.
  - **Does not like:** working alone, seeing others lose, disharmony, rudeness, impersonal communication, put-downs, details and demanding routines.

### Red: Key Questions

**Where & How?** Where will things take place? How will it be accomplished?

**Personality Strengths**

People with a strong **Body** temperament are physical, inventive and competitive. They are matter of fact, don’t like to worry or hurry, and enjoy whatever comes along. Their energy is infectious and people count on them to liven up the party. They work well with tasks that are hands-on and creative. They are strong-willed individuals who make decisions quickly, and easily grasp physical tasks. This temperament places great value in taking action, being courageous and getting things done. People with these strengths thrive in sports, visual performing arts, industrial arts, pep rallies, and creative projects.

**Key intelligences**

- **Bodily-kinesthetic (body smart) and Visual-Spatial (picture smart)**
  - **Learns and works best with:** hands-on experiences, technologies, competition, multiple projects, facts more than theories, discovery learning, field trips, use of multiple senses, graphic organizers, practical applications of concepts, and things that can be handled, taken apart and put back together.
  - **Relates best with others when:** being playful, sharing their skills, recognized for being creative, being generous, encouraged to take action, and being independent.
  - **Does not like:** rules, long explanations, routines, boredom, details, conformity, waiting, predetermined goals, and being stuck at a desk.
Counting significant figures: Start the count from the first non-zero digit and count all digits from that point on. When the decimal point is present, count from the Pacific Ocean or left hand side of the number and if it is absent the start counting from the Atlantic Ocean side or right hand side.

Example:

0.003087

The decimal is present so the first non-zero digit from the left is 3 and there are then three more digits to the right of the 3 so there are four significant figures.

Example:

300,100

The decimal is absent so start counting from the right. The first non-zero digit is the 1 and there are a total of four total significant figures.
COMPUTATION RULES FOR SIGNIFICANT FIGURES

RULE 1: To express an experimental measurement, retain all digits including the first uncertain one, thereby recording only those digits known as significant figures.

RULE 2: When an experimental measurement is encountered, all non-zero digits are considered to be significant. However, when zeroes are involved the following rules apply:

(a). Zeros lying between two non-zero digits are always significant. \( 430.07 \) (5 significant figures)

(b). Zeros lying between the decimal point or implied decimal point and a non-zero digit are NOT significant if RULE 2 (a) does not apply. \( 0.0067 \) (2 significant figures)

409000 (3 significant figures)

200 (1 significant figure)

(c). Zeros lying to the right of a non-zero digit and to the right of the decimal point are significant. \( 0.000120300 \) (6 significant figures)

\( 2.00 \times 10^2 \) (3 significant figures)

4.0900 \( \times 10^5 \) (5 significant figures)

RULE 3: To round off numbers--

(a). increase the last retained digit by one if the residue is larger than 5, or

(b). retain the last digit unchanged if the residue is less than 5.

Examples: When rounded to four digits, the number

1.02343 becomes 1.023
1.0207 becomes 1.021
1.0235 becomes 1.024
874.555 becomes 874.600
0.0477350 becomes 0.04774

RULE 4: In addition and subtraction, retain only as many decimal places, not digits, in the answer as there are in that measurement with the least number of decimal places.

Examples:

- Addition:
  
  \[
  \begin{array}{c}
  \text{Addition} \\
  21.1 \\
  2.035 \\
  0.4369 \\
  + 33.8210 \\
  \hline
  62.5 \text{ not } 62.5329
  \end{array}
  \]

- Subtraction:
  
  \[
  \begin{array}{c}
  \text{Subtraction} \\
  214.375 \\
  \underline{-211.0} \\
  0.4369 \\
  \hline
  3.4 \text{ not } 3.375 \\
  \end{array}
  \]

RULE 5: In multiplication and division, remember that when a doubtful figure is multiplied or divided by a number, the answer is likewise doubtful. Therefore, the product or quotient should not have more significant figures than the least precise factor. The following example will illustrate the rule for multiplication.

\[
3.54 \text{cm} \times 4.8 \text{cm} \times 0.5421 \text{cm} = 9.2 \text{ cm}^3 \text{ not } 9.2113632 \text{cm}^3
\]

The least precise factor in the number to be multiplied is the rightmost significant figure in the answer. Consequently, the answer should be recorded as 9.2 cm\(^3\). When more than one operation is involved in a calculation, the result may be rounded off to the figure more than the correct number of significant figures after each operation.

Example

Divide 8937.50 cm\(^2\) by 1.30 \( \times 10^2 \) cm.

Only three significant figures are required for the answer, so the quotient of 68.750 is rounded off to 68.8 cm.
RULE 6: In rounding off intermediate numbers, one more digit is generally retained than is necessary, and only the final answer is rounded to the required number of significant figures. This will save time in computations.

RULE 7: The logarithm of a number should have as many digits to the right of the decimal point as there are significant figures in the number.

Examples:
log (1.39) = 0.143

log (139) = 2.143

\[ \log (1.3900 \times 10^{-5}) = \log (1.3900) + \log (10^{-5}) \]
[0.14301 - 5 = -4.85699]

RULE 8: In a problem where words and numbers are used to represent measurements, the number of significant figures expressed in the answer shall be determined by the numerals given, and it shall be assumed that the measurements given in words are of comparable accuracy.

RULE 9: Numbers representing enumerative data (i.e., unit counts) are of unlimited significance since these values must necessarily be integral (whole numbers) and never fractional.

Example: 12 eggs, 4 electrons, 15 molecules, etc.

RULE 10: The numbers represented in numerical definitions are of unlimited significance. This situation exists within a given system of measurement (such as the English system), but NOT between different systems (such as the English and Metric systems).

Examples:
1 foot = 12 inches } unlimited significance
1 liter = 1000 ml

1.00 in = 2.540 cm } conversion factors
 } expressed to only 4
1.00 lb = 453.6 g } significant figures

In any problem involving the conversion from one system of measurement to another, always use conversion factors which contain more significant figures than the least precisely known number in the computation (usually in experimentally-determined quantity). In this manner the final answer will reflect the care used in data collection process.

RULE 11: When an answer to a problem is given in a printed publication (textbook, workbook, laboratory manual, etc.) and violates any of the above rules, that answer shall be considered as only an approximation and the correct answer shall be based upon the given data and the foregoing rules.
Measurements and Significant Figures:

Any measurement is subject to some degree of uncertainty. The uncertainties in a measurement are due to the process or method used to measure, the method used to construct and calibrate the instrument and the limitation to which the instrument can be read.

When expressing a measurement all digits including the first uncertain must be recorded. It is also true that all non-zero digits are considered to be significant. When recording measurements the degree of certainty with which a measurement is made is expressed. If the best a measuring instrument can be read is to the tenth then an example of the reporting a measurement is 11.1+ .1. This means that the measurement lies between 11.0 and 11.2. This is a form of precision.

Data collected during experimentation is evaluated in terms of its accuracy and precision. It is important to show how significant results are. If the errors and deviation are large then the results may not be considered viable. The data from an experiment should be scrutinized by the experimenter. If the data has great errors or deviation then better methods of measurements should be pursued. The experimenter will need to use the following calculations for accuracy and precision in analyzing data.

Accuracy is the degree to which a measurement agrees with an accepted value for those measurements. The accuracy of a measurement is dependent upon the production and calibration of the instrument. When an instrument is calibrated according to a reliable standard then measurement will be more closely aligned with the accepted value for that measurement. Measurement can be evaluated in absolute or relative terms. The absolute error is the absolute value of the difference between the accepted value and the measurement. This can be written as an equation as shown below.

\[
\text{Absolute error } = |\text{Observed} - \text{Accepted value}|
\]

This can be expressed as a percentage error also. The percentage error is the relative error. It is expressed in the following equation.

\[
\text{Relative error } = \frac{\text{Absolute error}}{\text{Accepted value}} \times 100\% \\
\text{Relative error } = \frac{|O - A|}{A} \times 100\%
\]

Data can also be evaluated in terms of how measurements, which are made in the same manner, deviate from one another. The deviation of experimental data is dependent upon the reproducibility with which the experimenter can take data. This is known as precision and is evaluated in terms of absolute and relative deviation. Absolute deviation is the absolute value of the difference between the mean or average value and the measured value. This is expressed below in the equation.

\[
\text{Absolute deviation } = |\text{Observed} - \text{Mean value}|
\]

Another way to express the deviation or precision is as a percentage. This is the relative deviation and is expressed as follows.

\[
\text{Relative deviation } = \frac{\text{Average absolute deviation}}{\text{Mean value}} \times 100\% \\
\text{Relative deviation } = \frac{|O - M|}{M} \times 100\%
\]

All data must be expressed with the uncertainty in that measurement and data is analyzed in terms of accuracy and precision.
Pre-Laboratory Format

**Title:** This does not include the word title. It does reflect the subject of the laboratory.

**Purpose:** The word purpose is used. The purpose is relevant to the lab and is written in the student's own words. It should read as if you were explaining to another student why the lab is being done.

**Hypothesis:** The word Hypothesis is used. The hypothesis is a statement for what you believe will happen or what will be discovered or determined when the lab is analyzed and interpreted.

**Procedure and equipment:** The word Procedure is used. You should include the equipment necessary to perform the experiment so the experimenter can gather them prior to beginning the activity. If you are developing the procedure then you will need to write a step-by-step process that guides the experimenter through the activity. If you are using a procedure from a source all you need to do is create a flow diagram that will allow you to perform the experiment. Include the hazards or safety requirement in this section.

**Results:** The word Results is used. You will need to create tables you will use when collecting the data. The table will have a title that describes the data that will be collected. The table has column headings with tolerance and metric units. There is a single straight line created by a ruler under the column headings that separates them from the data. This is the only line that is allowed for the table. Only values are placed in the columns of the table.

**Example:**

<table>
<thead>
<tr>
<th>Height of horizontal beam from floor (h)</th>
<th>Angle of beam from horizontal (°) ± .5 degrees</th>
<th>Distance of pivot point from wall (x) ± .0004 meters</th>
<th>Opposite side of triangle (y) meters</th>
<th>Height of room (H) meters</th>
</tr>
</thead>
<tbody>
<tr>
<td>± .0004 meters</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>.1043</td>
<td>59.3</td>
<td>1.3452</td>
<td>2.27</td>
<td>2.37</td>
</tr>
</tbody>
</table>
Common Report Format for the Laboratory Notebook

Title: This does not include the word title. It does reflect the subject of the laboratory

Purpose: The word purpose is used. The purpose is relevant to the lab and is written in the student's own words. It should read as if you were explaining to another student why the lab is being done.

Hypothesis: The word Hypothesis is used. The hypothesis is a statement for what you believe will happen or what will be discovered or determined when the lab is analyzed and interpreted.

Procedure and equipment: The word Procedure is used. You should include the equipment necessary to perform the experiment so the experimenter can gather them prior to beginning the activity. If you are developing the procedure then you will need to write a step-by-step process that guides the experimenter through the activity. If you are using a procedure from a source all you need to do is create a flow diagram that will allow you to perform the experiment. Include the hazards or safety requirement in this section.

Results: The word Results is used. You will need to create tables you will use when collecting the data. The table will have a title that describes the data that will be collected. The table has column headings with tolerance and metric units. There is a single straight line created by a ruler under the column headings that separates them from the data. This is the only line that is allowed for the table. Only values are placed in the columns of the table.

Example:

<table>
<thead>
<tr>
<th>Height of Room 302 at Paso Robles High School</th>
<th>Determined Using Trigonometry and the Angle of a Laser Beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height of horizontal beam from floor (h)</td>
<td>Angle of beam from horizontal (°) ± .5 degrees</td>
</tr>
<tr>
<td>± .0004 meters</td>
<td>Distance of pivot point from wall (x) ± .0004 meters</td>
</tr>
<tr>
<td></td>
<td>Opposite side of triangle (y) meters</td>
</tr>
<tr>
<td>.1043</td>
<td>59.3</td>
</tr>
<tr>
<td>1.3452</td>
<td>2.27</td>
</tr>
<tr>
<td>2.37</td>
<td>2.37</td>
</tr>
</tbody>
</table>

Sample Calculations: After the data is collected you will need to describe in detail sample calculations and show one set using the data that provides the value that is closest to the accepted and/or mean value. Make sure to describe the data used, the equations used and the process to arrive at the answer and show the steps separated from the test of the description. The error analysis occurs here including the calculations for absolute and relative errors.

Graphs: When graphing the data is required then the graphing format described in the graph on the next page should be used. It is very important to follow this format since it is the accepted method in the scientific community. If the slopes for a linear relationship or other instantaneous slope for a nonlinear relationship need to be calculated, then show the sample calculation on a different page from the graph. Calculation should not be performed on the graph. Treat this calculation as you did the previous calculations.

Analysis: This section is usually answering questions that accompany the laboratory handout. Make sure that you either include the question in the answer or write out the question so that the answers make sense. The answers must be in complete sentences.

Conclusion: In one or two paragraphs you need to describe the outcome of the results. Did the results support the hypothesis? Did the data support your understanding of the purpose for the laboratory? What errors occurred in collecting the data and how did they influence the results.
Graphs:

Graphs are often used in analyzing data. Graphs should be constructed on a full-page of graph paper using as much of the sheet as possible. The data should be spread across the entire sheet. It must have an accurate title. The independent variable is put on the x-axis and the dependent variable on the y-axis. A simple way to remember this is by using the acronym DRY MIX (Dependent Responding variable is on the Y axis and Manipulated Independent variable is on the X axis). Both the x and y axis are labeled including units and tolerance. The best curve that fits the data is drawn and all the data points are circled.

Example:
Formal Laboratory Report

In order to prevent unnecessary pandemonium in the scientific community, it was decided a long time ago that experimental results would be published in magazines called journals. Journals are published for everyone to read not just the privileged few. Each field and sub-field of science has their own area specific journals.

Most scientists subscribe to different journals to keep current in their field. This is how information is communicated most effectively. Publishing an article is not easy though. First of all there are thousands of people trying to publish articles at the same time. If the article is not written in the right format, the publishers can't be bothered by it. The appearance is very important. Other articles don't make any sense. Some parts may be missing or the language is confusing. Alas, these, too, are rejected. Just like journal publishers, your teacher is very selective.

The laboratory report used in many college science classes follows similar formats to that use for journals. One challenge is the fact that personal pronouns such as we, she, they, I, you, he, etc are not to be used. This style of writing is very challenging and includes the following sections.

<table>
<thead>
<tr>
<th>Title - separate page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract – Summary of the Report</td>
</tr>
<tr>
<td>Introduction - Background Information &amp; Works Cited</td>
</tr>
<tr>
<td>Hypothesis/Experimental - Hypothesis and procedure</td>
</tr>
<tr>
<td>Results/Analysis - Present and discuss data and analyze for errors.</td>
</tr>
<tr>
<td>Conclusion - Suggestions for improvements to the laboratory procedure if it was to be repeated</td>
</tr>
</tbody>
</table>

1. How to write the Title
   The title is the very first part of the lab report. The title consists of a few well-chosen words indicating the subject of the report. Even more specifically it must indicate the cause and effect relationship tested in the laboratory. It is extremely important that you precisely describe the subject of the lab because when people are doing research on a topic, they often only see the title of the article or report. This is the only indication of the contents of the paper. They don't want to waste time reading a report that doesn't do what the title said it did. Refrain from using cute titles!

Example: Standing Waves are Produced in Spinning Corrugated Tubes

Location of the title: This is centered at the top of its very own page. It appears by itself without the work title. Also on this page, two inches from the bottom put your name (first/last) the date and the class title.

2. How to write the Abstract
   This section is the last section you write and is a summary of the entire report. Often the title of your report catches the eye of a researcher. They will want to discover more on the topic. This section overviews the laboratory report in one to three paragraphs. Each section of the report (introduction, hypothesis/experimental, results/analysis, and conclusion) will be briefly summarized. The first paragraph should describe the theory and the experimental procedure. An overview of the actual results should be shown in the second paragraph. The final paragraph should include the analysis and methods to improve the experiment.

3. How to write the Introduction
   Never use personal pronouns in formal work! This section gives the background of the experiment and the introduction to the experiment. It is important to read about the topic of your experiment to collect this information. This section includes an explanation of the important facts of the general problem or area being investigated, explaining why this problem is of interest and outlining what
information is already known. Use complete sentences in this section as well. You must site direct and indirect sources you use. (e.g. The sources quoted and those that you just got information from.)

All sources used (textbook, articles, etc.) must be listed in your "Works Cited" section at the end of the Introduction. Failure to do so is a serious offense; plagiarism, and will result in rejection of your lab report or worse. All of the sources used must be properly cited. This includes the author, name of the text or article and periodical, publisher, date and pages.


If it is a site on the Internet then you should use the following method of siting the source. First state the author, title of web page, title of complete work, URL (address of web page), and finally the date visited.

**Example:** Fairbank, Mark "Parabolic Motion Activity" Mr. Faibank Web site. 1996 http://207.62.24.7/prhs/fairbank/PUBLIC.WWW/homepage/Phypage.htm (9 September 2003)

4. **How to write the Hypothesis/Experimental**

   In this section formally present the question you are trying to answer or the hypothesis you are testing. Include what outcome you expect, and how it will help support or not support your hypothesis. A hypothesis is an educated statement based on background material that explains what you think is going to happen before the experiment begins. Make sure it is testable. (Notes: it is okay if your guess turns out to be wrong. That's how science works. Many famous scientists have made incorrect hypotheses. It happens and you still get lots of information from the results.)

   Now give the independent and dependent variables and the control. Share the design of your experiment. Include the number of time the experiment is run and how it is controlled. A hypothesis is often written in an If/Then statement. Example: if a force is applied then the cart will accelerate. The independent variable is the force and the dependent variable is the acceleration.

   After writing the hypothesis you will need to describe the materials used. Include all of the equipment used and how it was used. A diagram of the setup is a must. Label each diagram with Figure 1, Figure 2, followed by a descriptive title. Next include a concise description of the procedures. The experimental clearly describes the experiment situation, the control situation and the types of observations made. If the procedure was derived from a source then the source should be cited. If you altered the procedure from the source then describe the changes in detail. If you developed the procedure then there should be enough detail so that someone else could repeat your work.

5. **How to write the Results/Analysis**

   Introduce this section through an overview of the method used to collect the data. Present your findings in a logical order. Give the results that you found, NOT what you think you should have found. You may have to do some thinking to find out why the results came out as they did. This section contains a collection of clearly labeled data tables, graphs and figures or drawings. It requires a verbal description about the data, graph and figure. When you present each table or figure, briefly describe important patterns pointing out trends or inconsistencies. Following the tables, graphs and figures is the statistical analysis. Show your calculations for the data as well as deviations and error analysis. This will include a calculation using tolerances to see if the data falls in the range. You must provide a clear verbal description for each of the calculations.

   Next is the most important part of the laboratory report. You will analyze the results by explaining what the results of the experiment showed. In this final section you give your interpretation of the data and relate them to the question you asked in the hypothesis. If you have any odd data to explain, do it and then make a new hypothesis as to why the results came out in a way you did not expect. Use the results data and graphs to support your statements. Describe the significance of your results on this topic. Finally describe problems during experimentation, or sources of error that may have influenced your results.

6. **How to write the Conclusion**

   In this section you will discuss how further experimentation can be performed to clear up discrepancies or vague areas in the results. Finally, share how others can use your work or how it could be extended. What new hypothesis could be tested?
<table>
<thead>
<tr>
<th>Score</th>
<th>Title Page</th>
<th>Abstract</th>
<th>Introduction</th>
<th>Experimental</th>
<th>Results</th>
<th>Conclusion</th>
<th>Over all</th>
</tr>
</thead>
<tbody>
<tr>
<td>A = 90-100</td>
<td>*The title is centered at the top of its very own page. *Two inches from the bottom put your name (first/last) the date and the class title.</td>
<td>*Summarize the laboratory report in one to three paragraphs. Each section of the report (introduction, hypothesis/experimental, results/analysis, and conclusion) will be briefly summarized. *The first paragraph should describe the theory and the experimental procedure. *An overview of the actual results should be shown in the second paragraph. *The final paragraph should include the analysis and methods to improve the experiment.</td>
<td>*This is a formal essay on the theory or background. Complete explanation of the important facts of the general problem or area being investigated, explaining why this problem is of interest and what information is already known. *All sources are cited. That is the sources quoted and those that you just got information from.</td>
<td>*Formal presentation to the question or the hypothesis. Include expected outcomes and how they supported the hypothesis. *The independent and dependent variables and the control are stated. *The experimental design is given including the number of time the experiment was run and how it was controlled. *A complete description and diagram of the equipment and how it was used is given. The diagrams are labeled with Figure1, 2 … followed by a descriptive title.</td>
<td>*Introduce this section through an overview of the method used to collect the data. *Findings are presented in a logical order. Present data in clearly labeled data tables, graphs and figures or drawings with verbal description. The descriptions include important patterns pointing out trends or inconsistencies. *Next is the statistical analysis. Calculations for the data as well as deviations and error analysis are shown. This will include a calculation using tolerances to see if the data falls in the range. *A clear verbal description for each of the calculations is provided.</td>
<td>*Discuss how further experimentation can be performed to clear up discrepancies or vague areas in the results. *Finally, a description of how others can use your work or how it could be extended.</td>
<td>*Proper spelling and grammar are used. Word choice is clear and unfamiliar terms are defined in the context. *No personal pronouns are used. * The writing is natural, accurate, and causes no confusion.</td>
</tr>
<tr>
<td>C-B = 70-89</td>
<td>The title page is not summarized correctly as given above</td>
<td>All sections are not summarized in this section. The content of structure in the paragraphs is not complete.</td>
<td>*Brief explanation of the important facts of the general problem or area being investigated, explaining why this problem is of interest and what information is already known. *Sources are not cited.</td>
<td>*The variables and hypothesis are unclear *The experimental design is brief without the number of time the experiment was run and how it was controlled. *A brief description and diagram of the equipment and how it was used is given. The diagrams are labeled with Figure1, 2 … followed by a descriptive title. *A non concise description of the procedure is given which may not include the experiment situation, the control situation and the types of observations made. If the procedure was derived from a source then the source should be cited.</td>
<td>*Introduce this section through an overview of the method used to collect the data. *Findings are not presented in a logical order. Data is not clearly labeled in data tables, graphs and figures or drawings with verbal description. The descriptions include important patterns pointing out trends or inconsistencies. *The statistical analysis is missing some of the calculations for the data as well as deviations. *Verbal descriptions for each of the calculations is brief.</td>
<td>Experimental errors are not addressed with recommendations.</td>
<td></td>
</tr>
<tr>
<td>D-F= 0-69</td>
<td>No title page</td>
<td>The abstract is missing or one or more sections are not summarized.</td>
<td>The background information is sketchy. Sources are not cited.</td>
<td>The hypothesis is missing and the procedures are very unclear. No diagrams are shown</td>
<td>Results are presented in anillogical manner. Sample calculations are missing or lack explanations. Errors are not analyzed completely. Tables and graphs are missing or are described improperly.</td>
<td>Lack and addressing the hypothesis.</td>
<td>Poor word choice and use of personal pronouns.</td>
</tr>
</tbody>
</table>
Formal Laboratory Writing Process and Grading Rubric

The process of writing a formal laboratory report is challenging but very rewarding. As you prepare to attend college and a scientific course of study you will need skills in writing scientific reports. The process that we will embark on throughout the year will provide you with the opportunity to develop and hone skills in writing using a scientific style. This style is very formal and follows formats that have been standardized within the scientific community.

You have been provided with the standard and objectives that will allow you to evaluate your writing. We will have the opportunity to evaluate reports that have been completed in the past to help us get an overview of the writing expectations. Over the next three to four weeks we will begin the process of writing your first report. The report will be based upon your understanding and use of accuracy and precision in analyzing data.

The writing process will be done section by section. Each section will be evaluated by you, your peers and by me. You will not be graded on drafts but awarded points for the writing them. The purpose is to improve your writing as you progress. The goal at the end when the final draft is turned in is that you are progressing toward effective scientific writing. The final draft will be turned in and evaluated according to the following rubric.

Outline of the Grading Rubric

Value of 90 - 100 points: the paper is accurate, detailed, and complete including all sections in detail, thoughtful, neat, and well organized. Each section will follow the guidelines given in the handout titled Laboratory Report.

Value of 80-89 points: the paper is clear, some details, mostly complete including all sections listed above in detail, and organized. Each section will follow the guidelines given in the handout titled Laboratory Report.

Value of 70-79 points: the paper is brief, lacks details, some incorrect work, poor wording, and limited information in each section.

Value of 0-69 points: the paper is missing sections, no detail, many errors, sloppy, unorganized, and little information in each section.
Lab Title: (The effect of the independent variable (IV) on the dependent variable (DV))

Hypothesis: (Use an if/when…then… format. State the cause and effect relationship between the IV and the DV. The hypothesis must be testable.)

Independent Variable, IV: (What is the cause agent? What are you changing?)

Data Table Title

Sub Heading

Data

Dependent Variable, DV: (What is being measured?)

Control Group: (What is the experimental group being compared to?)

Experimental Constants: (Variables not altered during the experiment)

Sketch of experimental set-up, with labels:
Activity: Piston Rocket

**Standard:** Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept, and to address the content of the other four strands, students should develop their own questions and perform investigations. Students will:
- identify possible reasons for inconsistent results, such as sources of error or uncontrolled conditions.
- formulate explanations using logic and evidence.

**Reasoning Objectives:**
- I will use if/then statements to determine the independent and dependent variables; then display experimental data correctly using tables.
- I will make graphs of experimental data, graphing the dependent variable on the y axis and the independent variable on the x axis.

**Problem:**

**Hypothesis:** If _____________________ then _____________________________.
    (independent variable)     (dependent variable)

**Independent variable:** __________  **Dependent variable:** __________

**Constants:**

**Control (standard for comparison):**

**Materials:**

**Procedure:**

**Data Table Title:**

<table>
<thead>
<tr>
<th></th>
<th>Dependent Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Independent Variable</td>
<td>Trial 1</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Sample Calculations**

**Conclusion:**
Collecting Experimental Data: Measurements

Standards: Regarding students’ understanding about scientific inquiry, NSTA recommends that teachers help students understand

- That science involves asking questions about the world and then developing scientific investigations to answer their questions.
- That there is no fixed sequence of steps that all scientific investigations follow; different kinds of questions suggest different kinds of scientific investigations.
- That scientific inquiry is central to the learning of science and reflects how science is done.
- The importance of gathering empirical data using appropriate tools and instruments.
- That the evidence they collect can change their perceptions about the world and increase their scientific knowledge.
- The importance of being skeptical when they assess their own work and the work of others.
- That the scientific community, in the end, seeks explanations that are empirically based and logically consistent.

Knowledge Objectives:

- I will learn the meanings of accuracy and precision and the equations that express these quantities.
- I will know how to present data using significant figures and tolerances.

Reasoning Objectives

- I will compare and contrast accuracy and precision.
- I will evaluate data in terms of accuracy and precision including tolerance.

Introduction:

Measurements are an important part in scientific investigations. Data collected by scientists is evaluated in terms of its accuracy and precision. It is important to show how significant results are. If the errors and deviation are large then the results may not be considered viable. The data from experiments should be scrutinized by the experimenter. If the data has great errors or deviation then better methods of measurements should be pursued. You, as the scientist, will use the following forms of evaluation to judge the validity of experimental data. Data is evaluated in terms of accuracy and precision in analyzing data.

Accuracy is the degree to which a measurement agrees with an accepted value for those measurements. They can be evaluated in absolute or relative terms. The absolute error is the absolute value of the difference between the accepted value and the measurement. This can be written as an equation as shown below.

\[ \text{Absolute error} = |\text{Observed} - \text{Accepted value}| \]

This can be expressed as a percentage error also. The percentage error is the relative error. It is expressed the following equation.

\[ \text{Relative error} = \frac{\text{Absolute error}}{\text{Accepted value}} \times 100\% \]

Another way to express the deviation or precision is as a percentage. This is the relative deviation and is expressed as follows.

\[ \text{Relative deviation} = \frac{\text{Absolute deviation}}{\text{Mean value}} \times 100\% \]
Relative deviation = \frac{\text{Average absolute deviation}}{\text{Mean value}} \times 100\% \quad \text{Dr} = \frac{\text{Da}}{\text{M}} \times 100\%

One other way to express the precision or uncertainty of measurements is through the tolerance of the measuring device. The degree of certainty with which a measurement is made is expressed with the value when it is reported. If the best a measuring instrument can be read is to the tenth, then an example of reporting of a measurement is $9.5 \pm .1$. This example is shown with the measuring of the pencil below.

An instrument that is calibrated with better resolution allows the measurer to determine the length of the pencil with a higher degree of tolerance. The pencil can now be measured to $9.52 \pm .01$.

In each of these measurements, the pencil had to be lined up at the zero end of the ruler and then the measurement was judged at the other end. This would compound the tolerance to double the value or $\pm .2$ or $\pm .02$ in each measurement. In other words the length of the pencil for the first ruler would lie some place between 9.3 and 9.7 when the measurement was reported as $9.5 \pm .2$ and between 9.50 and 9.54 for the second ruler and reported as $9.52 \pm .02$.

\textbf{Material:}  
Metric rulers and interactive notebook

\textbf{Procedure:}  
This investigation is used to assist you to understand the importance of measurements in scientific experimentation and the reliability of measuring instruments. You will learn about significant figures, accuracy and precision in measurements and means to express data in absolute and relative terms.

Use two meter sticks or metric rulers that were made by different companies. Line up the rulers side by side at the 1.00 centimeter marks or end of the ruler. Next view the calibration of each measuring device at the other end. In the diagrams below the rulers were different by one millimeter at the thirty centimeter mark. This difference was due to the different calibration standard used by each company.
Each ruler is different and thus neither may be calibrated accurately. No matter how hard you attempt to use an incorrectly calibrated measuring device you cannot make an accurate measurement. Thus, accuracy is dependent upon the instrument calibration.

Precision is the reproducibility of measurements made using the same method and instrument over and over. Measurement may be precise without being accurate, yet if all measurements are accurate, then they are also precise. How precise a measurement is depends on the level of the calibration or tolerance of that instrument. The degree of certainty or tolerance with which a measurement is made is expressed with arrange for the value when it is reported.

Now you will measure the height of a page in your interactive notebook. You will repeat each measurement without bias from previous measurements. Take at least 5 measurements and tabulate these values using both the ruler that is calibrated at the centimeters and then the one that is calibrated at the millimeter marks.

Analysis:
Evaluate the measurements that are made with the ruler that is calibrated to the millimeters by comparing your values to the accepted value and the mean or average value. If your notebook is 8.50 by 11.00 inches then the accepted value for the height of the page is 27.94 centimeters. The comparison can be done by making calculations for the absolute and relative error and deviation. These values should be tabulated in the table next to the measured values. Make a sample calculation for each value in your notebook. Each calculation should have descriptions of what you have done.

Now appraise your knowledge of uncertainties in measurements by comparing accuracy to precision using a Venn diagram or Bull’s Eye comparison and writing a poem about the concepts.

Questions:
1. What might happen if scientists did not use accuracy and precision in their experiments?
2. Predict how this is used in a real life situation such as home construction.
3. What are the benefits of using significant figures when recording data?
Experiment: Accuracy and Precision

Common Core Mathematics Processes
CCSS Math Practice 1: Make sense of problems and persevere in solving them.
CCSS Math Practice 2: Reason abstractly and quantitatively.
CCSS Math Practice 3: Construct viable arguments and critique the reasoning of others.
CCSS Math Practice 4: Model with mathematics
CCSS Math Practice 5: Use appropriate tools strategically.
CCSS Math Practice 6: Attend to precision.
CCSS Math Practice 7: Look for and make use of structure.
CCSS Math Practice 8: Look for and express regularity in repeated reasoning

Knowledge Objectives
- I will learn the meanings of accuracy and precision and the equations that express these quantities.
- I know how to present data using significant figures and tolerances.

Reasoning Objectives
- I will compare and contrast accuracy and precision.
- I will analyze data in terms of accuracy and precision including tolerance.

Introduction: Data collected by scientists is evaluated in terms of its accuracy and precision. It is important to show how significant results are. If the errors and deviation are large then the results may not be considered viable. The data from experiments should be scrutinized by the experimenter. If the data has great errors or deviation then better methods of measurements should be pursued. You as the scientist will need to use the following calculations for accuracy and precision in analyzing data.

Accuracy is the degree to which a measurement agrees with an accepted value for those measurements. They can be evaluated in absolute or relative terms. The absolute error is the absolute value of the difference between the accepted value and the measurement. This can be written as an equation as shown below.

\[ \text{Absolute error} = |\text{Observed} - \text{Accepted value}| \]

This can be expressed as a percentage error also. The percentage error is the relative error. It is expressed the following equation.

\[ \text{Relative error} = \frac{\text{Absolute error}}{\text{Accepted value}} \times 100\% \]

Data can also be evaluated in terms of how measurements, which are made in the same manner, deviate from one another. This is known as precision and is evaluated in terms of absolute and relative deviation. Absolute deviation is the absolute value of the difference between the mean or average value and the measured value. This is expressed below in the equation.

\[ \text{Absolute deviation} = |\text{Observed} - \text{Mean value}| \]

Another way to express the deviation or precision is as a percentage. This is the relative deviation and is expressed as follows.

\[ \text{Relative deviation} = \frac{\text{Average absolute deviation}}{\text{Mean value}} \times 100\% \]

One other way to express the precision of measurements is through the tolerance of the measuring device. The degree of certainty with which a measurement is made is expressed with the value when it is reported. If the best a measuring instrument can be read is to the a tenth, then an example of the reporting of a measurement is 11.1+.1.
In this lab, the prime focus will be on the accuracy and precision of measurements that you make. You will use trigonometry of right triangles to find the height of one object. If this is your first introduction to the trigonometry of right triangles, you will see that the concept is not too difficult. For a given angle, the sides of a right triangle are proportional to one another no matter what the triangle’s size. This ratio is described by sine, cosine, and tangent of an angle, depending on the sides of the triangle you select to use.

**Apparatus:** optic bench, laser, ruler, meter stick, protractor, bubble level

**Procedure - Determining the height of an object**

1. Attach the laser to the optics 3 cm x 12 cm board that is connected to the hinge on the optics bench.

2. Find the distance from the object to the pivot point of the laser beam, using meter sticks. Be sure not to move the block’s pivot point from the object until the entire part I procedure is complete. Record the data.

3. Turn on the laser. Determine the height of the horizontal laser beam from the floor. This can be accomplished by measuring from the center of the laser spot on the object to the floor. Record the data. See the following diagram.

4. Rotate the upper block until the laser beam just strikes the upper edge of the object. While in this position, measure the angle between the two inside edges of the block with a protractor. The center of the protractor should be located at the pivot point of the two blocks. Record the angle in a data table. See diagram below.

**Analysis:**
1. Calculate the remaining height of the object, using trigonometry. Now find the total height of the object by adding the two heights together. Show an example set of calculations.
2. Measure the actual height directly on the object and record the value. This will be your accepted value.
3. Repeat the procedure five more times and then make the calculations for accuracy and precision for the calculated heights. Include a table of the absolute and relative errors and deviations.
Motion and Forces

\[ F = ma \]

Linear and Two Dimensional Motion

Equal but Opposite Forces

Linear Motion of a Human for 20 Meters

Linear Motion of a Human for 20 Meters

[Graphs showing velocity and displacement over time]
Paper Tower

Forces and Interactions
Students who demonstrate understanding can:
HS-PS2-1. Analyze data to support the claim that Newton’s second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

Standard: HS-ETS-ED Engineering Design
HS-ETS1- 2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

Reasoning Objective
- I will use vectors to pictorially analyze problems to determine the net force on an object and the forces on objects that are static.
- I will solve force problems using vectors and trigonometry.
- I will plan and carry out an investigation with physical models to develop evidence on the effectiveness of design solutions, leading to at least two rounds of testing and improvement.

Activity: A tower is any structure relatively tall in proportion to the dimensions of its base. Undoubtedly, you have built towers out of sand or blocks. Have you ever made a tower with paper? How high can you make it using just one piece of paper? This is an activity to help you learn to work as a group. You need to pool everybody’s’ ideas together to obtain the best results.

Materials: 8 1/2” x 11” piece of paper, scissors, 30 cm of tape

Procedure:
Decide as a group how you are going to design your tower. Your structure must be self-supporting and fit the definition of a tower. Using only 1 piece of paper, make the tallest tower possible. You may use up to 30 centimeters of tape to assist you in building the tower. You may have up to 3 pieces of paper to try for the best results, but only 1 piece of paper and 30 centimeters of tape may be used per tower.

Analysis:
1. List as many factors as you can which effect how tall the tower is. Draw a diagram of your tower and show the forces that are acting on your tower using arrows. What major factors influenced the structural integrity of the tower? (i.e. explain design, effects of tape, etc.).
2. Were you able to use everybody’s’ ideas? Do you think it helped to work as a group? In problem solving exercises such as the paper towers, it is usually most beneficial to work as a group to obtain optimum results. Highly successful modern businesses use the group approach. We will be using this technique further as we go along in Physics.
Graphing Linear Motion

Standard:
HS-PS2-1. Analyze data to support the claim that Newton’s second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

Knowledge Objectives:
- I will use if-then statements with independent and dependent variables when developing a hypothesis.
- I will collect experimental data within the tolerance of the measuring instruments.

Reasoning Objectives
- I will graph experimental data placing the dependent variable on the y axis and the independent variable on the x axis.
- I will be able to explain the relationships between time, displacement, velocity, and acceleration using graphs.
- I will interpret the motion experienced in the experiment by a human through graphical analysis.

Introduction:
Throughout life you observe objects in motion relative to you. Motion is seldom constant. Objects speed up and slow down which is a change in velocity. Velocity has two components, one for direction and one for its size or magnitude. A change in either its direction or magnitude would represent acceleration. It requires a force to accelerate an object. When an object is pushed or pulled there will be a change in velocity.

You will analyze your motion through graphical analysis. The data will be graphed in two ways. The first will be distance traveled or displacement versus time and the other will be velocity versus time. These graphs represent two different views of the same data and motion. The graphs will allow you to see how well a human can achieve constant acceleration for a distance of 25 meters.

Average speed can be determined at a midpoint between timers who are set at distances of 5.0 meters apart. The set of data for time, total distance traveled or displacement, and average speed or instantaneous velocity at each successive distance can be graphed to analyze the motion. In the distance versus time graph the instantaneous velocity can be determined using the slope or tangent of the curve at a point on the graph.

Linear Motion of a Human for 20 Meters

Displacement (meters) vs. Time (seconds)

The slope of this line is the velocity of the person at the point the line is tangent to.

A method to determine the slope of the curve is to draw a tangent to the curve at a point. A flat mirror is placed alongside the curve so there is continuity between the curve and the mirror. This
continuity must be smooth and then a line along the base of the mirror represents the tangent to the curve at that point. A second method that can determine the tangent is to place a ruler at one point on the graph so that it touches the line at only that point on the graph as seen in the diagram above.

On the speed or velocity versus time graph the velocity can be determined at any point directly off the graph and the acceleration can be found from the slope of the line. The area under the graph can be used to determine the displacement of the object at a selected time.

![Linear Motion of a Human for 20 Meters](image)

An important aspect in developing experimental procedures and then making a graph of the data is to identify the independent and then dependent variables. The independent variable is the variable that is manipulated in the experiment and the dependent variable then responds and is measured. This can be identified through an if-then statement. If the independent variable is altered then the dependent variable will respond. It is also important to keep constant any other variables that may influence the dependent variable. This is a cause and effect relationship. With the independent variable being the cause and the dependent variable is the effect.

**GRAPHICAL RELATIONSHIPS**

**No Relationship between the Variables**

![No Relationship between the Variables](image)

Some data gathered in experiments may not have a relationship between the x and y variables. The graph above shows that the y variable is unchanged as the x variable becomes larger.
**Linear Relationship:**

\[ y = mx + b \]

The slope of the line, \( m \), is the change in \( y \) divided by the change in \( x \) or rise over run.

This is a direct relationship showing that as the \( x \) variable increases so does the \( y \) variable proportionately. This means that as the value for \( x \) increases the \( y \) value increases at a constant rate.

**Inverse Relationship:**

\[ y = \frac{m}{x} \]

In this relationship as the value of \( x \) increases \( y \) decrease proportionately. Thus, as \( x \) is increased, \( y \) is decreased proportionally. When the graph is split at a 45° angle from the origin the two halves are mirror images of each other since it is an inverse relationship.
Squared Relationship or Exponential Relationship

\[ y = ax^2 \quad (y = ax^2 + bx + c) \]

In this relationship as x increases, the value of y increases with the square of the x value. The a, b and c variables are constants in the equation. This is a parabolic relationship. Other exponent relationships can increase with the other powers of the x variable.

Inverse Square Relationship

\[ y = m \, 1/x^2 \]

As the x variable increases the y variable decreases with the inverse square of x.

**Apparatus:**
11 stopwatches per group, metric measuring tape or meter stick, string and marker

**Procedure:**
1. Use a meter stick to mark a piece of string at 5.0 meter distances with a black permanent marker. Next mark at 2.5, 7.5, 12.5, 17.5, 22.5, and 27.5 meter with a red permanent marker.
2. Take the string to an open field, such as an athletic field on campus. Now stretch out the string, anchoring it with a stake at each end.
3. Have five female timers with stopwatches stand at five meter intervals on the black marks. The six male timers will stand halfway between the female timers or at 2.5, 7.5, 12.5, 17.5, 22.5 and 27.5 meter marks on the string. These are the red marks.
4. The student selected to constantly accelerate will start at the zero marker and give the command to start the stopwatches; while simultaneously begin to accelerate across the 27.5 meters.
5. Each timer should stop their watch when the runner passes them.
6. Tabulate the time that the females have recorded for the five meter marks in the table.

<table>
<thead>
<tr>
<th>Displacement (+ .2 meters)</th>
<th>Time (± .2 seconds)</th>
<th>Velocity (meters/second)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7. The times the males take will be used to determine the average velocities at each five meter mark. The values that the males take should be recorded on a separate line as shown below.

Male times: $t_1 =$ _______ $t_2 =$ _______ $t_3 =$ _______ $t_4 =$ _______ $t_5 =$ _______ $t_6 =$ _______

The average velocity is determined by taking the difference between successive male times and dividing it into 5 meters. This average velocity is the instantaneous velocity of the accelerator at the location where the females were standing at each five meter mark.

$$\text{velocity at 5 meter intervals} = \text{average velocity} = \frac{\text{displacement}}{\text{difference in time}} = \frac{5 \text{ meters}}{t_2 - t_1}$$

8. Tabulate the velocities in a third column in the table.

Analysis:

1. You will interpret the actual motion through graphical analysis of the data. The independent variable is the time and should be graphed on the x axis while displacement and speed or velocity are the dependent variables and are graphed on the y axis.

2. One of the most challenging aspects of the graphical analysis is setting up the axis. The displacement on the y axis is relatively simple since it can be divided into 5.0 meter division. The time or x axis on each graph and the velocity or y axis on the second graph must be divided into equally spaced divisions. First count the number of divisions. The number of divisions should then be divided into the total time that was recorded at the 25.0 meter mark to determine the time per division.

3. Once the graphs are constructed, evaluate how well the person accelerated at constant velocity by observing how linear the second graph is. The slope of this graph is the acceleration or change in velocity versus time. The slope should be constant if the acceleration is constant and the graph should be linear.

4. The data on each graph can be compared. The slope at a point on the displacement versus time graph is the velocity at that point in time. The slope at a point is the tangent at that point on the graph. Draw a tangent to the curve at a point using a mirror or ruler. Remember the slope of a line or the tangent is the change in y over the change in x. Record the x and y values for two points on the tangent line and determine the slope or velocity.

5. This slope value can then be compared to the velocity for the same time on the velocity versus time graph. The two values should be the same.

$$\text{velocity} = \frac{x_2 - x_1}{t_2 - t_1}$$
Linear Motion of a Human for 20 Meters

6. A second comparison can be made for displacement. The area under the velocity versus time graph is the displacement of the person at a particular time. This displacement should be equal to the displacement for the same time on the displacement versus time graph.

\[ \text{displacement} = \frac{1}{2} \text{velocity final} \times \text{time} = \frac{1}{2} vt = v_{\text{average}} t \]

Linear Motion of a Human for 20 Meters

7. Now determine the acceleration of the person using the slope of the velocity versus time graph.

\[ \text{acceleration} = \frac{v_2 - v_1}{t_2 - t_1} \]

Questions:
1. What might happen if you did not control the experiment with specific constants?
2. What are the benefits of designing a controlled experiment before you start to collect data? What are the disadvantages?
3. Predict what the relationship is between the velocity and acceleration?
4. Analyze the relationship of velocity and acceleration using the two graphs.
5. How do the graphs for the displacement versus time compare the graph of velocity versus time?

Conclusion: Express the relationship between the two graphs. The motion is expressed differently through the graphs, yet it is the same motion. Evaluate the relationships between the two graphs by determining the slope of the displacement versus time graph at a point and comparing it to the velocity for that time.
Technology: Interactive probe ware, ultrasonic motion detector and a computer can also be used to graph the motion. Graphical analysis of the data using the computer generated graph can be accomplished with the proper graphing program.

Experiment: Graphical Analysis of Linear Motion

Standard: HS-PS2-1. Analyze data to support the claim that Newton’s second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

Knowledge Objective
- I know how to present data using significant figures and tolerances.

Reasoning Objective
- I understand the relationships of time, displacement, velocity and acceleration through graphs.
- I can justify how an object is moving through the interpretation of experimental data.

Skill Objective
- I can collect experimental data within the tolerance of the measuring instruments.
- I can graph and tabulate experimental data.

Introduction:
Throughout life you observe objects in motion relative to you. Motion is seldom constant. Objects speed up and slow down which is a change in velocity. Velocity has two components, one for direction and one for its size or magnitude. A change in either its direction or magnitude would represent acceleration. It requires a force to accelerate an object. When an object is pushed or pulled there will be a change in velocity.

You will analyze the motion of a laboratory cart through graphical analysis. The data will be graphed in two ways. The first will be distance traveled versus time and the other will be velocity versus time. These graphs represent two different views of the same data and motion. The graphs will allow you to see what the cart is doing as it rolls across the counter.

The recording timer is used to measure small intervals of time. The motion of a dynamics cart accelerating across a laboratory table can be analyzed using the recording tape from a timer. A timer uses a regularly vibrating clapper and carbon disk to make dots on a recording tape. The dots are made at regular time intervals so the distance between the dots can be used to determine the distance traveled and the velocity of the cart at any time during the motion.

It is essential to determine the time for one interval of the timer for the velocity to be calculated. The timer can be calibrated using a digital strobe. A flashing strobe can be adjusted to coincide with the vibration of the timer and thus the recording timer will appear to remain still. The reading on the strobe can then be used to determine the time or period for one vibration. This is the time it takes the timer to move through one cycle. A cycle records a dot on the timer tape or the time it takes for the timer to move up from the previous dot and then move back down to place a second dot on the recording tape.

Once the timer is calibrated or the time for one cycle has been determined it can be used to measure time intervals while a dynamics car is moving. The record of the distance and time taken to move that distance can be recorded using the timer and a tape which is pulled through the timer by the dynamics cart. This permanent record of dots
shows how far the cart travels and the calibration of time per cycle shows the time it takes to move the distance between the dots.

The average speed of a cart can be determined at a midpoint of many periods. The set of data for time, total distance traveled, and average speed or velocity at each successive distance can be graphed to analyze the motion of the cart. In the distance versus time graph the instantaneous velocity of the cart can be determined using the slope or tangent of the curve at a point.

On the speed or velocity versus time graph the velocity can be determined at any point directly off the graph and the acceleration can be found from the slope or tangent to the curve.

A tangent to the curve is acceleration

A method to determining the tangent and thus the slope of the curve is by using a flat mirror. The mirror is placed alongside the curve so there is continuity between the curve and the mirror. This continuity must be smooth and then a line along the base of the mirror represents the tangent to the curve at that point.

Apparatus: recording timer, timing tape, digital strobe, cart, 200 gram mass, pulley, ruler, meter stick, string and mirror.

Procedure:

The recording timer can be calibrated using the strobe. Turn on the timer and then adjust the strobe in a darken room until the timer appears to stop. Once the two are synchronized the value on the strobe can be noted. The timer will appear to stop when the strobe flashes every third time it vibrates, every second, every time or other multiples. It is important to find a one-to-one correspondence between the number of flashes and the number of cycles or vibrations. To do this, raise the strobe to the fastest rate of flash and then dial down until the timer appears to stop. Record this value from the strobe. This value is the correct calibration since it is a one-to-one correspondence of flashes and timer cycle. Repeat this procedure five more times. Take the average of the six recorded times for a more precise value of time. These are flashes per minute and must be divided by 60 seconds in a minute to determine the number of flashes per second. Finally, the reciprocal of that value must be found to determine the seconds per period for the timer.

After the timer is calibrated it may be used to measure distance and time for the motion of the dynamics cart. Attach a 200 gram mass to the cart using a string and arrange the mass over the side of the table placing the string into the pulley at the end of the table to reduce friction. Hold the cart in place with a book so that it does not accelerate while the rest of the apparatus is set up. Attach a timer tape to the bottom of the cart with masking or adhesive tape. Thread the timer tape through the timer over the top of a carbon disk so that dots are tapped onto the tape as it is pulled through the timer. Make sure there is plenty of room between the pulley and the cart so that the mass will hit the floor before the cart is stopped in front of the pulley. Start the timer and then release
the cart. Catch the cart prior to it hitting the pulley. The dots corresponding to the motion of the cart will be on
the underside of the tape.

Circle the first dot and label it zero. Count over successive ten dots and circle each. Number each
successive circled dot with the next higher integer. Now count back three spaces and forward three spaces from
the circle dots to measure the distance, \( d_1 \), over six intervals surrounding the numbered dots. You will record
the distance for the first dot as zero; as that dot was made when the cart was at rest. Next, record the distance
for the six intervals surrounding each numbered dot in the table. Determine the time for six intervals by
multiplying the time per period, determined with the strobe, by six. Divide each of the distances by the time for
the six periods to determine the average velocity over that distance. This is the instantaneous velocity or speed
at each numbered point. Record that speed or velocity in the table next to the distance interval. Make note that
this distance is used to determine the average speed or velocity and will not be used in the graph. Now the total
distance or \( d_2 \) traveled will be determined for each successive numbered dot. The distance from zero to each
dot must be measured and recorded since this is the total distance traveled to reach each of the velocities at the
numbered points. The distance \( d_2 \) is used in the graph of distance versus time. To determine the total time
interval to reach each successive numbered dot it is necessary to multiply the time per period by the total
number of periods recorded from zero to that dot. For dot number 1 the total time to reach that point is 10
periods times the time per period. For dot number 2 the total time is 20 times the time per period and for 3 it is
30 times the time per period. Record the time values in the table next to the corresponding distance to the dot.

**Analysis:**
Create two graphs: one with the distance traveled to the numbered points versus the total time required
to reach each successive numbered point and the other velocity at each point versus the time required to reach
that point. The slope of the first graph is the velocity and the slope of the second graph is the acceleration.
Describe the motion of the cart by analyzing the graphs. This slope value can then be compared to the velocity
for the same time on the velocity versus time graph. The two values should be the same.

A second comparison can be made for displacement. The area under the velocity versus time graph is
the displacement of the person at a particular time. This displacement should be equal to the displacement for
the same time on the displacement versus time graph.

\[
\text{displacement} = \frac{1}{2} \text{velocity final} \times \text{time} = \frac{1}{2} vt = v_{\text{average}} t
\]

Finally, determine the acceleration of the person using the slope of the velocity versus time graph.

\[
\text{Acceleration} = \frac{v_2 - v_1}{t_2 - t_1}
\]

**Questions and Conclusions:**
1. What are the numbers of significant figures in the speed values?
2. What is the limiting factor for this number of significant figures?
3. Speed was determined using a six period interval. What determines the size of the interval used to
find the speed?
Experiment: Determining the Acceleration Due to Gravity

Standard: HS-PS2-1. Analyze data to support the claim that Newton’s second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

Knowledge Objective
- I know how to present data using significant figures and tolerances.

Reasoning Objective
- I can describe and explain the relationships of time, displacement, velocity and acceleration for a falling object.

Skill Objectives
- I can collect experimental data within the tolerance of the measuring instruments.
- I can graph and tabulate experimental data.

Introduction:
Throughout life you observe objects in motion relative to you. Motion is seldom constant. Objects speed up and slow down, which is a change in velocity. Velocity has two components, one for direction and one for its size or magnitude. A change in either its direction or magnitude would represent acceleration. A force is required to accelerate an object; when an object is in free fall, that force is gravity. The acceleration due to this force is a constant at the surface of the earth. Newton’s second law states that a mass undergoes acceleration when a force is applied to it. The acceleration is directly proportional to the force that is applied. The constant of proportionality is the inertial mass. The equation form of Newton’s second law is:

\[ F = ma \]

Here are three equations that can be used to analyze accelerated motion.

\[ a = \frac{v - v_0}{t} \quad x = v_0t + \frac{1}{2}at^2 \quad 2ax = v^2 - v_0^2 \]

In these equations, the acceleration is represented by \( a \), \( t \) is the time that elapses, \( v_0 \) is the initial velocity, and \( v \) is the final velocity. The variable for the acceleration, \( a \), is replaced by \( g \) for objects that are in free fall.

Apparatus: free fall apparatus, ring stand, utility clamp, steel marble, meter stick

Procedure: Your task it to determine the value for the acceleration due to gravity in this inquiry activity. You will be provided with a free fall apparatus. The challenge is to use your knowledge of the above equations to determine the constant value for the acceleration due to gravity. To operate the apparatus you will attach the release mechanism to a ring stand using a utility clamp.

Place a steel marble in the apparatus and pull the center pin, compressing the spring and pressing the metal plate against the ball, to hold it in position. Tighten the set screw so that the marble remains in place. Adjust the plate of the free fall apparatus under the marble so that when it is released it will land on the plate.
Reset the timer and then release the marble. The timer will automatically start when the marble is released and stop when it hits the bottom plate.

You will need to measure the distance from the bottom of the marble to the plate and take the time for each trial. Move the utility clamp to different distances above the plate for each trial and collect at least five sets of data. Graph your data to determine the line of best fit that will give you a slope of the line that is the value for the acceleration due to gravity. Compare this value to the accepted value of $9.81 \text{ m/sec}^2$. If you have measured your values in centimeters please convert them to meters before you graph.

**Conclusion:** Discuss how close your value came to the accepted value and analyze it in terms of absolute and relative errors. Include in your discussion how the apparatus can contribute to the errors. Make sure to include numerical analysis of the error.
Activity: One Dimensional Motion with a Red Rocket

Standard: HS-PS2-1. Analyze data to support the claim that Newton’s second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

Reasoning Objective
- I will use knowledge of linear motion to solve problems.
- I will justify how an object is moving through the interpretation of experimental data.

Activity: Fire a rocket into the air from as close to ground level as possible and measure the time for the flight.

Goal: Students will gain an understanding of one and two-dimensional motion.

1. Draw the free body diagram (forces that act on the rocket) for the rocket while it is in flight ignoring friction.
2. Find the initial velocity knowing the time for travel.
3. Find the time the rocket takes to reach the top of its flight.
4. Find the maximum height the rocket reaches.
5. If the rocket were shot from the top of a 55-meter high cliff straight up how long would it take to reach the bottom of the cliff?
6. How high would the rocket go if it were launched on the moon?

Extension: Two Dimensional Motion

7. If it were fired at an angle of 35.0° what distance would it travel along a horizontal surface?
8. If it were fired from the top of the cliff at an angle of 35.0° what horizontal distance would it travel?
9. If wind had a speed of 5.0 meter/second horizontally at what angle would the rocket have to be fired to go straight up?
Activity: Monkey Shoot

Standard: HS-PS2-1. Analyze data to support the claim that Newton’s second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

Reasoning Objectives
- I will use vectors to pictorially analyze two dimensional motion.
- I will solve two dimensional word problems for an object in constant velocity and accelerated motion using vectors and trigonometry.

Activity: Shoot the ball directly up in the air and measure the maximum height the ball moves above the top of the cannon opening. Find the mass of the ball.

Goal: Students will gain an understanding of one and two-dimensional motion.

1. What is the velocity of the ball at the top of the flight?

2. How far does the ball travel by the time it returns to the top of the piston cannon?

3. What is the time it takes to reach the top of the flight and what is the time it takes to fall from the top of the flight?

4. How fast is the ball traveling when it reaches the same height that it was when it left the piston cannon?

5. If the ball is fired off the edge of the laboratory table at an angle of 45° what are the distance equations with respect to time?

6. If the ball is fired off the edge of the laboratory table at an angle of 45°, what will its displacement be horizontally from the base of the table? You must measure the vertical distance the object falls from the end of the cannon to the floor. Remember that this distance is negative.
Experiment: Parabolic Motion

Standard: HS-PS2-1. Analyze data to support the claim that Newton’s second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

Reasoning Objective
- I will use vectors to pictorially analyze two dimensional motion.
- I will solve two dimensional word problems for an object in constant velocity and accelerated motion using vectors and trigonometry.

Goal: It is your task to determine the velocity of the ball as it first appears on a multi-flash photograph. Secondly, you will need to determine the acceleration of the ball in a horizontal direction.

Introduction:
The path of a projectile fired from a cannon at the earth’s surface is a parabola. This parabolic motion can be analyzed in terms of two components. These are the horizontal, \( v_x \), and the vertical, \( v_y \), components as shown in the diagram below.

The initial velocity is shown by the \( v_i \) and the components for vertical and horizontal directions are shown by the \( v_x \) and \( v_y \). The horizontal component of velocity is unaffected by the force of gravity. It is constant as long as friction is neglected. The vertical component of velocity is affected by gravity since the force of gravity is parallel to this component. The force decelerated the ball in its upward motion and accelerated it as it moves down. The two components are unaffected by each other. They are totally independent even though they are not real. These components can be used to analyze the motion of an object.

Apparatus:
Piston cannon, Teflon ball, tripod for the strobe, strobe, tripods for the cameras, digital and film cameras, black backdrop with grid of 30.00 x 50.00 centimeters, film developer, paper developer, fixer, stop bath, photographic paper, dark room, photo enlarger, trays for chemicals, ruler and tongs.

Procedure: The details of the procedure will be discussed in class. You will have the opportunity to write up an experimental for the report using the techniques discussed and used in this laboratory.

Take a multi-flash photograph of a ball in projectile motion. This will be done in a darken room with a grid background. The ball will be projected through the air by a cannon while a strobe is flashing. The shutter of the camera should remain open as long as the ball is in flight but no longer or the digital and film or pictures will be over exposed.

After the digital image is printed and the film has been developed you will have the opportunity to expose and develop the paper to make a print. Once you have accomplished this task you will analyze the photograph in order to determine the velocity of the ball at the first image followed by determining the acceleration in the horizontal direction.

Analysis:
The initial velocity is the addition of the vertical and horizontal components of the velocity. This can be determined using the Pythagorean Theorem as shown below.

\[ a^2 + b^2 = c^2 \]

\[ V_{yo}^2 + V_x^2 = V_0^2 \]

![Diagram of velocity components](image)

Not only does the magnitude of the velocity vector need to be determined so does the angle with respect to the horizon since it is a velocity vector. Remember that velocities have both direction and magnitude. The angle that the velocity vector makes with the horizontal is theta, (θ). This can be determined using the tangent function or:

\[ \tan \theta = \frac{a}{b} = \frac{V_{yo}}{V_x} \]

Since both the vertical and horizontal component need to be determined you will need to find these using the equation for accelerated motion in the case of the vertical component and the constant velocity equation for the horizontal velocity. In both of those equations the unknown variable is the time. To determine the time you can find the frequency of the strobe. To do this, determine the vertical distance the ball travels from the maximum position of the arc where the \( V_x \) is equal to zero to the lowest image of the ball. The following equation can be used to calculate the time for the total number of flashes between the maximum and the lowest position the ball appears.

\[ x = v_0t + \frac{1}{2} at^2 \]

Since \( v_0 \) is equal to zero equation 1 becomes:

\[ x = \frac{1}{2} at^2 \]

Equation 2 can be rearranged to become:

\[ t = \sqrt{\frac{2x}{a}} \]

Now that you have calculated the time for the fall, it is possible to find the frequency of the strobe by dividing this time by the total number of periods for the fall. After the frequency of the strobe is determined, you can work backward until you determine the initial velocity.

While you were calculating the initial velocity, you made the assumption that there wasn’t air friction. Since this is a false assumption, please calculate what that value is for the horizontal acceleration. This can be done using the final and initial horizontal velocities. You have already calculated the initial horizontal velocity. Use the same equation with the measurement of the horizontal distance between the last two images of the ball to determine the final horizontal velocity. Finally use these two values with the total elapse time from half way between the first two images and half way between the last two images to find the horizontal acceleration.

\[ a = \frac{V_f - V_i}{t_{total}} \]

**Conclusion:** After performing the calculations please determine the errors in the results. Finally, determine how the above value of acceleration would affect your calculation for the frequency of the strobe.
Activity: Ring Stand Rodeo

Standard: HS-PS2-1. Analyze data to support the claim that Newton’s second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

Reasoning Objectives
- I will use vectors to pictorially analyze two dimensional motion.
- I will solve two dimensional word problems for an object in constant velocity and accelerated motion using vectors and trigonometry.

Goal: Students will analyze parabolic motion using equations.

Activity: Students will roll a marble down the momentum apparatus one time to make measurements. This will be followed by calculations and the placement of rings using ring stands for the marble to pass through at two different heights.

Apparatus: Ramp, C clamp, bubble level, spheres, plumb bob, a sheets of carbon, and meter stick

Procedure:
1. Clamp the momentum ramp to the counter and make sure that the end of the ramp is level using the bubble level.
2. Place the carbon paper on the floor and put a piece of white paper on top of it so when the marble is rolled down the ramp it will leave a spot on the paper on top of the carbon.
3. Tie a plumb bob onto the end of the ramp so that the vertical distance can be measured.
4. Measure the vertical distance.
5. Roll the marble down the ramp one time and then measure the horizontal distance.

6. To find the velocity of the sphere, you shall use what you have learned about projectile motion. We know that objects projected with different horizontal velocities from the edge of a table take the same time to fall to the floor. If we neglect air resistance, the horizontal component of their velocity remains unchanged and therefore the distance they go horizontally is proportional to their horizontal velocity. You can use this fact to calculate the horizontal velocity. You can also find the vertical velocity knowing that the ball leaves the ramp horizontally or with no vertical velocity.

7. Calculate where to place the two rings so that the ball will pass through without touching the rings.
Experiment: Newton’s Second Law (Force and Acceleration)

Standard: HS-PS2-1. Analyze data to support the claim that Newton’s second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

Knowledge Objectives
- I will explain the motion of an object in terms of forces and acceleration.
- I will describe how vectors are added to determine the net force on an object causing acceleration.

Reasoning Objectives
- I will justify the relationship between force and acceleration for an object through the interpretation of experimental data.

Skill Objectives
- I will collect experimental data within the tolerance of the measuring instruments.

Product Objectives
- I will use if then statements to determine the independent and dependent variables then display experimental data correctly using tables.
- I will make graphs of experimental data graphing the dependent variable on the y axis and the independent variable on the x axis.

Introduction:
Throughout life you observe objects in motion relative to you. Motion is seldom constant. Objects in one dimension speed up and slow down. This change in speed or velocity represents accelerated motion. Velocity has two components, one for direction and one for its size or magnitude. A change in either its direction or magnitude would represent acceleration. It requires a force to accelerate an object. When an object is pushed or pulled the velocity it has will change.

You will determine the total mass of laboratory cart, masses string and paperclips through graphical analysis. Five sets of velocity data will be graphed versus time. The slopes of these graphs that represent acceleration will then be determined. Once the slopes or acceleration values are found they will be graphed versus the force that is accelerating the cart. The slope of the force versus acceleration graph will be determined. This value is the mass of the entire system. According to Newton’s Second Law force is equal to mass times the acceleration of that mass.

F = ma

The above equation can be written as F/a = m. In the graph of force versus time the slope of a force versus acceleration graph should be the mass of the apparatus.

The recording timer is used to measure small intervals of time. The motion of a dynamics cart accelerating across a laboratory table can be analyzed using the recording tape from a timer. A timer uses a regularly vibrating clapper and carbon disk to make dots on a recording tape. The dots are made at regular intervals so the distance between the dots can be used to determine the distance traveled and the velocity of the cart at any time during the motion.

It is essential to determine the time for one interval of the timer for the velocity to be calculated. The timer can be calibrated using a digital strobe. A flashing strobe can be adjusted to coincide with the vibration of the timer and thus the recording timer will appear to remain still. The reading on the strobe can then be used to determine the time period for one vibration or the time it takes the timer to move through one cycle. A cycle records a dot on the timer tape or the time it take for the timer to move up from the previous dot and then move back down to place a second dot on the recording tape.
Once the timer is calibrated or the time for one cycle has been determined it can be used to measure time intervals for the travel of a dynamics cart. The record of the distance and time taken to move that distance can be recorded using the timer and a tape which is pulled through the timer by the dynamics cart. This permanent record of dots shows how far the cart travels and the calibration of time per cycle shows the time it takes to move the distance between the dots.

The average speed of a cart can be determined at a midpoint of many periods. The set of data for time and average speed or velocity at successive intervals can be graphed to analyze the motion of the cart. On the speed or velocity versus time graph the velocity can be determined at any point directly off the graph and the acceleration can be found from the slope of the curve.

A method to determining the slope of the line would be to find the change of the y value or the speed over the change in the x value or the time. This is the rise over the run. The steeper the slope the greater the acceleration the cart has. One of the values to determine the change in can be zero since the cart always starts from rest at time zero.

**Apparatus:** recording timer, timing tape, digital strobe, cart, ruler, meter stick, 50.0, 100.0 and 200 gram masses, pulley, and paper clips

**Procedure:**
The recording timer can be calibrated using the strobe. Turn on the timer and then adjust the strobe in a darken room until the timer appears to stop. Once the two are synchronized the value on the strobe can be noted. The timer will appear to stop when the strobe flashes every third time it vibrates, every second, every time or other multiples. It is important to find a one-to-one correspondence between the number of flashes and the number of cycles or vibrations. To do this, raise the strobe to the fastest rate of flash and then dial down until the timer appears to stop. Record this value from the strobe. This value is the correct calibration since it is a one-to-one correspondence of flashes and timer cycle. Repeat this procedure five more times. Take the average of the six recorded times for a more precise value of time. These are flashes per minute and must be divided by 60 seconds in a minute to determine the number of flashes per second. Finally, the reciprocal of that value must be found to determine the seconds per period for the timer.

After the timer is calibrated it may be used to measure distance and time for the motion of the dynamics cart. Place the three masses, 50.0, 100.0, and 200.0 gram mass on the cart. Attach timer tape to the bottom of the back of the cart. Thread the other end of the tape through the timer over the top of a carbon disk.
so that dots are tapped onto the tape as it is pulled through the timer. Next attach a string to the top of the front side of the cart. Run the string over the side of the pulley that is attached at the end of the table. To eliminate the effect of friction add paperclips to the end of the string that is hanging over the end of the pulley. Give the cart a push. When the cart rolls without accelerating or stopping then the paper clips apply a force that exactly offsets the frictional force.

Hold the cart in place with a book so that it does not accelerate while the rest of the apparatus is set up. Attach 50.0 gram mass to the paperclips. Make sure there is plenty of room between the pulley and the cart so that the mass will hit the floor before the cart is stopped in front of the pulley. Start the timer and then release the cart. Catch the cart prior to it hitting the pulley. On the underside of the tape will be the dots corresponding to the motion of the cart. Repeat this procedure with the 100.0 gram mass. Place the 100.0 gram mass on the paperclips and return the 50.0 gram mass to the cart. The mass of the entire apparatus that is accelerating should not change. You will need a new piece of tape for this second trial. Make sure it is the same size as the first tape so that the mass of the apparatus does not change. Take data with 150.0 grams of mass, 200.0 grams and finally 250.0 grams of mass. When you are accelerating the cart with the 150.0 and 250.0 grams you will need to use two masses hanging on the clips.

On each of the five tapes you will need to collect the data in the following way. Circle the first dot and number it zero. Count over successive ten dots and circle each. Number each successive circled dot with the next higher integer. To determine the total time interval to reach each successive numbered dot it is necessary to multiply the time per period by the total number of periods recorded from zero to that dot. For dot number 1 the total time to reach that point is 10 periods times the time per period. For dot number 2 the total time is 20 times the time per period and for 3 it is 30 times the time per period. Record the time values in the first column of the table. Now count back three spaces and forward three spaces from the circle dots to measure the distance over six intervals surrounding the numbered dots. You will record the distance for the first dot as zero; as the cart was at rest when that dot was formed. Next, record the distance for the six intervals surrounding each numbered dot on the tape. Determine the time for six intervals by multiplying the time per period by six. Divide each of the distances by the time for the six periods to determine the average velocity over that distance. This is the instantaneous velocity or speed at each numbered point. Record that speed or velocity in the table.
Make note that this distance is used to determine the average speed or velocity and will not be used in the graph. Each tape will have a different column in the table for the values.

Finally, prior to taking the apparatus down you must measure the mass of the cart, one of the tapes, the string, the paperclips, and the masses. This will be recorded as the total mass that is accelerating. This is the accepted value of the apparatus. The experimental value will be found from the graphs.

**Analysis:**
Create graphs of all five sets of data for velocity versus time. Time will be on the x axis since it is the independent variable and velocity is on the y axis since it depends upon the time. Each set of data should be graphed using a different color. Determine the slopes of the velocity versus time graph for all five sets of data. Remember the slope of a line is the change in y or the velocity over the change in x which is the time. Record the x and y values for two points on each line and determine the slope; which is the acceleration of the cart.

\[
\text{acceleration} = \frac{v_2 - v_1}{t_2 - t_1}
\]

Record those values in a second table. Also in the second table record the force that was acting on the cart for each acceleration value. This can be determined using the value of the mass that was hanging over the side of the table and multiplying it by the acceleration due to gravity. This represents the weight of the mass and the force pulling the cart across the table. Remember to change the mass into kilograms so that the force is determined in Newton’s. An example using the 50.0 gram mass is shown below.

\[
50.0 \text{ g} \times \frac{1.00 \text{ kilograms}}{1000.0 \text{ grams}} = .0500 \text{ kilograms}
\]

Weight = Forces of pull = \( F_p \) = .0500 kg x 9.81 m/sec\(^2\) = .491 Newtons

After all of the slopes and forces are tabulated then graph this data. Put the force on the y axis and the acceleration on the x axis. The slope of this graph is the mass of the entire apparatus that is accelerating.

Finally, calculate the absolute and relative error for the mass of the apparatus that was accelerated. The accepted value is the measured mass and the slope of the force versus acceleration graph is the experimental value.

**Conclusion:** Describe why six periods were used in the laboratory to determine the velocity of the cart at each circled dot. Explain how the laboratory verified Newton’s second law of force equals mass times acceleration. Discuss factors that influence the results of the laboratory leading to experimental errors.
Spring Constant

Standard: HS-PS2-1. Analyze data to support the claim that Newton’s second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

Knowledge Objective
- I can describe how vectors are added to determine the net force on an object.

Skill Objective
- I can collect experimental data within the tolerance of the measuring instruments to determine the spring constant for two springs.

Product Objectives
- I will use if-then statements to determine the independent and dependent variables, and then display experimental data correctly using tables.
- I will make a graph of experimental data, graphing the dependent variable on the y axis and the independent variable on the x axis.

Introduction:
Springs can either be compressed or stretched using a force over a distance. The work done on the spring is transferred into potential energy in the spring. A force directly proportional to the distance, \( x \), is required to stretch or compress a spring. This is given by the following equation.

\[ F_p = kx, \]

In the equation \( k \) is the spring constant and is a measure of the stiffness or tensile strength of the spring. The spring itself exerts a force in the opposite direction,

\[ F_s = -kx. \]

The above equation, Hooke’s law, is known as the spring equation. This equation is accurate for springs as long as \( x \) is not too great. Beyond a point the spring will no longer resume its original position.

The potential energy of a stretched spring is equal to the work required to stretch it. The work done on the spring is:

\[ W = Fx \]

The amount the spring is stretched from its normal length is the \( x \) value. The force is not constant. It varies over the distance, becoming greater the more the spring is stretched. This is shown on the graph below.

In the diagram \( x_0 \) is the initial displacement or equilibrium position and \( x_f \) is the final displacement of the spring from the equilibrium position. The average force is used to calculate the work done. Since \( F \) varies linearly, from zero at the unstretched position to \( kx_f \) when stretched to \( x_f \), the average force is
\[ F = \frac{1}{2}(0 + kx_f) = \frac{1}{2} kx_f \]

The work done is given by the force times the displacement as shown below.

\[ W = F_p \cdot x = \left( \frac{1}{2} kx \right) x = \frac{1}{2} kx^2 \]

Since the work is equal to the potential energy stored in the spring, it is proportional to the square of the amount stretched. The following equation shows the elastic potential energy in a spring.

Elastic PE = \( \frac{1}{2} kx^2 \).

**Apparatus:** 2 springs with different tensile strengths, set of metric masses, spring stand with metric scale (Hooke’s law apparatus).

**Procedure:**
In this activity you will determine the spring constant for two springs using Hook’s law apparatus. Hang the spring from the apparatus. Attach masses onto the spring to determine the amount of stretch that the spring undergoes. Remember to use mass times the acceleration, due to gravity, to determine the force due to gravity on the mass and, thus, on the spring. Tabulate the data for mass, force, and stretch or the \( x \) value for five different masses on each spring. Make sure to title your table and include sub-headings. Use caution when hanging the masses so as not to overstretch the spring and damage it. The silver spring should not have over 250 grams of mass hung on it and the black spring should be limited to 100 grams.

**Analysis & Conclusion:**
Graph the data and determine the spring constant for each spring from the graphed data. Make sure to label the axis and title the graph. Describe the type of relationship that exists between the force and the stretch. Draw a free body diagram of the mass hanging on the spring. Describe any deviations the data has from the linear relationship that should exist between force and stretch.
Activity: Tug of War

Standard: HS-PS2-1. Analyze data to support the claim that Newton’s second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

Reasoning Objective
- I will use vectors to pictorially analyze problems to determine the net force on an object and the forces on object that are static.
- I will solve force problems using vectors and trigonometry.

Apparatus: rope

Objective: Student will gain an understanding of components of forces.

Activity: A rope will be tied off to the pillar outside of the classroom. Students will tug on the other end of the rope. The teacher will push down in the middle of the rope with a force using one hand. Students will make a rough measurement of the angle the rope makes with horizontal after the teacher pushes down on the rope.

1. Draw a vector diagram of the force in the system.

2. If the force that the teacher applies is 300 N or about 60 pounds, what is the amount of force the teacher applies to the students.

3. What happens to the advantage that the teacher has as the angle the rope makes with the horizontal increases? Please explain this using equations and words.
Catapult Contest

Standards:
HS-PS2-1 Analyze data to support the claim that Newton’s second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
HS-PS2-3 Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.
HS-ET 1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

Objective: I can design and build a catapult that will propel a "Double A" raw egg over a 1-meter high wall placed 1.5 meters from the catapult and achieve a maximum horizontal displacement.

See the next page for the activity instructions.
Announcement of the Great Paso Robles High School Physics Class Catapult Contest

Goal:
To design and build a catapult that will propel a "Double A" raw egg over a 1-meter high wall placed 1.5 meters from the catapult and achieve a maximum horizontal displacement.

Restriction:
1. Catapult must be less than 2 kilograms mass.
2. Catapult must possess a lever arm from which the egg is launched.
3. Contest will occur on grass. If your catapult is to be staked into the ground the stakes may not exceed 20 centimeters in length and will be part of the mass of the catapult.
4. Each group will be given 3 minutes to set up and launch the eggs. You must provide your own eggs. The longest flight during the three minutes time span will be recorded.

Class Credit:
1. You may enter individually or with a partner.
2. You will receive 35 points for the construction of the catapult and 25 points for a paper describing the forces on the egg from the firing of the egg until it lands. Make sure to include force vector diagrams for the egg in the catapult, in the air and on the ground. You should also include a description of the type of motion the egg follows through the air.

Extra Credit Contest Scoring:
1. The egg must clear the wall to score.
2. The longest distance will be recorded.
3. If the egg lands without breaking, 3 bonus meters will be added to the length.

Bonus points will be awarded according to placement in the contest. First place will receive 10 points, second place will receive 8 points, third place will receive 6 points, fourth place will receive 4 points and fifth place will receive 2 points.

Sources of Information: Anyone and anything but me. I answer only procedural questions.
Work, Power, Energy and Momentum

Energy

Conservation of Momentum
Experiment: Work and the Incline Plane

HS-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system is known.

HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).

Knowledge Objective
- I can acquire vocabulary and learn relationships of variables expressed in the equations for Newton’s Laws of motion.
- I can explain the motion of an object in terms of forces.
- I can acquire vocabulary and learn relationships of variables expressed in the equations for work and energy.

Reasoning Objective
- I can predict and justify how Newton’s Laws relate a cart on an incline.
- I can use vectors to pictorially analyze problems to determine the net force on an object and the forces on object that is static.
- I can solve force problems using vectors and trigonometry.
- I can use vectors to pictorially analyze problems for work.
- I can analyze data in terms of accuracy and precision including tolerance.

Skill Objective
- I can collect experimental data within the tolerance of the measuring instruments.

Introduction:
Work done to move an object is equal to the energy gained. In this experiment a dynamics cart will be pulled up an incline using a force. The force times the distance that the cart is moved is equal to the work done. The work done in pulling the cart up the incline is converted into gravitational potential energy and heat due to the frictional force acting over that same distance.

\[ W_{\text{done}} = PE + W_{\text{friction}} \]

The equation for work is the force, \( F \), times the distance, \( x \). The potential energy equation is mass times the acceleration due to gravity times the height of the object is above a reference point.

\[ W_{\text{done}} = F_{\text{pull}} \times x \quad PE = mgh \quad W_{\text{friction}} = F_{\text{friction}} \times x \]

In this laboratory investigation the force of pull will be determined using a spring scale and the distance up the incline. A meter stick will be used to measure the height of the cart above the bottom of the ramp. The force of friction is calculated using two forces. First the force used to pull the cart up the incline at constant velocity and the second force used to move the cart down the incline at constant velocity. The force due to friction can be found in the following manner. In figures 1 and 2 the cart is pulled up the incline and lowered down the incline at constant velocity. The force of friction and the parallel component of gravity both act against the force used to pull the cart up the incline in figure 1. In figure 2 as the cart is lowered down the incline, the force of friction assists the retarding force as the cart is lowered down the hill at constant velocity.
The cart does not accelerate either up or down the incline so the forces are equal but opposite along the direction of the plane. The following equations are derived using the force vector diagram in figures 1 and 2. The force to pull the cart up the incline is equal to the force of friction plus the component of gravity that is parallel to the plane.

\[ F_{\text{pull up}} = F_f + F_\parallel \]

The force used to lower the cart down the plane at constant velocity is shown in figure 2. In this case the component of gravity that is parallel to the plane is equal to the force of pull plus the force of friction.

\[ F_\parallel = F_{\text{pull down}} + F_f \]

In both of these scenarios the parallel component of gravity and the force of friction are constant. The two equations can be set equal to each other when they are both in terms of the parallel force.

\[ F_\parallel = F_{\text{pull up}} - F_f = F_{\text{pull down}} + F_f \]

The above equation can be rearranged as follows to determine the force of friction.

\[ F_{\text{pull up}} - F_f = F_{\text{pull down}} + F_f \]

\[ 2F_f = F_{\text{pull up}} - F_{\text{pull down}} \]

\[ F_f = \frac{F_{\text{pull up}} - F_{\text{pull down}}}{2} \]

After all the variable are measured and calculated the conservation of work and energy can be determined.

**Apparatus:** dynamic cart, ticker tape timer, C clamp, ring stand, extra pole, right angle clamp, incline plane, Newton spring scale, 500 gram mass, meter stick, and balance with set of masses
Procedure:

Set up the inclined plane with a small ring stand rod through the hole in the ramp. Use the angle clamp to attach the rod to a ring stand that is clamped to the counter with a C clamp. Place a 500 gram mass on the cart. Now pull the cart slowly up the incline at a constant velocity. Determine the force needed pull the cart up the incline, $F_{\text{pull up}}$. Next let the cart down the incline at constant velocity and determine the force, $F_{\text{down}}$ that is used to maintain that velocity. Record both of these values in the table.

![Figure E: Pulling the Cart up the Incline at constant velocity](image1)

![Figure F: Lowering the Cart down the Incline at constant velocity](image2)

Determine both the x distance the cart is moving up the incline and the difference in heights between the cart at the bottom of the ramp and the top of the ramp. Record both of these values in the table. Finally determine the mass of the cart and 500 gram mass; record that value.

![Diagram showing forces](image3)

Repeat the procedure twice more using different slopes or angles for the ramp.
Forces and Distance to Move a Cart up and Down an Incline Plane at Constant Velocity

<table>
<thead>
<tr>
<th>Force to Pull the Cart up the Ramp ((F_{\text{pull up}})) Newtons</th>
<th>Force to lower the Cart down the Ramp ((F_{\text{down}})) Newtons</th>
<th>Length of Ramp ((x)) meters</th>
<th>Height the Cart was Raised ((x)) meters</th>
<th>Force of Friction ((F_{\text{friction}})) Newtons</th>
</tr>
</thead>
</table>

**Analysis:** When calculating the variable show sample calculations for each. Determine the force due to friction by taking the difference between the forces up and down and dividing it by 2. Next calculate the amount of work needed to raise the cart up the hill for each trial and record it in a table. Determine the amount of potential energy the cart achieves and record it in the table. Calculate the amount of work done by friction as the cart is moved up the incline. Now determine the sum of the potential energy and the work due to friction.

Work to Move a Cart up and Down an Incline Plane at Constant Velocity

<table>
<thead>
<tr>
<th>Work Input ((W_{\text{in}})) Joules</th>
<th>Potential Energy ((PE)) Joules</th>
<th>Work due to Friction ((F_{\text{friction}})) Joules</th>
<th>PE + (W_{\text{friction}}) Joules</th>
<th>Efficiency (%)</th>
</tr>
</thead>
</table>

1. How does the work to raise the cart compare to the sum of the potential energy and work due to friction?

2. What became of the energy used to overcome friction?

3. What happened to the amount of friction as the angle of the incline increased?

4. The efficiency of the incline plane as a simple machine is the ratio between the potential energy gained compared to the work done to pull it up the incline times 100. Determine the efficiency for each trial and record it in the table. How does the angle of the ramp affect the efficiency of the plane? Explain why this is the case?

**Conclusion:**
Describe how work and energy are related. Describe the errors involved, the difference between the work done, and the energy gained. Give an overall description of how the data was collected and used to show that energy is conserved.
Activity: Simple Harmonic Motion Activity

Standard: HS.PS-E Energy
HS-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system is known.
HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).

Knowledge Objective
- I will explain the relationship between force and the displacement of a spring.
- I will describe how the conservation of energy works for a spring system.

Reasoning Objective
- I can use vectors to pictorially analyze problems for work.
- I can solve conservation of energy word problems.

Goal: In this activity you will gain an understanding of simple harmonic motion, SMH.

Apparatus: Spring, masses, spring stand with metric scale.

Activity:
1. You will determine the spring constant for a spring using experimental techniques. Devise a method to determine the spring constant using the masses and spring stand for the spring provided.
2. Once you have determined the spring constant attach a 50.0-gram mass to the lower end of the spring. Pull it down .010 meters and release it from rest. Determine the frequency of oscillation of the mass both experimentally and mathematically. Now graph the displacement versus the time.

3. Suppose that the spring is now used in a spring scale that is limited to a maximum value of .50 N, but you would like to weigh an object of mass M that weighs more than .50 N. You must use commonly available equipment and the spring scale to determine the weight of the object without breaking the scale. Draw a clear diagram that shows one way that the equipment you choose could be used with the spring scale to determine the weight of the object. Explain how you would make the determination.

Conclusion: Describe the concepts you learned through this activity including conservation of energy.
Experiment: Conservation of Energy (Potential and Kinetic)

Standard: HS.PS-E Energy
HS-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system is known.
HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).

Knowledge Objectives
- I will acquire vocabulary and learn relationships of variables expressed in the equations for work, power, and energy.
- I will explain the relationship for the conservation of energy.

Reasoning Objectives
- I will solve power and conservation of energy word problems.
- I will analyze data in terms of accuracy and precision including tolerance.

Skill Objective
- I will collect experimental data within the tolerance of the measuring instruments.

Introduction:
Energy comes in many forms yet it can be classified as kinetic or potential. Both of these types can be forms of mechanical energy that can do work. Energy is converted between forms but never lost or gained. This is known as the law of the conservation of energy. A system may appear to lose energy but it is just converted. In the example of a dynamics cart rolling across a counter, friction slows the cart down until it stops. The kinetic energy of motion is converted through friction into heat. This energy is converted into kinetic energy of the molecules in the cart and the table. The random motion of the molecules is heat. The relationship for the conversion of mechanical energy to heat is that the work done by friction is equal to the heat gained. Work is the force times the distance over which the force acts. In this case the cart is slowing down due to the frictional force. In the equation below \( Q \) is heat, \( W \) is work, \( F_f \) is the force due to friction and \( x \) is the displacement.

\[ Q = \text{heat} = W = F_f x \]

Energy can also be potential or the energy of position. In this investigation the potential energy is due to the height the object is above the counter top. The energy is gravitational potential energy. In the following equation \( PE \) or \( U \) is potential energy, \( m \) is the mass of the object, \( g \) is the acceleration due to gravity and \( h \) is the height of the object above a reference point.

\[ U = \text{PE} = mgh \]

Kinetic energy is the energy of motion and is expressed in terms of the velocity of an object:

\[ KE = \frac{1}{2} mv^2 \]

In the above equation, \( m \) is the mass of the object that is in motion and \( v \) is the velocity of that object.

In this experiment you will explore the conservation of the energy as it is converted between gravitational potential energy to kinetic and heat energy.

\[ \text{PE} = \text{KE} + Q \Rightarrow mgh = \frac{1}{2} mv^2 + F_f x \]

The force due to friction can be found in the following manner. The figures show the cart being pulled up the incline in 1 and lowered down the incline in 2 at constant velocity. The force of friction and the parallel component of gravity both act against the force to pull the cart up the incline in figure 1. In figure 2 as the cart is lowered down the incline at constant velocity the force of friction assists the retarding force.
The cart does not accelerate either up or down the incline so the forces are equal but opposite along the direction of the plane. The following equations are derived using the force vector diagram in figures 1 and 2. The force to pull the cart up the incline is equal to the force of friction plus the component of gravity that is parallel to the plane.

\[ F_{\text{pull up}} = F_f + F_{\parallel} \]

The force used to lower the cart down the plane at constant velocity is shown in figure 2. In this case the component of gravity that is parallel to the plane is equal to the force of pull plus the force of friction.

\[ F_{\parallel} = F_{\text{pull down}} + F_f \]

In both of these scenarios the parallel component of gravity and the force of friction are constant. The two equations can be set equal to each other when they are both in terms of the parallel force.

\[ F_{\parallel} = F_{\text{pull up}} + F_f = F_{\text{pull down}} + F_f \]

The above equation can be rearranged as follows to determine the force of friction.

\[ F_{\text{pull up}} - F_f = F_{\text{pull down}} + F_f \]
\[ 2F_f = F_{\text{pull up}} - F_{\text{pull down}} \]
\[ F_f = \frac{F_{\text{pull up}} - F_{\text{pull down}}}{2} \]

You will roll a dynamics cart down an incline. The height of the cart at the top of the ramp will be measured and the velocity at the bottom will be found using the dots on the ticker tape timer tape. You will also measure the length of the plane that the cart transverses. With this data you will be able to show the conservation of energy.

**Apparatus:** dynamic cart, ticker tape timer, two C clamps, ticker tape timer tape, carbon disc, ring stand, extra pole, right angle clamp, incline plane, meter stick, Newton spring scale and balance with set of masses
Procedure:

The recording timer can be calibrated using the strobe. Turn on the timer and then adjust the strobe in a darken room until the timer appears to stop. Once the two are synchronized the value on the strobe can be noted. The timer will appear to stop when the strobe flashes every third time it vibrates, every second, every time or other multiples. It is important to find a one-to-one correspondence between the number of flashes and the number of cycles or vibrations. Raise the rate at which the strobe flashes to the highest value. Reduce the speed of the strobe until the timer appears to stop. This will be the value that corresponds to the one-to-one correspondence. Record this value and repeat this procedure five more times. Take the average of the six recorded times for a more precise value of time. These are flashes per minute and must be divided by 60 seconds in a minute to determine the number of flashes per second. Finally, the reciprocal of that value must be found to determine the seconds per period for the timer.

After the timer is calibrated it may be used to measure distance and time for the motion of the dynamics cart. Set up the inclined plane with a small ring stand rod through the hole in the ramp and angle clamp the rod to a ring stand. The ring stand should be attached to the laboratory counter with a C clamp. Now to determine the force due to friction the cart should be pulled up the incline at constant velocity using the spring scale. The force to pull the cart up at constant force should be recorded and then the cart should be lowered down the incline at constant velocity with the same spring scale. That force should also be noted. The difference between the force to pull the cart up the incline and the force to let the cart down the incline is determined. This value divided by 2 gives the force due to friction. Record the value for friction in the table.

Use the second C clamp to attach the ticker tape timer to the top of the ramp. Attach the timer tape to the bottom of the cart. Thread the other end of the tape through the timer over the top of a carbon disk so that dots are tapped onto the tape as it is pulled through the timer.

Turn on the timer and allow the cart to roll down the incline. Stop the cart at the bottom of the ramp. Now measure the distance, \(x\), the cart moves down the ramp and the height, \(h\), the cart drops. See the diagram below. Record both the height and distance down the ramp in the table.
Conservation of Energy of a Dynamics Cart

<table>
<thead>
<tr>
<th>Force of Friction ($F_f$) (Newtons)</th>
<th>Distance Down Plane (x) meters</th>
<th>Height Cart Drops (h) meters</th>
<th>Velocity of Cart (v) meters/sec</th>
<th>Potential Energy PE joules</th>
<th>Kinetic Energy KE joules</th>
<th>Work due to Friction W joules</th>
</tr>
</thead>
</table>

Find the end of the tape where the cart arrives at the bottom of the ramp. Here the dots will be furthest apart. Find a dot near the end, circle it and measure the distance from one period to the left to one on the right. A period is the time for the cart to move between dots. Now determine the average velocity for that period which would be the distance divided by two periods. This is the instantaneous velocity or speed at the circle point. Record that speed or velocity in the table.

Finally, prior to taking the apparatus down you must measure the mass of the cart and the tape. This will be recorded as the total mass that is accelerating.

**Analysis:** Calculate the potential energy of the cart at the top of the ramp, the kinetic energy at the bottom and the amount of work done by friction as the cart moved down the ramp. Compare the potential energy to the sum of the work done by friction and the kinetic energy at the bottom of the ramp.

**Conclusion:** Discuss the difference between the energy at the top of the ramp as compared to the energy at the bottom and the energy lost due to friction. Explain how friction was calculated.
Activity: Monster Spring

Standards:
HS-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system is known.
HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).

Knowledge Objective
- I will explain the relationship for the conservation of energy.

Reasoning Objective
- I will solve power and conservation of energy word problems.

Skill Objective
- I will collect experimental data within the tolerance of the measuring instruments.

Apparatus: meter stick, balance and spring toy

Activity: Your task is to determine the spring constant in the small spring toy. This is an inquiry investigation. Use your knowledge of the conservation of energy to solve for the spring constant. Make sure to show diagrams and explanation for each of the steps you used to solve the problem. You will also need to show the calculations you used in this process.

Conclusion: Describe the process you used to solve this problem and explain uncertainties in data collected that affected the results. Identify problems and suggest design solutions to optimize the energy transfer into and out of a spring monster.
Activity: Springs and Parabolic Motion (Spring Gun)

Standards
HS-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system is known.
HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).

Knowledge Objective
- I will acquire vocabulary and learn relationships of variables expressed in the equations for work and energy.
- I will explain the relationship for the conservation of energy.

Reasoning Objective
- I can solve problems for the conservation of energy word problems.

Apparatus: This lab will use one set up and we will collect common data. You will use one spring gun, a wood ball (projectile) a couple of rulers and meter sticks, a spring scale and ditto paper for making the landing spot.

1. What is the distance the front of the piston travels? What is the mass of the ball?

2. Determine the spring constant for the spring using different masses hung from the end. You will need to remove the spring from the apparatus.

3. Determine the potential energy in the piston.

4. Determine the initial velocity of the ball.

5. Determine the distance the ball travels horizontally both theoretically and experimentally.

Conclusion: Explain the mathematical representations that show that over time the total energy within an isolated system is constant, including the motion and interactions of matter within the system.
Activity: Springs and Parabolic Motion: Spring Gun 2

Standard:
HS-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system is known.
HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).

Knowledge Objective
- I will acquire vocabulary and learn relationships of variables expressed in the equations for work and energy.
- I will explain the relationship for the conservation of energy.

Reasoning Objective
- I can solve problems for the conservation of energy word problems.

Goal: Students will calculate potential energy in a spring as well as use their knowledge of parabolic motion to calculate the horizontal distance the ball travels.

Apparatus: This lab will use one set up and we will collect common data. You will use one spring gun, a wood ball (projectile) a couple of rulers and meter sticks, a spring scale and ditto paper for making the landing spot.

Procedure: The idea is simple, the procedure a bit more complicated. The goal is figure out how much potential energy is stored in a spring gun and then use that number to predict the velocity of a projectile. With that velocity it is possible to determine where the projectile will land when fired horizontally off a laboratory counter.

1. First the work to "cock" the gun is calculated. This is done by pulling on the cocking lever with a spring scale just enough to free it from the stopper. This will give the initial force to hold the spring in compression. Next pull back on the cocking lever with the spring scale to the cocked position and note the force on the lever at that point

   Force (un-cocked) = \( \text{________}_N \) (Make sure the readings are in Newtons)

   Force (cocked) = \( \text{________}_N \)

2. Figure the energy in the spring. Since the spring is already under compression it has some stored energy. We wish to find the additional energy in the spring from un-cocked to cocked position.
The figures on the previous page give us an indication how to proceed. The figure on the left shows the energy stored in the spring in the shaded area. The figure on the right allows us to find the area by using the equivalent rectangle whose height is the Average Force and the base is the cocked displacement minus the un-cocked displacement. The difference is the Net Displacement.

Net Displacement = ____________ m

The average force can be found by averaging the two forces found in #1.

3. The velocity of the projectile can be found by finding its mass plus the mass of the sliding rod, lever, the ball and half of the mass of the spring or everything that accelerate. That mass can be used to determine the velocity in the following equation.

\[\text{Cocking energy} = \frac{1}{2} mv^2.\]  
\[m = \text{___________ kg}\]

4. The target spot can be found using two-dimensional kinematics and noting that

\[y = \frac{1}{2}gt^2\] since the initial vertical velocity is zero.
\[x = vt\]  
x is the horizontal distance the projectile travels.
\[y = \text{___________ m}\]  
y is the initial height of the projectile from ground - take this measurement carefully!

5. Solve the equation for the horizontal distance, x in terms of y, the distance the object falls. Now measure the actual x and compare results using percent error.

\[x = \text{___________ m}\]

**Conclusion:** Analyze the data and describe how the energy shifts toward more uniform energy distribution.
Activity: Conservation of Momentum

HS.PS-FM Forces and Motion
HS-PS2-2 Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system. HS-PS2-3 Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.

Knowledge Objective
- I will describe the relationships between momentum and vectors.

Reasoning Objective
- I will be able to solve problems for the conservation of momentum using vectors and trigonometry.

Goal: Students will calculate the conservation of momentum using the ideas of conservation of energy and impulse.

Apparatus: This lab will use one set up and we will collect common data. You will use one block of wood, clay ball pendulum and rubber ball pendulum.

Procedure: What we intend to do is figure out how much potential energy is stored in the balls that are converted to kinetic energy and then the amount of impulse impacted on the block. Each pendulum bob will be massed followed by raising it to a specific angle and then releasing the pendulum so that it collides with the block. Make observations and then answer the following question.

1. Determine the masses of the clay ball and the rubber ball.

2. Measure the height the pendulum is raised. Use this height to determine the amount of potential energy in the ball.

3. Determine the velocity of each ball right before it hits the block.

4. Determine the height the ball reaches after the collision and then determine the velocity of the ball right after the collision.

5. Determine the change in momentum or impulse on the block for both cases.

6. Explain why the block reacts in the fashion it does in each collision.

7. Draw a force vector diagram for the ball when it is just released from the highest point.

8. Determine the tension in the string when the ball is just released.

9. Determine the centripetal acceleration of the ball at this point.
Experiment: Conservation of Linear Momentum

HS-PS-FM Forces and Motion

HS-PS2-2 Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system

HS-PS2-3 Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision

Knowledge Objective
- I can describe the relationships between momentum and vectors.

Reasoning Objectives
- I can justify the conservation of momentum through the interpretation of experimental data.
- I will analyze data in terms of accuracy.

Skill Objectives
- I will collect experimental data within the tolerance of the measuring instruments.
- I will use vectors to graphically represent the conservation of momentum.

Introduction: Momentum is conserved in any collision or explosion. When a gun is fired the bullet moves off in one direction and the gun will recoil. When a bomb explodes the pieces move off in all directions yet the sum of the momentum of all of the pieces is equal to the momentum of the bomb prior to the explosion. In the case of the gun the momentum of the gun/bullet system was zero prior to it being shot and thus the momentum of the bullet in the forward direction must be equal to the momentum of the gun in the opposite direction. The gun has more mass so it will move backwards with much less velocity than the bullet does in the forward direction. In this activity you will simulate a two fragment explosion by releasing the spring on one of the dynamics carts that is butted up against another. One of the carts will have a large mass resting on it. You will then determine the velocities of the carts and their masses. You will then calculate the momentums of each cart.

\[
\vec{P}_b = \vec{P}_a \\
\vec{P}_b = 0 \\
\vec{P}_a = \vec{P}_1 + \vec{P}_2
\]

Remember that the momentum of the cart that is moving to the left is negative so the vectors are added and the net momentum after the collision is zero.

\[
\vec{P}_1 = m_1 \vec{V}_1 \\
\vec{P}_2 = M_2 \vec{V}_2
\]

The mass of cart one is small and thus its velocity will be large. The mass of cart 2 is large so it velocity should be small. Since the overall momentum of the system was zero to begin it will also be zero after they spring apart. The velocity of cart one is negative and thus its momentum after the collision is also negative. Since the overall momentum is zero then the momentum values of each cart must be equal in magnitude.

\[
0 = \vec{P}_a = \vec{P}_1 + \vec{P}_2 \\
0 = m_1 \vec{V}_1 + M_2 \vec{V}_2 \\
m_1 \vec{V}_1 = M_2 \vec{V}_2 \\
\vec{V}_1 = M_2 \vec{V}_2
\]
The conservation of momentum predicts that the ratio of the speeds of the carts will be inversely proportional to the ratio of the masses of the carts.

**Apparatus:** two dynamic carts (one with internal spring mechanism), two ticker tape timers, two C clamps, ticker tape timer tape, 1.0 kg, 0.50 kg masses, two rulers, and a balance with a set of masses

**Procedure:**

**Calibrating the Timers**

The recording timers can be calibrated using the strobe. Turn on the timer and then adjust the strobe in a darken room until the timer appears to stop. Once the two are synchronized the value on the strobe can be noted. The timer will appear to stop when the strobe flashes every third time it vibrates, every second, every time or other multiples. It is important to find a one-to-one correspondence between the number of flashes and the number of cycles or vibrations. Raise the rate at which the strobe flashes to the highest value. Reduce the speed of the strobe until the timer appears to stop. This will be the value that corresponds to the one-to-one correspondence. Record this value and repeat this procedure five more times. Take the average of the six recorded times for a more precise value of time. These are flashes per minute and must be divided by 60 seconds in a minute to determine the number of flashes per second. Finally, the reciprocal of that value must be found to determine the seconds per period for the timer.

**Data Collection**

To set up the apparatus place the ticker tape timers on opposite sides of the counter and clamp them in position. Attach a ruler to the bottom of each cart so that it extends out from the side. Next, attach the timer tape to the ruler and thread it through the timer over the top of a carbon disc that is facing up. See the picture below for a schematic of the set up.

Place a 1.0 kg mass on one of the carts. Now reset the spring loaded piston into the cart and place the cart next to each other on the counter.

Make sure that the tape is taught through the timers. Start the timers and then trip the spring loaded piston. The cart will move apart. Catch each cart before they roll off the counter.

Label the tapes according to the cart they were attached to. Take the carts with their tapes, ruler and mass and determine the total mass of each of the two cart systems and record those values for \( m_1 \) and \( m_2 \). The reason the mass of the cart system is found is that not only is the cart moving but all that is attached to the cart is also.

For each tape find the spot at which the dots are uniformly spread out. Circle the first dot in this sequence; label it zero and then count over ten dots. Measure the distance for the ten dots in meters and record both values in the table as \( x_1 \) and \( x_2 \).
Use ten times the period, T, of the tickertape timer to calculate the average velocity of each cart. Record the velocity values in the table.

\[ v_1 = \frac{x_1}{10T} \]

Repeat the experiment without any masses on the carts and again with the 1.0 kg mass on one cart and a 0.50 kg mass on the other cart.

**Conservation of Momentum for the Explosion of a Pair of Dynamics Carts**

<table>
<thead>
<tr>
<th>Cart 1</th>
<th>Cart 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance Traveled (x_1) (meters)</td>
<td>Mass of Cart (1 m_1) (Kg)</td>
</tr>
</tbody>
</table>

**Analysis:**
Determine the momentum of both carts for each trial and record the values in a second data table. Next determine the ratio of \(v_1/v_2\) and the ratio \(m_2/m_1\). Tabulate the ratios. How close are the two momentums to each other? Do they support the law of conservation of momentum? Determine the absolute and relative or percentage error for each pair using the average of the two as the accepted or best value. Tabulate these values in the second table.

**Conclusion:**
Justify how the data supports the conservation of momentum. Explain how momentum is a vector quantity in your justification. Finally, describe the factors that led to the errors and how errors can be eliminated.
Experiment: Momentum, a Collision in Two Dimensions

HS.FM Forces and Motion
HS-PS2-2 Use mathematical representations to support the claim that the total
momentum of a system of objects is conserved when there is no net force on the system
HS-PS2-3 Apply scientific and engineering ideas to design, evaluate, and refine a device
that minimizes the force on a macroscopic object during a collision

Knowledge Objectives
- I will describe the relationships between momentum and vectors.

Reasoning Objectives
- I will be able to solve problems for the conservation of momentum using vectors and
  trigonometry.
- I can justify the conservation of two dimensional momentum through the interpretation of
  experimental data.
- I will analyze data in terms of accuracy and precision including tolerance.

Skill Objectives
- I will collect experimental data within the tolerance of the measuring instruments.
- I will use vectors to graphically represent the conservation of momentum.

Product Objectives
- I will use knowledge, reasoning, and skills to create a formal laboratory report that includes the
  following sections: Title page, Abstract, Introduction, Experimental, Results and Conclusion.

Introduction:
What happens when two bodies go off in different direction after colliding? To find out, you shall
roll one steel ball down an incline so that it makes a glancing collision with another steel ball, knocking it
off a support near the edge of the table. You shall then find the momentum of each from their masses and
velocities.

To find the velocities of the spheres, you shall use what
you have learned about projectile motion. We know that objects
projected with different horizontal velocities from the edge of a
table take the same time to fall to the floor. If we neglect air
resistance, the horizontal component of their velocity remains
unchanged and therefore the distance a sphere will travel
horizontally is proportional to the horizontal velocity. You can
use this fact and the vertical distance the sphere falls to
determine the velocities of the spheres after they have collided.

Apparatus: Ramp, C clamp, bubble level, large and small
spheres, plumb bob, four sheets of carbon and white paper,
meter stick and protractor

Procedure:
Level the end of the ramp to ensure
that the sphere that begins at the top of the
ramp will fly off horizontally. It will not
have an initial vertical velocity component.
To level the end of the ramp place a bubble
level on it, then level it by adjusting with a
folded piece of paper under the low side.
Clamp the ramp in place.
The target sphere rests in a slight depression on the top of the set-screw. Place the set-screw at an angle to the path of the incident sphere. Adjust the height of the set screw that the small ball is resting on so that the collision of the spheres is center to center.

Now using the plumb line, find the point on the floor directly below the position the incident sphere collides with the stationary smaller sphere.

Tape four sheets of white paper or tracing paper together to make a single large sheet. Be sure the sheets do not overlap. Place four sheets of carbon paper with the carbon side up on the floor. Set the white paper on top of it; the plumb bob should hang directly over the middle of the shorter side. Mark this point on the paper and tape the paper to the floor to hold it in place. Release a steel sphere from the top of the ramp without the small sphere on the pin. This will provide data points for the initial momentum. Roll the sphere, ten or fifteen times and circle the distribution of points on the paper. Make sure to release the large sphere the same way each time.

With a small steel sphere balanced on the screw, roll the large sphere down the ramp so that they collide. Make sure that both spheres impact the paper. Repeat this procedure 10 times. Make sure to release the incident sphere from the same point at the top of the ramp. Label the sets of points with large and small to make sure you can identify the marks after you pick up the paper. When all the points have been made, make a circle around all to find the average or most accurate point for the incident and impact balls.

**Analysis:**

Draw on the paper the vectors that represent the displacements of the balls after the collisions. These vectors should have an angle with respect to the incident sphere’s initial displacement.

Now determine if the initial momentum is equal to the final momentum. Make sure to report the absolute and relative error. In the results section, discuss the precision of reproducing the data, how the data was collected and used to calculate (use diagrams to show how the data was measured, collected and used in the calculations), and show and describe sample calculations.

**Conclusion:** Justify how the data supports the conservation of momentum. Explain how momentum is a vector quantity in your justification. Finally, describe the factors that led to the errors and how errors can be eliminated.
Bungee-Jumping for Humpty Dumpty

Standard: HS.PS-FM Forces and Motion
Students who demonstrate understanding can:
HS-PS2-1 Analyze data to support the claim that Newton’s second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
HS-PS2-3 Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.

Standard: HS.PS-E Energy
HS-PS2-2 Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system
HS-PS3-2 Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision
HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).
HS-PS3-3 Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

Standard: HS-ETS-ED Engineering Design
Students who demonstrate understanding can:
HS-ET 1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

Knowledge Objectives
- I will acquire vocabulary and learn relationships of variables expressed in the equations for work, energy and momentum.
- I will explain the relationship for the conservation of energy.

Reasoning Objectives
- I can solve conservation of energy word problems.
- I will analyze data to support claims that closed systems move toward more uniform energy distribution.
- I will use computational thinking to create, simulate, and compare different design solutions, checking to be certain that the simulation makes sense when compared with the real world.

Introduction:
Energy comes in many forms yet it can be classified as kinetic or potential. Both of these types can be forms of mechanical energy that can do work. Energy is converted between forms but never lost or gained. This is known as the law of the conservation of energy. A system may appear to lose energy but it is just converted. In the example of an object on a bungee strap, there is a frictional force between air and the object and the friction in the bungee strap as it expands and contracts. Friction slows the object down until it stops. The kinetic energy of motion is converted through friction into heat. This energy is converted into kinetic energy of the molecules in the strap, object, and air. The random motion of the molecules is heat. The relationship for the conversion of mechanical energy to heat is that the work done by friction is equal to the heat gained. Work is the force times the distance over which the force acts. In this case the bungee jumper is slowing down due to the frictional force. In the equation below $Q$ is heat, $W$ is work, $F_f$ is the force due to friction and $x$ is the displacement.

$$Q = \text{heat} = W = F_f x$$

Energy can also be potential, the energy of position. In this investigation, the potential energy is due to the height the object is above the ground. The energy is gravitational potential energy. In the following equation $PE$ or $U$ is potential energy, $m$ is the mass of the object, $g$ is the acceleration due to gravity and $h$ is the height of the object above a reference point.

$$U = PE = mgh$$
Kinetic energy is the energy of motion and is expressed in terms of the velocity of an object:

\[ KE = \frac{1}{2} mv^2 \]

In the above equation, \( m \) is the mass of the object that is in motion and \( v \) is the velocity of that object.

In this activity you will explore the conservation of the energy as it is converted between gravitational potential energy to kinetic and heat energy.

\[ U = PE = KE + Q \rightarrow mgh = \frac{1}{2} mv^2 + Fx \]

**Introduction:**
You are to design and create a bungee-jump ride for an egg. The challenge is to design and construct a ride that is both fun and safe. Build the ride so that your passenger, a raw egg, comes close to but does not hit the ground. You will attach rubber bands to the egg and drop it from the height of the counter top. You receive only one egg. Your challenge is to get your egg as close to the ground as possible.

**Materials:**
Ring stand, raw egg, paper towels, utility clamp, C clamp, rubber bands, and golf balls

**Procedures:**
1. Attach the ring stand to the counter with a C clamp and attach the utility clamp to the ring stand so that it hangs over the side of the counter.
2. Lay paper towels on the floor and over the top of your desk.
3. Create a “bungee cord” and cage for the egg using the rubber bands.
4. Test your cage by putting a less fragile passenger into it. For a “test pilot,” use a golf ball. A few trial runs with the test pilot may help you to adjust your seat and cord.
5. You will have one attempt with the real passenger or egg.

**Analysis & Conclusions**
1. Is the ride both thrilling and safe for the egg? Why or Why not?

2. How did your trial runs help you improve your design?

3. What adjustments could you make so that the ride is either safer or more thrilling?

4. Explain how the energy was transferred from one form to another as the egg was released from the height of the table until it came to rest.
Circular and Rotary Motion

\[ a = \frac{v^2}{r} \]

Constant Speed Circular Motion

Conservation of Energy (Linear and Rotational)
Activity: Force on Revolving Ball

HS.PS-FM Forces and Motion
Students who demonstrate understanding can:

HS-PS2-1 Analyze data to support the claim that Newton’s second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

Knowledge Objectives
- I can acquire vocabulary and learn relationships of variables expressed in the equations for circular motion.
- I can explain the relationship between force, acceleration, and velocity for circular motion.

Reasoning Objectives
- I can use vectors to pictorially analyze problems for circular.
- I can interpret the relationship between the force on an object and the velocity of the object for circular motion through the analysis of experimental data.

Objective: Students will diagnose the circular motion of a small ball rotating at the end of a string using circular motion equations and the free body diagram.

Activity: Rotate a small ball at the end of a string on a rod extended from a disk.

Measure the length of the string to the center of the mass.
Measure the radius of the circle traced by the rotating mass.

1. Draw a free body diagram for the ball.

2. Determine the angle the string makes with the pole.

3. Determine the tangential velocity of the mass.

4. Determine the rotational velocity of the mass.

5. Determine the period of the mass and then measure this value and determine absolute error.

6. Find the mass of the ball and determine the force of tension in the string.
Experiment: Centripetal Motion

**HS.PS-FM Forces and Motion**

Students who demonstrate understanding can:
a. Plan and carry out investigations to show that the algebraic formulation of Newton’s second law of motion accurately predicts the relationship between the net force on macroscopic objects, their mass, and acceleration and the resulting change in motion.

**Knowledge Objectives**
- I will acquire vocabulary and learn relationships of variables expressed in the equations for circular motion.
- I will explain the relationship between force, acceleration, and velocity for circular motion.

**Reasoning Objectives**
- I will use vectors to pictorially analyze problems for circular motion.
- I will interpret the relationship between the force on an object and the velocity of the object for circular motion through the analysis of experimental data.
- I will analyze data in terms of accuracy and precision including tolerance.

**Skill Objectives**
- I will collect experimental data within the tolerance of the measuring instruments for a circular motion laboratory.

**Goal:** Your task is to determine the relationship between the centripetal force acting on an object moving in a circle of constant radius and the tangential velocity of the object.

**Introduction:** An object that moves in a circle at constant speed $v$ is said to experience uniform circular motion. The direction of the velocity is continuously changing as the object moves around the circle. A force is required to change the velocity vector. That force is directed along the radius toward the center of the circle. The force causes the object to accelerate perpendicular to the velocity thus changing the direction of the velocity vector without changing its magnitude. The magnitude of the acceleration is given in the following equation

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

The time taken by a body to go around the circle once and return to its starting point is called a period. The velocity of the object is given by the distance the object moves or a circumference divided by the period.

$$v = \frac{2\pi r}{T}$$

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According to Newton’s second law force is equal to mass times the acceleration the object experiences due to that force. When the equation for centripetal acceleration is plugged into Newton’s second law the equation for force centripetal is found.

\[ F = ma \quad \text{and} \quad a = \frac{v^2}{r} \quad \text{then} \quad F_c = \frac{mv^2}{r} \]

From the centripetal force equation it is apparent that to keep an object moving in a circular path with a constant radius the velocity must increase as the force increases.

**Apparatus**: fire polished glass tube with rubber hose housing that is 15 cm long, nylon twine, washers, paperclip, masking tape, rubber stopper, stop watch, and balance

**Procedure**: Measure the mass of a rubber stopper. Cut a piece of twine approximately 1.20 meters long and tie one end to the rubber stopper. Pass the other end of the twine through the glass tubing and attach a bent paperclip of known mass to the end of the twine. The paper clip will be used to hold the washers. Measure a distance between .8 and 1.0 meters from the top of the glass tube to the middle of the rubber stopper along the string. Record this value using the tolerance of the meter stick. This will be the constant radius for the experiment. Place a piece of tape to slightly below the bottom of the glass tube on the string. This will assist you in keeping the radius of the revolving stopper at a constant value.

Mass of Rubber Stopper: ______Kg   Length of String or Radius of Circle: ________m

Determine the mass of five washers and the paperclip and hook the washers onto the paper clip. Record the total mass of the washers and the paperclip in your data table. Now determine the weight or force the washers have on the rubber stopper. This can be done by multiplying the mass in kilograms of the washers and paperclip by the acceleration of gravity or 9.81 m/s². This force should be recorded in the data table.

\[ F_g = W = mg \]

Hold the glass tubing in your hand and rotate the rubber stopper in a horizontal circle above your head. Keep the tape close but not touching the bottom of the glass. The force of the washers on the rubber stopper determines the speed that the rubber stopper must be revolving. Have a partner determine how long the rubber stopper takes to make 30 revolutions. To find the period or the time it takes the rubber stopper to make one revolution divide the total time by 30 revolutions and record the period in the table.

Now determine the velocity of the rubber stopper by dividing the circumference of the circle by the period.

\[ v = \frac{2\pi r}{T} \]
Repeat the procedure using multiple of five extra washers each time. Make sure to find the total mass of all the washers and paperclip each time.

**The Effect of Force on the Circular Motion of a Rubber Stopper**

<table>
<thead>
<tr>
<th>Mass of Washers and Paperclip, M (kg)</th>
<th>Force due to Washers and Paperclip, F (N)</th>
<th>Period of a Revolution, T (sec)</th>
<th>Velocity of Rubber Stopper v (m/sec)</th>
<th>Velocity Squared v² (m/s)²</th>
<th>Ratio of Force/Velocity F/v²</th>
</tr>
</thead>
</table>

**Analysis:** Make a graph of force versus the velocity squared of the rubber stopper. Determine the slope of the line and compare that value to the mass of the rubber stopper divided by the radius of the circle. Determine the absolute and relative error between the slope or calculated value and the ratio of mass and radius.

**Conclusion:** Justify how the data and graph support the equations for force centripetal. Explain how an object can be accelerating without changing speed. Finally, describe the factors that led to the errors and how errors can be eliminated.
Activity: Rotational Dynamics

Standard: HS.PS-E Energy
Students who demonstrate understanding can:
HS-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).

Knowledge Objectives
- I will acquire vocabulary and learn relationships of variables expressed in the equations for circular and rotary motion.
- I will describe the relationships between torque and angular acceleration.

Reasoning Objectives
- I will use vectors to pictorially analyze problems for circular and rotary motion.
- I will solve problems for torque in rotary motion using vectors and trigonometry.
- I will use vectors to pictorially analyze problems for work and conservation of energy problems.
- I will solve conservation of energy word problems.

Goal: Students will determine the final speed of a ring and a disk with equal mass as they roll down an incline.

Apparatus: This activity will use one set up that the class will use to collect common data. (ring, disk of the same mass, balance, meter stick, ramp, two ring stands, two right angle clamps, and one-rod)

Procedure:
1. Determine the rotational inertia for both the ring and the disk. You will need the mass of the two objects as well as their radii.
2. You will start the ring and hoop from the same height. Determine that height and calculate the potential energy stored in each.
3. Since the ring and the disk have the same mass and diameter, which will reach the bottom of the incline first?
4. Find the translational velocity of the ring and disk as the bottom of the ramp.
5. Determine the linear and rotational kinetic energy for both the ring and disk at the bottom of the ramp.
Activity: Loop de Loop

Standard: HS.PS-E Energy
Students who demonstrate understanding can:

HS-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.

HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).

Knowledge Objectives
- I will acquire vocabulary and learn relationships of variables expressed in the equations for circular and rotary motion.
- I will describe the relationships between torque and angular acceleration.

Reasoning Objectives
- I will use vectors to pictorially analyze problems for circular and rotary motion.
- I will solve problems for torque in rotary motion using vectors and trigonometry.
- I will use vectors to pictorially analyze problems for work and conservation of energy problems.
- I will solve conservation of energy word problems.

Objective: Students will determine the minimum height necessary for the Teflon ball to roll through the loop de loop.

Apparatus: This lab will use one set up and the class will collect common data. (loop de loop apparatus, electronic balance, Teflon ball, calipers, and meter stick)

Procedure: The idea is simple. The procedure is a bit more complicated. What we intend to do is figure out how much potential energy is stored in the height of the ball and then use that information to find the linear and rotational kinetic energy. You will need to make the following measurements to assist you in answering the questions. Find the mass of the Teflon ball, the radius of the ball and the radius of the loop.

Mass: ____________________________
Radius of ball: ____________________
Radius of the loop: __________________

1. What is the momentum of inertia of the Teflon ball?
2. Show the equation for the total energy of the ball at the top of the ramp and at the bottom.
3. Determine the velocity of the ball at the bottom of the loop in terms of height.
4. Calculate the minimum height the Teflon ball must be released from in order to make the loop without leaving the track.
5. Now release the ball from that height and see if it makes the loop. If it does not, explain why.
6. If the ball does not go over the loop when released from $\frac{7}{10}R_{loop}$, determine the height the ball can be released from to make the loop through trial and error. Record that value.
7. Using this new height determine the amount of energy lost to friction.
Fluids

Fluid Statics

Fluid Dynamics

\[ F_{\text{buoyancy}} = m\ g \]

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Water Rockets

**Standard:** HS.PS-FM Forces and Motion
Students who demonstrate understanding can:
HS-PS2-1 Analyze data to support the claim that Newton’s second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

**Standards:** HS-ETS-ED Engineering Design
Students who demonstrate understanding can:
HS-ET 1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

**Knowledge Objective:**
- I will develop an understanding of projectile motion, Newton's Laws and fluid dynamics.

**Product Objectives:**
- I will design and build a launching mechanism and water rocket.
- I will launch the rocket to transverse 50 meters and hit a target.

**Description:** In this activity you will have the opportunity to design a water rocket and launch pad so that you can fire the rocket and hit an object that is 50 meters down range. The rocket must be constructed out of a two-liter plastic soda bottle. In your design, you may add to your rocket items to make it fly correctly such as fins, nose cone and mass to correctly arrange the center of pressure and center of gravity. You will also design and build a launching mechanism to direct the rocket at the correct angle and direction to hit the target.

This assignment is in two parts, the actual launch and the research report.

**Launch:** The actual launch is simple. On the day of the launch you and your team members will bring your rocket(s), launchers, pumps, water supply, etc. out to the front of the school. You will be graded on one thing only, the launch of the day that comes closest to the target. In other words, if all your launches fail but one and it hits the target, that is what will determine your grade. You will also be graded on how well you use your time on launch day.

**Report:** The second half of the grade comes from your report. **Every student is turning in a report** even though you are working as a team. You can share ideas but I want the report to reflect your thinking and organization of facts. Please include the following:

- Present the report with a title page, typed or neatly written with good drawings.
- Make sure that you carefully document everything you did that made your rocket perform well. I would like your failures mentioned as well as the successes if the failures lead to an improved design and performance.
- Somewhere in the report give me be a thorough description of everything that went into your final rocket and launcher. Include drawings, lists, descriptions, and anything else you can think of.
- Show me a progression of ideas, how one thing led to another so I can see how your work developed.
Use as much physics as you can come up to describe how you controlled launch angle, aerodynamic stability (fins, etc...), launch pressure, direction of flight, etc.....

If you did any research, I want to see where it came from and what it said.

The report is worth 75 points and the rocket and launcher are worth 75 points.

**Water Rocket Safety Guide**

**Safety First**

Never use a breakable container as the rocket - DO NOT USE GLASS;

Never take the rocket to a pressure greater than that at which it has been tested; aim it at anybody;

Never aim it anywhere at anything that you cannot see such as around a corner or out to sea;

Never aim it into or across a road or in the path of a vehicle;

Never launch near any buildings or cars or anything else that can be damaged; launch near any power lines or anything else that can damage you or anyone else;

Never use a bottle that is damaged such that it may fail when pressurized;

Never use a gas that will react with any of the parts of the launcher;

Never use a reaction mass that is likely to harm anybody - keep to water; and,

Never launch in high winds - Completely still is best.

Always be careful with compressed gas (remember that a bicycle pump can deliver 6 BarG or 90 psi);

Always make sure that the reaction mass inside is still - waves or circular motion can lead to unpredictability;

Always make sure that the people around the launch have a good idea of what to expect; and,

Always consider where the air that you are launching into will be when your rocket lands - if you are going for duration and anticipate a 30 second flight time, the air that you are launching into may have moved off-site during that time. Consider using a smaller chute in this case if doing so is reasonable.

**How much pressure should I use when pumping up the rocket?**

Caution: For a safety margin, pump the rocket no higher than 90 psi. This is approximately 50% of the industry specifications for this kind of container. Two liter bottles can handle a maximum pressure of between 150 psi and 180 psi.

**What do I need to take with me when I go launching water rockets?**

I need to take rockets (including chutes and so on), water, a pump, a launcher, a release cord, a whistle (or air horn to draw people's attention), possibly a camera and a stopwatch. Sometimes, children and other adults :-)  

**What is a safe place to launch a water rocket?**

A safe place to launch the rocket is flat ground, away from cars, away from houses and other property that may be damaged by a rocket falling from the air. Also, make sure that anyone who is within the possible landing area or is reasonably likely to wander into it knows what to expect.

**What is a safe distance from a launcher?**

Before the rocket is fired and assuming that there are no metal or heavy parts to the rocket (ie, it is just a pop bottle with plastic fins and plastic nose cone et cetera) a distance of 20 feet should be reasonably safe if you are pressurizing to 100 psi. You should remember that you should wear goggles. There have not been any reports of rockets bursting and spreading debris further than around 10-15 feet so, like any risk assessment, you should use your judgment and err on the side of safety.
Special Design Notes

Make sure that the Cp is between one and two rocket diameters behind the Cg or in English . . .

Center of Pressure

The Cp is the center of pressure. It is the effective center of the area of the rocket as viewed from the side. One way of finding the Cp is to make a cardboard profile of the rocket and find where it balances.

To make the cardboard profile, you can draw the outline from measurements, do it by eye or put it on the floor beneath a light in a room and draw around the edge of the shadow (a bare bulb works best). Once you have the outline on the card, carefully cut it out and then find the point where it balances.

You can find the point where it balances by sticking a pin in it with a piece of thread tied to the pin with a weight on the other end of the thread so that the thread is pulled down across the face of the cardboard. Draw a line with a felt tipped pen on the cardboard along the line of the thread and then take the pin out and stick it somewhere else on the cardboard, repeating the drawing exercise. This should give you two lines that cross. Repeat a third time and the third line should cross where the other two do. This point represents the Center of Pressure and adding weight should not change its position (unless the weight is bulky).

Finally, put a mark on the rocket in the position that corresponds to the mark on the card. You now have your Cp marked on your rocket.

Center of Gravity

To find the Cg, or Center of Gravity, (sometimes called COG), hold the rocket on its side and find the point where it balances. The diameter of the rocket is just the diameter of the body of the rocket and does not include the fins (they are usually not bulky enough). The balance point of the rocket, the Cg, should be between one and two rocket diameters in front of the Cp for the rocket to be stable. If your rocket balances behind the point that is one rocket diameter in front of the Cp, then add some weight to the nose to bring the Cg forward. Once the Cg is at least one rocket diameter in front of the Cp, the rocket should be stable.

Testing without launching - - -

To check for stability without launching it, tie a piece of string around the rocket at the Cg (note that this test may not be practical if the fins come this far forward) and swing it slowly around your head. Starting from any direction, if it is stable, it should soon end up pointing in the right direction.

Water Rocket Safety Guide and Special Design Notes are from Paul Grosse's Web Site, http://ourworld.compuserve.com/homepages/pagrosse/h2oRocketIndex.htm. The use of this information is with permission by Paul Grosse whose email address is pagrosse@compuserve.com
Activity: Density of a Block of Wood Using Archimedes' Principle

Standard: HS.PS-FM Forces and Motion
Students who demonstrate understanding can:
HS-PS2-1 Analyze data to support the claim that Newton’s second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

Knowledge Objective
- I will acquire vocabulary and learn relationships of variables expressed in the equations for fluids in statics and dynamics.

Reasoning Objective
- I can use vectors to pictorially analyze problems for objects that are static.

Goal: In this activity you will gain an understanding of Archimedes' Principle using the concept of fluid displacement.

Apparatus: container of water, wood block, ruler, balance

Activity:
1. Find the volume of the block of wood.
   Height: _________________ m   Width: _________________ m   Length: ________________ m

2. Determine the volume of the block of wood.

3. Derive the equation for the ratio of volume of displacement to volume of the object in terms of density of fluid and density of object.

4. Find the volume of the displaced liquid and then determine the density of the block and finally find the mass of the block.

5. Now find the mass of the block on a balance and calculate the absolute and relative error.

Conclusion: Justify claims that Newton’s laws apply to the static environment that the block is at when it is floating.
Activity: Clay Boats

Standard: HS.PS-FM Forces and Motion
Students who demonstrate understanding can:
HS-PS2-1 Analyze data to support the claim that Newton’s second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

Knowledge Objective
- I will acquire vocabulary and learn relationships of variables expressed in the equations for fluids in statics and dynamics.

Reasoning Objective
- I can use vectors to pictorially analyze problems for objects that are static.

Goal: You will gain an understanding of buoyancy and Archimedes’ Principle through the creation and analysis of a clay boat.

Apparatus: clay, container of water, balance, pennies and graduated cylinder

Activity: In this activity you will determine the maximum number of pennies your clay boat should hold and experimentally verify the answer.

Procedure:
Determine the mass and volume of the clay.  \( m = \) ________________

Make your boat and then determine the internal volume of your boat.  \( v = \) ________________

1. What is the total volume of the boat (clay + internal volume).

2. Calculate the density of your boat.

3. Draw a force vector or free body diagram of your boat when it is placed in water.

4. Determine the mass of one penny and then determine the total number of pennies that the boat should hold. (Hint: The density of the boat and pennies as a combined unit is equal to the density of the water that the boat will just float.)

5. Now perform the experiment and find out how many pennies the boat will hold before it sinks. If this number is different from what you calculated then explain why there is a difference.
Activity: Bernoulli's Principle and Torricelli's Theorem

Standard: HS.PS-E Energy
Students who demonstrate understanding can:
HS-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).

Knowledge Objective
• I will explain the relationship for Bernoulli’s Principle.

Reasoning Objectives
• I will solve problems for the flow of fluids
• I will justify the conservation of energy in fluid dynamics.

Goal: I will determine the distance horizontally water will travel prior to hitting the ground when released from a hole on the side near the bottom of a bucket filled with water.

Apparatus: five-gallon bucket with hole in the bottom, meter stick, ruler and pan for the floor

Procedure: Pinch off the outlet for the bucket and fill it with water. Place it at the edge of the counter. Measure the height of the water above the hole.

1. What will the velocity of the water be, when it leaves through the hole at the bottom of the bucket?

2. Measure the vertical distance the water falls and then determine the horizontal distance the water will travel. Now uncap the tube and measure the horizontal distance the water moves. Calculate the percentage error.

3. What will the final velocity of the water be right before it hits the pan?
Walk on Water Activity and Report

**Standard:** HS.PS-FM Forces and Motion
Students who demonstrate understanding can:
HS-PS2-1 Analyze data to support the claim that Newton’s second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

**Standards:** HS-ETS-ED Engineering Design
Students who demonstrate understanding can:
HS-ET 1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

**Knowledge Objective:**
- I will develop an understanding of Newton's Laws of motion and fluid statics.

**Product Objectives:**
- I can design and build a pair of water shoes to walk across a pool.
- I can walk across a pool on my water shoes.

**Goal:** To apply your knowledge of physics to develop shoes to walk on water.

**Description:** In this activity you will have the opportunity to design shoes that enable you to walk across a pool on top of the water. Your challenge is to be able to walk as quickly as you can across the pool. You may work in a team of up to 4 students.

This assignment is in two parts, the actual walk and the research report.

**WALK:** The actual walk is very challenging. On the day of the launch, you and your team members will bring your shoes, swim suit or clothing that you do not mind getting wet, to school. We will walk over to the pool. You will be graded on your ability to walk across the pool on top of the water. You will also be graded on how well you use your time on walking day.

**REPORT:** The second half of the grade comes from your report. **Every student is turning in a report** even though you are working as a team. You can share ideas but I want the report to reflect your thinking and organization of facts. Please include the following:
• Present the report with a title page, typed or neatly written with good drawings.
• Make sure that you carefully document everything you did that made your water shoes perform well. I would like your failures mentioned as well as the successes if the failures lead to an improved design and performance.
• Somewhere in the report give me a thorough description of everything that went into your final project. Include drawings, lists, descriptions, and anything else you can think of.
• Show me a progression of ideas, how one thing led to another so I can see how your work developed.
• Use as much physics as you can come up with to describe how you were able to make the shoes that enabled you to float, move across the pool, etc....
• If you did any research I want to see where it came from and what it said.

The report is worth 50 points and the shoes and walking activity are worth 50 points.

Walking on Water Safety Guide

Always be careful when trying out your shoes. Have someone on hand and in the water to assist you should you tip over.
Always make sure that the people around the pool have a good idea of what to expect.
Periodicity, Waves, & Sound

Reflection

Refraction

Diffraction & Interference
Experiment: Wave Properties

HS.PS-W Waves
Students who demonstrate understanding can:
HS-PS4-1 Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media

Knowledge Objectives
- I know that waves carry energy from one place to another.
- I understand that speed, wavelength and frequency are related and that the equation for this relationship is \( v = \lambda f \).

Reasoning Objectives
- I can calculate wave speed, frequency, and reflected angles.
- I can solve problems using the wave equations, \( v = \lambda f \).

Introduction:
Waves transfer energy from one location to another without transporting matter. Mechanical waves are periodic disturbances in a medium such as solids, liquids and gases. The particles oscillate in periodic motion as a wave passes. The phase of a particle is the displacement of the particle from its equilibrium position and the velocity of the particle as the wave passes.

All waves have similar properties. The frequency, \( f \), is the number of waves that pass a point in a given time. The unit for frequency is the hertz or waves per second and is written as sec\(^{-1}\). The period, \( T \), of a wave is the time for one wave to pass a point. It is the reciprocal of the frequency.

\[ \frac{1}{T} = f \quad \text{or} \quad 1/f = T \]

The wavelength is represented by the Greek letter \( \lambda \) and is the distance between two consecutive particles that are in phase or have the same displacement and velocity. The velocity of a wave is the distance a wave travels per time or the wavelength divided by a period.

\[ v = \frac{\lambda}{T} \quad \text{or} \quad v = \lambda f \]

Waves reflect off barriers. Reflection is the returning of a wave when it interacts with a barrier. Waves also propagate perpendicular to wave front.

In this laboratory you will investigate the reflection, propagation, and speed of waves in a wave tank.

Apparatus: Power supply, connecting wires, lamp, two ring stands, C clamp, two angle clamps, wood barriers, wave generator, wave tank, pieces of paper, two rulers, protractor, blue triangle and strobe

Procedure A: (Reflection of Waves): Begin by attaching the legs to the wave tank and then level the tank using the bubble level. The tank should be placed under the edge of a laboratory counter so that the light from the lamp projects an image on the floor below the tank. Attach the wave generator to a ring stand using an angle clamp. Make sure that the wood bar on the wave generator is not touching the tank. It should rest slightly above the bottom of the tank. Place a power supply on the counter and connect it to the wave generator. Attach a ring stand to the counter using a C clamp and use an angle clamp and attach the light to the ring stand.
Now add water to the tank until the bottom of the wave generator is submerged. This should be about \( \frac{3}{4} \) of a centimeter of water in depth. The wave generator can be regulated using the rheostat on the power supply. The waves that are generated in the tank produce shadows on the floor as light and dark lines corresponding to the crests and troughs in the tank.

Begin to collect data by touching the water in the middle of the ripple tank. Observe and draw the propagation of the wave. What is the shape of the wave? How can the shape of the wave be explained in terms of the propagation speed? Record your answer to the questions next to your drawing. Use complete sentences.

Set up the wood blocks so that they form a straight barrier in the tank. Generate a circular pulse using your finger about 5 cm in front of the barrier. Observe the incident and reflected waves and draw a diagram of your observations. What is the shape of the reflected wave? What position does the reflect wave appear to originate? How far behind the barrier does the origin of the reflect wave appear to come from? Record your answer to the questions next to your drawing. Use complete sentences.

Next, you will determine the angles of incident and reflection. First on a piece of paper on the floor draw a line along the front of the shadow of the wood barrier. Turn on and then off quickly the wave generator to produce a small series of straight waves that will reflect off the straight barrier. View the propagation of the incident and reflecting waves. Align a ruler parallel to the incident wave front by turning on and off the wave generator. Place a second ruler perpendicular to the first and draw a line up to the shadow of the wood barrier.

<table>
<thead>
<tr>
<th>Incident ray</th>
<th>barrier</th>
</tr>
</thead>
<tbody>
<tr>
<td>reflected ray</td>
<td></td>
</tr>
</tbody>
</table>

Turn on and off the generator to produce a short series of waves and align a ruler with the reflected waves. Place a second ruler perpendicular to the wave front at a location where it will intersect with the barrier and incident lines. Draw a third line along the ruler to have the three lines intersect.
Repeat the procedure for two more angles by rotating the wood barrier to a new angle. After collecting the data draw a perpendicular line to the barrier so that it intersects with the two rays and the barrier. Measure the angle of incident between the perpendicular and incident ray and the angle of reflection that is between the refracted ray and the normal line. Record the angles in a table showing incident and reflected rays. How do these angles compare?

**Procedure B: Speed of Waves in the Tank:** In this second procedure the speed of the waves in the tank will be found. The equation for the speed of waves is:

\[ v = \lambda \cdot f \]

To calculate the speed, the wavelength and frequency will be measured. The frequency is easily determined with the strobe. Turn on the wave generator and then turn on the strobe. Rest the strobe on the counter above the wave tank; **do not let go**. Hold the strobe at one level not allowing it to move up or down. Adjust the strobe so that the waves appear to stop moving. To do this it is easier to use the auditory skill first. Adjust the strobe until the frequencies match, then make the final adjustment by watching the waves. This is easily done with the fine adjustment to stop the waves. Record the frequency from the strobe.

To measure the wave length place a piece of paper on the floor under the wave tank. Next take two pencils and place one of them on one of the dark lines or shadow of a wave. Count over five waves or five dark lines and set a second pencil at that point. Mark the paper at the ends of the pencils and label it five waves. You will be able to measure the distance between the marks and divide the distance by five to determine the wavelength of the shadow. It is important to understand that the wavelength of the shadow is not the same as the wavelength in the tank. The light spreads out from the strobe making the waves on the floor larger than the ones in the tank.

To compensate for this difference turn off the wave generator and place the blue triangle into the tank. The blue triangle will cast a shadow on the floor from the strobe light. Measure the length of one side of the triangle shadow and then measure the same side of the triangle from the tank. The ratio of the side of the blue triangle to the shadow should equal the ratio of the wave in the tank to the shadow of the wave on the floor.

\[ \frac{\text{Side of Blue Triangle}}{\text{Side of the Shadow of the Blue Triangle}} = \frac{\lambda}{\lambda_{\text{shadow}}} \]

Determine the wavelength for the wave in the tank and record that value in the table. Repeat the procedure for two new frequencies of waves. Do this by adjusting the rheostat on the power supply and then readjusting the strobe. Determine the velocity of the waves and record those values in the table.

To empty the tank without spilling water it can be siphoned. Fill the small hose with water using the faucet. Pinch the ends and then place one end in the water in the tank and the other end into the small tub on the floor. Relax the pinching of the hose and the water will drain out of the tank. Tip the tank as the water is draining.

**Analysis:**
1. How does the frequency of the wave generator affect the wavelength?
2. Does the frequency of the waves affect the velocity of the waves?

**Conclusion:** Describe the properties of waves in terms of reflection. Explain the overall characteristics of velocity, frequency and wavelength. Describe where error influenced the results.
Experiment: Refraction of Waves

HS.PS-W Waves
Students who demonstrate understanding can:
HS-PS4-1 Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media

Knowledge Targets
• I know that waves carry energy from one place to another.
• I understand that speed, wavelength and frequency are related and that the equation for this relationship is \( v = \lambda f \)

Reasoning Targets
• I will calculate wave speed, frequency, and refraction angles.
• I will solve problems using the wave equations, \( v = \lambda f \).

Introduction:
All waves have similar properties. Water waves will be diagnosed for their refractive properties in a wave tank. Refraction is the bending of waves as they pass at an angle other than perpendicular from one medium into another. The incident and refracted angles are measured from the normal at the surface to the direction the waves propagate or travel. As waves pass from a less dense medium to a denser medium the waves will bend toward the perpendicular or normal to the surface. When waves pass from a denser medium to a less dense medium they are bent away from the normal. This shows that waves are reversible. Snell’s Law expresses the relationship between the incident and refracted angles. Snell’s Law is the ratio of the sine of the angles is directly proportional to the ratio of the velocities of light in the two mediums and equal to the index of refraction. The index of refraction is constant for a particular difference in depths of the water.

\[
\frac{\sin \theta_1}{\sin \theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}
\]

The following diagram illustrates the refraction of a wave front as it enters from deep water into shallower water that is the denser medium.

To determine the velocity of a wave in the wave tank the wavelength and frequency will be determined. The frequency, \( f \), is the number of waves that pass a point in a given time. The unit for frequency is the hertz or waves per second and is written as \( \text{sec}^{-1} \). The period, \( T \), of a wave is the time for one wave to pass a point. It is the reciprocal of the frequency.
The wavelength is represented by the Greek letter $\lambda$, and is the distance between two consecutive particles that are in phase or have the same displacement and velocity. The velocity of a wave is the distance a wave travels per time or the wavelength divided by a period.

$$v = \frac{\lambda}{T} \quad \text{or} \quad v = \lambda f$$

Once the velocity is determined for two different water depths, the index of refraction between the two depths can be determined. A second method used to find the index of refraction is through the use of the ratios of the sine of the angles. The angles can be determined using the shadow of the waves produced when a light is shown through the tank with waves in it.

**Apparatus:** Power supply, connecting wires, lamp, two ring stands, C clamp, two angle clamps, wood barriers, wave generator, wave tank, pieces of paper, two rulers, protractor, blue triangle and strobe

**Procedure:** Begin by attaching the legs to the wave tank and then level the tank using the bubble level. The tank should be placed under the edge of a laboratory counter so that the light from the lamp projects an image on the floor below the tank. Attach the wave generator to a ring stand using an angle clamp. Make sure that the wood bar on the wave generator is not touching the tank. It should rest slightly above the bottom of the tank. Place a power supply on the counter and connect it to the wave generator. Attach a ring stand to the counter using a C clamp and use an angle clamp and attach the light to the ring stand.

Add water to the tank until it just covers the blue triangle. The wave generator can be regulated using the rheostat on the power supply. The waves that are generated in the tank produce shadows on the floor as light and dark lines corresponding to the crests and troughs in the tank.

You will determine the angles of incident and refraction. First on a piece of paper on the floor draw a line along the front of the shadow of the blue barrier. Now turn on and then off quickly the wave generator to produce a small series of straight waves that will refract over the blue triangle. View the propagation of the incident and refracted waves. Now align a ruler parallel to the incident wave front by turning on and off the wave generator. Place a second ruler perpendicular to the first and draw a line up to the shadow of the blue barrier.

Turn on and off the generator to produce a short series of waves and align a ruler with the refracted waves. Place a second ruler perpendicular to the wave front at a location where it will intersect with the barrier and incident lines. Draw a third line along the ruler to have the three lines.
Repeat the procedure for two more angles by rotating the blue barrier to a new angle and collect the data again. After collecting the data draw a perpendicular line to the barrier so that it intersects with the two rays and the barrier. Measure the angle of incident between the normal and incident ray and the angle of refraction that is between the refracted ray and the normal line. Record the angles in a table showing incident and refracted angles.

**Speed of Waves:** In this second procedure the speed of the waves in the deep and shallow water over the blue triangle will be found. The equation for the speed of waves is:

\[ v = \lambda f \]

To calculate the speed, the wavelength and frequency will be measured. The frequency is easily determined with the strobe. Turn on the wave generator and then turn on the strobe. Rest the strobe on the counter above the wave tank, do not let go. Hold the strobe at one level not allowing it to move up or down. Adjust the strobe so that the waves appear to stop moving. To do this it is easier to use the auditory skill first. Adjust the strobe until the frequencies match, then make the final adjustment by watching the waves. This is easily done with the fine adjustment to stop the waves. Record the frequency from the strobe.

To measure the wave length, place a piece of paper on the floor under the wave tank. Next take two pencils and place one on one of the dark lines or shadowsofa wave. Count over five waves or five dark lines and set a second pencil at that point. Mark the paper at the ends of the pencils and label it five waves. Repeat this for the waves in the shallow or in the shadow of the blue triangle. You will be able to measure the distance between the marks and divide the distance by five to determine the wavelength of the shadow. It is important to understand that the shadows...
wavelength is not the same as the wavelength in the tank. The light spreads out from the strobe making the waves on the floor larger than the ones in the tank.

To compensate for this difference turn off the wave generator and place the blue triangle into the tank. The blue triangle will cast a shadow on the floor from the strobe light. Measure the length of one side of the triangle shadow and then measure the same side of the triangle from the tank. The ratio of the side of the blue triangle to the shadow should equal the ratio of the wave in the tank to the shadow of the wave on the floor.

\[
\frac{\text{Side of Blue Triangle}}{\text{Side of the Shadow of the Blue Triangle}} = \frac{\lambda}{\lambda_{\text{shadow}}}
\]

Determine the wavelength for the waves in the tank and record those values in the table. Repeat the procedure for two more different frequencies of waves. Do this by adjusting the rheostat on the power supply and then readjusting the strobe. Determine the velocity of the waves and record those values in the table.

### Refraction of Water Waves in a Wave Tank

<table>
<thead>
<tr>
<th>Angle of Incident ($\theta$)</th>
<th>Angle of Refraction ($\phi$)</th>
<th>$\sin \theta$</th>
<th>$\sin \phi$</th>
<th>Velocity in Shallow $v_d$ (cm/sec)</th>
<th>Velocity in Shallow $v_s$ (cm/sec)</th>
<th>$v_d$</th>
<th>$v_s$</th>
</tr>
</thead>
</table>

To empty the tank without spilling water it can be siphoned. Fill the small hose with water using the faucet. Pinch the ends and then place one end in the water in the tank and the other end into the small tub on the floor. Relax the pinching of the hose and the water will drain out of the tank. Tip the tank as the water is draining.

**Analysis:**
1. How does the depth of the water affect the speed of the waves?
2. What is the relationship between the angle of incident and angle of refraction?
3. Is the frequency of the waves the same in the shallow and in the deep water? How do you know?
4. Predict what would happen to the waves if they pass from shallow to the deep water.

**Conclusion:** Describe the properties of waves in terms of refraction. Explain the overall characteristics of velocity, frequency and wavelength. Describe where errors influenced the results.
Experiment: Diffraction of Waves

HS.PS-W Waves
Students who demonstrate understanding can:
HS-PS4-1 Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media

Knowledge Objectives
• I know waves carry energy from one place to another.
• I will describe and illustrate the diffraction of waves.
• I understand that speed, wavelength and frequency are related and that the equation for this relationship is \( v = \lambda f \)

Reasoning Objective
• I will solve problems using the wave equations, \( v = \lambda f \).

Introduction:
All waves have similar properties. Water waves will be diagnosed for their diffractive properties in a wave tank. Diffraction is the bending of waves as they pass through a small opening in a barrier or around barriers. According to Huygen's principle all waves are made of an infinitesimal number of small circular waves. Every point on a wave front can be considered as a source of tiny wavelets that spread out in the forward direction at the speed of the wave itself. As a straight wave passes through a small opening or by a barrier a portion of the straight wave that moves along is circular and so the wave spreads out taking on the circular form.

Apparatus: Power supply, connecting wires, lamp, two ring stands, C clamp, two angle clamps, wood barriers, wave generator, wave tank, pieces of paper, two rulers, protractor, blue triangle and strobe

Procedure: Begin by attaching the legs to the wave tank and then level the tank using the bubble level. The tank should be placed under the edge of a laboratory counter so that the light from the lamp projects an image on the floor below the tank. Attach the wave generator to a ring stand using an angle clamp. Make sure that the wood bar on the wave generator is not touching the tank. It should rest slightly above the bottom of the tank. Place a power supply on the counter and connect it to the wave generator. Attach a ring stand to the counter using a C clamp and use an angle clamp and attach the light to the ring stand.
Now add water to the tank until the bottom of the wave generator is submerged. This should be about ¾ of a centimeter of water in depth. The wave generator can be regulated using the rheostat on the power supply. The waves that are generated in the tank produce shadows on the floor as light and dark lines corresponding to the crests and troughs in the tank.

Use the strobe to adjust the wavelength of the waves to 2.0 cm. It is important to understand that the shadows wavelength is not the same as the wavelength in the tank. The light spreads out from the strobe making the waves on the floor larger than the ones in the tank.

To compensate for this difference turn off the wave generator and place the blue triangle into the tank. The blue triangle will cast a shadow on the floor from the strobe light. Measure the length of one side of the triangle shadow and then measure the same side of the triangle from the tank. The ratio of the side of the blue triangle to the shadow should equal the ratio of the wave in the tank to the shadow of the wave on the floor.

\[
\frac{\text{Side of Blue Triangle}}{\text{Side of the Shadow of the Blue Triangle}} = \frac{\lambda}{\lambda_{\text{shadow}}}
\]

To find the length of the shadow that corresponds to a 2.00 cm wavelength in the tank put the values for the blue triangle, shadow of the blue triangle and the \(\lambda\) of 2.0 centimeters into the equation. Turn on wave generator and the strobe. Synchronize the strobe with waves so that they appear to stop. Measure the shadow of a wave and then adjust the generator and the strobe until the shadow is the correct wavelength. Record the value of the strobe. This value will be very important in the second part of the laboratory procedure.

Now the effect of the slit width on diffraction will be determined. With the waves at 2.0 cm the opening in the barrier will be adjusted and diagrams of the diffracted waves will be recorded. Use opening sizes of 6.0 cm, 4.0 cm, 2.0 cm, and 1.0 cm. Make sure to observe the curvature of the waves that emerge from the openings.
In the second part of the experiment the width of the opening will remain at 3.0 cm and the wavelength of the waves will be adjusted. The first wavelength is 2.0 cm so the setting from the above portion of the experiment can be used. Draw a diagram of the diffracted waves. Now the wavelength will be adjusted to 1.0 cm. This can easily be done by doubling the frequency or strobe reading from the first setting. Adjust the wave generator until the waves stop. Since the waves are being generated twice as fast they will have half the wavelength or 1.0 cm. Draw a diagram of the diffracted waves. Make sure to observe the curvature of the waves that emerge from the opening. Now adjust the strobe so that the waves have a wavelength of 3.0 cm and then 4.0 cm and make drawing of both of the diffraction patterns.

To empty the tank without spilling water it can be siphoned. Fill the small hose with water using the faucet. Pinch the ends and then place one end in the water in the tank and the other end into the small tub on the floor. Relax the pinching of the hose and the water will drain out of the tank. Tip the tank as the water is draining.

**Analysis:**
1. How does the amount of diffraction change as the width of the opening was changed?
2. How does the amount of diffraction or curvature of the wave change with the change in the size of the waves?
3. What general conclusion can you make about the wavelength, opening size and amount of diffraction?
4. Sound waves produced outside a door can be heard any place in a room. How does the width of a doorway compare with the wavelength of sound?

**Conclusion:** Describe the properties of waves in terms of diffraction. Explain the mathematical relationships among wave speed, frequency, and wavelength and how they are affected by the medium through which the wave travels. Describe how the opening in the boundary affected the transmission of waves crossing through the opening.
Experiment: Diffraction and Interference in a Wave Tank

HS.PS-W Waves
Students who demonstrate understanding can:
HS-PS4-1 Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media

Knowledge Objectives
- I know waves carry energy from one place to another.
- I can describe and illustrate the diffraction and interference of waves

Introduction:
All waves have similar properties. Water waves will be diagnosed for their diffractive and interference properties in a wave tank. Diffraction is the bending of waves as they pass through a small opening in a barrier or around barriers. According to Huygen’s principle all waves are made of an infinitesimal number of small circular waves. Every point on a wave front can be considered as a source of tiny wavelets that spread out in the forward direction at the speed of the wave itself. As a portion of a straight wave passes through a small opening or by a barrier the wave spread, out taking on the circular form.

![Diagram showing diffraction](image)

Interference occurs when waves from two different sources interact and either constructively or destructively combined. Constructive interference occurs when two waves with displacements in phase interact creating a larger wave. Destructive interference occurs when two waves of displacements that are out of phase interact.

![Diagram showing interference](image)

When straight waves pass through two opening in a barrier then the waves will diffract and interfere on the other side of the barrier.
This produces an interference pattern shown above. A similar interference pattern can be generated from two point sources.

**Apparatus:** Power supply, connecting wires, lamp, two ring stands, C clamp, two angle clamps, wood barriers, wave generator, wave tank, pieces of paper, two rulers, protractor, and strobe

**Procedure:** Begin by attaching the legs to the wave tank and then level the tank using the bubble level. The tank should be placed under the edge of a laboratory counter so that the light from the lamp projects an image on the floor below the tank. Attach the wave generator to a ring stand using an angle clamp. Make sure that the wood bar on the wave generator is not touching the tank. It should rest slightly above the bottom of the tank. Place a power supply on the counter and connect it to the wave generator. Attach a ring stand to the counter using a C clamp and use an angle clamp and attach the light to the ring stand.

![Wave tank setup](image1.png)

Now add water to the tank until the bottom of the wave generator is submerged. This should be about ¾ of a centimeter of water in depth. The wave generator can be regulated using the rheostat on the power supply. The waves that are generated in the tank produce shadows on the floor as light and dark lines corresponding to the crests and troughs in the tank.

Set up the barriers so that there are two small openings side by side through which the waves can diffract. The openings should be approximately 2 centimeters in width. Turn on the wave generator with the power supply on a low setting so the generated waves have long wavelengths. Observe the interference pattern produced after the waves diffract through the openings. Draw the pattern you observe. Now slowly increase the frequency of the wave generator and observe how the pattern changes with the change in frequency. Make two more drawings of the pattern at two successive higher frequencies.
In this section of the laboratory you will observe the pattern produced by two point sources that are in phase with each other. Disconnect the straight wave wooden bar from the wave generator and attach the two point sources.

Adjust the black knob on the side of the generator so that the two red balls vibrate up and down at the same time and are in phase.

Observe the interference pattern produced by the two point sources. Draw a diagram of this pattern.

Now rotate the knob 180° so that the two point sources oscillate 180° out of phase. One point source should produce a trough at the same time that the other is producing a crest. Observe how the pattern changes and make a drawing of the new pattern. Finally, rotate the knob back 90° so that the waves are ¼ of a wave out of phase. Observe and make a drawings of the resulting interference pattern.

To empty the tank without spilling water it can be siphoned. Fill the small hose with water using the faucet. Pinch the ends and then place one end in the water in the tank and the other end into the small tub on the floor. Relax the pinching of the hose and the water will drain out of the tank. Tip the tank as the water is draining.

**Analysis:**
1. How does the change frequency affect the interference pattern through the double slits?
2. How does the phase change affect the interference pattern of the two point sources?

**Conclusion:** Explain how the two point sources (either the red point sources or the double slit in the barrier) produce interference patterns. How do those patterns change due to frequency and phase changes?
Experiment: Resonance and the Speed of Sound

HS.PS-W Waves
Students who demonstrate understanding can:
HS-PS4-1 Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media

Knowledge Objectives
- I can describe the relationships between wave motion and particles in the wave.
- I can describe the following properties of waves: reflection, refraction, diffraction and interference.

Reasoning Objectives
- I can calculate wave speed, frequency, reflected angles and refraction angles.

Skill Objectives
- I will collect experimental data within the tolerance of the measuring instruments for wave property experiments.
- I will use vectors to graphically represent particle motion in a medium as waves pass through.
- I will collect experimental data within the tolerance of the measuring instruments.

Product Objective
- I will use if then statements to determine the independent and dependent variables then display experimental data correctly using tables.

Purpose: To diagnose the production of different tones when a flexible corrugated tube, “Flugal Horn,” is spun while holding onto one end.

Experimental and Controlled Variables: The variables to be tested should be discovered during a brainstorming session after the purpose is presented. Some possible variables and investigations are:

<table>
<thead>
<tr>
<th>Investigation</th>
<th>Control Variables</th>
<th>Experimental Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investigation 1</td>
<td>Speed that the tube is spun (revolutions/second)</td>
<td>Frequency of sound produced</td>
</tr>
<tr>
<td>Length of tube</td>
<td>Diameter of tube</td>
<td></td>
</tr>
<tr>
<td>Diameter of tube</td>
<td>Tube remains open at both ends</td>
<td></td>
</tr>
<tr>
<td>Tube remains open at both ends</td>
<td>The tube is corrugated</td>
<td></td>
</tr>
<tr>
<td>The tube is corrugated</td>
<td>The room temperature and pressure</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Investigation 2</th>
<th>Length of tube</th>
<th>Frequency of sound produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter of tube</td>
<td>Speed that the tube is spun (revolutions/second)</td>
<td></td>
</tr>
<tr>
<td>Tube remains open at both ends</td>
<td>Tube remains open at both ends</td>
<td></td>
</tr>
<tr>
<td>The tube is corrugated</td>
<td>The tube is corrugated</td>
<td></td>
</tr>
<tr>
<td>The room temperature and pressure</td>
<td>The room temperature and pressure</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Investigation 3</th>
<th>Diameter of the tube</th>
<th>Frequency of sound produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of tube</td>
<td>Speed that the tube is spun (revolutions/second)</td>
<td></td>
</tr>
<tr>
<td>Tube remains open at both ends</td>
<td>Tube remains open at both ends</td>
<td></td>
</tr>
<tr>
<td>The tube is corrugated</td>
<td>The tube is corrugated</td>
<td></td>
</tr>
<tr>
<td>The room temperature and pressure</td>
<td>The room temperature and pressure</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Investigation 4</th>
<th>The end of the tube that is held onto is opened or closed</th>
<th>Sound is produced or not produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of tube</td>
<td>Diameter of tube</td>
<td></td>
</tr>
<tr>
<td>Diameter of tube</td>
<td>Speed that the tube is spun (revolutions/second)</td>
<td></td>
</tr>
<tr>
<td>The tube is corrugated</td>
<td>The tube is corrugated</td>
<td></td>
</tr>
<tr>
<td>The room temperature and pressure</td>
<td>The room temperature and pressure</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Investigation 5</th>
<th>Whether the tube is</th>
<th>Sound is produced or</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of tube</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Diameter of tube
Speed that the tube is spun (revolutions/second)
Tube remains open at both ends
The room temperature and pressure | corrugated or not | not produced

Procedure:

The procedure will vary with respect to the experimental variables. You will work in groups and be guided by the teacher to help develop procedures. The teacher will facilitate the process by describing how different variables can be measured as you progress through the process of procedural design. The constant for the speed of sound is 330 meters/sec at 0°C and the value of .6 meters/sec °C can be added on to compensate for temperatures above 0°C. The equipment will include corrugated tubes and non-corrugated tubes of different diameters and lengths. You will also need to have means and equipment to measure the frequency of the sound produced by the spinning horn. This could be a microphone connected to an oscilloscope or computer through the Labpro or a frequency meter from a music store.

Analysis and Manipulation of Data:

The main calculations will be for wavelength of the sound after calculating the speed and measuring the frequency. If an oscilloscope is used to determine the frequency the instructor will provide instructions on how to read and use the measurements from the scope to find the number of waves per second or frequency.

The data of tube length, frequency, wavelength, and spin velocity should be tabulated so that relationships can be determined.

Sample Questions:

As you determine relationships among the data consider how the wavelengths relate to the length of the tube and how the wavelength is related to velocity of the spinning horn.

Reporting Findings:

Present your findings in front of the class and assist the different groups who explored other variables understand the relationships between the variables that they explored.
Activity: Flugal Horn

HS.PS-W Waves
Students who demonstrate understanding can:
HS-PS4-1 Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media

Knowledge Objectives
- I will describe the relationships between wave motion and particles in the wave.
- I will describe the following properties of waves: reflection, refraction, diffraction and interference.

Reasoning Objective
- I will calculate wave speed, frequency, reflected angles and refraction angles.

Skill Objectives
- I will collect experimental data within the tolerance of the measuring instruments for wave property experiments.
- I will use vectors to graphically represent particle motion in a medium as waves pass through.
- I will collect experimental data within the tolerance of the measuring instruments.

Product Objectives
- I will use “if then” statements to determine the independent and dependent variables then display experimental data correctly using tables.

Goal: In this activity you will determine the speed of sound using a Flugal horn. The objective of this activity is for you to understand standing sound waves in an open tube.

Apparatus: The activity will be conducted as a class since there is one set of apparatus. The apparatus includes a Flugal horn, oscilloscope connected to a microphone and meter stick.

Procedure:
1. Spin the Flugal horn. Listen, as the tone becomes pure and loud. Describe below what is happening and draw a diagram of the standing wave in the horn.

2. Now determine the frequency of the horn using the microphone connected to the oscilloscope or computer through the Labpro and Vernier software. Determine the speed of sound in the horn.
Experiment: Standing Waves and the Speed of Sound

HS.PS-W Waves
Students who demonstrate understanding can:
HS-PS4-1 Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media

Knowledge Objectives
• I know that waves carry energy from one place to another.
• I understand that speed, wavelength and frequency are related and that the equation for this relationship is \( v = \lambda f \)

Reasoning Objective
• I can solve problems using the wave equations, \( v = \lambda f \).

Introduction:
Sound is a longitudinal wave, a wave in which the particles vibrate parallel to the motion of the wave. The particles vibrate between compression and refractions with the maximum displacement occurring at both compressions and refractions. A particle at its equilibrium position has a maximum velocity toward the compression. The velocity of the particles are shown by the small arrows.

Wave motion

Compression Rarefaction or Expansion

A particle in the longitudinal wave will move toward the compression as it approaches. As the compression arrives the particle slows to a stop. As the compression passes the particle follows the compression moving fastest as it passes through the equilibrium position. It then slows and comes to rest as the rarefaction arrives. The particle turns and begins to move back toward the next compression reaching its fastest velocity in the opposite direction when it is back at its equilibrium position and slowing to a standstill by the time the compression arrives.

Sound waves form standing waves in tubes when the length of the tube is adjusted to match the frequency of the waves. A pipe organ is an example of a tube that resonates with standing sound waves. When a sound source like a tuning fork is placed above the top of a tube that is suspended in a tub of water the sound waves reflect off the water and return to the source. If the length of the tube allows the returning wave to arrive at the tuning fork at the same time that the tuning fork produces another wave they add together and produce an amplified sound. This is known as a standing wave. The sound wave not only reflects off the water it also reflects off a difference in pressure at the open end of the tube. There is a greater pressure in the tube than there is outside of the tube. This difference in pressure acts as a different medium at which a small portion of the wave reflects back into the tube. Most of the sound does come out of the tube.
Since the velocity of a wave is equal to the frequency times the wavelength the speed of sound in air can be determined. The length of the tube is \( \frac{1}{4} \) of a wavelength. Since the frequency of the tuning fork is known, the velocity of the sound can be found using the follow equation.

\[
v = f\lambda
\]

The shortest length of the tube is \( \frac{1}{4} \) of a wavelength. To compensate for the random motion of molecules in the air a compensation factor is introduced into the equation for the wavelength.

\[
\lambda = 4(L + 0.3d)
\]

The length is represented by \( L \) and \( d \) is the diameter.

**Apparatus:** bucket of water, tube, rubber mallet, and set of tuning forks

**Procedure:** Fill a bucket with water. Hold a tube in the water and then strike a tuning fork on a rubber mallet. Hold the fork over the end of the tube. Raise the tube until resonance is achieved. That is the point at which the sound is the loudest. Measure the length of the tube that is above the level of the water. Measure the diameter of the tube and note the frequency of the tuning fork. Record these values in the table.

### Speed of Sound Determined Using a Standing Wave in a Tube

<table>
<thead>
<tr>
<th>Frequency ( F ) (hertz = 1/sec)</th>
<th>Length of Air Column ( L ) (+.0004m)</th>
<th>Diameter of Tube ( d ) (+.0004m)</th>
<th>Wavelength ( \lambda ) (meters)</th>
<th>Speed of Sound ( v ) (m/sec)</th>
</tr>
</thead>
</table>

**Analysis:** Calculate the wavelength of sound for each frequency. Use each wavelength with the frequency to determine the velocity of sound. The accepted value for the speed of sound can be determined using the following equation and the temperature, \( T \), in the room.

\[
v = 330 \text{ m/sec} + (0.6 \text{m/s}^\circ \text{C}) T
\]

Calculate the absolute and relative errors and deviations for the speed of sound found using the data.

**Conclusion:** Give an overview of how the speed of sound was calculated in this laboratory. Explain factors that affect the data creating errors in the results.
Activity: Resonating Rod

HS.PS-W Waves
Students who demonstrate understanding can:
HS-PS4-1 Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media

Knowledge Objectives
- I can describe the relationships between wave motion and particles in the wave.
- I can describe the following properties of waves: reflection, refraction, diffraction and interference.

Reasoning Objectives
- I can calculate wave speed, frequency, reflected angles and refraction angles.

Skill Objectives
- I will collect experimental data within the tolerance of the measuring instruments for wave property experiments.
- I will use vectors to graphically represent particle motion in a medium as waves pass through.
- I will collect experimental data within the tolerance of the measuring instruments.

Product Objective
- I will use “if then” statements to determine the independent and dependent variables then display experimental data correctly using tables.

Goal: In this activity you will determine the bulk Modulus of the resonating rod and create an understanding of a standing sound wave in a rod.

Apparatus: The activity will be conducted as a class since there is one set of apparatus. The apparatus includes a 1.5 meter long aluminum rod that resonates when taped at the end, oscilloscope connected to a microphone or Labpro and computer with Vernier software and a two meter stick.

Procedure:
1. Strike the resonating rod on its end while holding the middle of the rod. Listen, as the tone becomes pure. Describe below what is happening and draw a diagram of the standing wave on the rod.

2. Now determine the frequency of the rod using the microphone connected to the oscilloscope or computer. Determine the speed of sound in the rod.

3. Determine the elasticity modulus for aluminum using the density of aluminum of $2.70 \times 10^3$ kg/m$^3$. The accepted value is $70 \times 10^9$ N/m$^2$. Determine the absolute and relative error for your calculated value.
Activity: Sound

HS.PS-W Waves

Students who demonstrate understanding can:

HS-PS4-1 Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media

Knowledge Objectives
- I can describe the relationships between wave motion and particles in the wave.
- I can describe the following properties of waves: reflection, diffraction and interference.
- I know that waves carry energy from one place to another.

Reasoning Objectives
- I will apply my knowledge of interference, standing waves, beats and reflection by analyzing the following apparatus, resonating bars, resonating boxes with mounted tuning forks, and parabolic dish.

Skill Objectives
- I will use vectors to graphically represent particle motion in a medium as waves pass through.

Introduction:
Sound travels in waves and has wave properties similar to other mechanical waves. Sound is a longitudinal wave, a wave in which the particles vibrate parallel to the motion of the wave. The particles vibrate between compression and refractions with the maximum displacement occurring at both compressions and refractions. A particle at its equilibrium position has a maximum velocity toward the compression. The velocity of the particles are shown by the small arrows.

Wave motion

A particle in the longitudinal wave will move toward the compression as it approaches. As the compression arrives the particle slows to a stop. As the compression passes the particle follows the compression moving fastest as it passes through the equilibrium position. It then slows and comes to rest as the rarefaction arrives. The particle turns and begins to move back toward the next compression reaching its fastest velocity in the opposite direction when it is back at its equilibrium position and slowing to a standstill by the time the compression arrives.

Sound waves form standing waves in tubes when the length of the tube is adjusted to match the frequency of the waves. A pipe organ is an example of a tube that resonates with standing sound waves. When a sound source like a tuning fork is placed above the top of a tube that is suspended in a tub of water the sound waves reflect off the water and return to the source. If the length of the tube allows the returning wave to arrive at the tuning fork at the same time that the tuning fork produces another wave they add together and produce an amplified sound. This is known as a standing wave. The sound wave not only reflects off the water it also reflects off a difference in pressure at the open end of the tube. There is a greater pressure in the tube than there is outside of the tube. This difference in pressure acts as a different medium at which a small portion of the wave reflects back into the tube. Most of the sound does come out of the tube.
Interference is the addition of waves either in phase to create a louder sound or out of phase to cancel each other out. When there are two sources of sound of the same frequency there are locations where they will cancel each other out and locations where the waves will add together similar to what happens in the wave tank with two different point sources. Destructive interference occurs at any point whose distance from one point source is greater than its distance from the other source by \( \frac{1}{2} \) wavelength. If this extra distance is a whole wavelength then the waves will be in phase and constructive interference occurs.

Beats occur due to interference of two waves from two sources that have close to the same frequency. The sound level will alternately become louder and then softer at a regular rate. The beat frequency is the difference between the frequencies of the two sources.

**Apparatus:** tuning fork, rubber mallet, strobe, tone bars, resonating boxes with tuning forks, oscilloscope, microphone, parabolic dish, two speakers, two angle clamps, two ring stands, connecting cables, sound tubes and audio generator
**Procedure:**

Look at the production of sound from a tuning fork by hitting the tuning fork on the rubber mallet and see how it vibrates in the light of the flashing strobe. Describe how sound is produced by the tuning fork. The waves that are formed are longitudinal waves. Now describe how sound is transmitted in longitudinal waves as you did for the wave unit. Include diagrams in your description of how particles oscillate.

Sound has the same properties as other waves. There is an oscilloscope connected to a microphone. The sound is transformed into a wave pattern on the scope. Place the microphone about 5 centimeters from the center of the parabolic dish. Describe the properties as shown in this experiment of reflection from a parabolic dish. Please use diagrams to help in your explanation.

Resonance occurs when waves superimpose on top of each other. Please hit one of the tuning forks on top of one of the boxes when the openings of the boxes are facing each other. Now remove the box by grabbing the tuning fork and lifting the box out of the way. Why do you hear sound coming from the second box? Repeat the experiment by placing the smaller box with the smaller tuning in front of the box with the large tuning fork. Now hit the large tuning fork with a mallet and finally remove this tuning fork by grabbing the fork that you hit. Explain the results.

Constructive and destructive interference occurs with two speakers when the same frequency of sound is produced by each. The waves either add or cancel each other. Draw a diagram of the waves as they constructively and destructively interfere from the two speakers.

When two slightly different frequencies of sound are produced at the same time the ear detects an oscillation of the sound called a beat. Hit the two tone bars that are on top of the wooden boxes and listen to the beats. Now describe how the beats are produced. Use diagrams of the waves in your description.

Place your ear near the end of each pipe and listen for the sound. Each tube resonates with a different frequency of sound from the background noise due to the different lengths. Explain and draw diagrams of the standing half waves formed in the tubes and then make a calculation for the frequency of the wave using a velocity of 343 meters per second for the speed of sound and the wave equation.
Gas Laws, Kinetic Theory, & Thermodynamics

- Water and steam
- Water (all liquid)
- Water vapor (steam)

Heating Curve:
- Temperature (°C)
- Heat Added (kcal)

Phase Changes:
- Ice
- Water and ice
- Water (all liquid)
- Water and steam
- Water vapor (steam)
Experiment: Boyle’s Law (Pressure versus Volume)

**Standard: HS.PS-SPM Structure and Properties of Matter**

Students who demonstrate understanding can:

HS-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.

HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).

**Knowledge Objectives**

- I know the kinetic theory of matter states that all matter is made of tiny particles that are in constant motion and are colliding with each other.
- I can recall that the collisions of the molecules with surfaces create pressure.

**Reasoning Objective**

- I will analyze the relationship between pressure and volume of an ideal gas.

**Introduction:** For a given quantity of gas it is found experimentally that the volume of a gas is inversely proportional to the pressure applied to it when the temperature is kept constant. This relationship is true at temperatures and pressures near room temperature and one atmospheric pressure. That is,

\[ V \propto \frac{1}{P} \]

This is known as Boyle’s Law. \[ PV = \text{constant} \]

You will verify this relationship between pressure and volume of a given quantity of gas. The gas is air and the volume will be that of a syringe. The position of the syringe will be altered and the pressure will be measured using a gas pressure sensor connected to a computer. You will be able to verify the relationship by selecting the best mathematical relationship for the data after it is graphed.

**Apparatus:** Computer, Lab Pro with USB connection, pressure sensor, syringe, Logger Pro computer program and Boyle’s Law Laboratory Experiment
**Procedure:** Connect the Lab Pro to the electrical outlet and then connect the USB cable to the computer. Attach the pressure sensor to port 1 on the Lab Pro. Adjust the syringe to 10ml and attach it to the pressure sensor with a gentle twisting motion.

Open the Logger Pro program on the computer. Next, click on file and open Chemistry with Computers.

In this folder is an experiment called Boyles Law. Select that experiment.

The experiment will open in Logger Pro and the atmospheric pressure in Kilo-Pascals will show up on the bottom left corner of the computer window.

Click the start button on the top of the window. Push the front of the syringe to the inside of the black ring at the 5.0 ml mark. Hold the syringe here and then click keep. Type 5.0 ml in the Volume box. Click OK to keep the data point. This will record the pressure and volume of the gas. A data point will also be graphed. Repeat the procedure for 7.5, 10.0, 12.5, 15.0, 17.5, and 20.0 ml.

When you finish collecting data push the stop button. Examine the graph and decide what relationship is shown by the graph. Now analyze the data by clicking on the Analyze button in the main menu and selecting Curve fit. Select the relationship that you believe fits the curve. Click try fit to see if you...
have selected the best fitting relationship. When you get the right fit, select OK.
Once you have selected the best fit print the graph. You may label your graph prior to printing.
Print a copy for everyone in your group. Record the volume and the pressure from the computer in a table.

**Adjusting the Volume of a Fixed Amount of Gas in a 20 ml Syringe with Respect to Changing Pressure**

<table>
<thead>
<tr>
<th>Volume (V)</th>
<th>Pressure (P)</th>
<th>Constant (k)</th>
</tr>
</thead>
<tbody>
<tr>
<td>mL</td>
<td>Pascal’s</td>
<td>(P/V or P V)</td>
</tr>
</tbody>
</table>

**Analysis:** When answering the questions refer to the data and for the calculations show the given, desired, equation, solution with units.

1. How does the pressure change as the volume is doubled from 5.0 mL to 10.0 mL?
2. When the volume was halved from 20.0 mL to 10.0 mL how did the pressure change?
3. When the volume was tripled from 5.0 to 15.0 mL what happened to the pressure?
4. Do your answers to the questions show that the relationship is inverse, one where the volume increase as the pressure decreases or a direct relationship in which as the pressure increases so does the volume?
5. Predict what would happen if the volume of the syringe was increased to 40.0 mL. Now predict what would happen if it was decreased to 2.5 mL.
6. What experimental factors were kept constant during this activity?
7. Based upon your answers to questions 4 and 5 use one of the formulas (P/V or P V) to calculate the constant values for each of the sets of data in the table above.

**Conclusion:** Evaluate the constant in terms of absolute and relative deviation. What factors in the apparatus would cause the values to deviate from the average of all of the k values?
Activity: Latent and Specific Heat of Water

HS.PS-E Energy
Students who demonstrate understanding can:
HS-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).
HS-PS3-4 Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics)

Knowledge Objectives
• I know the kinetic theory of matter states that all matter is made of tiny particles that are in constant motion and are colliding with each other.
• I understand the difference between heat and temperature.
• I can recognize the different means that heat flows including convection, conduction and radiation.
• I understand that energy is used to create phase changes and this is known as latent heat.

Reasoning Objective
• I can perform calculations involving heat flow and temperature changes, using known values of specific heat, and latent heat of phase change.
• I will analyze data to support claims that closed systems move toward more uniform energy distribution.

Introduction:
Heat is the transfer of energy from an object of lower temperature to one of higher temperature. Heat can be transferred by conduction, convection or radiation. Conduction is heat transferred through the random motion of molecules colliding with each other. Convection occurs as heated fluids creating currents. Radiation is in the form of electromagnetic waves in the infrared region propagating from one location to another. A sample of ice will be heated in the flame of a Bunsen burner. As heat is added at a constant rate the temperature will be measured with respect to time. As heat is added the temperature of the ice will rise to zero at which point the ice will melt. The cold water will then be heated to one hundred degrees. Then the water will turn to steam.

Substance will change temperature while being heated at different rates. The specific heat, \( c \), of a substance is the amount of heat needed to change one kilogram one degree centigrade. The equation for the specific heat is

\[
c = \frac{\Delta Q}{m\Delta T}
\]

For water the specific heat is \( 4.186 \times 10^3 \text{J/Kg}^\circ \text{C} \) and for ice it is \( 2.09 \times 10^3 \text{J/Kg}^\circ \text{C} \). To determine the amount of heat a substance absorbs the above equation can be rearranged to become:

\[
Q = mc\Delta T
\]

As a substance changes phase it remains at a constant temperature. The heat is absorbed in the phase change of the material. The amount of heat needed to change the phase of one kilogram of substance is known as the latent heat. The heat required to change 1.0 kg of a substance from the solid to the liquid state is called the heat of fusion; it is denoted by \( L_f \). The heat of fusion of water is 333kJ/kg (=3.33 \times 10^5 J/kg.) The heat required to change a substance from the liquid to the vapor phase is called the heat of vaporization, \( L_v \), and for water it is 2260 kJ/kg. The amount of heat to create a phase change is given by
\[ Q = mL \]

The mass, \( m \), times the latent heat, \( L \), is equal to the heat absorbed. A sample graph of temperature versus heat added is shown below.

In this activity you will graph the temperature change versus time as heat is added at a constant rate.

**Apparatus:** beaker with ice at subzero temperature, ring stand, ring, wire gauze, Bunsen burner, striker, balance

**Demonstration Procedure:** The teacher will heat the ice taking a temperature value every 30 seconds. You are to record the time and temperature until the ice, has melted and the water is boiling.

**Analysis:** Graph the data and then create small fabulous fold-ups. On the front of the fold-up, define latent and specific heat for each stage. Include a description of what is happening at the molecular level on the inside of the fold-up. Determine the heat absorbed at each stage and then determine the total heat energy absorbed.
Experiment: High Temperature of an Iron Rod

HS.PS-E Energy
Students who demonstrate understanding can:
HS-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).
HS-PS3-4 Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).

Knowledge Objectives
- I know the kinetic theory of matter states that all matter is made of tiny particles that are in constant motion and are colliding with each other.
- I understand the difference between heat and temperature.
- I know the difference between exothermic and endothermic.
- I can recognize the different means that heat flows including convection, conduction and radiation.

Reasoning Objective
- I will perform calculations involving heat flow and temperature changes, using known values of specific heat, and latent heat of phase change.
- I will analyze data to support claims that closed systems move toward more uniform energy distribution.

Introduction:
Heat is the transfer of energy from an object of lower temperature to one of higher energy. Heat can be transferred by conduction. This occurs through the random collision of molecules with each other. An iron bar heated in the flame of a Bunsen burner will be placed in water in a calorimeter. The heat energy will be transferred from the iron bar to the water and aluminum container of the calorimeter. Since energy is conserved the amount of heat energy lost by the bar should be the same as the energy gained by the water and aluminum container. Specific heat, $c$, mass, $m$, and the change in temperature, $\Delta T$, of an object can be used to determine the change in heat. The equation for this relationship is

$$\Delta Q = mc\Delta T$$

The heat transfer from the iron to the water and aluminum container can be calculated using the following equations.

$$\Delta Q_{\text{lost}} = \Delta Q_{\text{gained}}$$

$$\Delta Q_{\text{lost}} = m_{\text{iron}}c_{\text{iron}}\Delta T_{\text{iron}}$$

$$\Delta Q_{\text{gained}} = m_{\text{water}}c_{\text{water}}\Delta T_{\text{water}} + m_{\text{aluminum}}c_{\text{aluminum}}\Delta T_{\text{aluminum}}$$

The value for the specific heat of water is 4.186 J/g°C or 4186 J/Kg°C. The specific heat for iron is 488 J/Kg°C and for aluminum it is 899 J/Kg°C.

In this laboratory it is necessary to determine the high temperature of the iron. This can be accomplished using the change in temperature for the iron.

$$\Delta T_{\text{iron}} = T_{\text{low (final)}} - T_{\text{high (initial)}}$$
The change in temperature for the water and aluminum will be the same since they will both start and end at the same temperature. The final temperature for the iron will be the same as the final for the water and aluminum.

Two other common terms used when dealing with heat transfer are exothermic and endothermic. In exothermic process heat leaves the substance and in an endothermic process heat is absorbed or moves into the substance.

**Apparatus:** Iron bar, ring stand, ring, clay triangle, Bunsen burner, balance, calorimeter, tongs, thermometer, goggles, aprons, striker, and graduated cylinder

**Safety:** Wear goggles and aprons for this laboratory. Use caution when transferring the hot iron rod to the water since the water will flash boil.

**Procedure:**
Set up the ring stand with a ring and clay triangle. Place the Bunsen burner on the base of the ring stand just below the iron ring. Measure and record the mass of the iron rod and then place it on the clay triangle. Take the calorimeter apart and find the mass of the inner cup. Record this value.

Fill the aluminum cup about 2/3 full with cold water and the find the mass of the cup and the water together. The difference between the cup and the cup with water will be the mass of the water. Now reassemble the calorimeter so that it is ready to receive the hot iron rod.

Light the burner and adjust it so that the top of the blue cone touches the bottom of the iron rod. Heat the rod for 5 minutes or until it is red hot. Take the temperature of the water and calorimeter. This will be the initial temperature, \( T_{i(w)} \). Transfer the hot iron rod from the clay triangle to the calorimeter. **CAUTION:** The water may splatter as the iron rod is transferred to the calorimeter. Keep your face away from the top. Put the lid back on the calorimeter and stir the water with the thermometer. Record the highest temperature value as the final temperature for the iron rod, water and calorimeter.
Heat Exchange from an Iron Rod to a Calorimeter to
Find the High Temperature of the Iron Rod

<table>
<thead>
<tr>
<th>Trial 1</th>
<th>Trial 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of the Calorimeter $m_c$ $+$ .02 grams</td>
<td>Mass of the Calorimeter $m_c$ $+$ .02 grams</td>
</tr>
<tr>
<td>Mass of the cold water $m_w$ $+$ .02 grams</td>
<td>Mass of the cold water $m_w$ $+$ .02 grams</td>
</tr>
<tr>
<td>Initial Temperature of the Cold Water and Calorimeter $T_{i(c,w)}$ $+$ .5°C</td>
<td>Initial Temperature of the Cold Water and Calorimeter $T_{i(c,w)}$ $+$ .5°C</td>
</tr>
<tr>
<td>Final Temperature of Calorimeter, Iron Rod and Water $T_f$ $+$ .5°C</td>
<td>Final Temperature of Calorimeter, Iron Rod and Water $T_f$ $+$ .5°C</td>
</tr>
<tr>
<td>Heat Gained by Calorimeter Cup $\Delta Q_{\text{cup}}$ (Joules)</td>
<td>Heat Gained by Calorimeter Cup $\Delta Q_{\text{cup}}$ (Joules)</td>
</tr>
<tr>
<td>Heat Gained by Water $\Delta Q_{\text{water}}$ (Joules)</td>
<td>Heat Gained by Water $\Delta Q_{\text{water}}$ (Joules)</td>
</tr>
<tr>
<td>Total Heat Gained $\Delta Q_{\text{gained}}$ (Joules)</td>
<td>Total Heat Gained $\Delta Q_{\text{gained}}$ (Joules)</td>
</tr>
</tbody>
</table>

Analysis:
1. Determine the heat gained by the cup and the heat gained by the water.
2. Use the total heat gained to determine the high temperature of the iron rod.
3. Does the high temperature of the rod from both trials agree with each other? If they differ what would cause the difference?

Conclusion: What causes most of the deviations in the results? Where else was the heat transferred during this investigation. How was that heat transferred? Devise a method to eliminate some of these effects.
Electricity and Magnetism
Experiment: Electrostatics

HS.PS-IF Interactions of Forces
Students who demonstrate understanding can:
HS-PS2-4 Use mathematical representations of Newton’s Law of Gravitation and Coulomb’s Law to describe and predict the gravitational and electrostatic forces between objects
HS-PS3-5 Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

Knowledge Objectives
- I understand the difference between induction and conduction.
- I can recall the force relationship between two charged objects.

Reasoning Objective
- I will use Coulomb’s Law to predict the electrostatic forces between objects.

Introduction: The two types of electric charge are negative and positive. Electrons have a negative charge. They are free to move from one object to another. Protons have a positive charge and are located in the nucleus of atoms. They cannot move from one object to another. Objects that have similar charges repel and opposite charges attract. Charge is conserved. It can be transferred between objects.

Materials have different properties depending upon their electron configurations. Conductors are materials in which electrons are free to move. Metals are great conductors since they have electrons in the outer energy levels that are shared over all atoms. Insulators are materials in which the electrons are unable to move. They are trapped within bonds between atoms. Glass, rubber, silk and plastics are examples of insulators.

Semiconductors are a third class of materials characterized by electrical properties that are somewhere between those of insulators and conductors. Silicon and Germanium are examples of semiconductors.

Insulators and conductors can be charged by contact. This is known as conduction. Insulators can acquire a charge when they are rubbed with another insulator. Rubber rubbed with fur becomes negatively charged and the fur becomes positively charged. Glass can be rubbed with silk to give it a positive charge. Conductors transfer charges very well when they are attached to a charged object. Conductors can be charged by induction. An object can be charged when a charged object is brought near it. The field around the charged object induces or produces the movement of charges in the other object such as a conducting sphere. If the sphere is attached to the ground by a wire then the metal object can become the opposite charge as the charged object. A surface charge can be induced on insulators using an electric field. A great example of this is when a balloon is charged by rubbing it on fur or hair and then attached to the wall. The balloon induces a charge in the wall.

Apparatus: electroscope, fur, silk, rubber rod, glass rod and pith ball

Procedure:
Part A: Charge the rubber rod by rubbing it with the fur. Bring the pith ball toward the rubber rod. Make observations as to what is happening. Record the observations as diagrams and descriptions. Repeat the activity using the glass rod and silk.

Part B: Bring a charged rubber rod near the top of the electroscope and then remove the rod. Make observations as to what is happening. Record the observations as diagrams and descriptions. Repeat the activity using the glass rod and silk.
Part C: Rub the charged rubber rod all over the top of the electroscope and then remove the rubber rod. Make observations as to what is happening. Record the observations as diagrams and descriptions. Now touch the electroscope with your finger. Make observations as to what is happening. Record the observations as diagrams and descriptions. Repeat the activity using the glass rod and silk.

Part D: Move the charged rubber rod near the top of the electroscope but do not touch it. Now touch the electroscope with your finger while the rubber rod is still near. Remove your finger and then remove the rubber rod. Make observations as to what is happening. Record the observations as diagrams and descriptions. Touch the top of the electroscope with your finger to ground it. Repeat the activity using the glass rod and silk.

Analysis: Explain what is happening in each of the procedures using diagrams and a description of what the electrons are doing.

Conclusion: Write an overall description of conduction and induction. Explain how these concepts are related to each of the activities.
Experiment: Ohm’s Law

Standards: HS.PS-E Energy
Students who demonstrate understanding can:
HS-PS2-5 Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.
HS-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).

Standards: HS.PS-FE Forces and Energy
Students who demonstrate understanding can:
HS-PS3-5 Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

Knowledge Objective
- I know Ohm’s Law.

Reasoning Objective
- I can solve electric circuit problems using Ohm’s Law.

Skill Objective
- I can use electronic laboratory equipment safely to analyze resistor circuits.

Introduction: When working with circuits Ohm’s Law is a valuable tool in evaluating the current, resistance and voltage. Ohm’s Law states that the voltage, \( V \) or emf, \( \varepsilon \), supplied to a circuit is equal to the current in the circuit times the resistance of the circuit.

\[ V = IR \]

Apparatus: Voltage source, connecting wires, two multi-meters (one as the ammeter and one as the voltmeter), three five watt resistors: 10.0 \( \Omega \), 51.0 \( \Omega \) and 68.0 \( \Omega \).

Procedure:
Set up the single resistor in series with the ammeter and the voltage source as shown in figure below. Next connect the voltmeter across the resistor to measure the voltage drop. Adjust the volt sources so that the voltage across the resistor is approximately 2.5 volts. Record the printed value of the resistor, voltage across the resistor and amperage through the resistor. Use Ohm’s Law to calculate the resistance of the resistor using the measured values of voltage and amperage. Record the values in the table. Now use a
voltage of 5.0 volts and repeat the procedure. After collecting the data for the 10Ω resistor repeat the procedure with a 51.0Ω resistor and then with a 68.0Ω resistor.

Resistance of a Resistor in a Simple Ohm’s Law Circuit

<table>
<thead>
<tr>
<th>Printed resistor value, R (ohms)</th>
<th>Voltage reading, V (volts)</th>
<th>Amperage reading, I (amps)</th>
<th>Calculated value for resistor, R (ohms)</th>
</tr>
</thead>
</table>

**Analysis:** Determine the absolute and relative errors for the calculated resistance values.

**Conclusion:** Discuss if the errors are within the tolerance of the printed values of the resistors. Explain how the data is collected including how the ammeter and volt meter are connected in the circuit.
Experiment: Resistor and Capacitor Circuit (RC-Circuit)

Standards: HS.PS-E Energy
Students who demonstrate understanding can:
HS-PS2-5 Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.
HS-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).

Standards: HS.PS-FE Forces and Energy
Students who demonstrate understanding can:
HS-PS3-5 Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

Reasoning Targets
- I can analyze capacitor problems.
- I can solve electric circuit problems using Ohm’s Law and equations for resistor and capacitors in series and parallel.
- I will justify the claim that when objects interact at a distance, the energy stored in the field changes as the objects change relative position.
- I will analyze data to support claims that closed systems move toward more uniform energy distribution.

Skill Target
- I can use electronic laboratory equipment safely to analyze resistor and capacitor circuits.

Introduction:
A capacitor is an electronic device that stores electric charge and thus electric potential energy. It consists of two conducting plates that are separated by an insulator called a dielectric. The layers of the capacitor are often rolled up and placed in a protective outer coating. Capacitors are used in a camera flash and car ignition system.

When a voltage is applied across a capacitor it quickly becomes charged. One plate will be positive and other will be negative. When the voltage source is disconnected from the circuit and the circuit is closed the electric potential that is stored in the capacitor can then be used to do work in the circuit.

The amount of charge, $Q$, on the plates will be directly proportional to the voltage, $V$, across the plates. The constant of proportionality is the capacitance, $C$. The capacitance depends upon the area, $A$, of the plates, the distance, $d$, between the plates and the type of insulating material.

$$Q = CV$$

$$C = \varepsilon A/d$$

The constant $\varepsilon$ is the permittivity of the insulating material. When the insulating material is free space the constant $\varepsilon_0$ is $8.85 \times 10^{-12} \text{C}^2/\text{Nm}^2$.

The SI unit for capacitance is the farad, F, which is equivalent to a coulomb per volt (C/V). In practice, most typical capacitors have a capacitance range from microfarads ($1\mu\text{F} = 1 \times 10^{-6}\text{F}$) to picofarads ($1\text{pF} = 1 \times 10^{-12}\text{F}$).

A circuit with a resistor and a capacitor will be analyzed in terms of the amount of charge that flows onto a capacitor with respect to time. The capacitance will be determined experimentally. This experimental value will be compared to the printed value for accuracy.
**Apparatus:** voltage source with switch, volt meter, milli-ammeter, 1500 μF capacitor, 22 kΩ and 47 kΩ resistors, stop watch and connecting wires

**Procedure:**

Set up a multi-meter as a volt meter and dial the knob to the 40 volt scale. Connect it across the voltage supply and adjust the voltage to approximately 15 volts. This reading does not have to be exactly 15.00 volts. Record the value from the volt meter to the hundredth place. Now without turning the black knob or rheostat on the voltage supply, turn it off.

Set up the series circuit with the power supply, resistor, milli-ammeter and capacitor as shown in figures 2 and 3. The capacitor must be connected with the positive plate connected to the positive side of the voltage source. **CAUTION:** capacitors such as these contain caustic chemicals. Now, set the second multi-meter to 4m on the ammeter setting. This will read up to 4 milliamps. Your maximum amperage should not exceed 1 milliamp. The leads on this ammeter should be connected to the common and the μA mA. If either meter is connected improperly there will be a high pitch noise coming from that meter. See figure 5 for the connection of the ammeter. Work with a partner to collect the data. Have your partner turn on the switch of the power supply and start the stop watch at the same time. Read the highest value of the ammeter reaches within the first few seconds. Record that value. After every 5 seconds take ammeter readings and record those readings. Eventually the ammeter will remain constant for a few readings. When this occurs you may stop recording the values. Make sure the capacitor is completely charged by removing the resistor and the ammeter from the circuit. Connect the capacitor directly across the voltage source.
Now you will discharge the capacitor. Disconnect the leads from the voltage source and then reattach the resistor and ammeter to the circuit. Make sure the leads are reversed on the ammeter since the current will flow the opposite direction as it is being discharged. Your switch is the two leads that have been disconnected from the voltage source. When you are ready these two leads will be connected together at time zero and the maximum current will be taken. Every 5 seconds the amperage will be recorded until the ammeter levels off. See figure 6 for the set up.

Completely discharge the capacitor by connecting a wire from one side to the other.

You will now repeat the procedure with a 47 kΩ resistor. Take readings every 10 seconds during this trial. Record your values in the table.

### Charging and Discharging a 1500 μF Capacitor in Series with a 22 kΩ Resistor

<table>
<thead>
<tr>
<th>Charging</th>
<th>Discharging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Time</td>
</tr>
<tr>
<td>± .2 sec</td>
<td>± .2 sec</td>
</tr>
<tr>
<td>Current</td>
<td>Current</td>
</tr>
<tr>
<td>± .002 milliamps</td>
<td>± .002 milliamps</td>
</tr>
</tbody>
</table>

**Analysis:**
1. Why did the current start out high and approach zero?
2. Why did the current flow in the opposite direction when the capacitor was being discharged?
3. What was the function of the resistor in the circuit?
4. Graph the current versus time for charging and discharging of the capacitor with the 22 kΩ resistor and then on a second graph the data for the 47 kΩ resistor circuit. Time is the independent variable and should be plotted on the x axis.
5. The charge on the capacitor can be determined by finding the area under the curve. The area under the curve can be estimated by drawing a triangle that approximates the area under the curve. Determine the area of the triangle as the charge on the capacitor. Do this for both sets of graphs.
6. Calculate the capacitance of the capacitor using the voltage and the charge.
7. Predict what a graph of the current versus time would look like without the resistor in the circuit.
8. Predict what a graph of the current versus time would look like without the capacitor in the circuit.

**Conclusion:** Determine the absolute and relative error using the printed value of 1500 μF as the accepted value. Predict where in the experimental procedure error could have occurred.
Experiment: Series and Parallel Resistor Circuits

Standards: HS.PS-E Energy
Students who demonstrate understanding can:
HS-PS2-5 Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.
HS-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).

Standards: HS.PS-FE Forces and Energy
Students who demonstrate understanding can:
HS-PS3-5 Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

Knowledge Objective
- I can recognize the difference between series and parallel resistor circuits and the equations used to evaluate these circuits.

Reasoning Objective
- I can predict the voltage or current in simple direct current electric circuits constructed from batteries, wires, and resistors.
- I will identify problems and suggest design solutions to optimize the energy transfer into and out of a system.
- I will analyze data to support claims that closed systems move toward more uniform energy distribution.

Skill Objective
- I will use electronic laboratory equipment safely to analyze resistor circuits.

Product Objective
- I will evaluate experimental data to analyze series and parallel circuits

Introduction: When working with circuits Ohm’s Law is a valuable tool in evaluating the current, resistance and voltage. Ohm’s Law states that the voltage or emf, \( \varepsilon \), supplied to a circuit is equal to the current in the circuit times the resistance of the circuit.
\[
V = IR
\]
Series circuits consist of resistors that are connected one after another. The total current in the circuit flows through each consecutive resistor. The total resistance in the circuit is the sum of each of all of the resistors in the series. The total voltage is the sum of the voltage dropped across each resistor.
\[
I_{\text{total}} = I_1 = I_2 = I_3 \ldots
\]
\[
R_{\text{eff}} = R_1 + R_2 + R_3 \ldots
\]
\[
V_{\text{total}} = V_1 + V_2 + V_3 \ldots
\]

Figure 1:

Parallel circuits are composed of resistors that are connected parallel to each other as rungs on a ladder are parallel to each other. The effective resistance is reduced below the smallest resistor since each resistor
offers another path for the electrons to pass through. The effective resistance is given by the following equation.

\[
\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots
\]

Since the total current has different paths through which to travel the sum of the current in each path is equal to the total current.

\[
I_{\text{total}} = I_1 + I_2 + I_3 \ldots
\]

The voltage drop across parallel resistor are equal. This is due to the fact that the electric potential is measured from the same place and thus has to be the same.

\[
V_{\text{total}} = V_1 = V_2 = V_3
\]

**Figure 2:**

**Apparatus:** Voltage source, connecting wires, two multi-meters (one as the ammeter and one as the voltmeter), three five watt resistors: 10.0 Ω, 51.0 Ω and 68.0 Ω.

**A. Series Circuits Procedure:** Set up the single resistor in series with the ammeter across the voltage source as shown in figure 3. Next connect the voltmeter across the resistor to measure the voltage drop across it. Adjust the volt sources so that the voltage across the resistor is approximately 5 volts. Record the printed value of the resistor, voltage across the resistor and amperage through the resistor. For this first resistor use Ohm’s Law to calculate the resistance of the resistor using the measured values of voltage and amperage.

Printed resistor value, \(R_1 = \) ___________. Voltage reading, \(V_1 = \) ___________.

Amperage reading, \(I_1 = \) ___________. Calculated value for resistor, \(R_1 = \) ___________.

**Figure 3: Single Resistor**  
**Figure 4a, 4b: Two Resistors in Series**

Now wire in a second resistor in series with the first resistor as shown in Figure 4. Connect the volt meter across both resistors and adjust the voltage source so that the volt meter reads approximately 5 volts. Make readings and record the values for the total current or amperage, \(I_{\text{total}}\), voltage across the
combined resistors, \( V_{\text{total}} \), and then voltage across each individual resistor, \( V_1, V_2 \). Record the printed values for both resistors, \( R_1 \) and \( R_2 \).

Printed resistor value, \( R_1 = \) __________. Printed resistor value, \( R_2 = \) __________.

Voltage reading, \( V_1 = \) __________. Voltage reading, \( V_2 = \) __________.

Voltage reading, \( V_{\text{total}} = \) __________. Amperage reading, \( I_{\text{total}} = \) __________.

Now calculate the effective resistance using the printed values of the resistors and compare that with the calculated value for the total resistance using the Ohm’s Law and the measured values of \( V_{\text{total}} \) and \( I_{\text{total}} \).

Calculated effective resistance for the circuit using the printed resistor values, \( R_{\text{eff}} = \) __________

Calculated resistance using the \( V_{\text{total}} \) and \( I_{\text{total}} \), \( R_{\text{eff calculated}} = \) __________

Now calculate the total voltage using \( V_1 \) and \( V_2 \) and compare that with the measured value for \( V_{\text{total}} \).

Calculate \( V_{\text{total}} = \) __________

B. Parallel Circuits Procedure: Set up two resistors in parallel as shown in Figure 5. The resistors should be connected to the same junction on the left and to another junction on the right. Set the voltage across the parallel resistors at 5 volts. Make readings and record the values for the total current or amperage, \( I_{\text{total}} \), voltage across the combined resistors, \( V_{\text{total}} \), and then voltage across each individual resistor, \( V_1, V_2, V_3 \). Record the printed values for all resistors, \( R_1, R_2, \) and \( R_3 \).

Printed resistor value, \( R_1 = \) __________. Printed resistor value, \( R_2 = \) __________.

Printed resistor value, \( R_3 = \) __________. Voltage reading, \( V_1 = \) __________.

Voltage reading, \( V_2 = \) __________. Voltage reading, \( V_3 = \) __________.

Voltage reading, \( V_{\text{total}} = \) __________. Amperage reading, \( I_{\text{total}} = \) __________.

Now calculate the effective resistance using the printed values of the resistors and compare that with the calculated value for the total resistance using the Ohm’s Law and the measured values of \( V_{\text{total}} \) and \( I_{\text{total}} \).

Calculated effective resistance for the circuit using the printed resistor values, \( R_{\text{eff}} = \) __________

Calculated resistance using the \( V_{\text{total}} \) and \( I_{\text{total}} \), \( R_{\text{eff calculated}} = \) __________

Now calculate the total voltage using \( V_1, V_2, \) and \( V_3 \) and compare that with the measured value for \( V_{\text{total}} \).

Calculate \( V_{\text{total}} = \) __________

Figure 5: Two resistors in parallel

Figure 6: Three resistors in parallel
Printed resistor value, \( R_1 = \) ____________, Printed resistor value, \( R_2 = \) ____________.

Voltage reading, \( V_1 = \) ____________, Voltage reading, \( V_2 = \) ____________.

Voltage reading, \( V_{\text{total}} = \) ____________, Amperage reading, \( I_{\text{total}} = \) ____________.

Amperage in resistor 1, \( I_1 = \) ____________, Amperage in resistor 2, \( I_2 = \) ____________

Calculate the effective resistance using the printed values of the resistors and compare that with the calculated value for the total resistance using the Ohm’s Law and the measured values of \( V_{\text{total}} \) and \( I_{\text{total}} \).

Calculated effective resistance for the circuit using the printed resistor values, \( R_{\text{eff}} \) __________

Calculated resistance using the \( V_{\text{total}} \) and \( I_{\text{total}} \), \( R_{\text{eff calculated}} \) __________

Now calculate the total current using \( I_1 \) and \( I_2 \) and compare that with the measured value for \( I_{\text{total}} \).

Calculate \( I_{\text{total}} \) __________

Set up three resistors in parallel as shown in Figure 6. The resistors should be connected to the same junction on the left and to another junction on the right. Set the voltage across the parallel resistors at 5 volts. Make readings and record the values for the total current or amperage, \( I_{\text{total}} \), current in resistor 1, 2 and 3 or \( I_1, I_2 \) and \( I_3 \), voltage across the combined resistors, \( V_{\text{total}} \), and then voltage across each individual resistor, \( V_1, V_2, \) and \( V_3 \). Record the printed values for all three resistors, \( R_1, R_2, \) and \( R_3 \).

Printed resistor value, \( R_1 = \) ____________, Printed resistor value, \( R_2 = \) ____________.

Printed resistor value, \( R_3 = \) ____________, Voltage reading, \( V_1 = \) ____________.

Voltage reading, \( V_2 = \) ____________, Voltage reading, \( V_3 = \) ____________.

Voltage reading, \( V_{\text{total}} = \) ____________, Amperage reading, \( I_{\text{total}} = \) ____________.

Amperage in resistor 1, \( I_1 = \) ____________, Amperage in resistor 2, \( I_2 = \) ____________

and Amperage in resistor 3 \( I_3 = \) ________________

Calculate the effective resistance using the printed values of the resistors and compare that with the calculated value for the total resistance using the Ohm’s Law and the measured values of \( V_{\text{total}} \) and \( I_{\text{total}} \).

Calculated effective resistance for the circuit using the printed resistor values, \( R_{\text{eff}} \) __________

Calculated resistance using the \( V_{\text{total}} \) and \( I_{\text{total}} \), \( R_{\text{eff calculated}} \) __________

Calculate the total current using \( I_1, I_2, \) and \( I_3 \) and compare that with the measured value for \( I_{\text{total}} \).

Calculate \( I_{\text{total}} \) __________

**Analysis:**

1. State and explain the relationships for current, voltage and resistance in a series circuit. Show the equations for these relationships and explain how they represent the relationships.
2. State and explain the relationships for current, voltage and resistance in a parallel circuit. Show the equations for these relationships and explain how they represent the relationships.
3. Explain how Ohms law applies to series and parallel circuits.
Conclusion: Discuss the errors and the overall concepts related to series and parallel circuits.
Experiment: Magnetic Field near a Long Straight Wire

Standards: HS.PS-E Energy
Students who demonstrate understanding can:
HS-PS2-5 Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.
HS-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).

Standards: HS.PS-FE Forces and Energy
Students who demonstrate understanding can:
HS-PS3-5 Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

Knowledge Objectives
- I know the equations used to analyze magnetic fields surrounding current carrying wires.
- I understand the relationships between electric and magnetic fields in electromagnetic induction.
- I will be able to describe how magnetic materials and electric currents (moving electric charges) are sources of magnetic fields and are subject to forces arising from the magnetic fields of other sources.
- I know the magnitude of the force on a moving particle (with charge q) in a magnetic field is \( qvB \sin \theta \) where \( \theta \) is the angle between \( v \) and \( B \) \( (v \) and \( B \) are the magnitudes of vectors \( v \) and \( B \), respectively), and students use the right-hand rule to find the direction of this force.

Reasoning Objectives
- I can solve problems with magnetic fields near current carrying wires.
- I can evaluate experimental data to analyze the magnetic field near a long straight wire.
- I will plan and carry out an investigation in which a force field is mapped to provide evidence that forces can transmit energy across a distance.
- I will develop arguments to support the claim that when objects interact at a distance, the energy stored in the field changes as the objects change relative position.

Introduction: It was observed in 1820 by Hans Christian Oersted that a small compass needle deflected when brought near a wire carrying an electric current. This was the first evidence of a link between electricity and magnetism. Oersted discovered that forces exist between a magnet and moving electric charges.

A current carrying wire produces a magnetic field that surrounds the wire. The magnetic field is proportional to the current and inversely proportional to the perpendicular distance, \( r \), from the wire.

\[ B \propto \frac{I}{r}. \]

The proportionality constant is \( \mu_0/2\pi \); where the constant \( \mu_0 \), called the permeability of free space, is \( 4\pi \times 10^{-7}\text{Tm/A} \)

\[ B = \left(\frac{\mu_0}{2\pi}\right)(I/r) \]

In this experiment the magnetic field will be measured directly and indirectly. The deflection of a compass needle from due north will be determined. This deflection is directly proportional to the magnetic strength.

\[ \angle = B \]

It is also true that the deflection of the compass needle is proportional to the current and inversely proportional to the radius. In the next equation \( k \) is the constant of proportionality.

\[ \angle = k(I/r) \]

You will determine the constant using a small magnetic compass and you will calculate the magnetic strength of the field with respect to the radius.
**Apparatus:** meter stick, tape, ring stand, utility clamp, graph paper, brick or book, ammeter, wire, voltage source with a rheostat and switch, C clamp, ruler, protractor and compass, magnetic field probe, VernierLabPro, USB connector, computer and power supply for LabPro

**Procedure:**

Attach a voltage supply with a rheostat and switch to the end of a long wire. Thread the wire along a meter stick that is attached to a right stand using a utility clamp. Use a C clamp to attach the ring stand to the side of the counter. The rheostat can act as an anchor for one end of the wire. Pass the wire along the edge of the counter as far from metallic materials as possible. Tape the wire to the side of the table so that it does not move. Hold the wire straight by setting a book or brick on the floor on top of the wire. Use a connecting wire to attach the other end of the long wire to an ammeter. Complete the circuit by attaching the ammeter to the other lead of the voltage source. Place a piece of graph paper on the counter next to the wire. Adjust the paper so that a line radiating away from the wire is parallel to the magnetic field of the earth. This can be accomplished using a small magnetic compass needle and turning the paper until it is aligned. Tape the paper down to the counter.

Turn on the voltage supply and adjust the rheostat until the ammeter reads approximately 5 amps and record this value.

Determine the deflection of the compass by holding the center of the compass on the line radiating away from the wire and marking each end of the compass with a pencil that does not have metal on it. Do this for different distances out to about 20 cm, moving the compass in steps along a line parallel to the horizontal component of the earth’s field. You will need to start at a distance of about 3 cm since error will arise when you are closer. The magnetic field along the length of the compass needle is different when the compass is near the wire. Connect the two dots for each reading and measure the angle of deflection with respect to the parallel line. Finally measure the distance from the center of the wire to the location where these drawn lines intersect the radiating line parallel to the magnetic field of the earth. Record all of the values.
Now the magnetic field intensity can be measured using a VernierLabPro connected to a magnetic field sensor in channel one. Once you have the USB connected from the computer to the LabPro and logger Pro software up on the desk top go to File Open and select Probes & Sensors, Magnetic Field and then (Mag lo mT) for the magnetic field sensor low milli-tesla. You can now measure the magnetic field strength with no current flowing and take the difference between that measurement and the measurements that you make for the magnetic field at the distance that you took the data for the angle deflection. Record these values in the table.

### Magnetic Field near a Wire Carrying 3 amps of Current

<table>
<thead>
<tr>
<th>Angle of Deflection &lt; (+ .5 cm)</th>
<th>Radius or Distance from the Center of the Wire (+ .04 cm)</th>
<th>Measured Magnetic Field Strength B (tesla)</th>
<th>Calculated Magnetic Field Strength B (tesla)</th>
<th>Constant of Proportionality k (m/amps)</th>
<th>Absolute Deviation for k (m/amps)</th>
</tr>
</thead>
</table>

**Analysis:**
1. Calculate the magnetic field strength using the current distance from the wire and $\mu_0$ that is equal to $4\pi \times 10^{-7}$ Tm/A. Tabulate these values and describe how they correspond to the measured values.
2. Calculate the constant $k$ for your compass and record these values in the table. Determine the absolute and relative deviations for these values.
3. Graph the angle of deflection versus the distance from the wire. The independent variable is the distance from the wire since you varied that variable. How does the strength of the field due to the current vary as a function of the distance from the wire? How did you arrive at this conclusion?
4. Why was it necessary to keep the rest of the wire and iron objects far away from the compass?
5. How would the results be different if the vertical wire had been only 20 cm long?
6. How would the accuracy of your results have been affected if you had used a current 100 times larger?
7. How would the accuracy of your results have been affected if you had used a current 100 times smaller?

**Conclusion:** Where caused errors when collecting data? How could these have been reduced?

**Extension:** Set up two parallel vertical wires about 20 cm apart in a plane parallel to the direction of the earth’s field. Find how the magnetic field varies along a line between them (a) when the currents in the wires are in opposite directions; (b) when the two currents are in the same direction. How do you explain your results?
I. Abstract: This is a summary of the laboratory report. It should include a brief statement from the introduction, experimental, results and conclusion.

II. Introduction: This is an essay on the theory of magnetic field near long straight wires.
   A. Hans Christina Orsted and his findings
   B. Describe magnetic flux and show a diagram
   C. Derive the equation for magnetic flux and for the angle of deflection.
   D. Since this is an essay you should include an introduction and conclusion.

III. Experimental: This section includes a description of the apparatus, procedure and tolerances in the equipment.

IV. Results:
   A. Introduce the results section
   B. Describe how the data was collected
   C. Perform sample calculations for magnetic flux.
   D. Show the Data Table here.
   E. Describe the graph and how it relates to the equation and errors.
   F. Show the graphs here
   G. Analyze the deviation: include calculations of absolute and relative deviation.
   H. Discuss possible reasons for the deviations as the concluding paragraph.

V. Conclusion: Describe how to improve the laboratory to make the results more accurate.
Electromagnetic Demonstrations

Standards: HS.PS-IF Interactions of Forces
Students who demonstrate understanding can:
HS-PS2-4 Use mathematical representations of Newton’s Law of Gravitation and Coulomb’s Law to describe and predict the gravitational and electrostatic forces between objects

Standards: HS.PS-E Energy
Students who demonstrate understanding can:
HS-PS2-5 Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.
HS-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).

Standards: HS.PS-FE Forces and Energy
Students who demonstrate understanding can:
HS-PS3-5 Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

Knowledge Objectives
- I will describe the relationships between electric and magnetic fields.
- I know that changing magnetic fields create changing electric fields and moving charges create magnetic fields.

Reasoning Objective
- I will apply my knowledge of the right hand rules for electricity and magnetism to explain the following demonstrations: two coils that transfer music, speakers, rail gun, magnetic fields around current carrying wires, motors, and electromagnets.

Skill Objective
- I will use left and right hand rules to explain the properties of the demonstrations.

Introduction:
A few metals have strong magnetic effects and can be made into permanent magnets. The materials are iron, cobalt, nickel, and gadolinium. When permanent magnets were made from these substances they always have two poles. These poles are named according to the pole of the earth that they are attracted to. The north pole of a magnet is attracted to the north pole of the earth. The north pole of the earth is thus a south magnetic pole since opposite poles attract. Scientists draw magnetic field lines to represent the magnetic field. These lines point out from the north pole and into the south pole of a permanent magnet. The direction and magnitude of the field at a point can be thought of as the force on a north mono pole placed at that point in the field.

In 1820 Hans Christian Oersted found that when an electric current flowed through a wire, a magnetic field was created around the wire. The direction of the magnetic field lines follows a right-hand rule. For that rule, the wire is grasped with the right hand so that your thumb points in the direction of the (positive) current. The fingers encircle the wire in the direction of the magnetic field.
Careful experiments show that the magnetic field \( B \) at a point near a long straight wire is directly proportional to the current, \( I \), in the wire and inversely proportional to the perpendicular distance \( r \) from the wire. The proportionality constant is written as \( \mu_0/2\pi \) where the value of the constant \( \mu_0 \), which is called the permeability of free space, is \( 4\pi \times 10^{-7} \text{Tm/A} \). The \( T \) in the units represents Tesla, the unit for magnetic field strength.

\[
B = \frac{\mu_0}{2\pi} \left( \frac{I}{r} \right)
\]

A second right hand rule is for the magnetic field in a current carrying loop. The fingers on the right hand wrap around the wire loop in the direction of the current and the thumb points in the direction that the magnetic field is through the loop.

It was also shown that a current carrying wire placed in a permanent magnetic field has a force exerted on it. It was found that the direction of the force is perpendicular to the direction of the current and also perpendicular to the direction of the magnetic field, \( B \). A third right hand rule can be used to determine the direction of the force as seen in the diagram below.

This force is proportional to the perpendicular component of the length of the wire in the field, the amount of current and the strength of the magnetic field.

\[
F = BI\sin\theta
\]

If the direction of the current is perpendicular to the field (\( \theta = 90^\circ \)), then the force is

\[
F_{\text{max}} = BI
\]

This set up is shown in the diagram.

The magnitude of the magnetic field, \( B \), can be found by rearranging the above equation and measuring the other variables experimentally.
\[ B = \frac{E_{\text{max}}}{l} \]

where \( F_{\text{max}} \) is the magnitude of the force on a straight length of wire carrying a current \( I \), when the wire is perpendicular to \( B \). The SI Unit for magnetic field \( B \) is the tesla (T). One tesla is defined as one Newton per amp meter.

\[ 1 \text{ T} = 1 \text{N/Am}. \]

The force on a single electric charge moving in an electric field follows the same principles as multiple charges in a current-carrying wire. Current can be expressed as charge flowing per time. Length per time is the velocity. Thus, the force equation for a current-carrying wire becomes:

\[ F = B Il \sin \theta = B (q/t) l \sin \theta = B q v \sin \theta \]

This equation gives the magnitude of the force on a particle of charge \( q \), moving with velocity \( v \), in a magnetic field of strength \( B \), where \( \theta \) is the angle between \( v \) and \( B \). The force is greatest when the particle moves perpendicular to \( B \) (\( \theta = 90^\circ \)):

\[ F_{\text{max}} = B q v \]

There is a force between two parallel wires since each produces a magnetic field. Consider two long parallel conductors separated by a distance \( L \), as in the figure. They carry currents \( I_1 \) and \( I_2 \), respectively. Each current produces a magnetic field that is exerted on the other so that each must exert a force on the other. For example, the magnetic field \( B_1 \) produced by \( I_1 \) is given by \( B_1 = (\mu_0/2\pi)(I_1/l) \). At the location of the second conductor, the magnitude of this field is

\[ B_1 = (\mu_0/2\pi)(I_1/L) \]

According to the equation \( F_{\text{max}} = B Il \), the force \( F \) per unit length \( l \) on the conductor carrying current \( I_2 \) is

\[ F/l = I_2 B_1 \]

Note that the force on \( I_2 \) is due only to the field produced by \( I_1 \). Of course \( I_2 \) also produces a field, but it does not exert a force on itself. We substitute in the above formula for \( B_1 \) and find

\[ F/l = (\mu_0/2\pi)(I_1 I_2/L) \]

It was also noticed that when a magnet moved near a wire an electric current was produced. When the number of magnetic field lines passing through a conducting loop of wire changed, an electromotive force was created. That force had an effect on charged particles creating a current in the wire. When the magnet was moved toward the coil a current was created. The induced current was opposite when the magnet was moved away from the coil. Note that the zero reading for the galvanometer is at the center of the scale and the needle deflects left or right depending on the direction of the current. When the magnet was stationary no current was detected.
The electromotive force or *emf* was proportional to the rate of change of magnetic flux in the loop. Magnetic flux is defined as the perpendicular component of the magnetic field strength times the cross sectional area of a loop or surface through which the magnetic field is passing. The magnetic flux, $\Phi_B$ passing through the loop or area $A$, which is defined as

$$\Phi_B = B_\perp A = BA \cos \theta.$$  

Here $B_\perp$ is the component of the magnetic field $B$ perpendicular to the face of the surface, and $\theta$ is the angle between $B$ and the line drawn perpendicular to the face of the coil.

The electromotive force or *emf*, $\mathcal{E}$, created by a changing flux, $\Delta \Phi_B$, through $N$ loops of wire during a time $\Delta t$ is

$$\mathcal{E} = -N \frac{\Delta \Phi_B}{\Delta t}$$

This is known as Faraday’s law of induction. The minus indicates that an induced *emf* always produces a current whose magnetic field opposes the original change in flux. This is known as Lenz’s law.

An electromotive force can also be produced when a conducting wire is moved along a conducting loop perpendicular to a magnetic field. The diagram below shows this relationship.
When the rod is moved at a speed $v$, it travels a distance $\Delta x = v\Delta t$ in a time $\Delta t$. Thus the change in the area of the loop during $\Delta t$ is:

$$\Delta A = l\Delta x = lv\Delta t$$

The magnitude of the induced emf, $\varepsilon$, is

$$\varepsilon = \frac{\Delta \Phi_B}{\Delta t} = B \frac{\Delta A}{\Delta t} = Blv\Delta t/\Delta t = Blv.$$ 

An electric field is produced by a changing magnetic flux. The electrons in a moving conductor within a magnetic field are affected by a force. Thus, there is an electric field in the conductor. An electric field is the force per unit charge, $E = F/q$, the effective field $E$ in the rod is:

$$E = F/q = qvB/q = vB$$

In any region in space, an electric field will be produced where there is a changing magnetic field.

An electric generator produces an alternating electromotive force as the amount of flux alternates from a maximum value to a minimum and back to a maximum. In the figure below, the loop is being rotated clockwise in a uniform magnetic field $B$.

The emf is induced in the segments ab and cd, whose velocity components perpendicular to the field $B$ are $v_s\sin \theta$. The velocity of the two lengths ab and cd at this instant are shown. Although the sections of wire bc and da are moving, the force on electrons in these sections is toward the side of the wire, not along its length. The emf generated is thus due only to the force on charges in the sections ab and cd. From the right-hand rule, we see that the direction of the induced current in ab is from a to b. And in the lower section, it is from c to d; so the flow is continuous in the loop. The magnitude of the emf generated in ab is given in the equation $\varepsilon = Blv_\perp$ where the component of the velocity is perpendicular to $B$:

$$\varepsilon = Blv_\perp$$

In the diagram $l$ is the length of ab. In the diagram $v_\perp = v \sin \theta$ where $\theta$ is the angle the face of the loop makes with the vertical. The emf induced in cd has the same magnitude and is in the same direction. Therefore they add, and the total emf is

$$\varepsilon = 2NBlv \sin \theta,$$

In the equation $N$ is the number of loops in the coil. If the coil is rotating with constant angular velocity $\omega$, then the angle $\theta = \omega t$. The angular equation for velocity is $v = \omega r = \omega (h/2)$, where $h$ is the length of bc or ad. Thus

$$\varepsilon = 2NB\omega (h/2) \sin \omega t,$$

or

$$\varepsilon = NBA \omega \sin \omega t,$$

In the above equation $A = lh$ is the area of the loop.

The equation is true for all shapes of loops. Thus, the emf of the generator is a sine wave. The angular speed of the loop, $\omega$, is expressed in radians per second. Another angular equation for the angular speed is $\omega = 2\pi f$, where $f$ is the frequency.

An alternating current generator produces an alternating current that is produced by the alternating electromotive force or alternating electric field. The output emf $\varepsilon = \varepsilon_0 \sin \omega t$, where $\varepsilon_0 = NBA\omega$.

**Apparatus**: 3 bar magnets, plastic sheath, iron filings, jar with magnet in test tube with iron filings around it, power supplies, connecting wires, University Apparatus Co. conducting wire apparatus, small
compasses, coil, aluminum foil parallel wires apparatus, galvanometer, coil and iron cylindrical bar, paper clips, 2 audio sources, 2 audio amplifiers and speakers, coil, AC generator, motors (simple cup motor, Saint Luis Motor, multiple coil motor), cup galvanometer and cup speaker  

**Procedure:**

Place two magnets in the plastic sheath. First have opposite poles facing each other. The magnets should be approximately two centimeters apart. Sprinkle iron filings on top of the plastic cover. Observe the pattern produced by the filings. Draw and describe the shape and direction of the field. Now repeat the activity with similar poles facing each other. Finally, observe the iron filings around the magnet in the jar. Draw and describe the shape and direction of the field in three dimensions.

**Caution must be used in the following demonstrations.** The resistance is low in most of the apparatus. The rheostats of the power supplies must be set at the lowest level to begin with. It can then be turned up slowly so as not to burn up the device and the fuse in the power supply. If the power supply begins to hum, turn down the rheostat.

Now observe the compasses on the apparatus around the wire connected to the power supply. Turn on and off the electric potential providing current to the wire. Draw and describe what happens to the compasses when the switch is on and when it is off. Turn off the switch and switch the leads on the power supply, then turn on and off the power supply. Draw and describe how the current flowing in the opposite direction effects the direction the compasses deflect. Use your knowledge of electricity and magnetism to explain your observations.

Now observe the compasses in the coil of wire as the power supply is turned on and off. Draw and describe how the compasses react to having the current flowing through the coil. Turn off the switch and switch the leads on the power supply and then turn on and off the power supply. Draw and describe how the current flowing in the opposite direction effects the direction the compasses deflect. Use your knowledge of electricity and magnetism as well as the right hand rules to explain what is happening.
In this activity you will observe what happens when a current is passed through a wire that is in a magnetic field. First make sure that the rheostat is turned all the way down and then turn on the power supply. Turn up the power supply and watch the wire that is resting on the copper strips. The copper wire is between two sets of permanent magnets. Now turn off the power supply and flip the leads. Turn it back on and watch the reaction of the copper wire. Draw and describe what happens to the wire. Explain what you are seeing in terms of the concepts related to electricity and magnetism. Use the right hand rules to assist in your explanation.

The next activity is the observation of two parallel current carrying wires and how they interact with each other. Check to see if the rheostat is in the lowest position. Turn on the power supply and turn up the power slowly observing what happens as the current begins to flow through the aluminum foil wires. Draw and describe your observations and then explain your observation using your knowledge of electricity and magnetism as well as the right hand rules.

In this activity observe what happens when you move a magnet in and out of a coil. The coil is attached to a galvanometer. Observe what happens when you push the magnet into the coil and then when you pull it out of the coil. What happens if you move the magnet faster? Draw diagrams and describe your observations. Now explain how the current is produced.

This activity is one that you may have explored previously in elementary or middle school. This is an electromagnet. Turn on the power supply with the rheostat in the lowest position. Place the cylindrical bar into the coil and hold the coil in the vertical position. Slowly turn up the rheostat on the power supply and observe what happens to the bar. Now place the bar next to the paper clips. Make observations and record your observation. Draw diagrams of the apparatus and describe what happens when the current is turned on. Explain what is happening in terms of electricity and magnetism.
The next activity is one that will excite and baffle you. It is one of the most challenging activities to explain. You will need to work in a group and use your collective knowledge of electricity and magnetism as you explore the apparatus. First of all one of the coils is attached to the audio jack of the device that is playing an audio recording. The second coil is attached to the amplified speaker. Explore by moving the coils close to each other, on top of each other, and next to each other. Switch the coils around. Draw the apparatus and describe your observation for each trial. Once you have made discoveries explain concepts in terms of electromagnetism.

This activity is fun to perform with other students. Have multiple students hold hands and the ones at the ends of the chain touch the two leads at the sides of the generator. One final student can turn the crank of the generator. The students are the circuit and the generator is generating alternating current. It is your task to explain how a generator works. Please see the introduction section for an explanation of this activity. As you explain, make sure to include the equations to support your explanation.

Now that you have explored the major concepts of electricity and magnetism it is time to apply your knowledge. The following activities will allow you to use your knowledge to explain real world applications of these concepts. As you conduct these activities make sure that you use the caution that is associated with the power supplies.

**Motors**

**Analog meter (galvanometer)**

**Speaker**

**Conclusion:** Describe the activity that was most challenging and what made it challenging. Describe the activity that was the most fun and explain why you thought it was the most fun to explore.
Experiment: Properties of a Diode

Standards:
Students who demonstrate understanding can:
HS-PS2-5 Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.
HS-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).
HS-PS3-3 Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
Students who demonstrate understanding can:
HS-PS4-2 Evaluate questions about the advantages of using a digital transmission and storage of information
Students who demonstrate understanding can:
HS-PS4-5 Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.

Reasoning Objectives:
- I will construct and analyze a circuit to determine how a diode functions.
- I will evaluate designed systems where there is an exchange of energy between objects and fields and characterize how the energy is exchanged.
- I will analyze input and output data and functioning of a human-built system.

Introduction:
The diode is a semiconductor device through which the electrical current flows in the forward direction as well as compared to the current in the backwards direction. The resistance in the forward direction is small but in the reverse direction it is very large. The current in reverse direction is very small. This allows the diode to be used as a rectifier. A rectifier can convert alternating current into direct current flowing in one direction. The current flows forward when the positive pole of the voltage source is connected to the p region and the negative pole is connected to the n region of the diode. The diode will break down in the reverse direction at a high voltage and the current will then flow in the opposite direction. A diagram showing the current flow versus the voltage across the diode is shown below in Figure 1.

Figure 1: Current flow with respect to Voltage for a Diode

Apparatus: breadboard, connecting wires, voltage source, two paperclips, diode, 1.5 KΩ resistor
Procedure: You will be studying the properties of a forward and reverse biased junction diode. To do this you will wire the following circuit as shown in Figures 2 and 3.

Figure 2: Variable Voltage supply with a 1.5 KΩ Resistor and Diode circuit

The electrical components will be attached to a breadboard. The breadboard is shown in Figures 3 and 4. The columns on the sides of the board are all wired together and will be the location where the voltage source is connected. The rows on the left of the center divider are connected and the rows on the right of the center divider are wired together.

Place the paper clips in the columns on the sides of the breadboard. One clip will be wired to the positive pole of the voltage source and other will be wired to the negative pole. **Make sure that the voltage source is off before you make the connections.** Use alligator clips to connect the two ends to the power supply. Place the resistor in the positive column and then in the row where the diode will be connected. Connect the p region or end of the diode in the same row as the resistor and then connect the n region or other end to the negative column, see Figures 3 and 5.

Turn the rheostat all the way down and then turn on the power supply. Make measurements for the voltage across the source and the resistor as you adjust the voltage supply in steps of 0.1 volts up to 1 volt. Record
these values in Table 1. Next increase the voltage by 0.5 volts from 1 to 4 volts and record the values in the table.

**Table 1: Forward Biased Diode**

<table>
<thead>
<tr>
<th>Voltage across the source $V_s$ (volt)</th>
<th>Voltage across the resistor $V_r$ (volt)</th>
<th>Forward Voltage $V_f$ (volts)</th>
<th>Forward current $I_f$ (mA)</th>
</tr>
</thead>
</table>

Determine the voltage across the diode and current through the circuit. The voltage across the diode in the forward direction is found by taking the difference between the voltage of the source and the voltage dropped across the resistor.

$$V_f = V_s - V_r$$

The current can be found by taking the voltage dropped across the resistor and dividing it by the resistance of the resistor.

$$I_f = \frac{V_r}{R}$$

Now rewire the circuit according to the circuit diagram in Figure 6. Measure the voltage in steps of 0.2 volts from zero to 1 volt. Record the voltage and the current reading in data Table 2. The ammeter should be set on the milliamp setting. Next, adjust the voltage by 1 volt steps from 1 volt to 4 volts and record the voltage and the current.

![Figure 6: Reversed Biased](image)

**Table 2: Reverse Biased Diode**

<table>
<thead>
<tr>
<th>Reverse Voltage $V_R$ (volts)</th>
<th>Reverse Current $I_R$ (milliamps, mA)</th>
</tr>
</thead>
</table>

**Analysis:** Graph the data from both tables on a graph with the voltage on the x axis and current on the y axis. Compare your data to the graph in Figure 1. What happens to the current as you increased the voltage in the forward and reverse biased.

**Conclusion:** Describe and explain what you have discovered about a diode. Include diagrams and explanations for how the transistor acts as a switch and an amplifier.
Experiment: Transistor Properties

Standards:
Students who demonstrate understanding can:
HS-PS2-5 Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.
HS-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).
HS-PS3-3 Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
Students who demonstrate understanding can:
HS-PS4-2 Evaluate questions about the advantages of using a digital transmission and storage of information
Students who demonstrate understanding can:
HS-PS4-5 Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.

Reasoning Objectives:
- I will construct and analyze a circuit to determine how a transistor functions.
- I will evaluate designed systems where there is an exchange of energy between objects and fields and characterize how the energy is exchanged.
- I will analyze input and output data and functioning of a human-built system.

Introduction:
The transistor is a semiconductor device that amplifies electrical signals. They replaced the less reliable vacuum tubes amplifiers used in electronic devices. The first point contact transistor was invented by Walter Brattain and John Bardeen on December 16, 1947. This was improved upon by William Shockley, who developed the junction sandwich transistor on paper, the weeks following December 16. It was constructed two years later. Bell Laboratories unveiled the invention that replaced the cumbersome vacuum tubes amplifiers on June 30, 1948. The transistor was first invented with germanium as the semiconductor that was later replaced by silicon. There are three contact points on the transistor. These are the collector, base and emitter. A small electrical signal that is put into the base is used to control the current between the collector and emitter. The signal between the collector and emitter can amplify the signal of the base input. The base can be used to turn on and off the current between the collector and emitter.

Figure 1: Transistors

The emitter arrow is directed toward the n side of the transistor.

Materials: Transistor, 470 Ω resistor, 10 kΩ resistor, light emitting diode, bread board, alligator clip wires, voltage supply, connecting wires and 2 paper clips
**Procedure:** This is an inquiry laboratory where you will investigate the operation of a transistor. The electrical components will be attached to a breadboard. The breadboard is shown in figure 2. The columns on the sides of the board are all wired together and will be the location where the voltage source is connected. The rows on the left of the center divider are connected and the rows on the right of the center divider are wired together.

You will be wiring the two circuits shown in figure 3 to explore the function of the transistor.

**Circuit A:** First connect the positive pole of the power supply to the left hand side of the board using a paper clip.

Now put the transistor into the board with the emitter, base and collector in separate rows as shown to the right.

Wire a 10 kΩ resistor to the base and a 470 Ω resistor to the collector. Connect both resistors to the left hand positive power. The light emitting diode will be connected to the emitter and then to the negative strip on the far right of the circuit board. The long wire on the LED is closest to the emitter of the transistor. Complete the circuit by connecting the far right column of the circuit board back to the negative pole of the power supply using a paperclip. See figure 2 and the pictures on the following page in figure 4a,b. Have the teacher check your circuit before turning on the power supply. Apply 6 volts of electric potential across the circuit by adjusting the rheostat of the power supply and using a volt meter connected across the power supply from the black lead to the red lead.

**Figure 2:** Each individual region shown by a bracket and the blue line is wired together.

**Figure 3:** Circuit A

**Circuit B**
Determine when the LED is on by opening and closing the switch. This is accomplished by pulling the left hand wire of the 10 kΩ resistor out of the positive strip on the breadboard and then reconnecting it. Measure the voltages across the resistors with the switch open and then closed. Use Ohm’s law to calculate the currents through the base and the collector. Calculate the ratio of the current through the collector as compared to the current through the base or the amplification factor. What can you infer about the transistor from this ratio? Measure the voltage across the collector to the emitter when the LED is lit.

After completing the data collection for Circuit A, rewire the circuit according to the schematic and picture shown for Circuit B and repeat collecting data.

### Diagnosis of a Transistor

<table>
<thead>
<tr>
<th></th>
<th>Circuit A</th>
<th></th>
<th>Circuit B</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Switch</strong></td>
<td>Open</td>
<td>Closed</td>
<td>Open</td>
<td>Closed</td>
</tr>
<tr>
<td>LED (on or off)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V across 470 Ω</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V across 10k Ω</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I_b (mA) calculated current to base</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I_c (mA) calculated current to collector</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amplification factor I_c/I_b</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V_{ce} voltage across collector to emitter</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

**Conclusion:** Describe and explain what you have discovered about a transistor. Include diagrams and explanations for how the transistor acts as a switch and an amplifier.
Light

Reflection

Refraction

Diffraction & Interference
Experiment: Reflection of Light

Standard
Students who demonstrate understanding can:
HS-PS4-1 Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media

Reasoning Targets
- I can use my knowledge of the wave properties of light and can evaluate the light apparatus in terms of rays, electromagnetic properties and reflections.
- I will evaluate the experimental data for the mirror and lens laboratories in terms of the mirror equations.
- I will create ray diagrams for each of the cases for mirrors.
- I will carry out investigations to determine the mathematical relationships among wave speed, frequency, and wavelength and how they are affected by the medium through which the wave travels.
- I will carry out an investigation to describe a boundary between two media that affects the reflection, refraction, and transmission of waves crossing the boundary.

Skill Targets
- I can use physics laboratory equipment safely to collect data for a reflection laboratory

Introduction: In this experiment you will verify that light acts in a similar fashion to water waves in a wave tank. Light will be reflected off a plane mirror. You will measure the incident and reflected angles.

Light is an electromagnetic wave that has wave properties. The reflection of light from a plane mirror will follow the same reflective properties as other waves. The angle of incident is equal to the angle of reflection.

\[ \angle i = \angle r \]

Apparatus: laser, laser stands, cardboard, polar graph paper, mirror, mirror stands, and pin

Procedure:
1. Set the mirror into two mirror stands.
2. Place a sheet of polar graph paper on a piece of cardboard.
3. Mount the mirror along the line of 90° and 270°.
4. Mount the laser in the supports and place it next to the polar graph paper.
5. Point the laser at the middle of the mirror at the + sign. You will see the incident and reflect rays entering and leaving the front surface of the mirror. Make sure the + sign is centered between these two rays. The reflective surface is the back of the mirror so there is a small amount of refraction occurring in the glass of the mirror.
6. Use a pin to locate the incident ray and then determine the incident angle. This is the angle between the perpendicular and the light ray. The perpendicular is along the zero degree line. Record this angle in a table with a tolerance of $\pm 0.5^\circ$.

7. Now without moving the laser or polar paper locate the reflected ray using the pin. This is the angle between the reflected ray and the perpendicular. Record that angle in the table with a tolerance of $\pm 0.5^\circ$.

8. Repeat the procedure for three other angles.

**Analysis and Conclusion:** Describe your conclusion about the incident and reflected angles. Describe what factors would create errors in this procedure if your angles are not the same.
Experiment: Converging and Diverging Mirrors

Standard
Students who demonstrate understanding can:
HS-PS4-1 Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media

Reasoning Objectives
- I can use the mirror equations to determine the image sizes and distances.
- I can evaluate the experimental data for the mirror laboratory in terms of the mirror and mirror equations.

Skill Objective
- I can draw ray diagrams for mirrors and mirrors.

Introduction:
A mirror is a reflective surface that creates an image by reflecting rays. Concave and convex mirrors converge or diverge rays to real or virtual points. Reflection is the returning of waves when they encounter a barrier. Converging or concave mirrors produce real and virtual images depending upon where the object is located. Diverging or convex mirrors produce virtual images that are viewed inside the mirror.

Mirrors have focal lengths where rays arriving parallel to the principle axis are focused. The focal point for a converging mirror is located where light rays parallel to the principle axis meet after reflecting. The focal point for a diverging mirror is the location where the parallel rays appear to reflect from. The focal length is the distance from the focal point to the center of the mirror. The diagram below show types of mirrors. The concave mirrors are convergent and the convex mirrors are divergent with virtual foci.

![Mirror Types Diagram](image)

Three types of rays are used to locate images in ray diagrams. The first ray is the one that approaches parallel to the principle axis, reflecting off the mirror and moving on to the focal point.

![Ray Diagram](image)

Another ray used is the one that reflects off the center of the mirror. The angle of reflection and incidence are the same as they are for all reflection.
The last type of ray passes through the focal point and reflects from the mirror parallel to the principle axis.

There are six cases that illustrate where an image can appear for converging mirror. In the first case the object is at infinity. The light rays arrive parallel to the principle axis and reflect to the focal point. The image appears at the focal point and it is real.

Case 1: Object at infinity
Real image is a point located at F

In the second case the object is placed beyond the center of curvature, c, or twice the focal length. The light ray that arrives parallel to the principle axis reflects to the focal point. A second ray that first passes through the focal point will reflect from the mirror parallel to the principle axis. In this case the image is real, inverted, smaller, and between the focal point and twice the focal length.

In the third case the object is placed at c. The light ray that arrives parallel to the principle axis reflects to the focal point. Also the light rays pass through the focal point and reflect parallel to the principle axis. This causes the image to be real, inverted, the same size as the object, and is at c.
In the fourth case the object is placed between the focal point and $2f$. The image is real, inverted, enlarged, or larger than the object, and is beyond $c$.

In the fifth case the object is at the focal point. To locate the image the ray that reflects off the center of the mirror is used with the ray that arrived parallel to the principle axis. These two rays reflect off the mirror parallel to each other. In this case if the image did exist it would be at infinity, real, and infinitely enlarged.

In the sixth case the object is between the focal point and the mirror. The two light rays used to locate this image are the one that reflects off the center of the mirror and the one that arrives parallel to the principle axis. The two rays diverge and only intersect when traced back to the opposite side of the mirror. The image is a virtual image. This means it is not real, is upright, on the opposite side of the mirror as the object, and is enlarged.

The single case with a diverging or convex mirror uses the rays that approach the mirror parallel to the principle axis and the ray that reflects off the center of the mirror. The ray that approaches parallel to the principle axis is reflected away from the axis. When the rays are traced back they intersect producing a virtual image that is upright and smaller than the object.
In the picture shown below $h_i$ is the height of the image and is equal to $A'B'$. The height of the object, $h_o$, is equal to $AB$. The image distance, $d_i$, is equal to $B'O$. The object distance, $d_o$, is equal to $BO$.

The following two equations are known as the mirror equations. The first shows the magnification of the mirror. The second shows the relationships between the object distance, image distance and focal length.

$$M = \frac{h_i}{h_o} = \frac{d_i}{d_o}$$

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

In this laboratory the mirror equations will be used to diagnose four of the six cases. It is not possible to take data for case 5 and 6 since the image for case 5 is at infinity and the image for case 6 is a virtual image.

**Apparatus:** meter stick, stands, candle, candle holder, concave mirror, mirror holder, card, card holder, and ruler

**Procedure:** The optics bench is made of a ruler mounted on stands. The concave mirror and card are mounted in the respective stands and placed on the ruler. Place the mirror at the 5 centimeter mark. Next, take the apparatus outside and point the ruler at the sun. Focus the rays of the sun off the mirror onto the card. The location where the image becomes smallest is the location where the focal point is. It is best to view this image from the backside of the card since it is very bright. Record the difference between the location that the mirror is or 5.00 cm and the location of the card as the focal point. Repeat this procedure
at least five times. The average value will be the focal length used to perform the calculations. Record all of the values as you take them.

Return to the classroom and remove the card from the meter stick and set the candle on the optics bench. Set up a second optic bench and place the card on that meter stick. Align the 1.00 cm mark of the bench with the card beside the mirror that is located on the other ruler. Measure the width of the top of the candle. This will be the object size. Record the value of the object size or \( h_0 \). Light the candle and place it beyond twice the focal length from the mirror. Focus the image on the card by moving it back and forth until the image is clear. Record the object distance, \( d_o \), from the mirror and the image distance \( d_i \) from the mirror. Finally, measure the distance across the top of the image of the candle on the card and record that value in the table as \( h_i \).

### Formation of an Image Using a Converging Mirror and a Candle

<table>
<thead>
<tr>
<th>Case</th>
<th>Object Distance ( d_o ) ±0.0004 (meters)</th>
<th>Image Distance ( d_i ) ±0.0004 (meters)</th>
<th>Object Width ( h_o ) ±0.0004 (meters)</th>
<th>Image Width ( h_i ) ±0.0004 (meters)</th>
<th>Calculated Image Distance (meters)</th>
<th>Calculated Image Width (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
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<tr>
<td>4</td>
<td></td>
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</tr>
</tbody>
</table>

Repeat the procedure for case 3 by placing the candle at twice the focal length and for case 4 by placing the candle between the focal length and twice the focal length.

**Analysis:**

1. Calculate the image distance using the average focal length and the measured object distance. This value is the accepted value and can then be used to find the absolute and relative errors. Create a table and tabulate the values of errors for all three cases. Make sure to show a sample calculation for the image distance.

2. Calculate the image width of the image using the magnification equation, the measured object distance, \( d_o \), calculated image distance, \( d_i \), and the measured object width, \( h_o \). This is the accepted value for the image width and can be used to find the absolute and relative errors for the measured values. Tabulate those values for all three cases in the same table as the error for the image distance. Make sure to show a sample calculation for the image height.

3. Describe why data for cases 5 and 6 was not collected. Use diagrams in your explanation.

**Conclusion:** Discuss factors that created error in this laboratory. Make suggestions on how they can be eliminated.
Experiment: Refraction of Light

Standard
Students who demonstrate understanding can:
HS-PS4-1 Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media

Knowledge Objective
- I know Snell’s Law and how to apply it to the refraction of light through different media.

Reasoning Objective
- I can use my knowledge of the wave properties of light and can evaluate the light apparatus in terms of rays, electromagnetic properties and refraction.

Skill Objective
- I can use physics laboratory equipment safely to collect data for the refraction laboratory.

Introduction: In this experiment you will verify that light acts in a similar fashion as water waves from the wave tank. Light will be refracted from air into a medium of water. You will measure the incident and refracted angles and then use Snell’s Law to determine the index of refraction.

Refraction of light is the bending of light rays as they pass at an angle other than perpendicular from one medium into another. The incident and refracted angles are measured from the normal to the surface and the ray. As light passes from a less dense medium to a denser medium the ray will bend towards the perpendicular or normal to the surface. When light passes from a denser medium to a less dense medium the ray is bent away from the normal. This shows that light rays are reversible. Snell’s law expresses the relationship between the incident and refracted rays. Snell’s Law is the ratio of the sine of the angles and the ratio of the velocities of light in the two mediums.

\[
\frac{\sin \theta_1}{\sin \theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}
\]

In the equation the ratio of the sine of the angels is equal the inverse of the indices of refraction for the two media.

The following diagram illustrates the refraction of the light as it enters from air into a denser medium.

Apparatus: laser, laser stands, cardboard, polar graph paper, semicircular dish, and pin

Procedure:
1. **CAUTION:** Never look directly down the beam of a laser since it will do permanent eye damage.
2. Place a sheet of polar graph paper on a piece of cardboard.
3. Set the flat side of the semicircular dish along the line of 90° and 270°. Make sure that the center of the dish is located at the center of the polar graph paper.
4. Mount the laser in the supports and place it next to the polar graph paper.
5. Point the laser at the middle of the dish at the + sign following along the ray that traces out approximately 10°. You will see the incident ray entering the front surface of the dish.

6. Use a pin to locate the laser beam and then determine the incident angle that the ray approaches the dish. This is the angle between the perpendicular to the dish along the 0° and the incident ray. Record this angle in a table with a tolerance of ± 0.5°.
7. Now without moving the laser or polar paper locate the refracted ray on the other side of the dish. This is the angle between the perpendicular to the dish along the 180° and the refracted ray. Record that angle in the table.
8. Repeat the procedure for angles of approximately 20, 30, 40, and 50 degrees. Finally repeat the procedure for an angle of 0°.

<table>
<thead>
<tr>
<th>Angle of Incident</th>
<th>Angle of Refraction</th>
<th>Sine of Incident Angle</th>
<th>Sine of Refraction Angle</th>
<th>( \sin i / \sin r )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( i \pm 0.5° )</td>
<td>( r \pm 0.5° )</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Analysis:** Calculate the sine of the angles of incident and refraction and then determine their ratio. The ratio should be a constant. Determine the absolute and relative errors and deviation for the index of refraction for water. The accepted value for the index of refraction or ratio of sine of the angles is 1.33. Make a table of the absolute and relative errors and the absolute deviation. Make sure to show sample calculations for all of the calculations including one for the relative deviation.

**Conclusion:** Describe your conclusion about the incident and refracted angles. Describe what factors would create errors in this procedure since not all of the indices of refractions are the same for each set of measurements. What do you conclude about the light ray that passes at an angle of incident of 0°?
Experiment: Critical Angle and Total Internal Reflection

**Standard**
Students who demonstrate understanding can:
HS-PS4-1 Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media

**Knowledge Targets**
- I know Snell’s Law and how to apply it to the refraction of light through different media.

**Reasoning Targets**
- I can use my knowledge of the wave properties of light and can evaluate the light apparatus in terms of rays, electromagnetic properties and refraction.

**Skill Targets**
- I can use physics laboratory equipment safely to collect data for the refraction laboratory.

**Introduction:** In this experiment you will study what happens to light as it passes from a denser medium into one that is less dense. Light will be refracted from water into air. You will need to calculate the critical angle. Next, measure the incident and refracted angles and then use Snell’s Law to determine the index or refraction. These measurements will continue until the critical angle is reached.

Refraction of light is the bending of light rays as they pass at an angle other than perpendicular from one medium into another. The incident and refracted angles are measured from the normal to the surface to the incident ray. As light passes from a less dense medium to a denser medium the ray will bend toward the perpendicular or normal to the surface. When light passes from a denser medium to a less dense medium the ray is bent away from the normal. This shows that light rays are reversible. Snell’s law expresses the relationship between the incident and refracted rays. Snell’s Law is the ratio of the sine of the angles and the ratio of the velocities of light in the two mediums.

\[
\frac{\sin \theta_1}{\sin \theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}
\]

In the equation the ratio of the sine of the angles is equal the inverse of the indices of refraction for the two media.

The following diagram illustrates the refraction of the light as it enters from air into a denser medium. The index of refraction for air is approximately 1.000.
Light bends away from the perpendicular as it leaves a denser medium thus there will be a point where the refracted ray will bend 90°. This is the point at which the light will not leave the denser medium. The light ray will be reflected off the surface back into the dense medium. This is known as total internal reflection.

![Diagram of light bending and reflecting](image)

**Apparatus:** laser, laser stands, cardboard, polar graph paper, mirror, mirror stands, and pin

**Procedure:**
1. **CAUTION:** Never look directly down the beam of a laser since it will do permanent eye damage.
2. Place a sheet of polar graph paper on a piece of cardboard.
3. Set the flat side of the semicircular dish along the line of 90° and 270°. The circular side should be closest to the 0°. Make sure that the center of the dish is located at the center of the polar graph paper.
4. Mount the laser in the supports and place it next to the polar graph paper.
5. Point the laser through the circular side of the dish toward the middle of the flat side of the dish. You will direct the beam at the + sign following along the ray that traces out approximately 10°. You will see the incident ray entering the circular surface of the dish and exit the flat surface.

![Laser and polar graph paper](image)

6. Use a pin to locate the laser beam and then determine the incident angle that the ray approaches the dish. This is the angle between the perpendicular to the dish along the 0° and the incident ray. Record this angle in a table with a tolerance of ±0.5°.
7. Now without moving the laser or polar paper locate the refracted ray on the other side of the dish. This is the angle between the perpendicular to the dish along the 180° and the refracted ray. Record that angle in the table.

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8. Repeat the procedure for angles of approximately 20, 30, 40, and 50 degrees. Finally repeat the procedure for an angle of 0°.

![Diagram of light refraction through water]

**Refraction of Light through Water**
*(Laser Beam)*

<table>
<thead>
<tr>
<th>Angle of Incident &lt;i + .5°</th>
<th>Angle of Refraction &lt;r + .5°</th>
<th>Sine of Incident Angle</th>
<th>Sine of Refraction Angle</th>
<th>sin&lt;i / sin&lt;r</th>
</tr>
</thead>
</table>

**Analysis:** Determine the critical angle by putting 90° for the reflected angle in Snell’s law. Use an index of refraction for water as 1.33 and for air 1.00. Calculate the sine of the angles of incident and refraction and then determine the ratio of the sine of the angles. The ratio should be a constant. Determine the absolute and relative errors and deviation for the index of refraction for water. The accepted value for the index of refraction or ratio of sine of the angles is 1.33. Make a table of the absolute and relative errors and the absolute deviation. Make sure to show sample calculations for all of the calculations.

**Conclusion:** Describe the relationship between the incident and refracted angles for the light ray moving from water into air. As the incident angle increased from 10° to 40° what direction did the refracted ray move with respect to the normal? How did the velocity of light change as it moved from water into air? What happened to the light as the incident ray changed from 40° to 50°?
**Experiment: Converging and Diverging Lenses**

**Standard**
Students who demonstrate understanding can:
HS-PS4-1 Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media

**Reasoning Objectives**
- I can use the lens equations to determine the image sizes and distances.
- I can evaluate the experimental data for the lens laboratory in terms of the mirror and lens equations.

**Skill Objectives**
- I can draw ray diagrams for mirrors and lenses.

**Introduction:**
A lens is a transparent object that refracts light and creates an image by converging or diverging rays to a real or virtual point. Refraction is the bending of waves as they enter at an oblique angle into a medium of different optical density and either speed up or slow down. Converging lenses are thicker in the middle and produce real and virtual images depending upon where the object is located. Diverging lenses that are thicker on the outside, spread light out and produce virtual images. The human eye is a type of lens. It converges light to the back of the eye where the retina is.

Lenses have focal lengths on each side of the lens because light can enter through either side of the lens. The focal point for a converging lens is located where light rays parallel to the principle axis meet after passing through the lens. The focal point for a diverging lens is the location where the rays appear to originate. The focal length is the distance from the focal point to the center of the lens. The diagram below shows types of lenses. The convex lenses are convergent and the concave lenses are divergent with virtual foci.

Three types of rays are used to locate images in ray diagrams. The first ray is the one that approaches parallel to the principle axis, passing through the lens and moving on to the focal point.
Another ray used is the one that passes through the center of the lens. There is a slight amount of refraction as it enters and exits the lens but the incident and exiting rays are parallel to each other.

The last type of ray passes through the focal point and emerges from the lens parallel to the principle axis.

There are six cases that illustrate where an image can appear for converging lenses. In the first case the object is at infinity. The light rays come in parallel to the principle axis and as they pass through the lens they bend, focusing at the focal point. The image appears at the focal point and it is real.

In the second case the object is placed beyond 2f or twice the focal length. The light ray that arrives parallel to the principle axis passes through the focal point. A second ray that first passes through the focal point will emerge from the lens parallel to the principle axis. In this case the image is real, inverted, smaller, and between the focal point and twice the focal length.

In the third case the object is placed at 2f. The light ray that arrives parallel to the principle axis emerges and passes through the focal point. Also the light rays pass through the focal point and come out of the lens parallel to the principle axis. The image is real, inverted, the same size as the object, and is at 2f.

In the fourth case the object is placed between the focal point and 2f. The image is real, inverted, enlarged, or larger than the object, and is beyond 2f.

In the fifth case the object is at the focal point. The ray that passes through the origin and moves straight through the lens is used with the ray that arrived parallel to the principle axis to locate the image. These
two rays emerge from the lens parallel to each other. In this case if the image did exist it would be at infinity, real, and infinitely enlarged.

Case 5

In the sixth case the object is between the focal point and the lens. The two light rays used to locate this image are the one that passes through the center of the lens and the one that arrives parallel to the principle axis. The two rays diverge and intersect only when traced back to the same side of the lens as the object. The image is a virtual image, which means it is not real, is upright, is on the same side of the lens as the object, and is enlarged.

Case 6

The single case with a diverging lens uses the rays that approach the lens parallel to the principle axis and the ray that passes through the center of the lens. The ray that approaches parallel to the principle axis is refracted away from the axis. When the rays are traced back they intersect producing a virtual image that is upright and smaller than the object. This image is viewed through the lens.

In the picture shown below \( h_i \) is the height of the image and is equal to \( A'B' \). The height of the object, \( h_o \), is equal to \( AB \). The image distance, \( d_i \), is equal to \( B'O \). The object distance, \( d_o \), is equal to \( BO \).

The follow two equations are known as the lens equations. The first shows the magnification of the lens. The second shows the relationships between the object distance, image distance and focal length.

\[
M = \frac{h_i}{h_o} = \frac{d_i}{d_o}
\]

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

In this laboratory the lens equations will be used to diagnose four of the six cases. It is not possible to take data for case 5 and 6 since the image for case 5 is at infinity and the image for case 6 it is a virtual image.
**Apparatus:** meter stick, optic bench, light source, light power source, optics bench, lens, lens holder, card, card holder, screen, and ruler

**Procedure:** A lens and index card are mounted in the respective stands and placed on a meter stick. Place the lens at the 50 centimeter mark. Next, take the apparatus outside and point the ruler at the sun. Focus the rays of the sun through the lens onto the index card by sliding the card. The location where the image becomes smallest is the location where the focal point is. It is best to view this image from the backside of the card since it is very bright. Record the difference between the location that the lens is at, or 50.00 cm, and the location of the card as the focal point. Repeat this procedure at least five times. The average value will be the focal length used to perform the calculations.

Return to the classroom and set the light source on the side opposite the screen on the optics bench. Take the lens out of the metal holder and place it into the sliding holder. Measure the width of the cross. This will be the object size. Record the value of the object size or $h_o$ in the table. Plug in the light source and place it beyond twice the focal length from the lens. Focus the image on the screen by moving it back and forth until the image is clear. Record the object distance, $d_o$, from the lens and the image distance $d_i$ from the lens. Finally, measure the height of the image of the cross on the screen and record that value in the table as $h_i$.

### Formation of an Image Using a Converging Lens and a Light Source

<table>
<thead>
<tr>
<th>Case</th>
<th>Object Distance $d_o$ (meters)</th>
<th>Image Distance $d_i$ (meters)</th>
<th>Object Width $h_o$ (meters)</th>
<th>Image Width $h_i$ (meters)</th>
<th>Calculated Image Distance (meters)</th>
<th>Calculated Image Width (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Repeat the procedure for case 3 by placing the light source at twice the focal length and for case 4 by placing the light source between the focal length and twice the focal length.

**Analysis:**

1. Calculate the image distance using the average focal length and the measured object distance. This value is the accepted value and can then be used to find the absolute and relative errors. Create a table for errors and tabulate the values for all three cases. Make sure to show a sample calculation for the image distance and errors.

2. Calculate the image width of the image using the magnification equation, the measured object distance, $d_o$, calculated image distance, $d_i$, and the measured object width, $h_o$. This is the accepted value for the image width and can be used to find the absolute and relative errors. Tabulate those values for all three cases in the same table as the error for the image distance. Make sure to show a sample calculation for the image height.

3. Describe why data for cases 5 and 6 was not collected. Use diagrams in your explanation.

**Conclusion:** Discuss factors that created error in this laboratory. Make suggestions on how they can be eliminated.
Activity: Interference Patterns

Standard
Students who demonstrate understanding can:
HS-PS4-1 Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media

Knowledge Objective
- I will explain diffraction and interference of light in terms of wave properties.

Reasoning Objective
- I will calculate the distance between two slits and the width of a single slit.

Goal: Students will gain an understanding of double slit and single slit interference through the measurements of the interference pattern and calculations to determine the distance between the two slits and the width of the single slit.

Apparatus: Laser, laser stands, double slit and single slit apparatus, meter stick, ruler, stands, cardboard, and white paper

Activity: In this activity you will determine the distance between a double slit apparatus as well as the distance across a single slit using the interference pattern created by monochromatic light that passes through the slits or slit.

Procedure:
Determine the distance from the screen to the slit apparatus. \( L = \) _____________ ± .0004 meters.

Determine the distance between the center bright spot and the first order bright spot in the interference pattern created when the light passes through the double slits.
\( x = \) ________________ ± .0004 meters.

Determine the distance from the center of the bright spot and the first minimum of the interference pattern created when the laser is shown through a single slit.
\( x = \) ________________ ± .0004 meters.

The wavelength of light from the helium neon laser is 632.8 nanometers or 6.328x10\(^{-7}\) meters.

1. What is the equation for double slit interference and how is it related to the distance between the bright spots and the distance to the screen where the interference pattern is projected?
2. Draw a diagram showing the interference pattern and how it relates to the equation for double slit interference.

3. Find the distance between the double slits using the equation for constructive interference and the relationship of x and L.

4. What is the equation for single slit interference and how is it related to the distance between the bright spots and the distance to the screen where the interference pattern is projected?

5. Draw a diagram showing the interference pattern and how it relates to the equation for single slit interference.

6. Find the distance of the opening in the single slit using the equation for destructive interference and the relationship of x and L for the single slit interference.
Activity: Bending Light around Obstacles and Through Slits

Standard
Students who demonstrate understanding can:
HS-PS4-1 Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media

Knowledge Objective
- I can explain diffraction and interference of light in terms of wave properties.

Reasoning Objective
- I will calculate the thickness of hair and the distance between lines in a spectrum grating using double and single slit interference.

Introduction:
Light will bend around obstacles which are placed in its path. This is known as diffraction. Diffraction/Interference patterns are formed when the light waves superimpose on top of each other. These patterns are due to the constructive and destructive interference of the waves. Light incident upon slits or the lines of a diffraction grating will diffract. The bright bands are locations where the light waves constructively interfere with each other. The dark areas are where the waves are out of phase and cancel each other out.

Consider the two slits shown below. The diagram shows the waves of light passing through the two slits and diffracting. After the diffraction they constructively and destructively interfere producing an interference pattern. Where the lines cross the wave crests are adding to each other forming large waves.

In diagram 2 you will notice that the waves are not shown as in the above diagram. The distances are shown. In the diagram y is the distance from the slits to the screen, x is the distance from the center of the central bright and the first order bright spot, L is the distance from the slits to the first order bright spot, d is the distance between the two slits and \( \phi \) is the angle between L and y as well as angle \( S_1S_2N \), and \( \lambda \) is the wavelength.

In the above diagram triangle \( S_1S_2N \) is similar to triangle OPoP. This is true when the slit opening or d is very small. The following equations express the relationships between the variables.

\[
\frac{x}{y} = \frac{\lambda}{d} \quad \quad \lambda = \frac{xd}{y}
\]

\[
\sin \phi \approx \tan \phi \approx \frac{x}{y} = \frac{\lambda}{d}
\]
The above equation will work for a single slit as well as a double slit. When using the equation for single slit interference the distance from the center bright to the first dark area of destructive interference is the x value. For this equation the two sides of the opening act as two different slits.

**Apparatus:** laser, laser stands, wood block, washer, holder, sticky tack, diffraction grating, meter stick, ruler, two stands, cardboard, white paper, and protractor

**Safety:** Caution should be used when using a laser since permanent eye damage can occur when the beam is projected at the eye. The chance of someone walking into the beam is very great in this activity. Watch out for reflection of shiny surfaces and block your beam path when doing calculations.

**Procedure:** You can calculate the distance between the two lines on a diffraction grating by exposing it to your laser beam. Measure the distances x and y as shown in Diagram II. Use the equation to determine the distance between the two lines on the grating. The value for the wavelength of red light from the laser is 633 nanometers or $633 \times 10^{-9}$ meters. Check your results using the calibration in lines per centimeter on the grating card.

Now, you are ready to measure the thickness of a hair. This can be done by sticking a strand of hair on a washer. Shine the laser beam onto it so that it is in the middle of the beam. Project the interference pattern on a screen and measure x and y. Use these to calculate the thickness of the hair. Check your answer using a protractor and measure the angle $\phi$.

**Conclusion:** Use drawings, or computer simulation models to explain that resonance occurs when waves add up in phase and out of phase producing interference patterns.
**Activity Thin Film Interference**

**Standard**
Students who demonstrate understanding can:
HS-PS4-1 Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media

**Knowledge Objective**
- I can explain thin film interference using the ideas of constructive and destructive interference of waves.

**Reasoning Objective**
- I can perform calculations using the equations for thin film interference.

**Objective:** Students will gain an understanding of thin film interference through the measurements of the interference pattern and calculations to determine the distance between the two glass plates.

**Apparatus:** two pieces of optically flat glass, thin piece of paper, ruler and white light source

**Activity:** In this activity you will determine the distance between constructive interference patterns formed between two optically flat pieces of glass that are separated by a thin piece of paper. Finally, you will determine the thickness of the piece of paper.

**Procedure:**

Determine the distance for the first five bright spectrums. \( l = \) _______________ ± .0004 meters.

Determine the distance from the end of glass to the opposite piece where the thin piece of paper holding the pieces of glass apart is located. \( L = \) _______________ ± .0004 meters.

The wavelength of violet light is 450 nanometers or \( 4.50 \times 10^{-7} \) meters.

1. Determine the equation for the interference pattern set up when two optically flat pieces of glass are separated on one end by a thin piece of paper.

2. Draw a diagram showing the interference pattern and how it relates to the equation for thin film interference.

3. Find the distance between the pieces of glass at the distance determined for the fifth interference pattern.

4. Now calculate the thickness of the piece of paper. You will use trigonometry to assist you in this calculation.
Atomic

\[ F = k \frac{(Ze)e}{r^2} \]
Experiment: Energy Levels of the Hydrogen Atom

Standards:
HS-PS4-1 Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media
HS-PS4-3 Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.
HS-PS4-4 Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.

Knowledge Objective
- I can describe the experimental basis for the development of the quantum theory of atomic structure and the historical importance of the Bohr model of the atom.

Reasoning Objective
- I can evaluate the difference between the energy levels of atoms in the hydrogen atom using spectral data from the discharge tube of gaseous hydrogen atoms.

Skill Objectives
- I can use laboratory equipment safely to gather hydrogen spectrum data.
- I can evaluate the energy levels between electrons in hydrogen using the colors of waves from a hydrogen discharge tube.

Product Objective
- I can develop a laboratory report in my spiral notebook for the hydrogen spectrum data.

Introduction: Light is emitted when rarefied hydrogen gas has a high voltage applied to it. When a high voltage excites a hydrogen spectral tube with low gas pressure a discrete spectrum is produced. The line spectrum that is produced has four visible lines. Each of these colors has a specific wavelength. J.J. Balmer analyzed the spectrum in 1885 and he showed that the lines fit the following formula

\[ \frac{1}{\lambda} = R \left( \frac{1}{2^2} - \frac{1}{n^2} \right), \quad n = 3, 4, \ldots \]

In the above equation the n value for the four lines are 3, 4, 5 and 6. The R-value is known as the Rydberg constant and has a value of 1.097 x 10^{-7} m^{-1}.

Bohr suggested that atoms couldn't lose energy in a continuous fashion as is expected as the electron orbits the nucleus. The electron must move in quantum jumps and exist in definite orbits with a quantity of energy. Electrons can jump from stationary states to lower states and emit energy in the form of a photon according to the following equation

\[ hf = E_u - E_l, \]

In the equation \( E_u \) is the energy of the upper state and \( E_l \) is the energy of the lower state. Bohr found that when assumed that the angular momentum was quantized according to \( n(h/2\pi) \), his theory for the hydrogen atom would follow Balmer's formula. In his assumption \( n \) is an integer. Angular momentum is given by \( L = I\omega \). The moment of inertia for a single particle moving in a circle is \( I = mr^2 \) and \( \omega = v/r \). Through substitution

\[ L = I\omega = (mr^2)(v/r). \]

\[ L = mvr_n = n(h/2\pi), \quad n = 1, 2, 3, \ldots \]

Bohr also assumed that the force holding the electron in its orbit was the electrostatic force between the electron and the proton. Coulomb's law in which \( Z \) is number of protons in the nucleus gives this

\[ F = k \frac{(Ze)(e)}{r^2} \]
In the above equation \( k = \frac{1}{4\pi\varepsilon_0} = 9.00 \times 10^9 \text{ Nm}^2/\text{C}^2 \) and \( e \) is the charge on the electron or proton. For the hydrogen atom \( Z = +1 \).

Going a step further it is known from Newton's second law that \( F = ma \) and the centripetal acceleration is \( a = \frac{v^2}{r} \). These values are set equal to the above expression of Coulomb's law producing the following expression

\[
\frac{kZe^2}{r^2} = \frac{mv^2}{r_n^2}
\]

When this expression is solved for \( r_n \), it produces

\[
r_n = k \frac{Ze^2}{mv^2}
\]

Finally when expression for angular momentum is solved for \( v \) and then substituted into the above equation, and expression for the radius in terms of constants is derived.

\[
L = mvr_n = n\frac{h}{2\pi} \implies v = \frac{nh}{2\pi mr_n}
\]

\[
r_n = \frac{n^2 \hbar^2}{4\pi mkZe^2} = \frac{n^2 r_1}{Z}
\]

where

\[
r_1 = \frac{\hbar^2}{4\pi^2 mkZe^2}
\]

This equation gives the radii of all possible orbits. The smallest orbit for hydrogen where \( Z = 1 \) and \( n = 1 \) the value is

\[
r_1 = \frac{(1)^2(6.626 \times 10^{-34} \text{ J s})^2}{4(3.14)^2(9.11 \times 10^{-31} \text{ kg})(9.00 \times 10^{-9} \text{ m}^2/\text{C}^2)(1)(1.602 \times 10^{-19} \text{ C})^2} = 0.529 \times 10^{-10} \text{ m}.
\]

Bohr then went one step further and found the energy the electron had in each orbit. The total energy was the sum of the potential and kinetic energies.

\[
E_n = KE + PE
\]

The potential energy of the electron is the charge times the voltage or \( PE = qV \) where \( q \) is the charge or \( -e \) and \( V \) is the electric potential. The voltage due to a point charge, the nucleus +\( Ae \) is given by \( V = \frac{kQ}{r} = kZe/r \). So
The kinetic energy is given by \( KE = \frac{1}{2} mv^2 \). The total energy is derived through substitution as shown below.

\[
E_n = \frac{1}{2} mv^2 - kZ\frac{e^2}{r_n}
\]

In the equation for the total energy the expression for \( v \) and \( r_n \) are substituted in and the final expression for the energy of each orbital is found. The expression for \( v \) and \( r_n \) are shown below.

\[
v = n\frac{h}{2\pi mr} = \frac{nh^4\pi^2}{2mkZe^2}
\]

Now through substitution the expression becomes

\[
E_n = \frac{1}{2} m\frac{(2\pi kZe^2/nh)^2 - kZe^2(4\pi^2 mkZe^2)}{n^2h^2}
\]

The above expression becomes the following where \( E_1 \) is the lowest energy level where \( n = 1 \).

\[
E_n = \frac{Z^2}{n^2} E_1
\]

For hydrogen \( (Z = 1) \) and the value of \( E_1 \) is

\[
E_1 = -\frac{2\pi^2 e^4 mk^2}{h^2} = -2.17 \times 10^{-18} \text{ J} = -13.6 \text{ eV},
\]

The wavelengths of the spectral lines emitted can be calculated by combining \( hf = E_n - E_1 \) and the equation for the energy of the orbits. It is known that \( hf = hc/\lambda \) so

\[
1/\lambda = hf/hc = 1/hc (E_n - E_1),
\]

Finally the equation for energy orbits is substituted into the above equation and Balmer's expression is derived.

\[
1/\lambda = -\frac{2\pi^2 Z^2 e^4 mk^2}{h^2c} (1/n^2 - 1/n^2)
\]

When the constant \( (2\pi^2 Z^2 e^4 mk^2/h^2c) \) in the above equation is evaluated with \( Z = 1 \), it is found to have the measured value of the Rydberg constant, \( R = 1.0974 \times 10^7 \text{ m}^{-1} \) in equation \( 1/\lambda = R(1/2^2 - 1/n^2) \).

**Apparatus:** hydrogen lamp, voltage source for lamp, two meter sticks, diffraction grating, optic bench card holder, 4 optic bench stands

**Procedure:**
It is your job to determine the wavelengths of the visible hydrogen spectrum. Then determine the energy difference between the orbits using this wavelength of light. Remember that the energy difference between orbits is given by \( hf = E_n - E_1 \) and that frequency is \( f = c/\lambda \). To determine the wavelength, \( \lambda \), you will use a diffraction grating and the following expression which shows the relationship between the distance between the slits, \( d \), and the angle to the first order spectral line as viewed through the grating. The \( m \) value represents the order of the spectral line and in this experiment it is 1 since you will measure to the first appearance of the line.
Set up the apparatus shown in the diagram. The discharge tube must be at the end of the ruler that has the diffraction grating on it. You will look through the diffraction grating and find the image of the spectral line on both the right and left of the discharge tube. Find the average distance for the spectral line using both distance A and B. This value will be X and then sine θ can be determined.

\[ X = \frac{(A + B)}{2} \]

You will have both the Y value and the X value so Z can be determined. Next, you can find sine θ since it is equal to

\[ \text{Sine } \theta = \frac{X}{Z} \]

Now determine the value of λ using the sine function and the knowledge that there are 13400 lines per inch on the diffraction grating. The distance between the lines, d, can be determined using the fact that there are 2.54 cm per inch. Once you have determined the wavelength for all four of the visible spectral lines, determine the energy of the photon using hf = E. This energy is the energy difference between the orbits of the electron in the hydrogen atom, hf = E\textsubscript{n} - E\textsubscript{l}.

**Analysis:**

1. Calculate the energy of each of the following orbits 2, 3, 4, 5, 6 using the following equations.

\[ E_n = -\frac{2\pi^2 Z^2 e^4 mk^2}{\hbar^2 n^2} \]

The above expression becomes the following where \( E_1 \) is the lowest energy level where \( n = 1 \).

\[ E_n = \frac{Z^2}{n^2} E_1 \]

For hydrogen (\( Z = 1 \)) and the value of \( E_1 \) is

\[ E_1 = -\frac{2 \pi^2 e^4 mk^2}{\hbar^2} \]

\[ E_1 = -\frac{2 (3.14)^2 (1.602 \times 10^{-19}) (9.11 \times 10^{-31} \text{ kg}) (9.00 \times 10^9 \text{ Nm}^2/\text{C}^2)^2}{(6.626 \times 10^{-34} \text{ J s})^2} \]

\[ E_1 = -2.17 \times 10^{-18} \text{ J} = -13.6 \text{ eV} \]

2. Now find the difference between energy of orbits 3, 4, 5 and 6 with respect to 2. Each of these values should correspond with one of the energies of the spectral lines.

3. Perform error analysis using the calculated values as the accepted value.

**Conclusion:** Discuss the errors and factors that lead to these errors.
Appendix

Fundamental Constants

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Quantity</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>c</td>
<td>Speed of light in a vacuum</td>
<td>$3.00 \times 10^8$ m/sec</td>
</tr>
<tr>
<td>$e^-$</td>
<td>Electronic Charge</td>
<td>$-1.60 \times 10^{-19}$ C</td>
</tr>
<tr>
<td>$k_c$</td>
<td>Coulombs Constant</td>
<td>$8.99 \times 10^9$ N m$^2$/C$^2$</td>
</tr>
<tr>
<td>G</td>
<td>Universal Gravitational constant</td>
<td>$6.67 \times 10^{-11}$ N m$^2$/kg$^2$</td>
</tr>
<tr>
<td>g</td>
<td>Acceleration due to free fall at earth surface</td>
<td>$9.81$ m/sec$^2$</td>
</tr>
<tr>
<td>h</td>
<td>Plank’s Constant</td>
<td>$6.63 \times 10^{-34}$ J s</td>
</tr>
<tr>
<td>R</td>
<td>Molar (universal) gas constant</td>
<td>$8.31$ J/K mole</td>
</tr>
<tr>
<td>$k_B$</td>
<td>Boltzmann’s constant R/N$_a$</td>
<td>$1.38 \times 10^{-23}$ J/K</td>
</tr>
<tr>
<td>$m_e$</td>
<td>Mass of Electron</td>
<td>$9.11 \times 10^{-31}$ kg</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$5.48597 \times 10^{-4}$ u</td>
</tr>
<tr>
<td>$m_n$</td>
<td>Mass of Neutron</td>
<td>$1.67482 \times 10^{-27}$ kg</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$1.00867$ u</td>
</tr>
<tr>
<td>$m_p$</td>
<td>Mass of Proton</td>
<td>$1.67252 \times 10^{-27}$ kg</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$1.00728$ u</td>
</tr>
<tr>
<td>J</td>
<td>Mechanical Equivalent of Heat (Joule)</td>
<td>$4.1840$ j/cal</td>
</tr>
<tr>
<td>$N_a$</td>
<td>Avogadro’s Number</td>
<td>$6.0225 \times 10^{23}$ per mole</td>
</tr>
</tbody>
</table>

Densities of Some Common Substances

<table>
<thead>
<tr>
<th>Substance</th>
<th>$\rho$ (kg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>1.29</td>
</tr>
<tr>
<td>Ice</td>
<td>$0.917 \times 10^3$</td>
</tr>
<tr>
<td>water (4°C)</td>
<td>$1.00 \times 10^3$</td>
</tr>
<tr>
<td>Aluminum</td>
<td>$2.70 \times 10^3$</td>
</tr>
<tr>
<td>Iron</td>
<td>$7.86 \times 10^3$</td>
</tr>
<tr>
<td>Copper</td>
<td>$8.92 \times 10^3$</td>
</tr>
<tr>
<td>Lead</td>
<td>$11.3 \times 10^3$</td>
</tr>
</tbody>
</table>

Specific Heat Capacities

<table>
<thead>
<tr>
<th>Substance</th>
<th>$c_p$ (J/kg°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>$8.99 \times 10^2$</td>
</tr>
<tr>
<td>iron</td>
<td>$4.48 \times 10^2$</td>
</tr>
<tr>
<td>water</td>
<td>$4.186 \times 10^3$</td>
</tr>
</tbody>
</table>
Moments of Inertia for Objects of Uniform Composition

<table>
<thead>
<tr>
<th>Object</th>
<th>Location of axis</th>
<th>Moment of inertia</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Thin hoop of radius $R$</td>
<td>Through center</td>
<td>$MR^2$</td>
</tr>
<tr>
<td>b. Thin hoop of radius $R$ and Width $W$</td>
<td>Through central diameter</td>
<td>$1/2 MR^2 + 1/12MW^2$</td>
</tr>
<tr>
<td>c. Solid cylinder of radius $R$</td>
<td>Through center</td>
<td>$1/2 MR^2$</td>
</tr>
<tr>
<td>d. Hollow cylinder of inner radius $R_1$</td>
<td>Through center</td>
<td>$1/2M(R_1^2 + R_2^2)$</td>
</tr>
<tr>
<td>and outer radius $R_2$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>e. Uniform sphere of radius $R$</td>
<td>Through center</td>
<td>$2/5MR^2$</td>
</tr>
<tr>
<td>f. Long uniform rod of length $L$</td>
<td>Through center</td>
<td>$1/12 ML^2$</td>
</tr>
<tr>
<td>g. Long uniform rod of length $L$</td>
<td>Through end</td>
<td>$1/3 ML^2$</td>
</tr>
<tr>
<td>h. Rectangular thin plate, of length $L$</td>
<td>Through center</td>
<td>$1/12M(L^2 + W^2)$</td>
</tr>
<tr>
<td>and width $W$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>