Physical Science 101 Lab

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CHAPTER OVERVIEW

1: The Scientific Method

The scientific method has been described in numerous textbooks as a set of steps to be followed. Steps may be memorized without understanding the true nature of the steps, the true nature of doing science. The way in which a scientist approaches answering an unknown is through informed experimentation. Scientists approach the unknown as a question to be answered and devise a method, based on prior knowledge and experience, to answer the question. The method relies on precise measurements which allows for the results to be verified. Because scientists are dealing with an unknown, something for which there is not an answer, they must often begin with a hypothesis. A hypothesis is what the informed scientists thinks the answer to the question will be; it is essentially an educated guess.

- Teresa Ciardi

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1.1: Interpreting Errors

Systematic Error

- Measurements deviate from the correct value by the same amount each time
- Errors have a pattern

Example: Time on a watch is always 5 minutes ahead of the true time

Random Error

- Errors have no pattern

Example: Everyone's watch shows a different time

Uncertainty in Measurement

- Number ± error
- It is the amount a number may be off from the correct value

Example: Age ±365 days

Ratio Comparison

- Shows how two numbers compare
- Reduced fraction shows comparison

Example:

$$\frac{65\text{mph}}{30\text{mph}} = \frac{2.2}{1} \text{ (Means one speed is 2.2 times faster than the other)}$$

Percent Error

- Percentage measurements are off from standard/correct value
- Absolute value

$$\text{Percent Error} = \frac{\text{Experimental/Measured Value} - \text{Accepted/Theoretical Value}}{\text{Accepted/Theoretical Value}} \times 100\%$$

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CHAPTER OVERVIEW

2: Investigation 1 - Making a Hypothesis

Learning Objectives

- Experience making a hypothesis, taking good measurements, and developing a procedure to solve a problem.

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2.1: Materials

- Pen or Pencil
- Metric Ruler
- Meter Stick

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2.2: Introduction

For many people, it is difficult in today's world to make a guess. People tend to prefer to look up the answer rather than use experience to attempt an answer. However, scientific theories and laws often begin with a guess based on logic and experience. Another important aspect of doing science is measurement. Good measurements and a good procedure can lead to a true answer.

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2.3: Pre-lab

A. What does the word hypothesis mean?

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2.4: Procedure

You will use your spatial abilities, knowledge of volume, and collective reasoning skills to make hypotheses and test those hypotheses.

1. Draw a table in which you can record all the data you will be collecting. You will need the following table headings. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 2.4.1: Data table

Table		Floor		Room	
Hypothesis	Measurement	Hypothesis	Measurement	Hypothesis	Calculation

Table Length

2. Choose one pen or pencil from your team and place it on the table. Without direct measurement, make a hypothesis for the number of pen lengths your entire lab table is. Record this hypothesis.
3. Measure the table in units of pen lengths. Record this measurement.

Floor length

4. Without direct measurement, make a hypothesis for the number of pen lengths your lab floor is, in one chosen direction. Record this hypothesis.
5. Measure the floor length, in units of pen lengths. Record this measurement.

Room Space

6. How many pens do you think it would take to completely fill the classroom? Record this hypothesis.
7. Use your collective knowledge to develop a procedure for determining the number of pens required to fill the classroom. List the steps of your process under your table of data. Include estimates and calculations; label your estimates and calculations to indicate what these estimates and calculations show. Record your calculated number of pens to fill the room in your data table.

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2.5: Analysis

1. Calculate the difference between your hypothesis and measurement/calculation for each system (table, floor, and room).
2. Use a ratio to compare your hypothesis and measurement/calculation for each system (table, floor, and room).

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2.6: General Question

1. A small gumball is 0.56 inches in diameter. How many gumballs would it take to fill the glass globe of a gumball machine that is 8 inches in diameters? List factors that should be considered in the calculation.

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CHAPTER OVERVIEW

3: Investigation 2 - Precision and Accuracy

Learning Objectives

- Distinguish between precision and accuracy as they are used in scientific measurement and analyze errors in measurements.

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3.1: Materials

- Candle
- Aluminum Foil (12x12 inch sheet - approximately)
- Matches
- Ruler

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3.2: Introduction

A principle objective of science is to describe the physical world through measurement. While we often begin with a hypothesis in science, it is important to make precise measurements and to determine the accuracy of these measurements. There is always some amount of error, so measurements should be made several times; the average of several measurements will lessen the amount of error introduced by the measuring process. The words precision and accuracy are often used interchangeably in common language, however, these two words have very different meanings.

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3.3: Pre-lab

A. Define what is meant by precision in scientific measurements
B. Define what is meant by accuracy in scientific measurements.

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3.4: Procedures

You will record measurements from three different systems and analyze errors.

Reaction Time

1. Draw a table in which to record your data for the distance a ruler falls, as you attempt to grasp it; you will need to have 5 successful trials recorded (see example table on following page). Do not fill in data until you have read the instructions for obtaining that data.

Table 3.4.1: Falling Ruler Data

Trial #	Distance Ruler Fell (cm)
1	
2	
3	
4	
5	

2. **Each person** will record only their own data, as each person in your group attempts to grasp a ruler while it falls. One person will hold the top of a ruler so that the ruler hangs down vertically, while you place your index finger and thumb at the bottom edge of the ruler as if **you** are about to pinch the ruler. (See image).

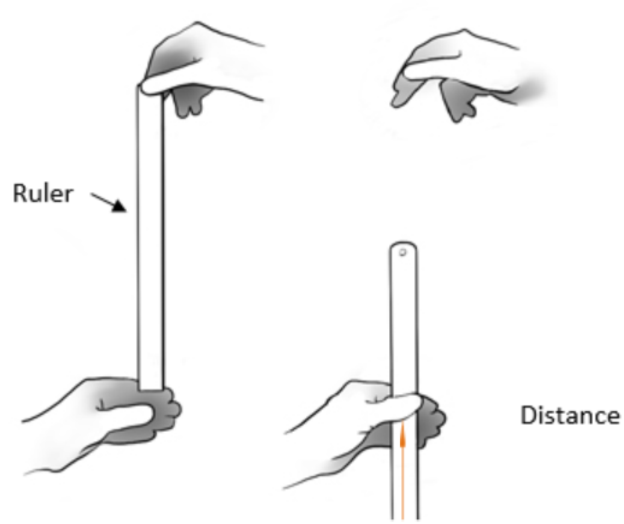

Figure 3.4.1: Image by BiologyCorner is licensed under CC BY-NC 3.0

3. The person holding the ruler should allow the ruler to drop without warning. **You** will then pinch the ruler as fast as you can. Record the distance the ruler falls **in centimeters**, for each of five successful trials. If the ruler falls to the floor, this is not a successful trial; repeat the trial.

Burning Candle

4. Draw a table in which to record your data for the length of the candle, before and after it burns, and every 2 minutes while it burns. Read the instructions for obtaining the data.

Table 3.4.2: Burning Candle Data

Time (minutes)	Length (centimeters)
Pre-burn	

Time (minutes)	Length (centimeters)
2	
4	
6	
8	
10	
Post-burn	

5. Use the aluminum foil to create a candle stand. Measure the length of the unlit wax candle **in centimeters**. Record this value as the pre-burn value.

Warning

Be careful that you do not burn yourself or the ruler during this experiment.

6. Light the candle and allow it to burn for the duration of this mini-experiment. Measure the total length of the candle + flame, **in centimeters**, every 2 minutes for a total of 10 minutes.

Figure 3.4.2: Candle by Teresa Ciardi is used under a CC-BY 4.0 license.

7. Extinguish the candle flame. Measure the length of the unlit wax candle **in centimeters**. Record this value as the post-burn value.

Clocks

8. Look at the clock in the room and record the time. Then look at the time on your watch or cell phone and record the time. You will only have one trial for this mini-experiment.

Table 3.4.3: Time on clock and watch/ phone

Time on Clock	Time on Watch/Phone

Clean-up:

- Rinse your match and throw it away
- Throw away the foil
- Clean up any spilled wax

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3.5: Analysis

Reaction Time

1. Draw a table in which to record the average distance the ruler fell for each person on your team. Calculate and record the average distance the ruler fell, in centimeters, as you attempted to grasp it. Also record the average distance the ruler fell for each of your team members.

Table 3.5.1: Reaction Time Averages

Team Member	Average Distance (centimeters)

2. Based on the data, who has the best reaction time? Explain.
3. List two possible sources of error in the reaction time experiment, and state whether each error was random or systematic.

Burning Candle

4. If your candle had been allowed to burn for 30 minutes, what do you predict the change in length, from pre to post burn, would have been? Explain your reasoning.
5. Describe the change in length of the candle that occurs while it is burning. Is there a steady decrease in height? Explain.
6. List two possible sources of error in the burning candle experiment. For each error, state whether it was a random error or a systematic error.

Clocks

7. Is it possible to measure the precision from the data you obtained in this mini-experiment? Explain.
8. List two possible sources of error in the clocks experiment. For each error, state whether it was a random error or a systematic error.

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3.6: General Questions

1. For which system (Reaction time, Burning Candle, or Clocks) did your team obtain the most precise measurements? Explain.
2. A systematic error will definitely affect (choose one)
   a. Precision
   b. Accuracy
   c. Both precision and accuracy
3. Teresa, Alexes, and Krystina, having received degrees in paleontology, each measure the length, in centimeters, of a dinosaur bone unearthed by their dog Bacall. Bacall, having more experience with bones, measured the bone once and obtained the correct value. Calculate the average measurement obtained by each person.

Table 3.6.1: Average measurement obtained by each person

	Teresa	Alexes	Krystina	Bacall
	2.0	7.3	7.0	7.3
	2.1	9.1	7.3	
	1.9	5.8	7.2	
	2.0	7.0	7.1	
Average				

   a. Whose measurements are accurate and precise?
   b. Whose measurements are precise but not accurate?
   c. Whose measurements are accurate but not precise?
   d. Whose measurements are accurate, but have no measure of precision?
   e. Whose measurements are probably a result of a systematic error?
   f. Calculate the percent error for Teresa, Alexes, and Krystina.

Table 3.6.2: Percent error calculation

	% Error
Teresa	
Alexes	
Krystina	

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CHAPTER OVERVIEW

4: Investigation 3 - The Best Paper Towel

Learning Objectives

- Analyze properties of different brands of paper towels and utilize a scientific approach to determine the best brand of paper towel for the money.

Adapted from a Lab written by Aulikki Pekkala-Flagan, with her permission

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4.1: Materials

- 4 Different Brands of Paper Towels (keep packaging details and price)
- 4 Small Index cards (3x5 inch size)
- Scissors
- Triple Beam Balance
- 250 mL Beaker
- 24 Clothespins (per group)
- Plastic Pipette
- Various Masses (20-1000 grams)
- Permanent Marker
- Metric Ruler
- Stop Watch

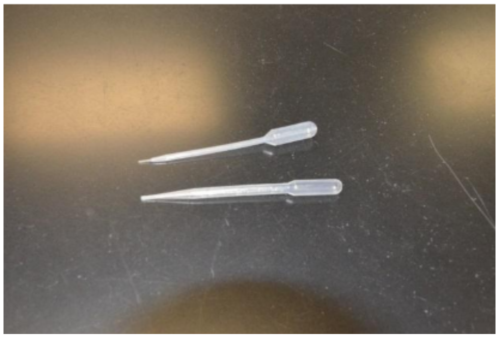

Figure 4.1.1: Pipette by Norihiro licensed under CCO

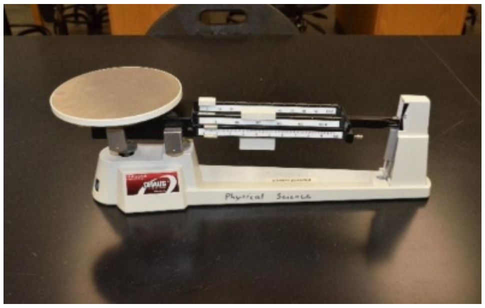

Figure 4.1.2: Triple Beam Balance by Norihiro licensed under CC0

Figure 4.1.3: 250 ml Beaker. Image by Lucasbosch licensed under a Creative Commons Attribution-Share Alike 3.0 Unported.

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4.2: Introduction

There are various properties that make a particular brand of paper towel appealing to a consumer which may include absorbency, durability, appearance, and/or cost. Paper towels have a variety of thicknesses and textures, and may vary in cost significantly. Scientists must devise a plan to answer a question, utilizing the information available and creating a process that is systemic so the same tests are applied and a consistent method of measurement is utilized. The question is, which paper towel is the best value?

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4.3: Pre-lab

A. What is the most important property to you that would promote you purchasing a particular brand of paper towel?

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4.4: Procedures

You will investigate and compare the properties of paper towels.

Absorbency

1. Choose the four brands of paper towels you will be testing and obtain 2 sheets of each. Label the sheets with the brand name.
2. Draw the table for absorbency data. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 4.4.1: Absorbency Data

Paper Towel Brand	Predicted Absorbency Ranking	Dry Mass (grams)	Wet Mass (grams)	Amount of Water Absorbed (grams)	Measured Absorbency Ranking

3. List the brand names of the paper towels your team chose, in your table. Number the predicted rankings for the paper towels, in your table; give a 1 to the paper towel you expect to have the best absorbency and a 4 to the paper towel you expect to have the least absorbency.
4. Cut an equal size piece of each brand of paper towel. Label these pieces with the brand name.
5. Devise a process for testing the absorbency, which includes measurements of the dry mass and wet mass for the paper towel pieces. Follow the process and complete your table.

Clean-up

- Throw away wet paper towel pieces
- Completely dry Triple Beam Balance
- Use classroom paper towels to dry the team table

Speed

6. Draw the table for speed data and list the brand names of the paper towels your team chose. Read the instructions for obtaining your *speed* data.

Table 4.4.2: Speed Data

Paper Towel Brand	Predicted Speed Ranking	Time to Absorb Water	Measured Speed Ranking

7. Cut an equal size thin strip of each brand of paper towel. Label these pieces with the brand name.
8. Number the predicted rankings for the paper towels, in your table; give a 1 to the paper towel you expect to have the fastest absorbency time and a 4 to the paper towel you expect to have the slowest absorbency time.
9. Devise a process for testing the speed at which each strip absorbs water, which includes time measurements. Follow the process and complete your table.

Clean-up

- Throw away wet paper towel pieces
- Use classroom paper towels to dry the team table

Strength

10. Draw the table for strength data and list the brand names of the paper towels your team chose. Read the instructions for obtaining your *strength* data.

Table 4.4.3: Strength Data

Paper Towel Brand	Predicted Strength Ranking	Observed Strength Ranking

11. Cut an equal size piece of each brand of paper towel. Label these pieces with the brand name.
12. Number the predicted rankings for the paper towels, in your table; give a 1 to the paper towel you expect to be the strongest and a 4 to the paper towel you expect to be the weakest.
13. Devise a process for testing the strength of the wet paper towel pieces, using the materials provided (clothespins and/or various masses), which includes specific observations. Follow the process and complete your table.

Clean-up

- Throw away wet paper towel pieces
- Use classroom paper towels to dry the team table

Cost

14. Draw the table for cost information and list the brand names of the paper towels your team chose. Read the instructions for obtaining your *cost* data.

Table 4.4.4: Cost Data

Paper Towel Brand	Cost per Roll	Square Feet per Roll	Calculated Cost per SQ FT

15. Use the information from the packaging to calculate the value of each paper towel (SQ FT per penny), and record this value in your table.

Clean-up

- Throw away any remaining pieces of paper towels at your team table
- Discard water outside (water plants)
- Use classroom paper towels to completely dry beaker

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4.5: Analysis

1. Which brand of paper towel absorbed the greatest amount of water?
2. Which brand of paper towel absorbed water the fastest?
3. Which brand of paper towel is the strongest?
4. Which brand of paper towel is the least expensive (has the lowest cost per SQ FT)?
5. Based on your data and calculations, which brand of paper towel would be the best paper towel for the price? Use your experimental results to defend your answer.

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4.6: General Questions

1. If you were to repeat this experiment, what would you change?
2. Now that you have completed this investigation, would your answer the pre-lab question be different?
3. What would you test to determine the best computer printer paper for the money? List at least two comparison tests you would want to make.

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CHAPTER OVERVIEW

5: Investigation 4 - Measuring a Wood Block

Learning Objectives

- Measure objects in inches and centimeters, and compare English and metric measurements.

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5.1: Materials

- Metric Ruler
- Wood Block (approximately 2x4x6 inches)
- Metal Cylinder (1000 grams)

Figure 5.1.1: Wood Block

Figure 5.1.2: 1,000 gram Mass

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5.2: Introduction

Measurement is an objective tool of science. When measurements utilize the same units, they may be qualitatively and objectively compared. The United States continues to use English units, such as the inch and the foot. The system of units used in the physical sciences are based on the metric system, which utilizes multiples of 10.

1 meter = 100 centimeters

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5.3: Pre-Lab

A. Write the formula for calculating the volume of a cube.
B. Write the formula for calculating the volume of a cylinder.

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5.4: Procedures

You will measure in English and metric units, and compare these measurements.

Quantifying a Wood Block

1. Draw a table for the Wood Block. Do not fill in data until you have read the instructions for obtaining that data.

Table 5.4.1: Wood Block Data

Units	Length	Width	Thickness	Volume
Inches				
Centimeters				
Meters				

2. Measure the length, width, and thickness of your wood block in inches and centimeters, and enter these values into your table.
3. Convert all of the centimeter measurements, for your wood block, to meters.
4. Calculate the volume of your wood block, for each set of units (inches, centimeters, and meters), and enter these values into your wood block table.

Quantifying a Metal Cylinder

5. Draw a table for the Metal Cylinder. Read the instructions for obtaining your *metal cylinder* data.

Table 5.4.2: Metal Cylinder Data

Units	Radius	Height	Volume
Inches			
Centimeters			
Meters			

6. Measure the radius and height of your metal cylinder in inches and centimeters, and enter these values into your table. Do not include the hook when you measure the height.
7. Convert all of the centimeter measurements, for your metal cylinder, to meters
8. Calculate the volume of your metal cylinder, for each set of units (inches, centimeters, and meters), and enter these values into your metal cylinder table.

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5.5: Analysis

1. Draw the table to record your analysis values for the wood block. Use a ratio to compare measured centimeters to inches, in each dimension, for the wood block; reduce fractions such that the smallest value is 1.

Example:

$$\frac{540 \text{ inches}}{15 \text{ yards}} = \frac{36\text{in}}{1\text{yd}}$$

Table 5.5.1: Wood Block Ratio Analysis

Ratio	Length	Width	Thickness/Height
$\frac{\text{centimeters}}{\text{inches}}$			

2. Draw the table to record your analysis values for the metal cylinder. Use a ratio to compare measured centimeters to inches, in each dimension, for the metal cylinder; reduce fractions such that the smallest value is 1.

Table 5.5.2: Metal Cylinder Ratio Analysis

Ratio	Radius	Height
$\frac{\text{centimeters}}{\text{inches}}$		

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5.6: General Questions

1. Based on your analysis calculations, what is the conversion factor for inches and centimeters?
2. How many places must you move the decimal to change from centimeters to meters? In what direction must you move the decimal in this case?

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CHAPTER OVERVIEW

6: Investigation 5 - Walking at a Constant Speed

Learning Objectives

- Compare average walking speeds, and distinguish between average and constant speed.

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6.1: Materials

- 2 Stopwatches (you may use your phones)
- Masking Tape
- Measuring Tape
- Mobile Phone

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6.2: Introduction

As we walk or drive, there are often distractions that may cause us to change our speed slightly. For motion in a straight line, the average speed (s) is the total distance (d) traveled divided by the time (t) it took to travel that distance. If the speed is constant, then the average speed for each time interval will have the same value.

$$s = \frac{d}{t}$$

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6.3: Pre-Lab

A. Is constant speed the same as average speed? Explain.

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6.4: Procedures

Each person in the group will walk a distance of 10 meters multiple times.

Just Walking

1. Use masking tape to mark a path with two equally spaced distance intervals (5 meters each) as shown below.

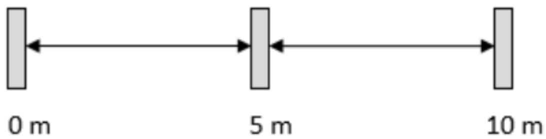

Figure 6.4.1: Two equally spaced distance intervals

2. Draw a table in which to record only your data for just walking. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 6.4.1: My Just Walking Data

Trial #	Time for 0-5 meters	Time for 5-10 meters
1		
2		
3		
Average Time		
Average Speed		

3. One team member will stand at the 5 meter mark to measure the time it takes for you to walk the first interval (0-5 meters). A second team member will stand at the 10 meter mark to measure the time it takes for you to walk the second interval (5-10 meters).
4. You will walk the full 10 meters, without pausing, while your team members collect your data, for a total of 3 trials. Record your data in your data table.
5. Repeat procedures 3 and 4 until each team member has their data.
6. Calculate your average time and speed for each interval and record these values in your data table.

Texting & Walking

7. Draw a table in which to record only your data for texting and walking.

Table 6.4.2: My Texting and Walking Data

Trial #	Time for 0-5 meters	Time for 5-10 meters
1		
2		
3		
Average Time		
Average Speed		

8. Use your mobile phone to send a text or look through your social media while walking the 10 meters for the texting and walking trials. Record your data and calculations in your texting and walking data table.

Clean-up

- Remove all masking tape from the ground, and throw it away

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6.5: Analysis

1. Look at your two data tables. Did you tend to walk faster when you were just walking or when you were texting and walking?
2. Look at each other's data tables and discuss any trends and/or differences your team notices.

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6.6: General Questions

1. You calculated an average speed for each interval. Are these values also your constant speed? Explain.
2. It is 2,790 miles from L.A. to N.Y. If you average 60 mph, how many days will it take you to travel from Los Angeles to New York by car, non-stop? Will your speed be constant?
3. If you leave L.A. on Monday at 8:00 am, stop for 7 hours of sleep each night, and stop for half an hour to eat three times a day, when (day and time) would you arrive in New York? Assume that you average 60 mph when you are driving.

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CHAPTER OVERVIEW

7: Investigation 6 - Falling Objects

Learning Objectives

- Observe falling objects and compare the acceleration of falling objects in air.

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7.1: Materials

- Bathroom Rug (about 2 feet by 3 feet)
- Meter Stick
- Measuring Tape
- Masking Tape
- g-Ball
- Stop Watch (you may use your phone)
- 6 objects (Feather, Paperclip, Marble, Various Balls, etc.)

Figure 7.1.1: g-ball g-Ball image courtesy of Arbor Scientific

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7.2: Introduction

There is always some delay between the time an observation is made and the time it takes for a person to react and push the stop watch button, so the g-Ball will be used initially to remove the reaction time of a person from the process. Objects falling in air all experience the same acceleration due to gravity, however, the air may affect these objects differently. The average acceleration (a) of an object as it falls through air depends on the distance (d) it falls, and the time (t) it took for the object to fall.

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

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7.3: Pre-Lab

A. If there was no air, what would the vertical acceleration be for each object?

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7.4: Procedures

You will drop the g-Ball and several objects, and compare the acceleration of these items in air.

Setting the Standard

1. Draw a table in which to record the data for the g-Ball. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 7.4.1: g-Ball Data

Distance (meters)	Trial 1 (seconds)	Trial 2 (seconds)	Trial 3 (seconds)	Average Time (seconds)	Average Acceleration m/s^2
1/2					
1					
2					

2. Place the bathroom rug on the floor or ground, under the place where you will be dropping the g-Ball.
3. Practice with the g-Ball so that you know how it works prior to starting the trials for your data. Drop the g-Ball 3 times from each of the heights listed in your data table, and record the time shown on the g-Ball. This is the time it took for the g-Ball to fall to the floor once released.
4. Calculate and record the average time for each of the heights from which you released the g-Ball.
5. Use the equation in the introduction and algebra to solve for the average acceleration (a). Calculate and record the average acceleration of the g-Ball for each distance dropped.

Testing Everyday Objects

6. Choose 6 objects of different masses and sizes; do not use the g-ball. Discuss how you will compare the acceleration of these objects when they are dropped from a height through air. Also, consider how you will compare the data for the 6 objects to the g-Ball. Draw a data table for the data you will be collecting.

Table 7.4.2: Everyday Objects Data

Object	Predicted Rank	Trial 1 (seconds)	Trial 2 (seconds)	Trial 3 (seconds)	Average Time (seconds)

7. List the 6 objects in your data table. Indicate next to each object, the predicted rank order for these objects to fall to the ground, from shortest time (1st) to longest time (6th).
8. Find a safe location from which to drop your 6 objects, a height of two to three stories if possible. Measure and record this distance in meters under your data table.
9. Proceed with dropping your 6 objects, 3 times each. Calculate and record the average time for each object.

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7.5: Analysis

1. Were the average acceleration values you calculated for the g-Ball very similar or very different?
2. Compare the rate of descent of the 6 objects. Was the acceleration for your 6 objects very similar or very different? Explain.
3. Describe any differences in properties of objects which may contribute to less/more downward acceleration. How do these properties of the objects compare to the properties of the g-Ball?
4. Which object had the greatest upward acceleration from air? Explain.
5. In general, what errors in your measurements may have occurred in this investigation?

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7.6: General Questions

1. In the absence of air, what would be the rate of acceleration for all of your everyday objects?
2. The Eiffel Tower is about 300 meters tall. In the absence of air, it would take an object 7.8 seconds to fall to the ground. What would be the speed of an object once it hit the ground, if it was dropped from the top of the Eiffel Tower?

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CHAPTER OVERVIEW

8: Investigation 7 - Traveling in a Circle

Learning Objectives

- Analyze the behavior of objects traveling in a circular path, and name some sources of centripetal force.

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8.1: Materials

- Aluminum Pie Tin (with part of sidewall removed)
- Marble
- Approximately 1-meter Length of Rope
- Soft Object (which can be secured to rope)
- Triple Beam Balance

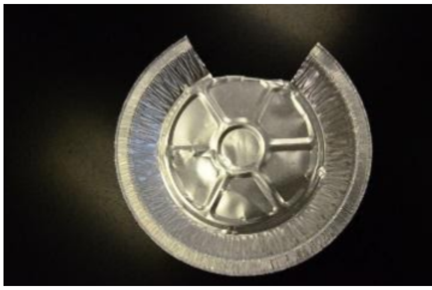

Figure 8.1.1: Pie Tin with Opening

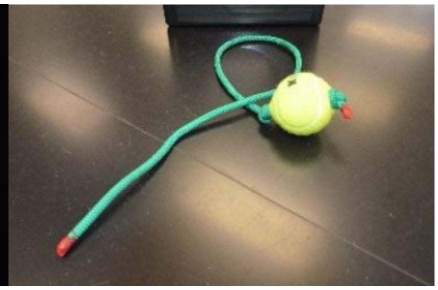

Figure 8.1.2: Tennis Ball with Rope (Ideal)

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8.2: Introduction

Circular motion may include the orbital motion of an object, or motion that outlines part of a circular path. According to Newton's 1st law of motion, an object will maintain straight line motion unless it is pushed or pulled by some force. Any force that causes an object to travel in a circular path is a centripetal force ("center-seeking" force). The push or pull forces the object to change direction and follow a circular path. The amount of force (F) required to keep a mass (m) traveling along a circular path depends the speed (v) with which the object travels around the circle and the radius (r) of the circle.

Centripetal Acceleration:

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

Centripetal Force:

$$\mathbf{F} = \mathbf{ma}$$

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8.3: Pre-Lab

A. What is the radius of a circle? You may describe or sketch this.
B. What is the distance around a circle called? What is the formula for this?

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8.4: Procedures

You will analyze three systems involving circular motion.

1. Draw a table in which to record your circular motion data and observations. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 8.4.1: Circular motion data and observations

System	Mass (grams)	Radius of Path (centimeters)	Centripetal Force	Push or Pull	Centripetal Force Direction
Marble & Pie Tin					
Ball & Rope					
Spaceship & Earth					

Marble around the Pie Tin

2. Predict the path the marble will take as it leaves the opening in the pie tin. Will it continue in a circular path or will it travel in a straight line when it leaves the pie tin? Describe or sketch your prediction.
3. Place the pie tin on the table, and start the marble traveling along the inside edge of the pie tin. You will need to give the marble a good, fast start with your hand; the pie tin should remain on the table for this. Describe or sketch the path of the marble <u>after</u> it leaves the pie tin through the opening.

Figure 8.4.1: Path of the marble

4. Name or describe the centripetal force that kept the marble traveling in a circle while it was in the pie tin. Record whether the marble was pushed or pulled into a circular path, and the direction of the push or pull that kept the marble circling while it was in the pie tin.
5. Measure the mass of the marble, and the radius of the pie tin. Enter these values in your data table.

Orbiting Object

Warnings

- Be careful that no one is impacted by your orbiting object, and do not let go of it.
- Impact safety glasses are recommended while circling the object on the rope.

6. Predict whether it will be more difficult to hold onto the rope when the object is circling with a slow or fast speed. Record your prediction.
7. Hold the rope firmly and circle the object at a steady rate. Then increase the speed at which your object is circling. In which case is more force required to hold onto the circling object, when it has a slow orbital speed or a fast orbital speed? Record your answer.

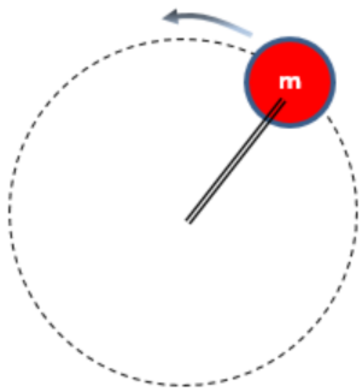

Figure 8.4.2: Circling the object at a steady rate

8. Name or describe the centripetal force that kept the object on the rope traveling in a circle. Record whether the object on the rope was pushed or pulled into a circular path, and the direction of the push or pull that kept the ball and rope circling.
9. Measure mass of the object and rope, and the radius of the system (length of the rope). Enter the mass and radius values in your data table.

Space Ship

10. A spaceship is in orbit 300 km above the surface of the Earth (r = 6.378 x 106 meters). Assume the spaceship is the USS Enterprise from Star Trek, with a mass of 9.6 x 107 kg. Record the mass of the ship and the radius of the orbit in your data table.

Figure 8.4.3: Spaceship Comic-Con 2006 - USS Enterprise by The Community - Pop Culture Geek is licensed under CC BY 2.0

Figure 8.4.4: Earth Blue Marble 2002 by NASA is in the public domain

11. Name or describe centripetal force that keeps the spaceship orbiting the Earth. Record whether the ship is pushed or pulled into a circular path, and the direction of the push or pull that keeps the ship circling.

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8.5: Analysis

1. In general, what is the direction of the push or pull if an object is traveling in a circle?
2. For each of the following quantities, determine whether changing the quantity would change the amount of push or pull when an object is circling. Explain each answer.
   a. Speed at which it circles
   b. Radius of circle
   c. Mass of the object
3. Which object (Marble, Object on Rope, or Spaceship) do you think has the greatest centripetal acceleration? Why?
4. Which object (Marble, Object on Rope, or Spaceship) do you think requires the greatest centripetal force to keep it circling? Why?

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8.6: General Questions

1. Assume that you have the object on the rope circling overhead. At which point in the orbit should you release the object if you want to hit a target (X marks the spot) directly in front of you? Draw a diagram. Do not attempt to confirm this experimentally!

Figure 8.6.1: Object on the rope circling overhead

2. If you maintain a constant rate of speed for the orbiting object, is there acceleration? Explain.
3. Draw the sketch below. Draw arrows to indicate the direction of the force keeping the spaceship in orbit.

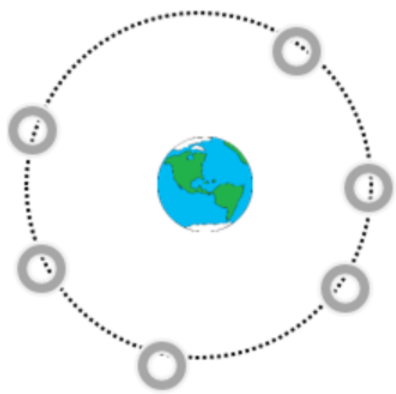

Figure 8.6.2

4. Assume the spaceship has a deflector screen which makes it immune to the force from Earth. If the ship is traveling along in its orbit, and the ship turns off its engines at the same time it turns on its deflector shield, what will happen? Choose one answer and defend it.
   a. The ship will continue traveling in a circle.
   b. The ship will travel in a straight line tangent to the circular orbit.
   c. The ship will spiral down to the Earth.
   d. The ship will come to a full stop, hovering above the Earth.

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CHAPTER OVERVIEW

9: Investigation 8 - Firing at a Distant Target

Learning Objectives

- Determine the optimal angle for a projectile, and calculate the range of a horizontal projectile.

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9.1: Materials

- Mini Launcher with 16 mm Solid Steel Ball
- C Clamp
- Photogate Timer
- Empty Soup Can
- Meter Stick
- Measuring Tape
- Ring Stand
- Stopwatch

Figure 9.1.1:

Ring Stand by Nasco

Figure 9.1.2: Mini Launcher by Pasco

Figure 9.1.3: Photo Gate from Arbor Scientific

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9.2: Introduction

An object that is launched outward from a height above the ground will follow a curved path. The curved path of a projectile is a combination of the horizontal motion it is given and the effect of gravity on the object. A projectile launched horizontally, parallel to the ground, is dropping at the same time as it is traveling horizontally, and the result is a curved path.

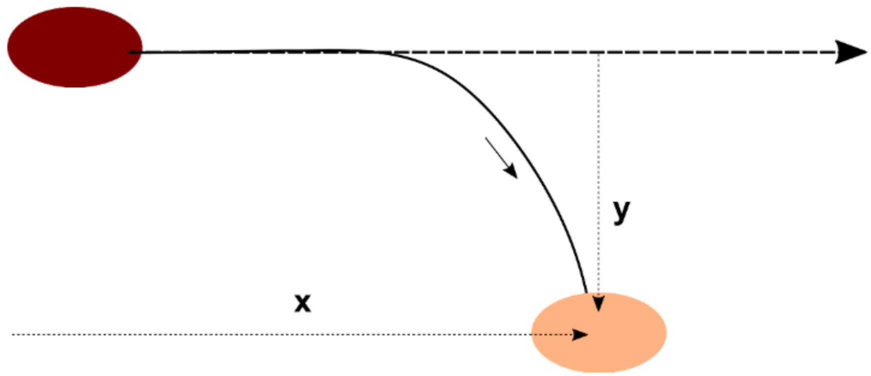

Figure 9.2.1: A projectile launched horizontally

The ball will travel a distance in the horizontal (x) plane while it is dropping in the vertical (y) plane.

Horizontal Motion:

$$x = vt$$

Vertical Motion:

$$t = \sqrt{\frac{2y}{g}}$$

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9.3: Pre-Lab

Do you think the angle at which a ball is thrown makes a difference in the horizontal distance the ball will travel?

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9.4: Procedures

You will launch a steel ball at a variety of angles and parallel to the ground.

Investigating Angle

1. Draw a table in which to record data for three different angles. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 9.4.1: Investigating Angles Data

Angle	Trial 1 Distance	Trial 2 Distance	Trial 3 Distance	Average Distance

2. Use the C-Clamp to secure the launcher to the table, near the edge of the table.

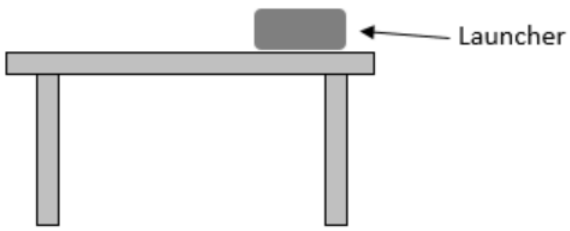

Figure 9.4.1: C-Clamp to secure the launcher to the table

3. Position the launcher such that it is horizontal, with a 0 angle. Use the push rod to press the ball into the launcher; pushing the piston back into the barrel will load the launcher and each click results in more force to launch your projectile. Make a couple of practice shots to familiarize yourself with the launcher.
4. Choose three non-zero angles from which you will release the ball, and record these angles in your table. Indicate the angle you think will result in the ball traveling the greatest distance.
5. Use the same number of clicks each time you load the launcher, and collect the data to complete your *Investigating Angles* data table. All of your distance measurements should be in meters. Once you have collected all of your data, calculate the average distances for the angles you chose.

Determining the Range

6. Draw a data table in which to record your measurements and calculations for horizontal range. Read the instructions for obtaining the data.

Table 9.4.2: Horizontal Range Data

Drop Distance y	Dropping Time t	Launch Speed v	Predicted/Calculated Horizontal Distance x	Measured Horizontal Distance x	Error

7. Measure and record the vertical distance (y), in meters, that the ball must drop from its release point to a can on the floor. **Do not attempt to launch the ball into the can yet.**

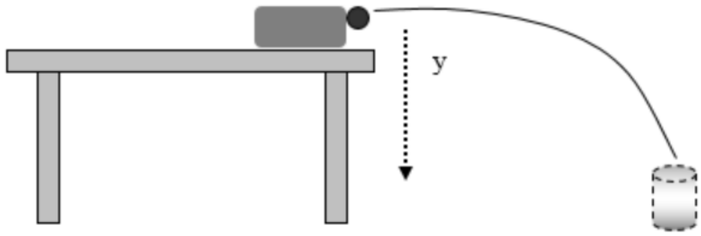

Figure 9.4.2: Measure and record the vertical distance (y)

8. Measure or calculate the time (t) for the ball to drop from the first drop height (y). The *vertical motion* equation and your measured (y) can be used to calculate the time (t) it will take the ball to fall from the release point to the can on the floor. Record the time (t) in seconds for your measured distance (y). Also record a time for the 1/2y drop.
9. Position the launcher such that it is horizontal, parallel to the ground, with a 0° angle.
10. Place the photogate in front of the launcher such that the ball will pass through the photogate when launched. Make a couple of practice shots through the photogate to determine the number of clicks that will work best with the launcher at a 0° angle.
11. Load the projectile. Launch the projectile with a 0° angle at least 3-4 times, and record the average launch speed (v) of the ball shown by the photogate. Record this value for in your *Horizontal Range* data table; this speed applies to both drop distances.
12. Predict the horizontal distance (x) you think the ball will travel for each drop distance. You may choose whether to make a hypothesis or use the *horizontal motion* equation to calculate the horizontal distance (x) that the ball should travel. Record your prediction or calculation for the horizontal distance (x) in your data table.
13. Measure from the table along the floor to where you predict the can should be placed, for the first drop distance (y). Place the can on the floor at the horizontal range (distance) you have predicted. Launch the projectile with a 0^0 angle and observe the actual horizontal distance (x) the ball travels. It may take a couple of trials to observe exactly where the ball hits. Measure and record the actual horizontal distance your ball travels. Calculate the difference between your predicted distance and the measured distance the ball travelled in the horizontal; record this as your error.
14. Use the ring stand to set up the launcher at 1/2 y. Maintain the 0° angle, so your projectile will launch horizontally.

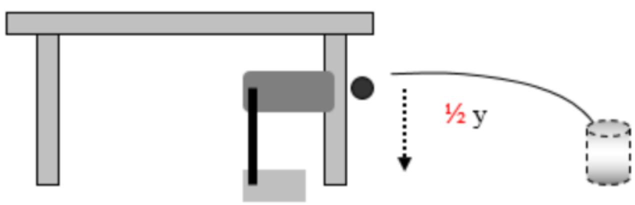

Figure 9.4.3: Set up the launcher at 1/2 y

Measure from the table along the floor to where you predict the can should be placed for the 2nd drop distance (1/2 y). Place the can on the floor at the horizontal range (distance) you have predicted of this drop. Repeat the launch process and record values for this drop distance.

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9.5: Analysis

1. Based on your data, which of the following angles would result in a football traveling the greatest distance when thrown for a long pass? (Choose one)
   a. 30^o
   b. 45^o
   c. 60^o
2. What errors in the ***determining the range*** process may account for missing the can?
3. In general, describe any relationship between the vertical distance (y) from which a projectile is launched and the horizontal distance (x) the projectile may be expected to travel.

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9.6: General Questions

1. A football player throws a football from 2.4 meters above the ground, with a horizontal velocity of 50 mph (22.35 m/s). What do you predict the horizontal range (x) will be for this football, in the absence of air? Explain how you made your prediction.
2. In another situation, a football is in flight and falling. The football falls a distance in the vertical (y) every 1/10th of a second as indicated by the values in the chart below. Use the chart to construct two different graphs. Analyze each graph, state the relationship shown by each graph, and describe the motion indicated by each graph.
   a. Graph 1: Distance (y) versus time (t)
   b. Graph 2: Distance (y) versus time squared (t^2)

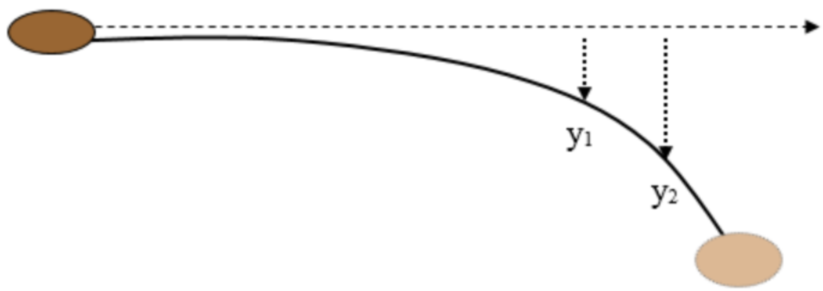

Figure 9.6.1

Table 9.6.1

	Time (t) seconds	Distance (y) meters	Time Squared (t^2) seconds
y_1	0.10	0.05	0.01
y_2	0.20	0.19	0.04
y_3	0.30	0.44	0.09
y_4	0.40	0.79	0.16
y_5	0.50	1.23	0.25

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CHAPTER OVERVIEW

10: Investigation 9 - Balanced and Unbalanced Forces

Learning Objectives

- Locate all forces acting on a system and determine whether forces are balanced.

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10.1: Materials

- 2 Dumbbells (equal weight)
- Stop Watch
- Meter Stick
- Ribbon (2 meters in length)
- Object/Pendulum Fob (such as heavy key chain)
- 1000 gram Mass

Figure 10.1.1: Ribbon/Rope

Figure 10.1.2: Example Key Chain

Figure 10.1.3: Dumbbells Image by honka13 is licensed under CC0

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10.2: Introduction

Usually, there are several forces acting on an object at the same time. However, the object will only change its motion if one of the forces is greater than the other(s). An object will be accelerated by a net force. A net force is the sum of all forces (both magnitude and direction) acting on an object. If all forces are balancing each other, then the object will not change its motion. Forces that are balanced are equal in magnitude, but are applied in opposite directions. A net force (F) on a mass (m) will cause an acceleration (a).

$$F = ma$$

Example: A person standing on the floor would experience two forces.

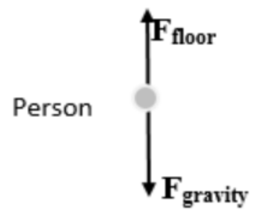

Figure 10.2.1

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10.3: Procedures

You will determine whether forces are balanced.

1. Draw a table in which to record balanced and unbalanced forces for each situation. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 10.3.1: Balanced and unbalanced forces for each situation

System	Forces Acting + Direction	Balanced or Unbalanced
Straight Arm lifting Dumbbells		
Straight Arms holding Dumbbells		
Bicep Curl with Dumbbells		
Bicep Curl holding Dumbbells		
Mass Placed on Meter Stick		
Mass Sitting on Meter Stick		
Pendulum at Position A		
Pendulum at Position B		
Mass Pushed		
Mass Sliding		
Mass Stopped		

Dumbbells

2. Stand with your arms at your side, and hold one dumbbell in each hand. Lift the dumbbells with straight arms (left image), and hold them in place for 10 seconds. Then lift the dumbbells with a bicep curl (right image), and hold them in place for 10 seconds. Each person on the team should try this. Name or describe the forces acting on the dumbbells for each action with the dumbbells, in your data table, and use an arrow to indicate the direction of each force. Record whether forces on the dumbbells were balanced or unbalanced for each action with the dumbbell, in your data table.

Figure 10.3.1: https://gethealthyu.com/Investigation/elevated-bicep-curl/

Mass on a Bridge

3. Make a long but stable bridge with the meter stick and 2 lab chairs. Place the 1000 gram mass in the center of the meter stick. Then allow the mass to sit on the bridge for 10 seconds. Remove the mass from the meter stick bridge. Name or describe the forces acting on the mass for each action with the mass, in your data table, and use an arrow to indicate the direction of each force. Record whether forces were balanced or unbalanced for each action with the mass, in your data table.

Pendulum

4. Make a pendulum that hangs from the center of the meter stick bridge, using a heavy key chain and ribbon by tying the ribbon in a bow (so it may easily be untied). Start the pendulum swinging, and observe its motion. Name or describe the forces acting on the mass for each position of the pendulum, in your data table, and use an arrow to indicate the direction of each force. Record whether forces were balanced or unbalanced for each position of the key chain, in your data table. Record whether the forces on the key chain were balanced or unbalanced for each position, in your data table.

Figure 10.3.2: Pendulum

Sliding

5. Place the 1000 gram mass on the table and give it a good push to send it sliding; allow the mass to slide on the table and come to a stop. Name or describe the forces acting on the mass for each action with the mass, in your data table, and use an arrow to indicate the direction of each force. Record whether forces were balanced or unbalanced for each action with the mass, in your data table.

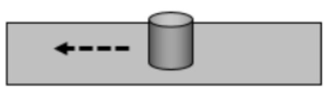

Figure 10.3.3: Sliding mass

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10.4: Analysis

1. Did you feel a different force on your bent arm as compared to your straight arm while lifting the dumbbells?
2. Did you feel a different force with straight arms as compared to the bicep curl while holding the dumbbells?
3. Explain why the meter stick only moved a small distance and then stopped moving as you placed the 1000 gram mass on meter stick-bridge. What happened with the forces?
4. Describe any differences shown by your force arrows for the sliding mass, when it was being pushed as compared to when it was sliding.
5. Compare and contrast your force arrows for the two positions of the pendulum as it is swinging. What is similar? What is different?

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10.5: General Questions

1. Is there a change in the motion of an object if forces are unbalanced?
2. Is there a change in the motion of an object if forces are balanced?
3. In order to maintain a constant 30 mph on a straight, flat road, you must apply pressure to the accelerator. Is there a net force on the car? Explain.

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CHAPTER OVERVIEW

11: Investigation 10 - Weight of Mass

Learning Objectives

- Learn your weight on other planets, and differentiate between weight and mass.

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11.1: Materials

- Intranet
- Bathroom Scale (optional)

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11.2: Introduction

Isaac Newton called mass the quantity of matter. Mass can also be thought of as a numerical measure of inertia, that exists in the absence of gravity. Weight is the pull of gravity on a mass, and depends both on the mass and on the amount of gravitational force present.

Equation for Weight:

$$W = mg$$

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11.3: Pre-Lab

A. Define what is meant by a fundamental quantity.
B. Write the standard metric units of mass and force.

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11.4: Procedures

You will analyze your weight and mass on the planets in our solar system.

1. Estimate or measure your weight on Earth. Convert this weight from pounds to Newtons. (1 Newton = 0.2248 lb).
2. Draw a table in which to record your weight data for all 8 planets, Pluto, and our Moon. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 11.4.1: Weight Data

Object	Weight in lbs	Weight in Newtons
Mercury		
Venus		
Earth		
Moon		
Mars		
Jupiter		
Saturn		
Uranus		
Neptune		
Pluto		

3. Utilize the following website to learn your weight on other objects in our solar system, including all 8 planets, Pluto, and our Moon. Enter your approximate weight on Earth, and choose "calculate". Your weight will be shown for each object in units of pounds. Record these weight values in your data table.

   http://www.exploratorium.edu/ronh/weight/

4. Convert each weight form pounds to Newtons, and record these values in your data table. (**1 Newton = 0.2248 lb**)
5. Draw a 2nd table for your calculated mass. Enter your weight in Newtons for Earth and Mars. Calculate your mass on Earth and on Mars, and complete the table.

Table 11.4.1: Mass Data

Planet	g (m/s^2)	W (Newtons)	m (kilograms)
Earth	9.8		
Mars	3.8		

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11.5: Analysis

1. Did you calculate approximately the same mass on Mars as you calculated for your mass on Earth? What may account for any difference?
2. On which planet is your weight the greatest? Why do you think your weight is greatest on this planet?

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11.6: General Questions

1. Describe what it would feel like to take a step on Mercury as compared to taking a step on Earth.
2. What would you expect your mass to be on Mercury?
3. What would you expect your mass to be on Saturn?
4. Which quantity is a fundamental quantity, mass or weight? Explain.

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CHAPTER OVERVIEW

12: Investigation 11 - High Flying Bottle Rocket

Learning Objectives

- Analyze the flight of a rocket and apply Newton's three laws of motion to a rocket.

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12.1: Materials

Available in Lab for Students

- Card Stock Colored Paper
- Duct Tape
- Masking Tape
- Clear Packing Tape
- Metric Ruler
- Permanent Marker
- Poster or Foam Board (1 per team)
- X-Acto knife (1 per team)
- Fast Drying Glue (1 per team)
- Scissors
- Markers
- Triple Beam Balance
- Stop Watch
- Platform Spring Scale
- Impact Glasses (strongly recommended)

Instructor Materials

- Bottle Rocket Launchers

Team Responsibility

- Empty 2-Liter Soda Bottle(s)
- Approved Materials of Choice

Figure 12.1.1: X-Acto Knife by Evan Amos is in the public domain

Figure 12.1.2: Manual Tire Pump Lezyne bike pump & bicycle tire by Your Best Digs is licensed under CC BY 2.0

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12.2: Introduction

There are several factors that determine how well a rocket will fly. Thrust propels a rocket upward with a net force that is greater than the downward forces on the rocket. As the rocket velocity increases, it encounters increasing air resistance, or aerodynamic drag, which opposes the motion of the rocket. Air resistance, or drag, increases as the square of the velocity. In rocket design, it is important to minimize air resistance. Gravity works in opposition to upward motion, slowing the rocket and eventually causing the rocket to fall toward the Earth. Every gram of mass requires fuel to propel the rocket away from Earth.

Equation for Weight:

$$W = mg$$

Basic Bottle Rocket

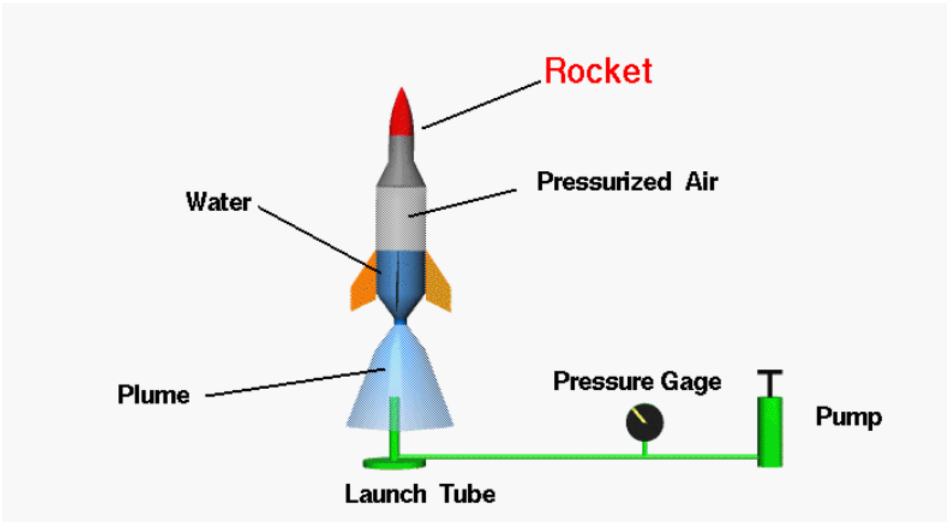

Figure 12.2.1: Water Rocket by NASA is in the public domain

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12.3: Pre-Lab

A. Research how to build a water bottle rocket prior to the scheduled investigation day.
B. Choose your wing and cone design prior to the scheduled investigation day.

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12.4: Procedures

You will build a bottle rocket and analyze rocket flight.

Rocket Construction

1. Draw a table in which to record your rocket data. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 12.4.1: Our Rocket Data

Vehicle Mass	Launch Mass	Total Weight Force

2. Check that the 2-Liter bottle your team brought will fit securely on the launcher. If it does not work with the launcher, check with your instructor.
3. Construct your rocket using the materials provided and any approved materials your team brought. Your team will have 30-40 minutes to complete the construction, record initial data, and be ready to launch.
4. Use the triple beam balance to measure the mass of your completed rocket, in kilograms. Record this value as your vehicle mass.
5. Fill your bottle rocket about 1/3 full of water. Use the platform spring scale to measure the total mass of your rocket now that the "fuel" has been added. Record this value as your launch mass.
6. Calculate the total weight force your rocket must overcome with thrust.

Rocket Competition

Warnings

- Rockets may curve, travel sideways, and/or may fall toward you.
- Impact glasses are strongly recommended.

7. Make sure someone on your team has a stop watch. There should also be someone prepared to write down the flight time for each rocket at the launch site.
8. Everyone will walk to the launch site together. Each team will be allowed 10 pumps with the manual bicycle tire pump. Your instructor will count down the launch, while someone on your team stands ready to launch your rocket. Teams will need to measure and record time of flight, for each rocket. Plan to observe and ascertain which rocket is the highest flying rocket with respect to nearby trees and buildings.

Clean-up

- Throw away all rocket building scraps
- Recycle 2-Liter bottle

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12.5: Analysis

1. Draw a table in which to record data for each rocket. Record the flight times your team recorded at the launch site, in your data table. Obtain and record the rocket launch weight from each team.

Table 12.5.1: Rocket Flight Data

Team	Launch Weight	Flight Time

2. Describe the design features of the highest flying bottle rocket. Indicate the design feature you think may have been primarily responsible for the altitude this rocket achieved.
3. Explain why the launch mass matters.

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12.6: General Questions

1. Use arrows to show the direction of all forces that act on a rocket as it travels upward. Note that you may have multiple words for the same force – show the direction of each.

Gravity	Thrust
Drag	Weight
Air Resistance	Friction

2. Describe how each of Newton's laws of motion were applied during the rocket launch.

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CHAPTER OVERVIEW

13: Investigation 12 - The Pressure on Your Feet

Learning Objectives

- Ascertain the difference between pressure and force.

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13.1: Materials

- Paper (2-4 sheets per person)
- Metric Ruler

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13.2: Introduction

Pressure is a measure of how force is distributed. The smaller the area of contact, the greater the pressure is from the force of the object. Our body weight is distributed onto the area of our feet, or a foot as we walk. The amount of contact our foot makes with a surface determines how our weight force is distributed.

$$P = \frac{F}{A}$$

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13.3: Pre-Lab

1. Write normal atmospheric pressure in units of pounds per square inch (lbs/in^2).
2. Write the equation to calculate the area of a rectangle.

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13.4: Procedures

Each person will determine the pressure on their own feet.

1. Predict whether the pressure your body exerts on one of your feet, as you walk is greater or less than normal atmospheric pressure. Record your prediction.
2. Draw a table in which to record the data for your foot/feet. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 13.4.1: Foot/Feet Data

Calculated Area (1 Foot)	% of Contact (1 Foot)	Net Area of Contact (1 Foot)	Net Area of Contact (Both Feet)

3. Remove one shoe and trace an outline of your foot on the paper. Sketch a rectangle that encases the tracing of your foot. Measure and calculate the area of the rectangle you sketched. Record this area as the *Calculated Area.*
4. Estimate the percentage of the area you calculated that is actually in contact with the paper (is actually touching the paper). Unless you have completely flat feet, not all of your foot touches inside the sketched outline of your foot. Record the percentage of the rectangle that you estimate your foot is actually touching as the *% of Contact*.
5. Calculate the *Net Area of Contact* by multiplying the decimal of the percentage you estimated and the *Calculated Area* from your data table. Record the value of your *Net Area of Contact* for your 1 foot, in your table.

   Example 70%: (0.7)(Calculated Area) = Net Area of Contact for 1 foot

6. Assume your feet are identical, and calculate the net area of contact when you stand on two feet. Record this value in your data table.
7. Draw another table in which to record pressure calculations. Read the instructions for obtaining data.

Table 13.4.2: Pressure Calculations

	Pressure (lbs/in^2)	Comparison to Air
1 Foot		
Both Feet		

8. Use your weight in pounds and the *Net Area of Contact* to calculate the pressure on one foot as if you were taking a step. Also calculate the amount of pressure on both feet as you stand on the floor. Record these values in the *pressure calculations* table.
9. Use a ratio to compare the pressure on your foot to normal atmospheric pressure from air, and the pressure on both feet to normal atmospheric pressure. Calculate the value of each ratio and record this as the *Comparison to Air* value

   Example: $\frac{3lbs/in^2}{7lbs/in^2} = 0.42$

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13.5: Analysis

1. Explain why sketching and measuring both feet may result in more accurate results.
2. Interpret the values you calculated in your comparison of the pressure on your foot/feet to normal atmospheric pressure from air. What do the values mean?

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13.6: General Questions

1. Explain what the units of atmospheric pressure lbs/in2 mean in terms of the “weight” of air on you.
2. Is there a difference in the amount of force exerted by you when you take a step and your full weight is on one foot as compared to when you stand and your full weight is on both feet? Explain.
3. If you or someone you know wears high-heeled shoes, placing most of the weight on the balls of the feet, does this affect the amount of force on the person’s feet as compared to wearing flat shoes? Does this affect the amount of pressure on the person’s feet as compared to wearing flat shoes? Explain.
4. When a ballerina goes up on point, the part of the Pointe shoe that touches the floor is about 2 inches by 1 inch. If a 110 lb ballerina has all of her weight on the toes in one Pointe shoe as she pirouettes, and there is only 33% area of contact between the toes and the Pointe shoe box, how much pressure is on the ballerina’s toes?

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CHAPTER OVERVIEW

14: Investigation 13 - Mass vs Volume vs Density

Learning Objectives

- Differentiate between mass and volume, and differentiate between mass and density.

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14.1: Materials

- 3 Identical Empty Water Bottles (labeled “water”, “sand”, and “air”)
- Simple Balance
- Triple Beam Balance
- Platform Spring Scale
- Metric Ruler
- Sand (from gallon containers)
- 250 mL Beaker
- Funnel
- Weight Boat

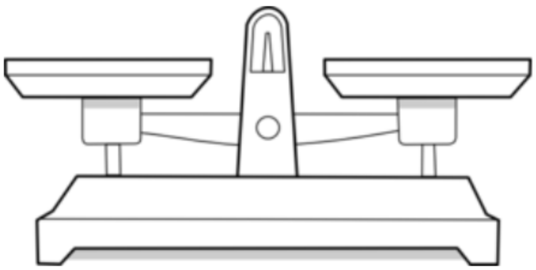

Figure 14.1.1: Simple Balance / scale

Figure 14.1.2: Disposable weighing boat

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14.2: Introduction

Mass is the amount of material contained in an object, while volume is the amount of space occupied by an object. Different amounts of mass may take up the same amount of space. Density has a dependency on both mass and volume. An object with a relatively high density will have a relatively large amount of mass contained in a particular volume. Density is often described as a measure of how compact a material is.

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

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14.3: Pre-Lab

A. Write the equation to calculate the volume of a cylinder.

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14.4: Procedures

You will make comparisons of mass, volume, and density.

Same Mass

1. Draw a table in which to record your values for same mass. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 14.4.1: Same Mass Data

Measured Water Height	Predicted Sand Height	Measured Sand Height	Difference in Measured Heights

2. Fill the bottle labeled “water”, to just below the point where the bottle begins to taper. Measure and record the height, in centimeters, to which the bottle is filled with water.

Figure 14.4.1

3. Predict the height to which you will need to fill an identical bottle with sand in order to have the bottle of water and the bottle of sand balance each other on the simple balance. Record your prediction.
4. Place the bottle with water on one side of the simple balance, and place an empty bottle on the opposite side of the simple balance. Obtain sand in your beaker. Use the funnel to add sand to the empty water bottle, until the bottle with sand balances the bottle with water.

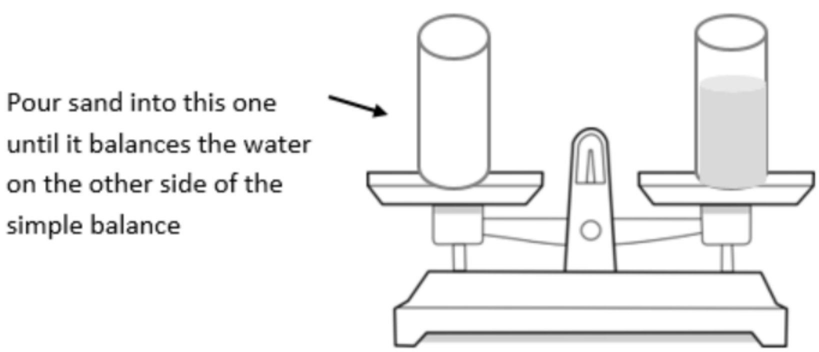

Figure 14.4.2: Balance/ scale by improlux licensed in public domain

5. Remove both bottles from the simple balance. Measure and record the height to which you filled the bottle labeled “sand”. Calculate and record the difference between the measured fill height of the water and the measured fill height of the sand.

Same Volume

6. Use the funnel to continue filling the bottle with sand until it is filled to the same height as the bottle with water. Lift both of the bottles a few times, with the bottle of water in one hand and the bottle of sand in the other hand. Record any differences you notice, under your data table.
7. Draw a table in which to record your values for same volume. Read the instructions for obtaining the data.

Table 14.4.2: Same Volume Data

Type of Material	Mass in Grams	Volume (cm3)	Density (g/cm3)
Air			
Water			
Sand			

8. Use the appropriate scales to measure the mass, in grams, of an empty water bottle labeled “air”, the bottle with water, and the bottle with sand. Record these values in your data table. Use the mass of the empty bottle as the mass of air.
9. Calculate and record the volume in which you have air, water, and sand; it is the same volume for each bottle. The height (h) is the measured water height from your first data table, and the radius can be measured at the bottom of a bottle.
10. Calculate and record the density for each bottle of matter.

Clean-up

- Pour sand back into original container
- Use a dry paper towel to remove any sand from the beaker
- Wash and completely dry your beaker
- Discard water outside (water plants)
- Place wet water bottle on the drying rack

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14.5: Analysis

1. Use ratios to compare the densities. Draw and complete the table below for all comparisons, reducing fractions when possible.

Table 14.5.1: Density comparison

Comparison	Ratio
$\frac{\text{Density of Sand}}{\text{Density of Air}}$	
$\frac{\text{Density of Sand}}{\text{Density of Water}}$	
$\frac{\text{Density of Water}}{\text{Density of Air}}$	

2. Explain why the same mass of sand and water had different fill heights.

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14.6: General Questions

1. Is it possible to have different amounts of mass fit into the same volume?
2. If two different objects have the same volume, they will also have the same mass. (True or False)
3. If two different objects have the same volume, they will also have the same density. (True or False)
4. Explain how density affects the weight of an object.

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CHAPTER OVERVIEW

15: Investigation 14 - Sinking and Floating

Learning Objectives

- Analyze relative density in relation to layers of liquids, and sinking & floating.

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15.1: Materials

Sample Small Objects

- Rubber band
- Metal paperclip
- Plastic Coated paperclip
- Popcorn
- Pencil eraser
- Bouncy ball
- Marble

Materials for Instructor

- 1000 mL Graduated Cylinder
- 2 250 mL Beakers
- 2 Colors Food Coloring
- Clear Corn Syrup (200 mL)
- Vegetable Oil (200 mL)
- 91% Isopropyl Alcohol (200 mL)
- Variety of Small Objects

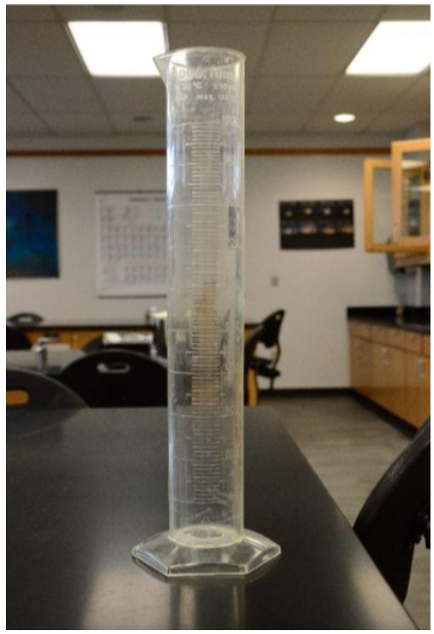

Figure 15.1.1: 1000 mL Graduated Cylinder

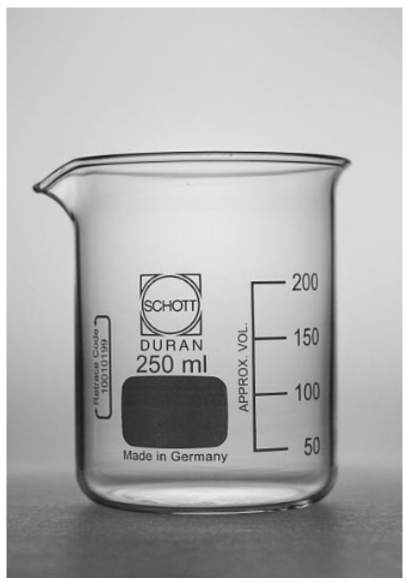

Figure 15.1.2: Beaker Schott Duran Beaker low form 250ml by Lucasbosch licensed under CC BY-SA 3.0

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15.2: Introduction

Sometimes fluids will remain separated such that one type of fluid is floating on top of another type of fluid. We see this if we add oil to water; the oil floats on the water. Whether a particular material will float may depend on relative density. An object that is less dense than the fluid will float. An object that has a higher density than the fluid may float under certain circumstances.

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15.3: Pre-Lab

A. Define what a fluid is.

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15.4: Procedures

A variety of objects will be tested to determine whether they sink or float.

Density Gradient

1. Choose whether to sketch a diagram of the system and indicate the level at which objects settle, or draw a list in which to record results. Sketch a cylinder with the layers of liquids, or start the list in which to record the level at which each object settles.

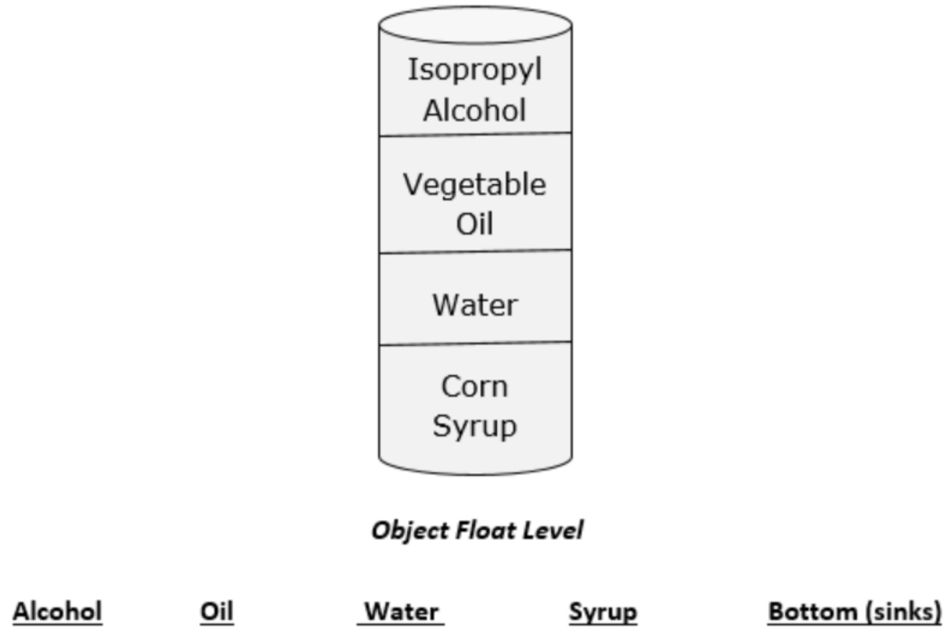

Figure 15.4.1: Cylinder with the layers of liquids and list to record the level at which each object settles

2. Observe as your instructor layers the liquids in the graduated cylinder.
3. As each small object is chosen for testing, predict in your mind where the item will settle. Share your predictions among your lab team. Then observe and record the position at which each item settles when dropped into the graduated cylinder.

Ice & Fluids

4. Fill one beaker with 150 mL of water and the other beaker with 150 mL of 91% isopropyl alcohol.

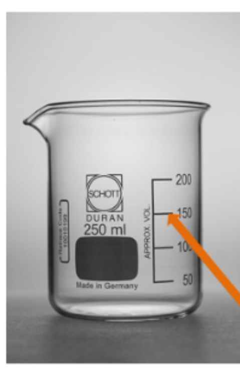

Figure 15.4.2: Image by Trudi Radtke, is under a CC BY 4.0 license.

5. Predict whether the ice will be able to float in the water and/or the isopropyl alcohol. Record your predictions.
6. Obtain 2 ice cubes and place one ice cube in each of the beakers. Record your observations for both the water and the isopropyl alcohol.

Clean-up

- Pour the ice and liquids from the 250 mL beakers down the sink
- Clean and dry your beakers

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15.5: Analysis

1. Why do the liquids remain layered?
2. Based on your observations, which has a lower density, alcohol or water?
3. Write a sentence which explains why the small objects settled at specific locations layers of liquids.

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15.6: General Questions

1. Ice and water are H_2O molecules in different states. Why do you think ice (frozen H_2O) floats in water (liquid H_2O); why are the densities different?
2. Is it possible to have an object float, even though the object has a higher relatively density than the fluid?

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CHAPTER OVERVIEW

16: Investigation 15 - Two Wood Rafts

Learning Objectives

- Apply Archimedes Principle, and compare two rafts made from different wood.

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16.1: Materials

- Pine Wood Raft (about 10x20 cm)
- Oak Wood Raft (about 10x20 cm)
- Plastic Container (about 6x12 inches)
- Triple Beam Balance
- Metric Ruler

*Wood rafts should be same size

**Any two types of wood will work

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16.2: Introduction

Whether an object will float may depend on density. However, ships made of metals are able to float, and metals have a higher density than water. Archimedes Principle explains how an object with greater density than a fluid, such as a steel ship in water, is able to float in the fluid. An object may float if the object is able to displace an amount of fluid equal to its weight. The depth of water to which a ship sinks, determines the amount of water that is displaced by the ship, and the amount of water displaced determines the amount of buoyancy force from the water. When an object is floating in a fluid, the objects pressure down and the fluid pressure up must balance which means the pressure up from the water must equal the pressure down from a boat.

$$P_{Boat} = P_{Fluid}$$

Pressure of Object:

$$P = \frac{F}{A}$$

Pressure from Fluid:

$$P = Dgh$$

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16.3: Pre-Lab

A. State Archimedes Principle.

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16.4: Procedures

You will determine the height of the water line required for a raft to float.

Do not place wood blocks into the water until specifically instructed.

1. Draw a table in which to record physical quantities for your wood rafts. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 16.4.1: Physical Quantities

	Mass (kg)	Weight (N)	Length (m)	Width (m)	Bottom Area (m^2)
Raft 1					
Raft 2					

Choose one of the wood blocks to be your 1st wood raft. Use this raft for the following procedures.

2. Measure and record the mass of your 1st raft, in kilograms. Calculate and record the weight of your 1st wood raft in Newtons. Repeat this process for your 2nd raft.
3. Measure and record the length and width of your 1st raft, in meters. Use these measurements to calculate the bottom area of your 1st raft, and record this value. Repeat this process for your 2nd raft.

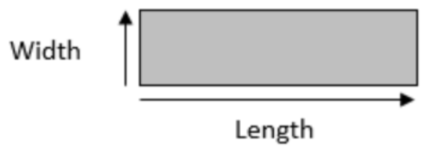

Figure 16.4.1

4. Draw a 2nd table in which to record water line information. Read the instructions for obtaining the data.

Table 16.4.2: Water Line Height

	Predicted	Measured	Error
Raft 1			
Raft 2			

5. Hold the 1st wood raft in your hand and hypothesize (guess) the level to which the raft will need to sink into the water in order to float. Predict where the water line will be, calculate or measure the predicted height from the bottom of the block to the level the water will rise, and record this height in centimeters, as the <u>predicted</u> water line height. You may choose whether to simply predict this water line height or use the two equations for pressure to calculate it. **The density of water is 1,000 kg/m3**.

Figure 16.4.2

6. Fill the plastic tub about half full of water. Gently place your 1st raft into the tub of water, carefully remove it, and measure the amount of the raft thickness that is wet, in centimeters. Record this value as your <u>measured</u> water line height.

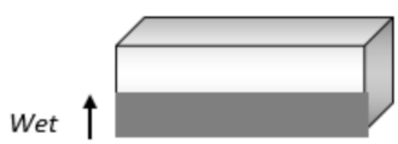

Figure 16.4.3: Copy and Paste Caption here. (Copyright; author via source)

7. Calculate and record the amount of error for this investigation, using your measured value as the standard value.
8. Hold both wood rafts in your hands. Discuss and hypothesize the level to which the 2nd wood raft will need to sink into the water in order to float. Predict where the water line will be, calculate or measure the predicted height from the bottom of the block to the level the water will rise, and record this height in centimeters, as the predicted water line height. You may choose whether to simply predict this water line height or use the two equations for pressure to calculate it. **The density of water is 1,000 kg/m3.**
9. Gently place your 2nd raft into the tub of water, carefully remove it, and measure the amount of the raft thickness that is wet, in centimeters. Record this value as your measured water line height for your 2nd wood raft. Calculate and record the amount of error, using your measured value as the standard value.

Clean-up

- Discard water outside (water plants)
- Thoroughly dry everything used in the experiment

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16.5: Analysis

1. Describe any differences you noticed when holding the two wood rafts.
2. Compare the measured water lines in a ratio, and explain the value you obtain.
3. Use Archimedes Principle to explain why one wood raft would be able to hold more cargo than the other.

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16.6: General Questions

1. Would the rafts used in this investigation float higher or lower in 91% isopropyl alcohol (810 kg/m^3) as compared to in water (1000 kg/m^3)? Explain.
2. Use Archimedes Principle to explain why so much of a steel cargo ship under water.

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CHAPTER OVERVIEW

17: Investigation 16 - Magic Coins and Paperclips

Learning Objectives

- Observe the effects of surface tension, and apply the scientific method to refine predictions.

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17.1: Materials

- 2 Pennies (must be clean and dry)
- 2 Nickels (must be clean and dry)
- Plastic Pipette (small tip)
- 250 mL Beaker
- 3 oz Paper Cup
- 1 Box Small Metal Paperclips
- 1 Container Liquid Dish Soap

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17.2: Introduction

Sometimes, if a person is very careful, a glass can be overfilled such that a bubble of water rises above the lip of the glass. The bubble of water is an example of surface tension. Water has molecular characteristics which allow the molecules to be strongly attracted to each other, and the molecular attractions are strongest at the surface. The water molecules and the glass molecules are also attracted to each other.

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17.3: Pre-Lab

A. Define cohesion.
B. Define adhesion.

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17.4: Procedures

You will test the properties of surface tension.

Two Sides to a Coin

1. Place the coins on the table such that each coin has a "heads" facing up and a "tails" facing up. Discuss which one each person thinks will hold the most drops of water. Record which surface you think will hold the most drops of water.
2. Draw a table in which to record your data. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 17.4.1: Two Sides to a Coin

Coin	Surface	1st Predictions	Adjusted Predictions	Actual Number of Droplets
Penny	Heads			
Penny	Tails			
Nickel	Heads			
Nickel	Tails			

3. Fill the beaker about half full of water. Place the pipette into the beaker, and draw some water into the pipette by first squeezing the bulb and then allowing it to expand. The pipette will not be completely full. Squeeze a few drops of water from the pipette onto the table. Based on the size of the water droplets, predict how many water drops can be placed on each coin surface before the water will spill over the edge. Record your 1st predictions. Each person on the team may have different predictions.
4. **Shhh, do not give away your counting to other teams.** Add one drop of water at a time to the top of your first coin surface, counting the number of drops, until the water spills over. Record the actual number of droplets.
5. Discuss whether any changes to the original predications should be made based on your first result. Record your adjusted predictions for the other three surfaces.
6. Test each of the remaining coin surfaces, and record the actual number of droplets for each surface.

Magic Paper Clip

7. Fill the 3 oz paper cup to over the brim with water, such that there is a "bubble" of water above the top of the cup. Gently place a small metal paper clip on top of the water, so that it floats. If the paperclip sinks, keep trying until a paperclip stays on top of the water. Write or sketch what you observe.
8. Once the paperclip stays on top of the water, add drops of liquid soap to the water until the paperclip sinks. Then make at least 3 attempts to float another paperclip on the top of the water. Record your observations.

Clean-up

- Discard water outside (water plants)
- Thoroughly dry each coin, and your beaker
- Retrieve the paperclips from the paper cup
- Thoroughly rinse and dry the paperclips
- Dispose of the paper cup
- Squeeze as much water as you can out of the pipette and place on drying towel

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17.5: Analysis

1. Write any differences you notice between your 1st predictions and your adjusted predictions in your *Two Sides to a Coin* data.
2. Explain why the paperclip was able to float on top of the water, and why paperclips sink when soap is added.

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17.6: General Questions

1. Sketch or describe where cohesion occurs when there is a bubble of water that rises above a coin or cup. Also, sketch or describe where adhesion occurs when there is a bubble of water that rises above a coin or cup.
2. Based on the density of metals and the density of water, should the paperclip be able to float on water? Explain.

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CHAPTER OVERVIEW

18: Investigation 17 - Weight Lifting

Learning Objectives

- Compare and contrast work and energy, and determine when mechanical work occurs.

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18.1: Materials

- Dumbbells (different weights – i.e. 2 lbs and 4 lbs)
- Meter Stick
- Measuring Tape

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18.2: Introduction

When lifting weights at the gym, you use energy to move the weights. Mechanical work occurs when energy is used to move an object a distance. Mechanical work and energy have the same units of Joules, which indicates that they are closely related. The use of energy does not always result in mechanical work; an object must be moved for there to be mechanical work done on an object.

$$W = Fd$$

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18.3: Pre-Lab

A. Is weight a force?
B. Is mass a force?

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18.4: Procedures

Two different weights will be lifted, held, and lowered.

1. Hold one dumbbell in each hand. Lift and lower both dumbbells 2-3 times, then hold them above your head for about 10 seconds. Each team member should try this. Discuss and record whether it takes more energy, in general, to lift, to lower, or to hold a dumbbell. Also discuss and record whether there is more work, in general, to lift, to lower, or to hold a dumbbell.

Figure 18.4.1

2. Draw at able in which to record the work a dumbbell could do on a person’s toe. **Do not fill in the data until you have read the instructions for obtaining that data.**

Table 18.4.1: Dumbbell & Toe

	Name Team Member	Weight Dumbbell	Distance Toe
1			
2			
3			
4			

3. Choose one of the dumbbells. While standing with one of the dumbbells overhead, have someone measure the distance from the overhead position of the dumbbell to your toe. Record the weight of the dumbbell chosen and the distance to the toe, for each person on your lab team.

Figure 18.4.2

4. Draw a table in which to record the force in Newtons for each dumbbell, and the mechanical work done lifting, holding, and lowering, each dumbbell**.** Read the instructions for obtaining the data.

Table 18.4.2: Mechanical Work

Dumbbell Weight (in lbs)	Dumbbell Weight (Newtons)	Work to Lift (Joules)	Work to Hold (Joules)	Work to Lower (Joules)

5. Write the weight in pounds (lbs) of each dumbbell in your data table. Convert pounds to Newtons. **1 Newton = 0.2248 lb**

6. Calculate and record the amount of mechanical work, in Joules, to lift each dumbbell 0.75 meters.
7. Determine and record the amount of mechanical work, in Joules, done while each dumbbell is held over head for about 10 seconds.
8. Determine and record the amount of mechanical work, in Joules, done to lower each dumbbell 0.75 meters.

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18.5: Analysis

1. Was the amount of energy you used to lift a particular dumbbell different than the energy used to lower that dumbbell? Explain.
2. Was the amount of mechanical work done to lift a particular dumbbell different than the work to lower that dumbbell? Explain.
3. Look at the list of measurements for your team while each person held a dumbbell overhead. In which case would there be the most work done on a toe if the dumbbell fell from overhead to the person's toe? Why?

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18.6: General Questions

1. Is mechanical work done on a mass, while it is held overhead?
2. Is energy used while a mass is held over head?
3. Explain why it is more difficult to lift a mass than it is to lower the same mass.

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CHAPTER OVERVIEW

19: Investigation 18 - Rolling Down a Hill

Learning Objectives

- Relate height to mechanical work and stopping distance, and analyze incline angle relationships to velocity and acceleration.

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19.1: Materials

Ramp to Carpet Different Slopes

- Ramp (metal wall corner) Adjustable Ramp (see image)
- Metric Ruler Photogate Timer
- Meter Stick Friction Motor Car
- Ring Stand with Adjustable Clamp
- Solid Steel Ball
- Measuring Tape
- Length of Carpet (4-6 meters)
- Styrofoam Cup (with cut out)
- Masking Tape
- Triple Beam Balance
- Weight Boat
- Extra meter sticks to use as bumpers (optional)

Styrofoam Cup with cut out

Ramp with Photogate and Car
https://www.arborsci.com

Figure 19.1.1: Cup and Ramp from www.arborsci.com

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19.2: Introduction

When a car rolls or slides down a hill, it gains speed and may do mechanical work on anything that is at the end of its path. This is an example of conservation of mechanical energy, the transfer of energy. Height gives an object gravitational potential energy and this energy is transformed into kinetic energy as the object travels downward. At the bottom of a hill, mechanical energy may be transformed into mechanical work when braking or when impacting another object.

Gravitational Potential Energy:

$$GPE = mgh$$

Kinetic Energy:

$$KE = \frac{1}{2}mv^2$$

Mechanical Work:

$$W = Fd$$

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19.3: Pre-Lab

A. Define gravitational potential energy.
B. Define kinetic energy.

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19.4: Procedures

You will analyze the motion of objects that travel down ramps from different heights.

Ramp to Carpet

1. Find a flat location that will allow you to utilize the full length of carpet. Assemble ring stand with the clamp at a height of your choice. Place the metal ramp such that the low end of the ramp is sitting on one edge of the carpet and the high end of the ramp is balanced on the clamp.

Figure 19.4.1

2. Discuss as a team where you predict the ball will stop when released from the high end of the ramp. Stand next to the carpet at the predicted stopping point while another team member releases the ball from the top of the ramp. If the ball continues past the end of the carpet your ramp is too high. Lower the ramp and repeat this process until the ball stops on its own before reaching the end of the carpet, when released from the high end of the ramp.
3. Use the weight boat and measure the mass of your steel ball. Also measure the mass of the Styrofoam cup. Record these values.
4. Draw a table for the steel ball, and a table for the Styrofoam cup. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 19.4.1: Steel Ball Data

	Height 1	Height 2	Height 3	Height 4
Initial Height (meters)				
GPE (Joules)				

Table 19.4.2: Styrofoam Cup Data

	Distance 1	Distance 2	Distance 3	Distance 4
Distance Moved (meters)				
Mechanical Work (Joules)				

5. Choose 4 locations on the ramp from which to release the ball, and mark each location with a piece of tape. Place the Styrofoam cup 1 meter from the low end of the ramp.

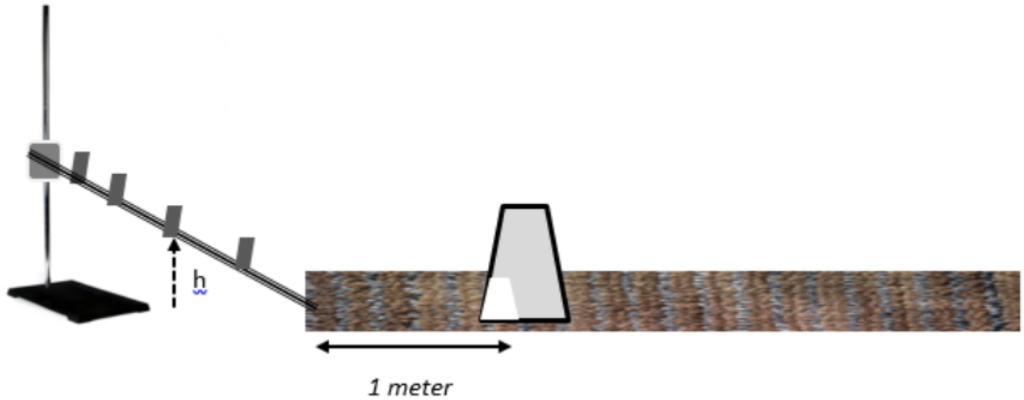

Figure 19.4.2

6. Measure and record the height (h), in meters, from the floor to each piece of tape on the ramp; these are the initial heights for your steel ball. Use these heights and the mass of the steel ball to calculate the GPE in Joules for each height, and record these values in your *Steel Ball* data table.

7. Release the ball from each of the heights. Measure and record the distance the Styrofoam cup moves as the ball is released from each of the heights. Use the distance the cup moves and the weight force of your Styrofoam cup to calculate the Mechanical Work done to move the cup, in Joules. Record these values in your *Styrofoam cup* data table.

8. Remove the Styrofoam cup from the system.

9. Draw another table in which to record stopping distance data and copy the initial heights for the steel ball to this table. Read the instructions for obtaining the data.

Table 19.4.3: Stopping Distance Data

	Initial Height (meters)	Trial 1 (meters)	Trial 2 (meters)	Trial 3 (meters)	Average Stopping Distance (meters)
Height 1					
Height 2					
Height 3					
Height 4					

10. Release the ball and observe where the ball stops. Measure and record the distance in meters from the low end of the ramp to the ball, for each height, completing three trials for each height. If the ball leaves the carpet, the trial does not count and must be redone. Calculate the average stopping distance for each height and record these values in your table.

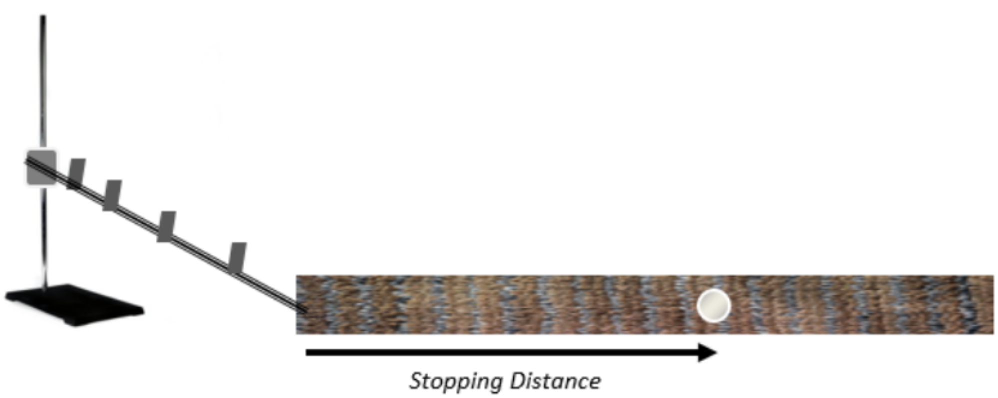

Figure 19.4.3

Clean-up

- Remove and dispose of all tape

Different Slopes

11. Set up the adjustable ramp on the floor, and position the photogate timer at the bottom of the ramp as shown in the image. Send the car down the ramp a few times and familiarize yourself with the photogate; it should be set to measure velocity.

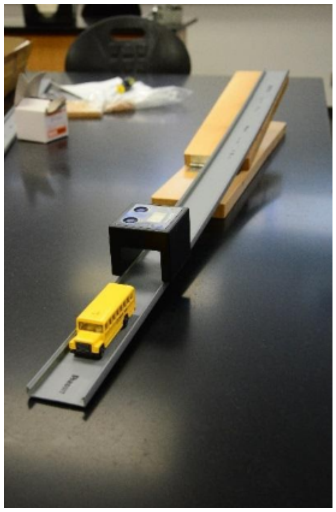

Figure 19.4.4: Car on track by Norihiro licensed under CC0

12. Draw a table in which to record the initial height and velocity for the three different angles (10^o, 20^o, and 30^o) of ramp incline. Read the instructions for obtaining the data.

Table 19.4.4: Different Slopes Data

Angle	Initial Height (meters)	Velocity (m/s)
10^o		
20^o		
30^o		

13. Set the ramp at the first angle. Position the car for release from the top, and hold it there. Measure and record the initial height of the car. Then release the car from the top of the ramp and observe the velocity shown by the photogate. Record the velocity your car had at the bottom of the ramp. Repeat the process for the other two angles.

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19.5: Analysis

Ramp to Carpet

1. Use the steel ball and Styrofoam cup tables to construct a graph of distance the cup moved versus height from which the steel ball was released. Based on your graph, how does the height from which the ball is released affect the amount of work done on the cup?
2. Was all GPE of the steel ball converted into mechanical work on the Styrofoam cup? Explain.
3. Construct a 2nd graph using your stopping distance data. Use the average stopping distance and the initial heights to construct your graph. Write a sentence which describes what your graph shows.

Different Slopes

4. Construct a 3rd graph using your angle and velocity data. How does this graph compare to your 1st and 2nd graphs?

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19.6: General Questions

1. In general, as height increases, which of the following increase? (record all correct choices)
   a. GPE
   b. Mechanical Work possible
   c. Stopping distance
   d. KE
   e. Velocity
2. In which case is more kinetic energy gained along an incline, when it has a relatively small incline angle or a relatively large incline angle? Explain.
3. The mass of an object does not contribute to the velocity at the bottom of a hill when energy is conserved within the system. Explain why.

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CHAPTER OVERVIEW

20: Investigation 19 -The Swing

Learning Objectives

- Ascertain the variable that determines the period of a swing through use of the scientific method, and apply conservation of energy to the motion of a swing.

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20.1: Materials

- Metal Rod (from ring stand)
- Key Chain
- Length of Ribbon/String (approximately 2 meters)
- Triple Beam Balance
- Protractor
- Stop Watch
- 1 Mass with Hook

Figure 20.1.1: Ribbon/Rope Spool of String by Fcb981 is licensed under CC BY-SA 3.0

Figure 20.1.2: Example Key Chain Image licensed under CC0

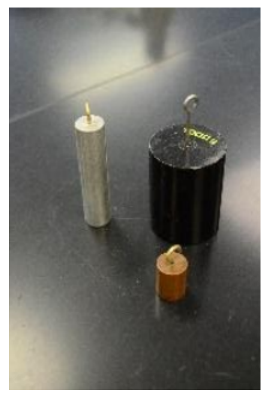

Figure 20.1.3: Mass with Hook by Norihiro

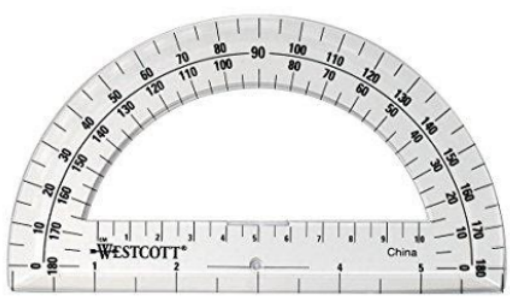

Figure 20.1.4: Protractor Available at Amozon.com

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20.2: Introduction

A swing at the park is an example of a pendulum. The period of a swing, or pendulum, is the time required for the pendulum to circle back to its beginning point, after traveling outward (i.e., from **A** to **B** back to **A**).

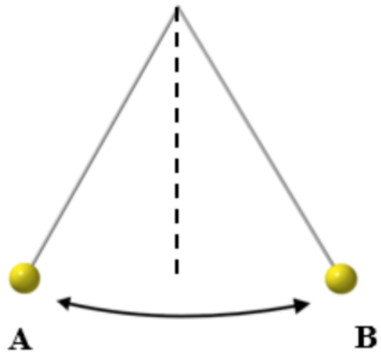

Figure 20.2.1: Period of a swing, or pendulum

Conservation of energy maintains the motion of the pendulum, as Gravitational Potential Energy (GPE) is converted to Kinetic Energy (KE), and KE is converted back into GPE. A swing at the park is just a pendulum with a length, and you are the mass. As you swing, the angle with respect to vertical changes.

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20.3: Pre-Lab

A. Does the weight of the person swinging affect the period of the swing, the time it takes to swing back and forth and back again?

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20.4: Procedures

You will determine which variable affects the period of a pendulum.

1. Discuss as a team which variable will affect the period of the pendulum, angle, mass, length, or all of these. Record your prediction.
2. Make a bridge with the metal rod and chairs, such that only the ends of the rod are on the chairs. You may want to secure the rods with masking tape.

Figure 20.4.1

Long Pendulum

3. Draw a table in which to record data for your 1st pendulum. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 20.4.1: 1st Pendulum

Length	Angle	Time for 5 Cycles 1st Mass	Period 1st Mass	Time for 5 Cycles 2nd Mass	Period 2nd Mass

4. The key chain should be tied at the center of the ribbon. Tie the ends of the ribbon in a bow at the middle of the rod, such that the longest possible pendulum hangs from the center of the rod. Measure the length of this pendulum, in meters. You will need to decide your end points of measurement and then be consistent with how you measure the length of each different pendulum during the investigation. Record your length measurement.

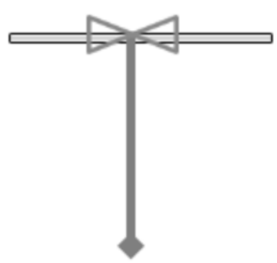

Figure 20.4.2

5. Choose two different angles from which to release the pendulum. Record these angles in your data table.
6. Place the protractor at the bottom of the metal rod, and use the protractor to release the pendulum from your first chosen angle; measuring the angle from vertical. Hold the pendulum from the bottom so that the ribbon/string remains straight. Release the pendulum. Measure and record the time for **5** complete cycles. Calculate and record the period for one cycle. Repeat this process for your second angle.

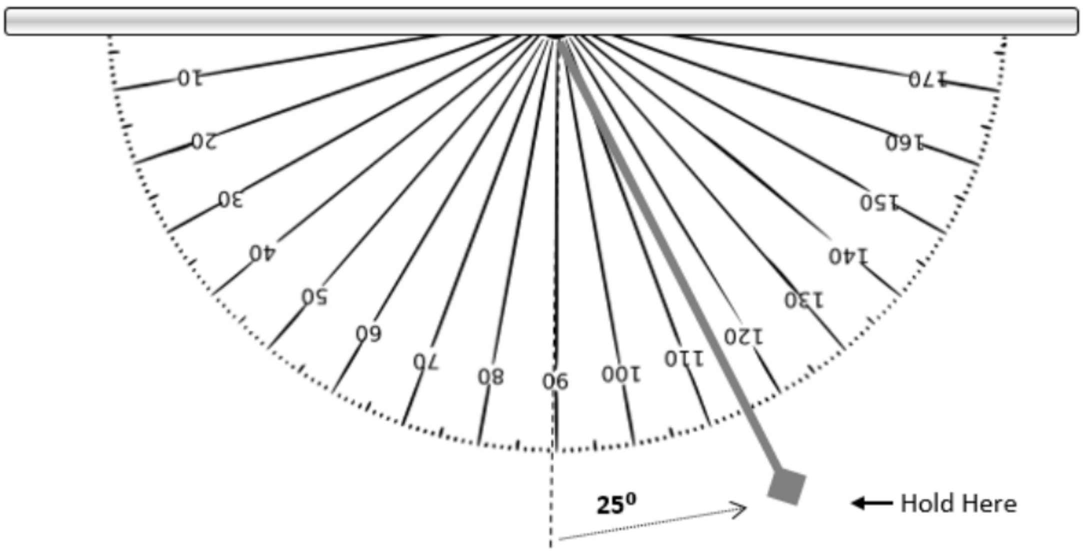

Figure 20.4.3: Protractor by yamachem licensed under public domain

7. Add a hooked mass to your pendulum, and repeat the processes in step 6 for this system with the added mass. Record all of your values in your data table. Remove the hooked mass.

Short Pendulum

8. Draw a 2nd table in which to record data for your 2nd pendulum.

Table 20.4.1: 2nd Pendulum

Length	Angle	Time for 5 Cycles 1st Mass	Period 1st Mass	Time for 5 Cycles 2nd Mass	Period 2nd Mass

9. Re-tie the ribbon in a bow such that your 2nd pendulum is about half the length of what your long pendulum was. Measure and record the length of your 2nd pendulum, in meters.
10. Use the same angles as you chose for the long pendulum, and repeat the same processes to acquire your data for the short pendulum. You will also be using the same hooked mass as you used for the long pendulum.

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20.5: Analysis

1. Use your data to determine which variable (length, mass, and/or angle) affects the period of a pendulum the <u>most</u>.
2. Based on your observations, at which point in the swing did your pendulum have maximum KE? You may describe or sketch this.

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20.6: General Questions

1. Would a small (20°) angle or a large (40°) angle result in the greatest gravitational potential energy? Explain
2. Is it possible for you and a person who is half your mass to swing with the same period on park swings? Why?

Figure 20.6.1: Swing Set by johnny_automatic licensed under public domain

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CHAPTER OVERVIEW

21: Investigation 20 - Balancing a See-Saw

Learning Objectives

- Analyze the effects of mass and distance on a lever, and compare forces at different distances from a fulcrum.

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21.1: Materials

- Meter Stick (width must accommodate knife edge clamps)
- Fulcrum
- Set of Slotted Masses (with hanger)
- 3 Objects of Unknown Mass (keys, sunglasses, etc.)
- 3 Knife Edge Clamps
- Triple Beam Balance
- Masking Tape
- String

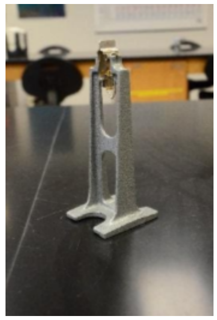

Figure 21.1.1: Fulcrum

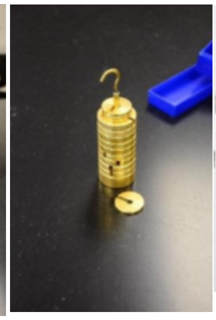

Figure 21.1.2: Slotted Masses

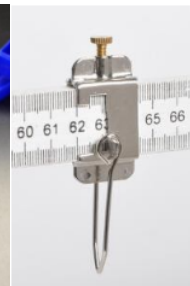

Figure 21.1.3: Knife Edge Clamp

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21.2: Introduction

Torque is force acting at a distance, tending to cause rotation around a point. The point about which the object rotates, the pivot point, is called the fulcrum. When force is applied perpendicular to a lever arm, the amount of torque depends on the perpendicular force (F) applied and the length of the lever arm (d) through which the force acts.

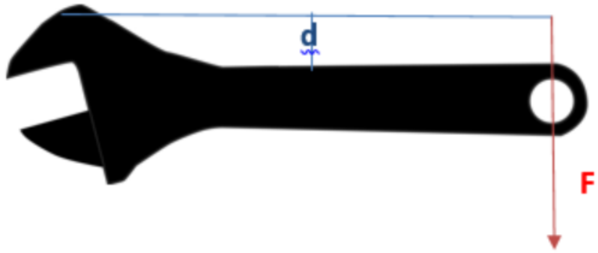

Figure 21.2.1

Torque:

$$\tau = Fd$$

Weight Force:

$$W = mg$$

The amount of torque on one side of a fulcrum is equal and opposite to the amount of torque on the other side of the fulcrum. This can allow a see-saw to be balanced if the two people sit at the correct distances from the pivot point.

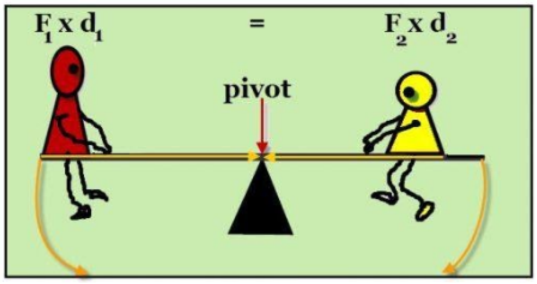

Figure 21.2.2

$$\tau_1 = -\tau_2$$

Although the torque on each side of the pivot point is equal, the amount of force on each side of the pivot can be very different.

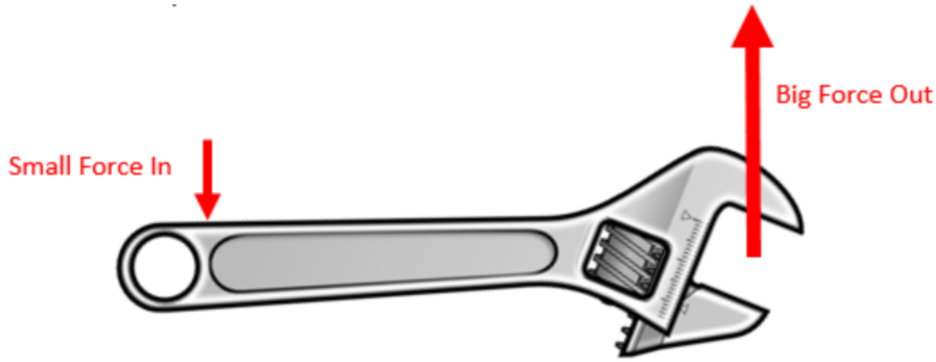

Figure 21.2.3

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21.3: Pre-Lab

A. What is meant by mechanical advantage?

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21.4: Procedures

You will analyze a see-saw system to determine mass and torque.

Center of Mass

1. Remove the hanging piece from one knife edge clamp. Place this clamp at the center of your meter stick, and use the clamp to place your meter stick onto the fulcrum; it may not balance yet. Adjust the position of the clamp until your meter stick is relatively balanced on the fulcrum. The position of your clamp is the center of mass of the meter stick. Record the center of mass for the meter stick, in centimeters (cm). The center of mass will not necessarily be 50 centimeters.

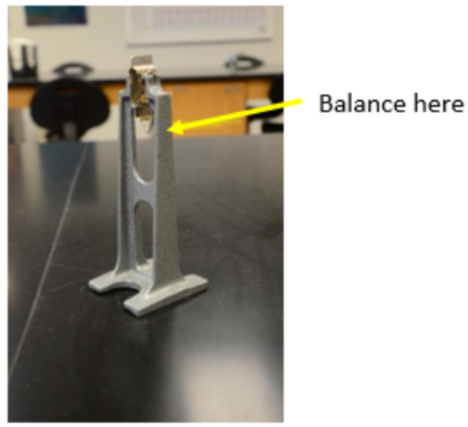

Figure 21.4.1: Knife edge clamp & fulcrum

Unknown Torque

2. Draw a table in which to record data for three systems. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 21.4.1: Balancing Torque Data

Object	Known Mass	Distance 1	Distance 2	Measured Unknown Mass

3. Place knife edge clamps at different distances on each side of the meter stick, such that there is one clamp on each side of the fulcrum. Choose random distances. It is okay if your meter stick is temporarily unbalanced.

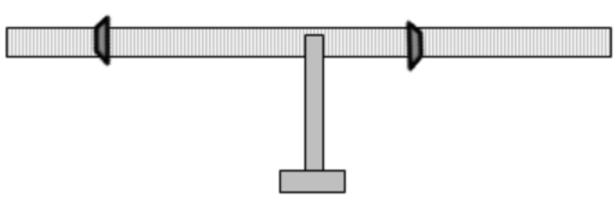

Figure 21.4.2

4. Attach an object (keys, sunglasses, or other object) to one of the knife edge clamps. Add individual slotted masses to the other knife edge clamp until you have balanced the system. As you add the slotted masses, you may need to adjust the positions of the knife edge clamps on either side of the fulcrum, to balance the meter stick. Record the grams of slotted mass that you added to balance the meter stick. Also record the final distances in meters from the fulcrum to each of the knife edge clamps. (see image)

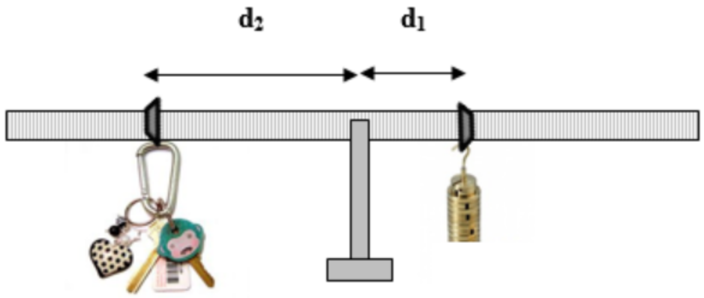

Figure 21.4.3

5. Reposition the two knife edge clamps at new distances and repeat the balancing process for two additional objects. Record your data in your *Balancing Torque* data table.
6. Use the triple beam balance to measure the mass of each object. Record the measured mass of each object, in grams.

Off Center

7. Draw a table in which to record the off center system data. Read the instructions for obtaining the data.

Table 21.4.2: Off Center Data

Mass (kg)	Distance (meters)

8. Adjust the center clamp on the meter stick so that the 75 centimeter mark is located at the fulcrum. Place a knife edge clamp on the short side of the meter stick. Add slotted masses to the knife edge clamp on the short side of the meter stick until the meter stick is balanced. You may need to adjust the fulcrum position slightly in order to balance the meter stick. Once the meter stick is balanced, record the total mass on the short side of the meter stick (slotted mass + mass of the knife edge clamp) and the distance from the fulcrum to the knife edge clamp.

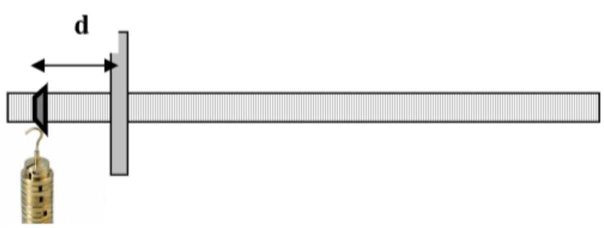

Figure 21.4.4: Copy and Paste Caption here. (Copyright; author via source)

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21.5: Analysis

1. Draw a table in which to record calculated Torque for each of your systems. Add the objects listed in your ***Balancing Torque Data*** table, to the table below

Table 21.5.1: Calculated Torque Data

Object/System	Known Mass Torque (Joules)	Object Torque (Joules)
Off Center		

2. Calculate the torque on the side of the known mass (slotted masses) for each system. Determine what the torque on the other side is for each object/system. Record these values.
3. Use the information in your data tables to ascertain whether there is a correlation between mass and torque. Record your answer and use the information you have collected to support your answer.
4. Explain why so much mass is needed on the short side of the off center system to balance the meter stick, even though the long side has no added mass.

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21.6: General Questions

1. If you weigh twice as much as your little sister, where should you sit with respect to the pivot point in order to balance the see-saw? Should you sit closer to the pivot or father from the pivot? How much closer/farther should you sit?

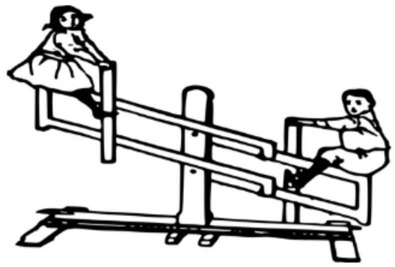

Figure 21.6.1: Kids on a Seesaw by j4p4n available in Public Domain

2. A person pulls on the long end of a crowbar with 150 lbs (667 Newtons) of force, applying the force perpendicular to the lever arm. The long end of the crowbar measures 90 centimeters from the pivot to where the force is applied.

Figure 21.6.2: Pry Bar

   a. Calculate the amount of torque on the long side of the crowbar.
   b. What is the torque on the short side of the crowbar?
   c. How much force is applied to the crate?
   d. Calculate the mechanical advantage gained by using the crowbar.

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CHAPTER OVERVIEW

22: Investigation 21 – The Temperature of a Molecule

Learning Objectives

- Observe the difference of molecular movement in hot and cold water, and predict the equilibrium temperature.

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22.1: Materials

- Heat Source (Bunsen Burner or Hot Plate)
- 2 Thermometers
- 2-250 mL Beakers
- 1 400-500 mL Beaker
- Food Coloring (2 colors)
- Aluminum Foil (for a lid)
- Heat Gloves
- Beaker Tongs

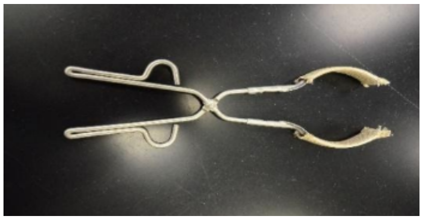

Figure 22.1.1: Beaker Tongs

Figure 22.1.2: Hot Plate The Lab Depot

Figure 22.1.3: Bunsen Burner wikipedia

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22.2: Introduction

The amount of kinetic energy, the amount of movement, is what determines how hot or cold something seems to be. If particles (atoms or molecules) have a relatively high average kinetic energy, then the material will feel hot. If particles have a relatively low average kinetic energy, then the material will feel cold. We may not be able to see the movement, but even solid objects have particles that are vibrating and may have translational motion. When two materials with different temperatures come into contact, they will come into thermal equilibrium.

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22.3: Pre-Lab

A. Define thermal equilibrium.

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22.4: Procedures

You will observe the movement of molecules in hot and cold water.

1. Draw a table in which to record temperature data. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 22.4.1: Temperature Data

	Temperature
Hot Water	
Cold Water	
Predicted Combined Water	
Measured Combined Water	

2. Add 100 mL of water to each 250 mL beaker. Place one of the beakers of water on the heat source, cover it with the foil, and heat until it boils. Once the water is boiling, turn off the heat source and remove the foil lid.
3. Add 2 drops of food coloring to each beaker (cold and hot) at the same time. Record your observations.

Warnings

- Do not allow thermometer to come into contact with the bottom of the beaker while the beaker is on the heat source.
- Always assume your heat source is hot, even if it is off.

4. Remove the beaker of hot water from the heat source. Place a thermometer in each beaker and record the temperature of the water in each beaker.
5. Predict what the temperature will be when the water from the two beakers (cold and hot) is combined. Record your predicted temperature of the combined hot and cold water.
6. Remove both thermometers, and pour the water from the two small beakers into the large beaker. Place both thermometers into the large beaker and determine the average "final" temperature; this should be an average of the temperature shown on each thermometer after the thermometers have settled. Record your average measured temperature of the combined hot and cold water.

Clean up

- Wash and dry all glassware
- Wash and dry thermometers

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22.5: Analysis

1. Do hot or cold water molecules have a higher average kinetic energy? What is the evidence for this?
2. Calculate the difference between your predicted and measured temperatures for the combined water. Describe any factors that could account for the difference.
3. What is the purpose of using 2 thermometers to measure the temperature of the combined hot and cold water?

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22.6: General Questions

1. Describe what happened to the kinetic energy of the cold molecules and the kinetic energy of the hot molecules when the water from the two small beakers was combined.
2. Would you expect the hot or cold water to have a higher density? Why?

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CHAPTER OVERVIEW

23: Investigation 22 - Heat Energy Transfer

Learning Objectives

- Analyze heat energy transfer and measure specific heat capacity.

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23.1: Materials

- Heat Source
- 250 mL Beaker
- 1 large Styrofoam Cup
- 2 Thermometers
- Triple Beam Balance
- 3 Solid Metal Samples
- Beaker Tongs
- Heat Gloves
- Tongs (for removing metal sample)
- Aluminum Foil (for lids)
- Rubber Band (to fit around Styrofoam cup)
- Graduated Cylinder

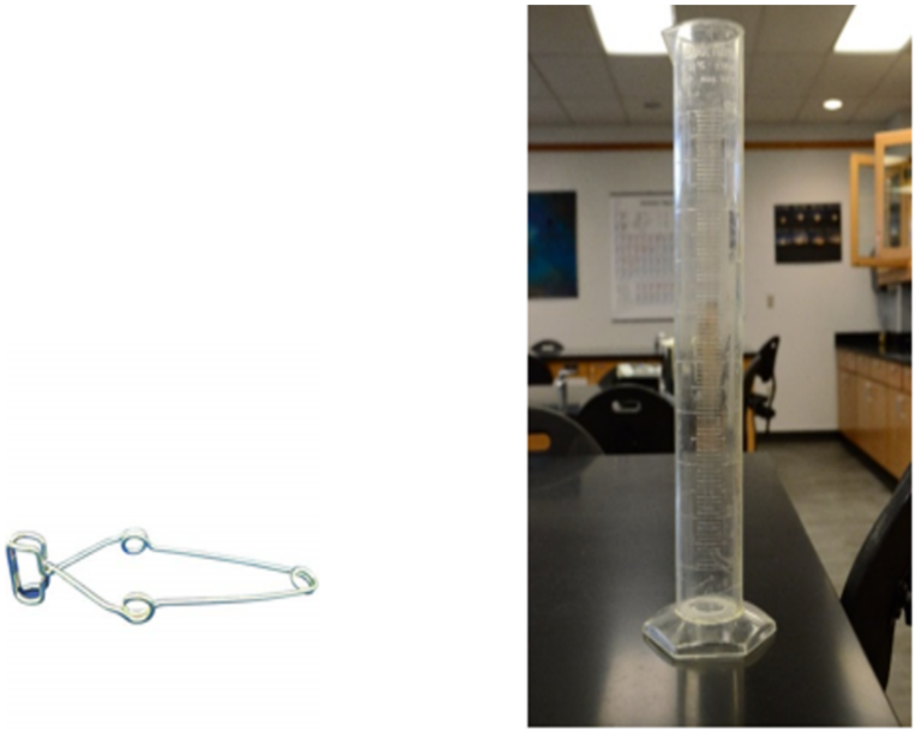

Figure 23.1.1: Tongs to remove sample and graduated cylinder

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23.2: Introduction

The specific heat capacity of a material is the amount of heat required to change the temperature of the material. The higher the heat capacity, the more energy the material must gain or lose to have a change in the temperature of that material. A material that has a relatively high specific heat capacity will tend to resist temperature change. Objects and materials that are placed into contact will reach thermal equilibrium after a time. The heat lost by one material is gained by the other material, as long as the system is isolated, until both materials are at the same temperature. While the heat energy exchanged may be equal, the temperature changes may be very different if the two materials have very different values of specific heat capacity.

Heat Energy Equation:

$$Q = cm\Delta T$$

Transfer of Energy:

$$Q_{lost} = Q_{gained}$$

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23.3: Pre-Lab

A. When hot metal is placed in cold water, which material (metal or water) will lose heat energy and which material (metal or water) will gain heat energy?

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23.4: Procedures

You will analyze the results of placing hot metal samples into cold water.

1. Draw a table in which to collect all of your data. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 23.4.1: Temperature Data

Sample	Mass Metal Sample (grams)	Mass Cold Water (grams)	T_i Water (Celsius)

2. Choose three metal samples. List the material or color for each metal sample. Measure and record the mass in grams for each of your metal samples.
3. Place your first metal sample into the beaker and add water until your metal is completely submerged in water. Place the beaker on the heat source, cover with a foil lid, and heat until boiling. While you are waiting for the water to boil, read the procedures that follow so you are ready for the transfer.

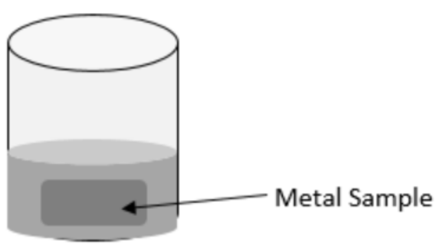

Figure 23.4.1

4. Use the graduated cylinder to measure an amount of cold water that you think will completely cover your metal sample when the metal sample is placed into the Styrofoam cups. Keep track of the amount of water you have in mL. Add the cold water from the graduated cylinder to the Styrofoam cup, while your metal is heating in the beaker. Record the total mL you add to the Styrofoam cup as the *mass cold water in grams*. (**1 mL = 1 gram of water**)
5. Place one thermometer into the cold water, in the Styrofoam cup. Measure the temperature in Celsius of the cold water in the Styrofoam cup, and record this value under T_i *Water*.

Warnings

- Do not place a thermometer in a beaker while the beaker is on the heat source.
- Always assume your heat source is hot, even if it is off.

6. Once the water in the beaker has boiled for at least 2 minutes, to ensure that the metal sample is hot, follow the next steps as quickly as you can while being safe.
   a. Remove the thermometer from the Styrofoam cup
   b. Transfer the metal sample from the beaker into the Styrofoam cup
   c. Cover the Styrofoam cup with foil, seal the foil onto the Styrofoam cup with the rubber band, and carefully poke the thermometer through the foil making as small of a hole as possible (you are isolating your system of hot metal and cold water)
   d. Remove the beaker with hot water from the heat source, and place the 2nd thermometer into the hot water
7. Observe both thermometers, the one in the Styrofoam cup and the one in the beaker. When it looks like the temperatures have settled, record the temperatures in the appropriate places, in your data table.
   - The temperature of the hot water is the assumed initial temperature for the hot metal sample, T_i *Metal.*
   - The temperature in the Styrofoam cup with the water and metal is the final temperature for both the water and the metal, T_f *Both*.
8. Repeat the processes to obtain data for your other metal samples. You may re-use the hot water in the beaker to heat your second metal sample; make sure there is enough water to completely cover your next sample. You will need to obtain new cold water in the Styrofoam cup for each sample.
9. Calculate and record the change in temperature (ΔT Water) for the cold water that occurred with each metal sample. This will be the difference between T_f *Both* and T_i *Water*.
10. Calculate and record the change in temperature (ΔT Metal) for each metal sample. This will be the difference between T_f *Both* and T_i *Metal*.

Clean-up

- Discard water outside (water plants)
- Wash and dry metal samples and beaker
- Wash and dry thermometers before replacing them in protective containers
- Completely dry Styrofoam cup
- Throw away aluminum foil lids

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23.5: Analysis

1. In general, which showed the greater temperature change when combined and isolated, the metal samples or the cold water. Explain why this happened.
2. Describe any possible sources of error that may have occurred during your investigation.
3. Based on the chart of specific heat capacities below, which of your metal samples would you expect to have the smallest change in temperature? Which metal would you expect to have the largest change in temperature?

Table 23.5.1: Chart of specific heat capacities

Material	Specific Heat Capacity (J/kg°C)
Aluminum	900
Brass	380
Copper	387
Iron or Steel	452
Lead	128
Tungsten	134
Zinc	390
Water	4186

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23.6: General Questions

1. Your hot water temperature was probably lower than the boiling point for water. Explain what may contribute to water boiling at a lower temperature than the standard boiling point for water.
2. Use a ratio to determine how many times greater the specific heat capacity of water is compared to the specific heat capacities of your metal samples.

Example:

$$\frac{\text{Water}}{\text{Gold}} = \frac{4186 J/kgC}{129 J/kgC} = \frac{32.4}{1}$$

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CHAPTER OVERVIEW

24: Investigation 23 - Rates of Heat Conduction

Learning Objectives

- Compare the thermal conductivity of different materials and examine properties of conductors versus insulators.

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24.1: Materials

Wire & Flame

- 4-inch Length of Steel Wire
- 4-inch Length of Copper Wire
- Stop Watch
- Matches
- Candle
- Aluminum Foil

Conduction & Containers

- Heat Source
- Large (400-500 mL) Beaker
- 250 mL Beaker
- Empty Metal Can
- Styrofoam Cup
- 3 Thermometers
- Masking Tape
- Heat gloves
- Beaker Tongs
- Aluminum Foil (for candle stand and lids)

**Both wires should be the same gauge*

**The Glass Beaker, Metal Can, and Styrofoam Cup should be about the same diameter*

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24.2: Introduction

The thermal conductivity of a material is a measure of the Joules per second which can be transferred through the material. The ability to conduct heat depends on the mobility of the electrons, how free the electrons are to meander and have collisions. The more free electrons are to move within a material, independent of the nucleus, the faster the material will conduct (move) heat energy. A substance in which electrons are not able to move freely will slow or impede the flow of heat energy. Substances which slow the transfer of heat energy are called insulators.

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24.3: Pre-Lab

A. Predict which wire will be the best conductor.
B. Predict which container will be the best insulator.

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24.4: Procedures

Warning

- Be careful not to burn yourself during this investigation.

Wire & Flame

You will hold two different types of wire in a candle flame.

1. Use the aluminum foil to create a candle stand. Light the candle and leave it lit.
2. Hold one wire in each hand such that about 2 inches of the length extends from your grasp.

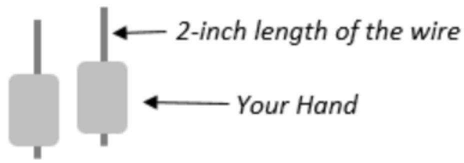

Figure 24.4.1

3. Place the ends of the 2-inch lengths of wire into the candle flame, at the same time (one person should be holding both wires), keeping both wires in the flame. **As soon as a wire becomes too hot to hold, let go of it.** Continue to hold the 2nd wire until it becomes hot; if the 2nd wire does not get hot within another 2 minutes then let go of it and end the experiment. Record which wire became hot first.

Conduction & Containers

You will be measuring the change in temperature on the <u>outside</u> of three different containers.

4. Obtain 300 mL of water in the 400-500 mL beaker. Place the beaker on the heat source, cover the beaker with a foil lid, and bring the water to a boil. While you are waiting for the water to boil, securely attach thermometers to each container (250 mL Beaker, Metal can, and Styrofoam Cup). Make sure the end of the thermometer is in full contact with the container. You may need to balance the Styrofoam cup against something so it does not fall over

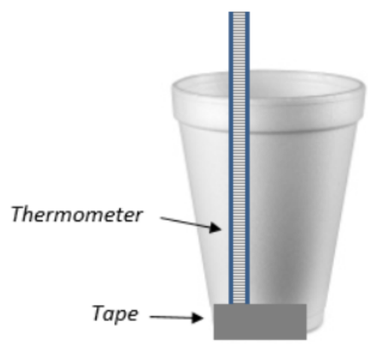

Figure 24.4.2

5. Draw a table in which to record temperature data for the three containers. **Do not fill in data until you have read the instructions for obtaining that data**.

Table 24.4.1: Container Temperature Data

	Initial Temperature (Celsius)	Final Temperature (Celsius)	Rank Order (Feel)	ΔT	Rank Order (ΔT)
Glass Beaker					
Metal Can					

	Initial Temperature (Celsius)	Final Temperature (Celsius)	Rank Order (Feel)	ΔT	Rank Order (ΔT)
Styrofoam Cup					

6. After the temperatures on the thermometers have settled, record the initial temperature of each container in your data table.
7. Once the 300 mL of water is boiling, use either heat gloves or beaker tongs to pour about 100 mL of boiling water into each container. Cover each container with foil. Observe the thermometers until the temperatures have peaked and then record the final temperature of each container in your data table.
8. Touch the outside of each container near the bottom of the container where the hot water is. Rank the order the containers from most conductive to least conductive, based on what you feel with your hand.
9. Calculate and record the change in temperature for each container. Rank order the containers from most conductive to least conductive, based on your calculated change in temperature, ΔT.

Clean-up

- Wash and dry copper and steel wires
- Dispose of all used foil
- Remove all tape from thermometers
- Completely dry all containers

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24.5: Analysis

1. Which of your wires was the best conductor?
2. Which of your wires has the higher specific heat capacity? What is your evidence?
3. Which container (Glass Beaker, Metal Can, or Styrofoam Cup) was the best conductor?
4. Which container (Glass Beaker, Metal Can, or Styrofoam Cup) was the best insulator?

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24.6: General Questions

1. Does a material with a high specific heat capacity move heat quickly or slowly?
2. Does an insulator add heat or trap heat?

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CHAPTER OVERVIEW

25: Investigation 24 - Phase Change of Water vs Salt Water

Learning Objectives

- Determine whether adding salt to water makes it boil faster than regular water.

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25.1: Materials

- 2 100-mL Beakers
- Triple Beam Balance
- 3 oz Paper cup
- 100 mL Graduated Cylinder
- 90 mL Distilled Water
- 10 grams Salt
- Plastic Spoon
- Hot Plate
- 2 Thermometers
- Heat Gloves
- 2 Stop Watches

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25.2: Introduction

Latent heat of vaporization is the amount of energy it takes to have a substance change phase between a liquid and a gas. The amount of energy required to change the phase of a substance depends on the amount of mass and the type of material. Once the boiling point is achieved for the substance, it will begin to phase change.

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25.3: Pre-Lab

A. Seawater has a specific heat capacity of 932 J/kgC while pure water has a specific heat capacity of 1,000 J/kgC. Do you think the salt water or pure water will boil first?

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25.4: Procedures

Warnings

- Do not place a thermometer in a beaker while the beaker is on the heat source.
- Always assume your heat source is hot, even if it is off.

You will boil pure water and salt water, simultaneously.

1. Use the graduated cylinder to add 50 mL of the distilled water one beaker and 40 mL of the distilled water to the second beaker.
2. Measure 10 grams of salt into a paper cup on the triple beam balance, and add the salt to the beaker that has 40 mL of water. Stir for 2 minutes or until the salt has completely dissolved, whichever comes first.
3. Draw a table in which to record water levels and peak temperatures. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 25.4.1: Water Level & Temperature Data

	Initial Water Line Level	Final Water Line Level	mL Vaporized	Peak Temperature
Pure Water				
Salt Water				

4. Use the grease pencil to carefully and accurately mark the level of the water line on each beaker. Record the initial number of mL in each beaker under *initial water line level*.
5. Place both beakers on the heat source. You will need to closely observe the two beakers so that you are able to determine which substance begins to boil first. Your team will need to decide what constitutes boiling and apply this to both beakers. Each substance will need to boil for 10 minutes total, and then be removed from the heat source to the lab table. Use the two stop watches to track the boiling of each substance. As you remove each beaker form the heat source, measure and record the peak temperature. Record which substance boiled first, under your data table.
6. View the level of the water line on each beaker, after each substance has boiled for 10 minutes, and record the final number of mL in each beaker under *final water line level*.
7. Calculate the number of mL vaporized by finding the difference between the initial water line level and the final water line level. Enter these values in your data table.

Clean-up

- **Wash and dry beakers**
- Wash and dry thermometers before replacing them in protective containers
- Dispose of 3 oz paper cup
- Place graduated cylinder on drying rack

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25.5: Analysis

1. Were the initial water lines the same for each substance? Should the initial water lines be the same? Explain.
2. Based on your observations, which substance has the higher specific heat capacity, fresh water or salt water? Describe the proof you have for this. Do your observations agree with your pre-lab answer?
3. Based on your experiment, which substance has a higher latent heat of vaporization, regular water or salt water? Describe the proof you have for this.
4. Describe any errors that may have resulted during this investigation.

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25.6: General Questions

1. There are different views regarding whether adding salt to your water will cook pasta faster. Based on your investigation, does it matter when you add the salt for the cooking time?
2. Describe the difference between the specific heat capacity of a material and the latent heat of a material.

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CHAPTER OVERVIEW

26: Investigation 25 - Magically Moving Objects

Learning Objectives

- Observe the interactions of charge and determine the method of charging.

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26.1: Materials

Note: fixed spacing

- Balloons (8 per team)
- 2 1-Yard Lengths of String
- 2 Empty Soda Cans
- Kleenex Tissue
- Small Container of Ground Black Pepper
- Scissors
- Sheet of White Paper
- Various Types of Cloth (Silk, Wool, Etc.)
- Masking Tape

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26.2: Introduction

A material with a higher number of electrons than protons is negatively charged. A material with fewer electrons than protons is positively charged. Some materials give up electrons easily and some materials accept electrons easily, causing each object to become charged. Opposite charges attract each other while like charges repel. Any charged object may electrically attract a neutral object, if particles in the neutral object are able to rearrange themselves. Coulomb's Law can be used to calculate the electric force between two charged objects.

$$F = \frac{k(q1)(q2)}{d^2}$$

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26.3: Pre-Lab

A. What is the charge in Coulombs for 1 electron?
B. What is the charge in Coulombs for 1 proton?

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26.4: Procedures

You will charge various objects and observe the effects of charge.

Hanging Balloon Bounce

1. Inflate two balloons, tie them closed, and attach each balloon to a 1-yard length of string. Hold the two strings, allowing the balloons to hang near each other without touching. The balloons should be about 2 inches apart. Have a team member charge one of the balloons with a piece of fabric or their hair, then gently return the balloon to the hanging position and observe. Record your observation.

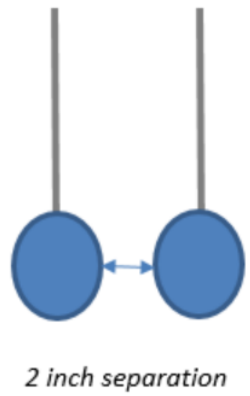

Figure 26.4.1

2. Have two team members each charge a balloon, then gently return the two balloons to the hanging position at the same time and observe. Record your observation.

Rolling Soda Can Race

3. Find a clear path for two soda cans to travel side by side. Lay the two empty soda cans on their sides, at the starting line. Also, decide where the finish line will be.

Figure 26.4.2

4. Choose two "runners" from your team. The runners will each need an inflated balloon. Allow the runners 1 minute to charge their balloons, and then race their cans using only static electricity from the balloon to make the can roll (do not touch the can). Record the winner of this competition and what the winner used to charge their balloon.

Sticky Tissue Competition

5. Tear the tissue into several tiny pieces and spread them on your team table. Everyone will need to have an inflated balloon for this competition.
6. Choose how long you will charge your balloons, and then compete for the tissue pieces. Record the winner of this competition and what the winner used to charge their balloon.

Jumping Pepper

> **Warning**
>
> - Pepper causes stinging of the eyes. Be careful not to get pepper in your eyes.
> - Balloons make a loud noise if popped.

7. Lay the piece of paper on a table and sprinkle a spoonful of ground black pepper onto the paper. Choose one team member to charge their balloon.
8. Position the charged balloon about 12 inches above the pepper and then slowly lower it while the rest of the team observes. Record your observations.

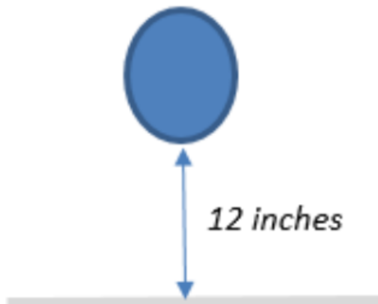

Figure 26.4.3

Clean-up

- Use the scissors to cut a small hole where balloons are tied so the air will escape quietly (or wash off the pepper if you want to keep your balloon)
- Dispose of the balloon, string, pepper, and pieces of tissue
- Wash your table

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26.5: Analysis

1. Explain the result of having only one hanging balloon charged. Why did the balloons behave the way that they did?
2. Explain the result of having both hanging balloons charged. Why did the balloons behave the way that they did?
3. How was each object charged? (friction, simple contact, or induction)
   a. Balloons
   b. Soda can
   c. Tissue paper
   d. Pepper
4. Discuss and describe any fabric softeners or hair products that may have resulted in a certain team member winning the *rolling soda can race*. Also discuss and describe any products that may have resulted in a certain team member winning the *sticky tissue competition*.
5. In general, does static electricity exhibit force at a distance? Explain.

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26.6: General Questions

1. Assume 10,000 electrons were transferred from your hair to the balloon.
   a. What is the charge in Coulombs on the balloon?
   b. What is the charge in Coulombs on your hair?
2. What is the amount of electric force between the balloon and your hair if they are positioned 1 centimeter apart? Add a + and a – to <u>each</u> square representing a piece of tissue in a chain, as the tissue pieces hang from a negatively charged balloon; show the relative positions of the + and – charges on each piece of tissue in the chain. Does each piece of tissue have a charge or is each piece neutral?

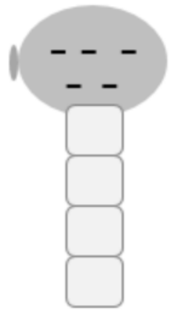

Figure 26.6.1

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CHAPTER OVERVIEW

27: Investigation 26 - Holiday Lights

Learning Objectives

- Construct, compare, and contrast series and parallel circuits.

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27.1: Materials

- 4 D-size Batteries
- 6-inch Length of Insulated Conducting Wire
- 12+ Electrical Leads with Alligator Clips (short length)
- 6 Flashlight Bulbs
- 6 Bulb Sockets
- Electrical Tape

Figure 27.1.1: Electrical Leads (Crocodile Clip Cables by Suyash Dwivedi licensed under CC 4.0.

Figure 27.1.2: Flashlight Bulb by Rainer Bielefeld is licensed under Public Domain

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27.2: Introduction

An electric circuit provides a complete path through which electrons may flow. There are two basic types of circuits: series and parallel. Devices in a series circuit are connected in one continuous loop while devices within a parallel circuit are connected in multiple loops. A short circuit is a path of least resistance in the electrical circuit which bypasses the devices that the circuit is intended to operate. When there is a short circuit, wiring may become hot. Circuit diagrams show how the different types of circuits are connected together. The lines in a circuit diagram represent wires.

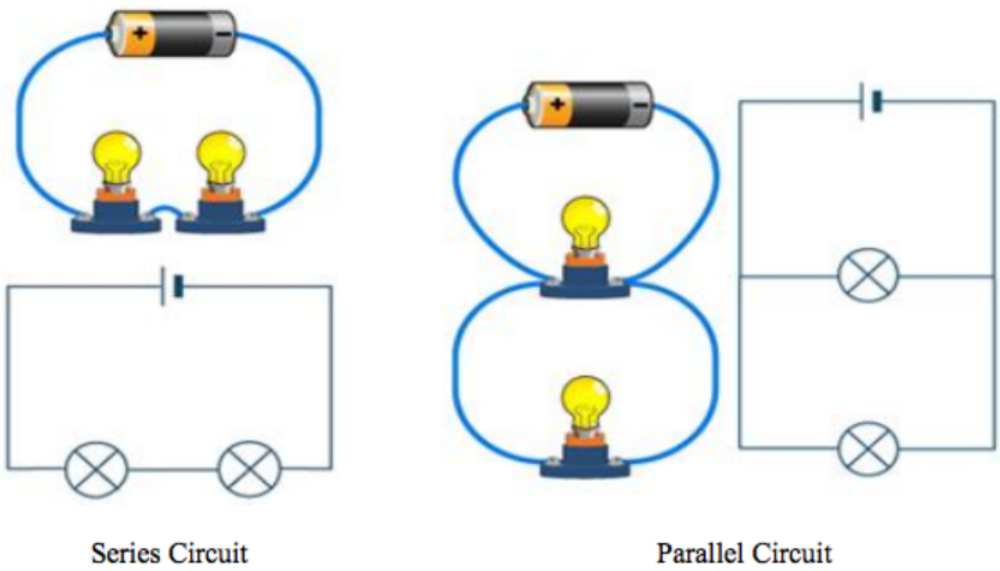

Figure 27.2.1: Series and Parallel Circuit. (sciencewithpizzi.weebly.com/25-parallel-circuits)

The resistance is added differently in each type of circuit because of how current flows across each device in series versus parallel circuits.

Table 27.2.1: Series and Parallel Resistance

Series Circuit Resistance	Parallel Circuit Resistance
$R = R_1 + R_2 + R_3$	$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

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27.3: Pre-Lab

A. Which string of holiday lights would you expect to remain lit if one bulb breaks, series or parallel?
B. Predict which type of circuit will result in brighter bulbs when the same number of bulbs are used, series or parallel, or will the bulb brightness be the same.

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27.4: Procedures

Warnings

- Exposed ends of wires can burn you.
- Wires will become hot if a short circuit is created.

You will construct a variety of circuits.

Simple Flashlight

1. **Your first task is to construct a simple circuit using a single wire, a single battery, and a single light bulb (no socket). This circuit may be used to test whether light bulbs are broken as you progress through the lab. You must have this circuit checked by your instructor before you continue.**
2. Draw two data tables in which to record working/not working results and brightness results for your circuits. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 27.4.1: Electric Circuit Data

	Working	Not Working
2 Bulb Series, 1 Bulb Removed		
2 Bulb Parallel, 1 Bulb Removed		

Table 27.4.2: Brightness Data

	Brightness Decreased	Brightness Unchanged
3 Bulb Series		
3 Bulb Parallel		

3. Tape two batteries together, making sure the batteries are “stacked” similar to how they would be placed in a regular flashlight.

Figure 27.4.1

Series Circuit

4. **You will need to have this circuit checked by your instructor once it is working.** Construct a series circuit using 2 batteries, 2 bulbs, 2 sockets, and as many pieces of electrical leads as you need. If the bulbs do not light, test each light bulb with a battery and a wire. Once you have a working circuit have it checked by your instructor. Then unscrew one bulb from a socket. Record whether the series circuit is working or not working after the bulb is removed.
5. Add a 3rd bulb with a socket to your series circuit. Record whether the brightness decreased or was unchanged when the 3rd bulb was added to your series circuit. Detach the batteries and set the taped batteries and series circuit aside; do not disassemble your series wiring.

Parallel Circuit

6. Tape the other two batteries together.
7. **You will need to have this circuit checked by your instructor once it is working.** Construct a parallel circuit using 2 batteries, 2 bulbs, 2 sockets, and as many pieces of electrical leads as you need. If any of the bulbs do not light, test them with a

battery and a wire. Once you have a working circuit, have it checked by your instructor. Then a un-screw one bulb from a socket. Record whether the parallel circuit is working or not working after the bulb is removed.

8. Add a 3rd bulb with a socket to your parallel circuit. Record whether the brightness decreased or was unchanged when the 3rd bulb was added to your parallel circuit. Detach the batteries and set the taped batteries and parallel circuit aside; do not disassemble your parallel wiring.

Comparing Series & Parallel

9. Re-attach the batteries to each of your circuits, series and parallel. Once you have both circuits operating, compare the overall brightness of the bulbs in each. Note that some bulbs may be brighter than others as a function of age. Record which type of circuit, in general, has the brightest bulbs.
10. Construct a combination circuit such that part of your circuit is wired in series and part of your circuit is wired in parallel. Sketch this circuit and indicate where you have series connections and where you have parallel connections. Record any differences in brightness you observe.

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27.5: Analysis

1. Compare and contrast series and parallel circuits, based on your observations.
2. Calculate the resistance for each of your 3 bulb circuits. Assume each bulb has 2 Ohms of resistance and neglect any resistance provided by the rest of the system.
3. How were you able to verify that you had both series connections and parallel connections in your combination circuit?

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27.6: General Questions

1. Can you unscrew a bulb from a series circuit without affecting the flow of electrons?
2. Can you unscrew a bulb from a parallel circuit without affecting the flow of electrons?
3. How do you think most of the circuits in your home are wired, in series or in parallel? What evidence do you have?

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CHAPTER OVERVIEW

28: Investigation 27 - Magnetic Field Patterns and Interactions

Learning Objectives

- Observe magnetic field patterns, and observe interactions between magnetic fields.

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28.1: Materials

- Box Small Paperclips
- 1 Large Paperclip
- 1 Container of Iron Filings
- 1 Piece of White Paper
- 2-4 Magnets (different shapes)
- 2 Strong Bar Magnets
- 1 Magnetic Compass

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28.2: Introduction

A material exhibits magnetic properties when electrons align in a particular way within the material. Each electron is basically a tiny magnet and when the magnetic fields of the electrons are aligned within a material, the magnetic moments of the electrons add together making the entire material magnetic. All magnets have both a north seeking pole and a south seeking pole which are based on the magnetic moment positioning of the electrons. Opposite poles are attracted together, while like poles repel. A magnet can induce magnetism in a ferromagnetic material. Iron filings are a ferromagnetic material, and thus, exhibit magnetic effects when they are near a magnet, and align themselves with the magnetic field of the magnet.

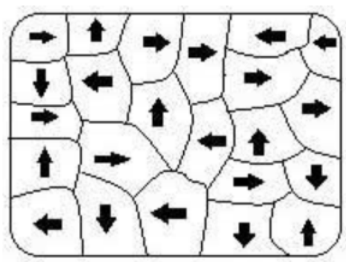

Figure 28.2.1: Unmagnetized

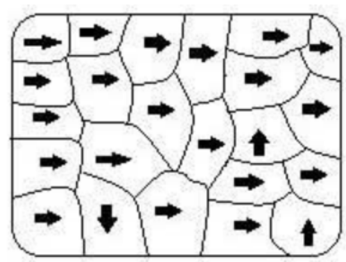

Figure 28.2.2: Magnetized

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28.3: Pre-Lab

A. Does magnetic attraction occur through any materials, such that magnets are attracted/repelled when separated by the material?
B. Is it possible to have a magnet with only one magnetic pole?

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28.4: Procedures

Warnings

- Do not bang or drop magnets; this may disorder the magnetic domains.
- Iron filings will not wash off a magnet; use the paper as a barrier.

You will observe several magnetic field patterns, and test magnetic attraction.

Patterns

1. Draw a table in which record your observations. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 28.4.1: Patterns Data

Shape of Magnet	Visible Looping (yes or no)

2. Choose 3 different magnet shapes; record the magnet shapes. Place one magnet under the piece of paper. Lightly sprinkle iron filings from the container onto the paper, like you are seasoning your food, until a pattern emerges. Observe and record whether there is any visible looping in the pattern. Sketch the shape of the magnet and the magnetic field pattern for this magnet, under your data table. Pour the iron filings from the paper back into the container. Repeat this process for the 2 additional magnet shapes you chose.

Example

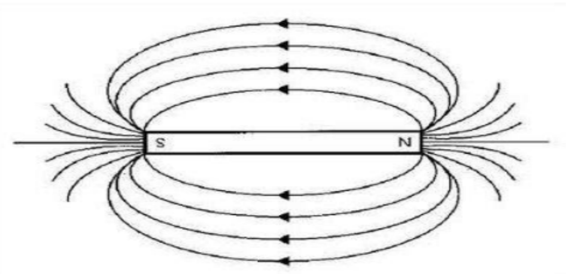

Figure 28.4.1

Magnetic Metal

3. Place the large paperclip on your lab table, and place a piece of paper over the paperclip. Lightly sprinkle iron filings onto the paper until. Record whether you are able to discern the paperclip, whether there is a magnetic field pattern.
4. Place one of the bar magnets on your lab table, and place the large paperclip on top of a bar magnet, at one end, such that the paperclip extends out from the top surface of the magnet. Place a piece of paper over this magnet-paperclip system. Lightly sprinkle iron filings onto the paper until the pattern emerges. Record whether you are able to discern the paperclip from the bar magnet.

Figure 28.4.2

Strongest Magnet

5. Spread the small paperclips onto the table. Have each team member choose a magnet. Have a team competition to determine which magnet is the strongest. Describe the properties of this magnet, like its shape and what it was able to do to win the competition.

Multiple Fields

6. Draw a table in which to record your observations of magnetic field interactions. Read the instructions for obtaining the data.

Table 28.4.2: Multiple Fields Data

	Interaction Visible (Yes or No)	Lines Connect or Bend Away
Opposite Poles		
Like Poles		

7. Orient the bar magnets such that the opposite poles are attracting, but are not touching. Place the piece of paper over this two magnet system. Lightly sprinkle iron filings onto the paper until the pattern emerges. Observe and record whether the pattern shows interaction between the magnets in your *multiple fields* data table. Also record whether magnetic field patterns appear to connect or bend away from each other.
8. Re-orient the bar magnets such that the like poles are repelling, but are not touching. Repeat the process you used for opposite poles and record your observations in the *multiple fields* data table.
9. Use a combination of magnets, or magnets and paperclips, to create a design. Place the piece of paper over this combination system. Lightly sprinkle iron filings onto the paper until patterns emerge. Sketch the orientations of the magnets and/or paperclips in your design. Describe or sketch what you observe happening to the magnetic fields in this system. Repeat the process for a 2nd combination design.

Mapping the Field

10. Place a strong bar magnet on the table. Slowly move the magnetic compass around the magnet and observe the compass needle. Place the compass at multiple locations, encircling the entire bar magnet, and sketch the direction the arrow points at these locations. Your sketch should result in a map of the field surrounding the bar magnet.

Example

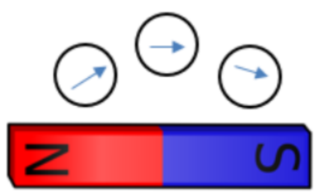

Figure 28.4.3

Magnetic Materials

11. Draw a table in which to list 5 magnetic and 5 non-magnetic materials/objects in your classroom. Read the instructions for obtaining the data.

Table 28.4.3: Magnetic & Non-magnetic Data

	Magnetic	Non-magnetic
1		
2		
3		
4		

	Magnetic	Non-magnetic
5		

12. Choose a strong magnet and test items in your classroom to complete your *magnetic and non-magnetic* data table.

Extension of the Field

13. Draw a table in which to record magnetic fields interacting through materials data. Read the instructions for recording data about these objects.

Table 28.4.4: Materials Data

Material	Interaction Felt (Yes or No)
Paper	
Wood	
Lab Table	
Rubber	
Glass	

14. Choose two strong magnets. Determine if the magnets are strong enough to interact through the items listed below. Record your results in your *materials* data table.
    a. A sheet of paper (Paper)
    b. A wood door (Wood)
    c. The thickness of the edge of your table (Lab Table)
    d. The seat of your chair (Rubber)
    e. A glass window (Glass)

Clean-up

- Clean up all iron filings
- Throw away the piece of paper
- Wash your team table

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28.5: Analysis

1. Describe evidence from your observations that prove opposite poles attract and like poles repel.
2. In general, do magnetic fields appear to form loops?
3. Were there any trends among magnetic or non-magnetic materials?
4. Magnetic fields may extend through materials/objects in the vicinity of the field. (True/False)

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28.6: General Questions

1. Explain what must take place in a paperclip for it to produce a magnetic field.
2. Are all metals magnetic? What is your evidence?
3. “One pole of the magnet is negative and the other pole of the magnet is positive.” Is this statement true or false?

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CHAPTER OVERVIEW

29: Investigation 28 – The Electromagnetic Connection

Learning Objectives

- Test the induction of a magnetic field from electricity, and the strength of an electromagnet.

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29.1: Materials

- 2 Large Iron Nails (such as 10d 3")
- 2 Large Iron Bolts or Screws (same diameter and length as nail)
- Insulated Conducting Wire (small gauge 20-28 AWG)
  - 2 12-inch lengths
  - 2 24-inch lengths
- 2 D Size Batteries
- Electrical Tape
- 1 Container of Iron Filings
- 1 Piece of White Paper
- 1 Box Small Paperclips
- Wire Strippers

Figure 29.1.1: Large Iron Nail www.bestmaterials.com

Figure 29.1.2: Large Iron Bolt or Screw

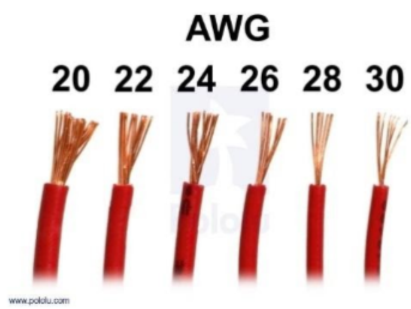

Figure 29.1.3: Standed Insulated Copper Wire

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29.2: Introduction

An electromagnet is a coil of conducting wire encircling an iron core that becomes a magnet when electric current is present in the wire. The iron core strengthens the magnetic effect. Electromagnets have a north magnetic pole and a south magnetic pole at the ends of the coil. Alternating current induces a magnetic field, so as long as there is electric current running through the coil, the coil will be magnetic. The magnetic field from the electromagnet forces the domains in the iron core to align, strengthening the overall magnetic effect.

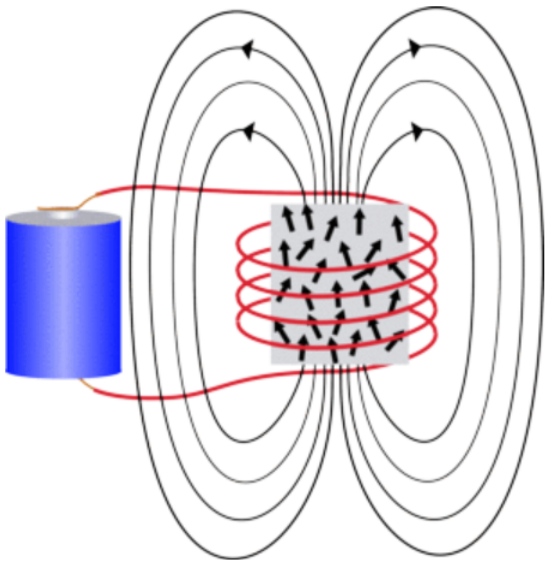

Figure 29.2.1: An Electromagnet.

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29.3: Pre-Lab

A. Research how to construct an electromagnet.

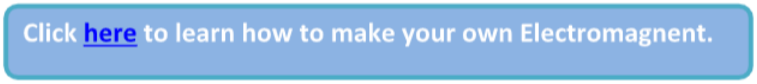

Figure 29.3.1

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29.4: Procedures

You will make four electromagnets and investigate the properties of electromagnets.

1. Strip the ends of your wires, if the ends are not already stripped.
2. Draw a table in which to record magnetic strength data. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 29.4.1: Magnetic Strength Data

Magnetic System	Windings	Paperclips
Nail, 12 Inch Wire		
Nail, 24 inch Wire		
Bolt, 12 Inch Wire		
Bolt, 24 Inch Wire		

Warnings

- Exposed ends of wires can burn you.
- Your battery may get hot.
- You may need to use a 2nd battery for your systems to work.

The Iron Nail

3. Leave about 2-3 inches of a 12-inch wire loose at one end of the nail, and wrap most of the rest of the wire around the nail (do not overlap wire loops), count the number of loops/coils. Record the number of windings on your nail. There should be about 2-3 inches of wire loose at each end of the nail.
4. While holding the insulated part of the wire, touch the exposed ends to one battery; be careful not to burn yourself. Attach the wire ends to the battery with electrical tape. Use your electromagnet to pick-up as many paperclips as it can attract. Record the number of paperclips your 12-inch wire electromagnet is able to hold. Detach this electromagnet from the battery.

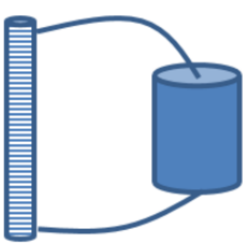

Figure 29.4.1

5. Repeat the process with your 2nd nail and the 24-inch wire. Record your data. If you receive a negative result for both the 12-inch wire and the 24-inch wire, use the 2nd battery and try again.

The Iron Bolt

6. Follow the same processes you used with the nail, but this time use an iron bolt for the core. Record your data.

Determining the Poles

7. Place the piece of paper over one of your electromagnets. Re-attach the battery to this electromagnet, and lightly sprinkle iron filings onto the paper. Describe or sketch the pattern; identify where the poles appear to be. Repeat this process for each of your electromagnets.

Clean-up

- Clean up all iron filings
- Throw away the piece of paper
- Wash your team table
- Unwrap and straighten all wire from nails and bolts

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29.5: Analysis

1. Describe any correlation between number of coils and magnetic strength.
2. Describe any differences between the nail electromagnets and the bolt electromagnets. Explain why any differences may occur.

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29.6: General Questions

1. Describe any correlation between number of coils and magnetic strength.
2. Describe any differences between the nail electromagnets and the bolt electromagnets. Explain why any differences may occur.

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CHAPTER OVERVIEW

30: Investigation 29 - Energy of Sound and Speed of Light

Learning Objectives

- Verify that sound is a wave which carries energy and detect the difference between the speed of sound and the speed of light.

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30.1: Materials

- Drum
- Box of Paperclips
- Tuning Fork
- 400-500 mL Beaker
- 2 Wood Stakes
- Firm Grip Work Gloves
- Rubber Mallet

Figure 30.1.1: Snare Drum available in the public domain

Figure 30.1.2: Tuning Fork by Helihark, is licensed under CC BY-SA 3.0

Figure 30.1.3: Tuning Fork Mallet Amazon.com

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30.2: Introduction

All waves begin as a vibration. For the vibration to produce sound, there must be a material through which the vibration may travel. The vibrations of atoms and molecules in air create compressions and rarefactions in the air.

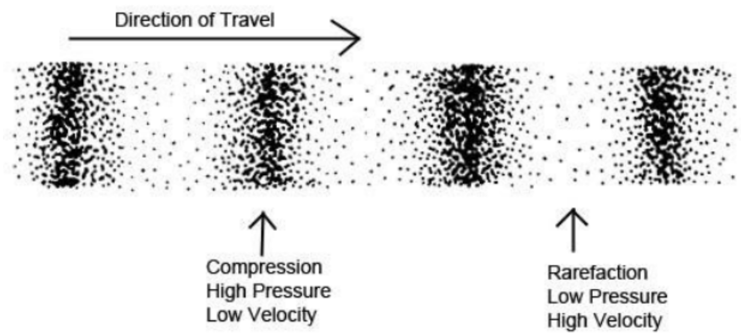

Figure 30.2.1: Copy and Paste Caption here. (Copyright; author via source)

Sound travels at an average speed of 343 m/s in air; this speed varies because it depends on the atmospheric pressure and temperature of the air. It takes time for the sound wave to travel. Light travels at a speed of 299,702,547 m/s in air. Light waves also take time to travel.

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

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30.3: Pre-Lab

A. What is a longitudinal wave? Describe and/or sketch it.
B. What is a transverse wave? Describe and or sketch it.

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30.4: Procedures

You will observe and analyze sound producing systems.

1. Draw a table in which to record your data. **Do not fill in data until you have read the instructions for obtaining that data**.

Table 30.4.1: Sound System Data

System	Vibration (yes or no)	Sound (yes or no)	Energy (yes or no)
Drum & Finger			
Drum & Drumstick			
Tuning Fork & Water			

Drum Energy

2. Place several paperclips on your drum. Use your finger to tap on the drum a few times and observe both the drum surface and the paperclips. Did you observe the surface of the drum vibrate (vibration)? Did you hear sound from the drum (sound)? Did you observe energy transferred to the paperclips (energy)? Enter all of your answers for this system in your *sound system* data table.
3. Use the drumstick to tap on the drum a few times and observe both the drum surface and the paperclips. Record your observations for this system.

Sound in Water

4. Fill the beaker about ¾ full with water.
5. Use the rubber mallet to strike the tuning fork, and then closely observe the tuning fork to determine whether you are able to see it vibrating. Did you see the tuning fork vibrate (vibration)? Record your answer.
6. Use the rubber mallet to strike the tuning fork again, and bring the tuning fork close to your ear to determine whether you can hear any sound. Did you hear sound from the tuning fork (sound)? Record your answer.
7. Strike the tuning fork with the rubber mallet, and place the tuning fork into the water; be careful not to touch the beaker with the tuning fork. Did you observe energy transferred to the water (energy)? Record your answer.

Sound versus Light

> **Note**
>
> This experiment must take place in a large outdoor space.

8. Draw a table in which to record your sound versus light observations. Read the instructions for obtaining the data.

Table 30.4.2: Sound versus Light Data

	Speed Difference Observed (Yes or No)
100 Paces	
200 Paces	
300 Paces	

9. Walk to a location where there is ample space and the ground is relatively flat. Ideally, you will have about 200-300 meters of flat ground.
10. Have one person put on the gloves, hold the two wood stakes, and walk 100 paces (regular steps) from the rest of the team. Observe as the person hits the stakes together and listen for the sound. Record whether your team observed the blocks hit <u>before</u> hearing the sound, in your *sound versus light* data table.

11. Increase the separation to 200 paces and repeat the process of observing the blocks and listening for the sound. Record whether the team observed the blocks hit before hearing the sound, in your *sound versus* light data table. Do this again for 300 paces.

Clean-up

- Discard water outside (water plants)
- Completely dry the beaker
- Completely dry the tuning fork

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30.5: Analysis

1. What was required to start each vibration, to make the system vibrate?
2. Which systems in your *sound systems* data table produced an audible sound? List all that apply.
3. For which systems in your *sound systems* data table was there a transfer of energy observed? List all that apply.
4. Assume that 100 paces equals 122 meters.
    a. Calculate the time for the sound wave to travel from the stakes to the observers, for 100 paces. The average speed of sound is 343 m/s.
    b. Calculate the time for the light wave to travel from the stakes to the observers, for 100 paces. The speed of light in air is 3 x 108 m/s.
    c. Use a ratio to calculate how much faster one wave arrives before the other.

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30.6: General Questions

1. When you speak, how is the sound produced? What must happen?
2. Why does a person typically see lightening before hearing thunder when both the lighting and the thunder travel the same distance from the same cloud?
3. As a storm cloud approaches, you count 5 seconds between the lightning and the thunder. How far away is the storm cloud? Provide mathematical proof for your answer.

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CHAPTER OVERVIEW

31: Investigation 30 - Waves on a Very Long Spring

Learning Objectives

- Analyze waves on a spring, and ascertain relationships between wave properties.

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31.1: Materials

- Long Spring (2 meters long - when un-stretched)
- Strong Metal Clamp
- Masking Tape
- Measuring Tape
- Impact Glasses (recommended)

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31.2: Introduction

A wave is a disturbance in a medium (material). All waves begin as a vibration, and this vibrational energy is carried from one location to another by the wave. The basic properties of waves include wavelength (λ), frequency (f), period (T), wave speed (v), and amplitude (A). Standing waves occur when one end of the medium is fixed; this allows the wave to make reflections of itself. In certain places, the vibrations will add to produce maximum amplitude and in other places the vibrations will cancel each other resulting in no vibration.

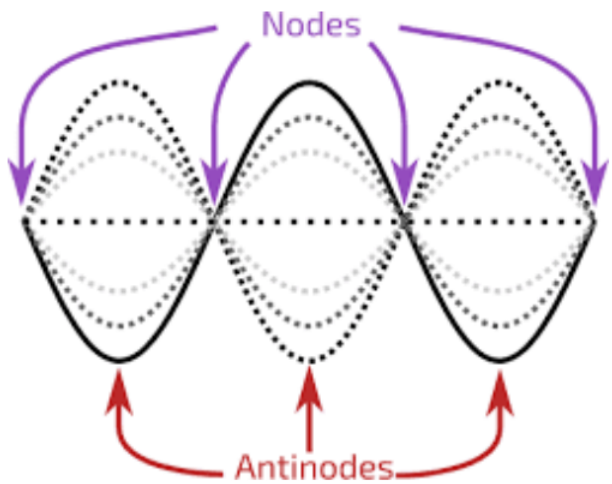

Figure 31.2.1: The Wave

Frequency & Period:

$$f = \frac{1}{T}$$

Speed & Frequency:

$$v = \lambda f$$

Speed & Period:

$$v = \frac{\lambda}{T}$$

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31.3: Pre-Lab

A. Define each wave property (wavelength, frequency, period, wave speed, and amplitude).

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31.4: Procedures

You will create different standing waves along the spring.

Warning

- Each person must pay attention and be ready in case the spring comes loose from the clamp.

1. Use the clamp to securely fasten one end of the spring to a table.
2. Stretch the spring out so that it does not touch the ground and is as close to horizontal as is possible, however, do not overstretch the spring! You do not have to use all of the spring, but you should have about 3 meters of horizontal spring. Any remaining length of spring may be coiled and held in your hand. Place a piece of tape on the spring where you intend to hold it, and place a piece of tape on the floor directly below your hold on the spring. Maintain this position for the entire experiment to ensure that the spring length is maintained.

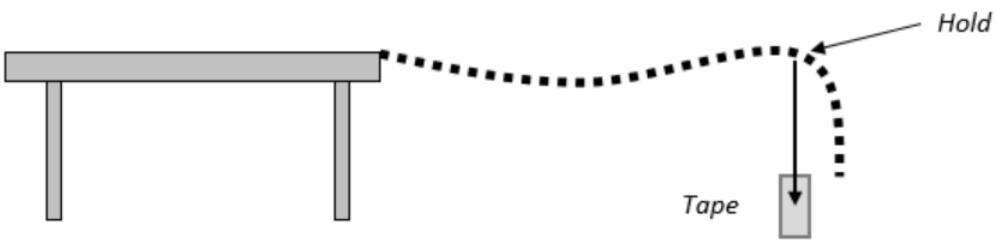

Figure 31.4.1

3. Measure and record the length of the horizontal spring in meters, from the clamp to where you are holding the spring. This measurement will be used to determine the wavelength of the waves you produce.

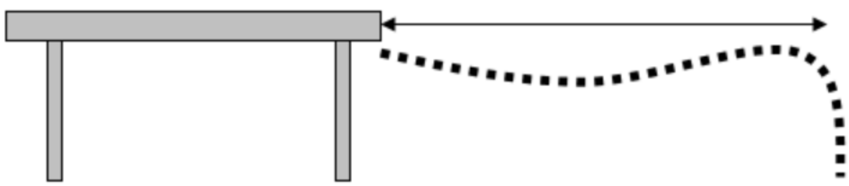

Figure 31.4.2

4. Draw a table in which to record your data. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 31.4.1: Wave Data & Analysis

	Time for 10 Cycles (seconds)	Period (seconds)	Frequency (Hertz)	Wavelength (meters)	Wave Speed (m/s)
1 bump					
1 high bump					
2 bumps					
2 high bumps					
3 bumps					

5. Create a wave on the spring by continuously moving your hand up and down in a maintained rhythm that sustains one bump. Be careful to maintain your positioning such that your hand remains aligned with the tape on the floor. While the one bump standing wave is sustained, measure the time it takes for 10 complete cycles. One cycle requires that the spring return to the start position, for example, begins at top and returns to top. Record the total time for 10 complete cycles in your data table.

Figure 31.4.3

6. Create a wave on the spring by continuously moving your hand up and down in a maintained rhythm that sustains one "high" bump. Be careful to maintain your positioning such that your hand remains aligned with the tape on the floor. Measure and record the time for 10 complete cycles of this wave.

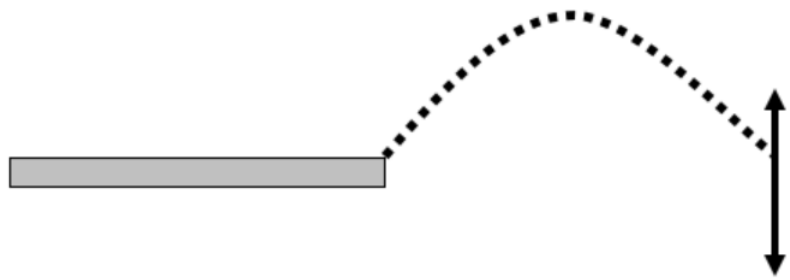

Figure 31.4.4

7. Repeat the one bump process for a two bump wave. Measure and record the time for 10 complete cycles of both the regular two bump wave and the "high" two bump wave.

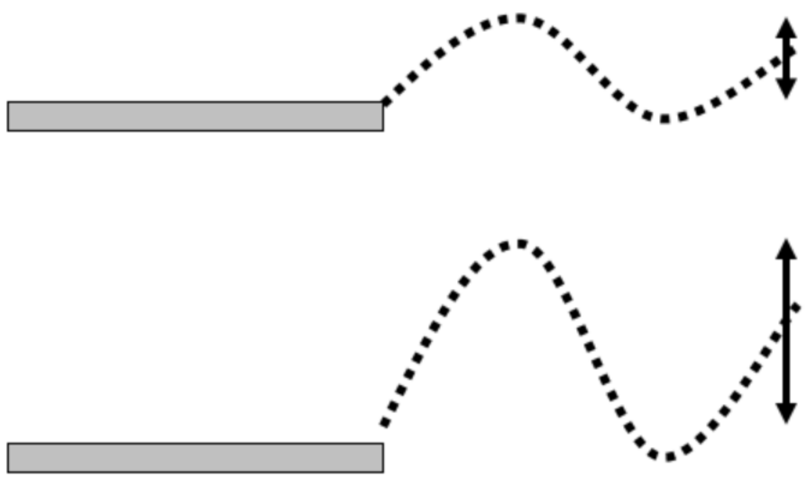

Figure 31.4.5

8. Repeat the one bump process for a three bump wave. Measure and record the time for 10 complete cycles of the regular three bump wave; you do not need to acquire data for a "high" three bump wave. The "high" three bump wave is very difficult to sustain.

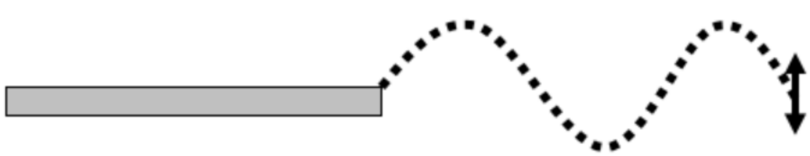

Figure 31.4.6

9. Investigate and determine the greatest number of bumps you can produce in this length of spring. Record your maximum number of bumps, counting both the up and the down bumps of the wave.
10. Calculate the period, frequency, and wavelength for each wave (except the wave with maximum number of bumps), and record these values in your data table.

Clean-up

- Remove tape from spring and floor, and throw tape away in the trash

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31.5: Analysis

1. Did changing the height of the wave significantly change any of the properties of the wave? If yes, which properties were significantly changed?
2. What was the medium, the material, through which the waves travelled?
3. What type of wave did you create, transverse or longitudinal?
4. Based on your experiment, what does increased amplitude require?

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31.6: General Questions

1. Sketch the original wave and its reflection for the two bump wave. Indicate locations on the spring where you would place a bell, while the two bump wave is sustained, if you wanted the bell to ring as quietly as possible. Are these locations nodes or antinodes?
2. Sketch the original wave and its reflection for the three bump wave. Indicate locations on the spring where you would you place a bell, while the three bump wave is sustained, if you wanted the bell to ring as loudly as possible. Are these locations nodes or antinodes?
3. Explain why the bell would ring quietly in certain locations on the spring, and loudly in certain locations on the spring, while a standing wave is sustained.
4. Standing waves of air molecules are produced in some wind instruments. Do you think the holes of a wind instrument are placed at the nodes or antinodes? Defend your answer.

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CHAPTER OVERVIEW

32: Investigation 31 - Bouncing Light

Learning Objectives

- Observe the law of reflection in different systems and compare a variety of reflective surfaces.

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32.1: Materials

Law of Reflection

- Flashlight
- Flat Mirror (single plane)
- Masking Tape
- Meter Stick
- Ramp (metal wall corner)
- Ring Stand with Adjustable Clamp

Comparing Reflectivity

- Sheet White Paper
- Sheet Smooth Foil
- Sheet Crinkled Foil
- Wood Block
- Flat Mirror
- Flashlight

The Bounce

- Small Basket or Box
- Your Lab Chair
- Tennis Ball
- Milk Crate (uneven surface)

Mirrors

- 2 Flat Mirrors
- Hand Held Concave/Convex Mirror
- Metal Spoon (shiny)
- Candle
- Matches
- Access to Concave Mega Mirror
- Access to Convex Mega Mirror

> Note
>
> This lab activity must be done in a darkened room.

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32.2: Introduction

The incoming angle of light and the outgoing angle of light are equal, with respect to a perpendicular line called the normal line, for all reflective surfaces; this is the law of reflection. The normal line is a line that is drawn perpendicular to the surface where the light is hitting the surface.

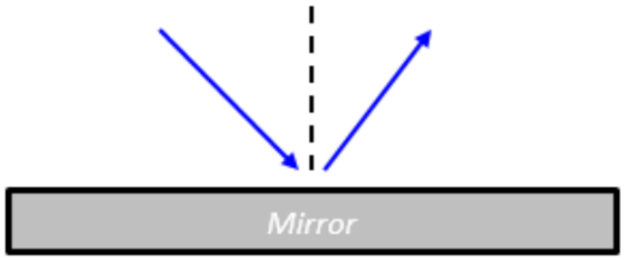

Figure 32.2.1

If the surface is smooth and flat, the light rays will leave the surface parallel to each other. However, if the surface is irregular, the light rays will leave in various directions.

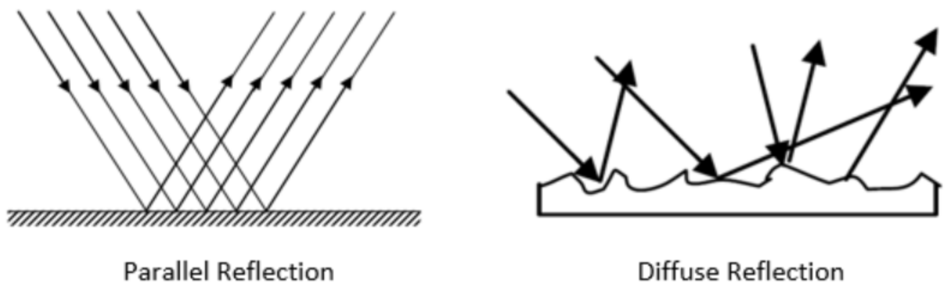

Figure 32.2.2

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32.3: Pre-Lab

A. What is a photon?

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32.4: Procedures

You will mimic the reflection of a photon and observe reflective properties of materials.

Law of Reflection Test

1. Draw a table in which to record your law of reflection data. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 32.4.1: Law of Reflection Data

	Same Center (Yes or No)	Δ Size
1st Ramp Height		
2nd Ramp Height		

2. Set-up the ramp such that the bottom end of the ramp is about one meter from a wall. The height of the ramp at the top end is not important. Rest the flashlight on the ramp, at the top of the ramp, and position the mirror on the floor where the light beam is shining. The light should be reflected from the mirror to the wall. Use a piece of masking tape to mark the center of the light shape on the wall.

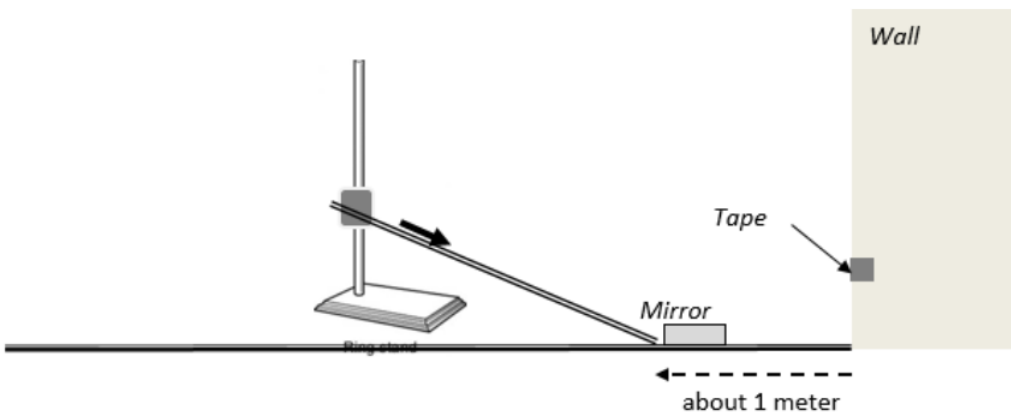

Figure 32.4.1

3. Slide the flashlight down along the ramp, closer to the mirror, while observing the light shape on the wall. Make sure the light from the flashlight continues to hit the mirror as you slide the flashlight down the ramp, and adjust the position of the mirror if needed. Record whether the light shape remained centered on the tape, in your *law of reflection* data table. Also record how the size of the light shape changed (larger, smaller, or unchanged).

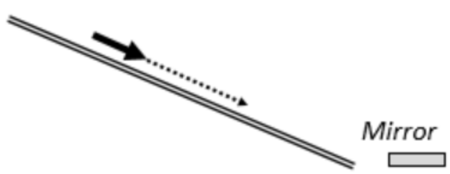

Figure 32.4.2

4. Change the height of your ramp, to change the angle of incidence. Repeat processes you completed for the lower ramp. Record whether the light shape remained centered on the tape. Also record how the size of the light circle changed (larger, smaller, or unchanged).

The Bounce Test

5. Place the basket or box on a chair. Stand about 2 meters from the chair, and make 3 attempts to bounce the tennis ball from the floor into the basket or box that is on the chair, while you observe the motion of the ball. Record the general motion of the ball; did the ball tend to bounce toward the chair or in random directions.

Figure 32.4.3

6. Place milk crate upside down on the floor between you and the chair, and make 3 attempts to bounce the tennis ball off the milk crate into the basket or box that is on the chair, while you observe the motion of the ball. Record the general motion of the ball; did the ball tend to bounce toward the chair or in random directions.

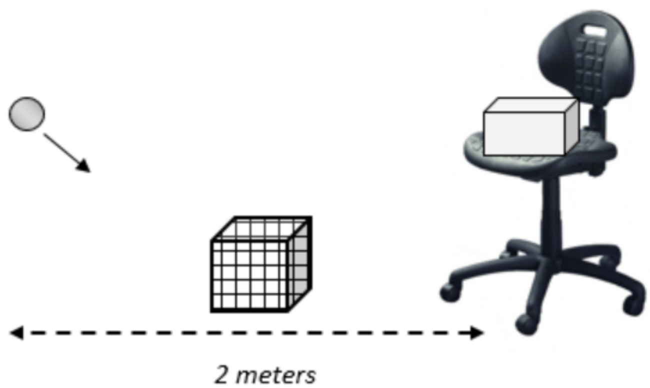

Figure 32.4.4

Comparing Reflectivity

7. Draw a table in which to record your reflective surfaces data. Read the instructions for obtaining that data.

Table 32.4.2: Reflective Surfaces Data

Object	Predicted Ranking	Observed Ranking
Mirror		
Wood		
Smooth Foil		
Crinkled Foil		
White Paper		

8. Predict the rank order from most reflective (1) to least reflective (5).
9. Place each of the reflective surfaces on your table. Alternately bounce light from each surface to the ceiling and observe the amount of reflected light on the ceiling, from each surface. Record the observed rank order of the listed reflective surfaces from most reflective (1) to least reflective (5), in your *reflective surfaces* data table.
10. Stand about 2 meters from a wall and turn on the flashlight. Shine the flashlight through the air toward the wall. Observe the light from the flashlight and compare the light in the air to the light on the wall. Record where the most light is seen, in the air or on the wall.

Mirrors

11. Draw a table in which to record information about each mirror image. Read the instructions for obtaining the data.

Table 32.4.3: Mirror Images Data

Type of Mirror	Apparent Size	Apparent Distance	Orientation
Flat Mirror			
Concave Mirror			
Convex Mirror			
Spoon-Concave side			
Spoon-Convex side			

12. Use your aluminum foil to create a candle stand and place your candle on the table. Light the candle with a match. Use each type of mirror (concave and convex) and each side of the spoon to view an image of the candle; you will need to position each reflective surface on the opposite side of the candle from where you are located.

Figure 32.4.5: Candle light reflection

Observe and record the following data for each reflective surface used to view the candle.

- Apparent size of the image (same, smaller, or larger) compared to the size of the candle
- Apparent distance of the image from the mirror (same, nearer, further) as compared to the candle distance from the mirror
- Apparent orientation of the image (same or upside down)

13. Use the two flat mirrors to create an "infinity mirror". Describe or sketch the positioning of the mirrors that results in the greatest number of images, the most reflections of the candle.

14. Hold one of the flat mirrors upright on the line identified as "mirror line" with the shiny side facing the letters in the boxes below. Sketch what the letters look like in the mirror; use large block letters.

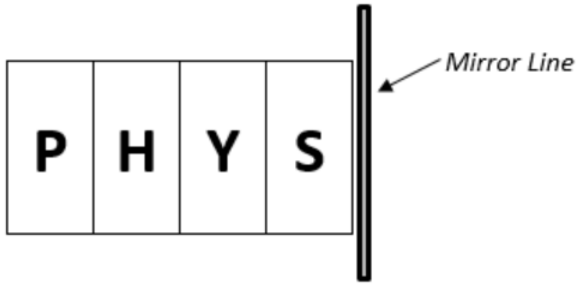

Figure 32.4.6

15. Hold one of the flat mirrors upright with the shiny side facing the letters you sketched in the previous step. Record a description of what you observe.
16. Draw a table in which to record your observations of your image in the Mega Mirrors. Read the instructions for obtaining the information.

Table 32.4.4: Mega Mirror Image Data

Type of Mirror	Apparent Size	Abrupt Change
Convex Mega Mirror		
Concave Mega Mirror		

17. Locate the Mega Mirrors in your classroom. View an image of yourself in the convex mega mirror. Record whether the apparent size of the image (same, smaller, or larger) than you. Move to within a few inches of the mirror and the then slowly back away from the mirror, while observing your image. Record any abrupt change in the image (change in size or image flips). Repeat the process for the concave mega mirror.

Clean-up

- Remove tape from the wall and throw it away
- Dispose of all aluminum foil

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32.5: Analysis

1. Based on your observations of the tape on the wall, does distance between light source and mirror affect the angle at which the light is reflected?
2. In which case was diffuse reflection modeled when you were bouncing the tennis ball, when the ball bounced from the floor or the milk crate?
3. Describe how the surfaces of the most reflective and least reflective items are different.
4. When the flashlight is shown through the air toward the wall, is more light seen in the air or on the wall? Explain why this happens.
5. Which shape (convex or concave) tends to produce an image that appears smaller than the object?
6. Which shape (convex or concave) tends to produce an image that appears larger than the object?

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32.6: General Questions

1. Do photons follow the law of reflection?
2. When light is bounced off a rough surface, not much light seems to be reflected from the surface. Why? Does the law of reflection apply to these surfaces? Explain.
3. Would you expect a city street to exhibit parallel or diffuse reflection? Use your data to defend your answer.

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CHAPTER OVERVIEW

33: Investigation 32 - Bending Light

Learning Objectives

- Observe the effects of light refraction, and investigate the images produced by different lenses.

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33.1: Materials

Explorations with Air and Water

- Plastic Rectangular Tub
- 2 Pennies (clean and shiny)
- 250 mL Beaker
- Wide Plastic Straw
- 2-3 Wood Skewers
- Masking Tape
- Metric Ruler
- Measuring Tape
- White Sheet of Paper
- Laser Refraction Tank

Images with Lenses

- Plano-Convex
- Plano-Concave
- Double Convex
- Double Concave
- Candle
- Matches
- Sheet Aluminum Foil
- Blank 3x5 Index Card

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33.2: Introduction

Light travels in a straight line at a constant speed, unless it interacts with a material. When light travels from one medium to another, one material to another, the light's velocity changes where the two mediums meet. The apparent location of an object may not be the actual position of the object if the light has travelled through more than one medium, for example, if the light passes through both air and water as it travels to you. If light passes from one medium to another at an angle, then the path of the light will change.

Figure 33.2.1

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33.3: Pre-Lab

A. Define refraction.

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33.4: Procedures

You will observe the effects of refraction in several systems.

Spear the Penny

1. Place one penny on the bottom of the plastic tub; it should be near the center. Fill the tub about half full with water.
2. Balance the straw at the edge of the plastic tub, keeping the entire straw in air, and use it as a sighting tool to see the penny. Do not allow the straw to go into the water. When you see the penny through the straw, tape or hold the straw in place. Use your fingers to send the wood skewer through the straw in an attempt to spear the penny. If you repeat shooting a skewer through the straw, use a dry skewer. Record whether you successfully speared the penny or missed the penny. If you missed the penny, record the approximate distance in centimeters between your skewer and the penny.

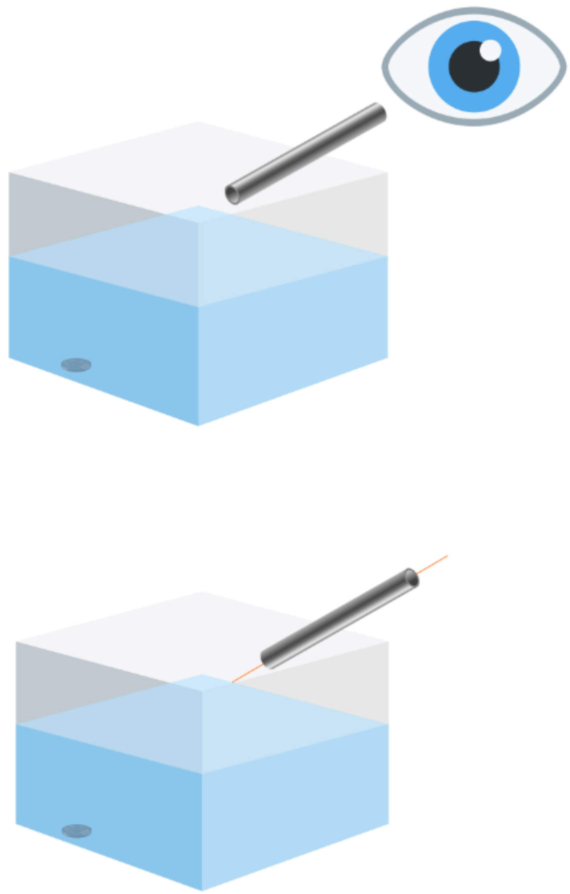

Figure 33.4.1

Bending Ruler

3. Place the ruler into the water, vertically, such that part of the ruler is in the water and part of the ruler is in the air; this is the “no angle” position. Allow the ruler to rest on the bottom of the plastic tub. Slowly move the ruler such that the angle is changed to a “small angle” and then a “large angle", and observe the shape of the ruler. Sketch the appearance of the ruler when it is at an angle, for both the small and large angle positions. Record the angle (small or large) at which the ruler appears most bent at the air/water line. Remove the ruler from the tub of water.

> **Note**
>
> The grey bow (water) should be fully in the rectangle (tub),

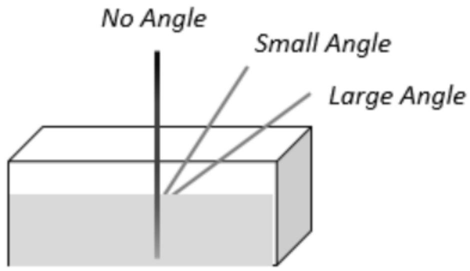

Figure 33.4.2: Copy and Paste Caption here. (Copyright; author via source)

Where is the Penny

4. Add 150 mL of water to the 250 mL beaker. Place the white sheet of paper on the table close to you, and set the beaker on the paper. Place one penny on the bottom of the beaker, and position the penny so that it is in the center; you may want to use the skewer to center the penny.

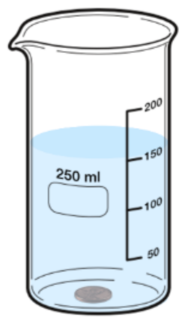

Figure 33.4.3

5. Position yourself such that you are eyelevel with the water in the beaker. While looking at the penny through the water, slowly change your angle of observation, moving from a parallel line of sight to a vertical line of sight. Record your observations, the changes that occurred in the appearance of the penny as your line of sight changed. Also record the greatest number of penny images you were able to see.

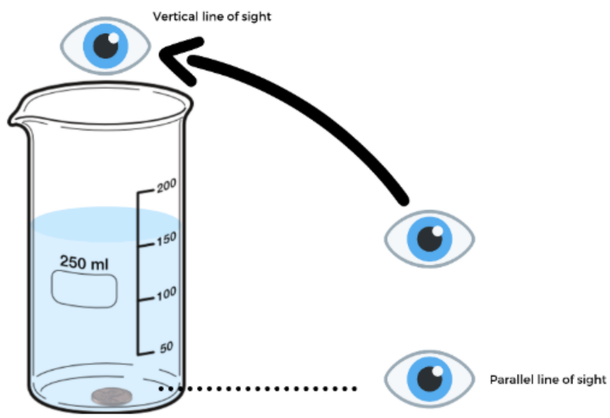

Figure 33.4.4

6. Move your beaker of water with the penny to a ledge where you have several meters to back away from it. Place the piece of white paper under the beaker and make sure the penny is in the exact center of the beaker.

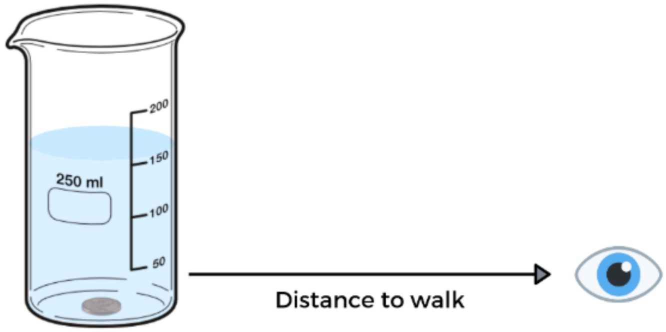

Figure 33.4.5

7. Position yourself so that your eyes are level with the water in the beaker, and look at the penny through the side of the beaker such that the light is traveling from the penny through water, beaker, and air, to you. Take a few steps backwards, away from the beaker, and then position yourself so that your eyes are level with the beaker again. Continue to take steps backwards and observe the beaker, until the penny has disappeared or you have run out of room. Each person on the team should try this. Record whether the penny changed appearance and/or disappeared as you walked backwards away from the beaker. Also record which team member (shortest or tallest) observed the penny disappear with the least distance from the beaker.

Angles of Refraction

8. Draw a table in which to record the angle of incidence and the angle of refraction for six positions/angles that you will choose. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 33.4.1: Refraction Angles Data

Angle of Incidence	Angle of Refraction	Light Reflected (Yes or No)
0º		
20º		

9. Add water to the midline of the Laser Refraction Tank. Position the laser at the bottom such that a vertical beam of light may travel from the bottom of the tank, through the water, to the top of the tank. Turn on the laser and record whether there is any refraction of the vertical light ray.

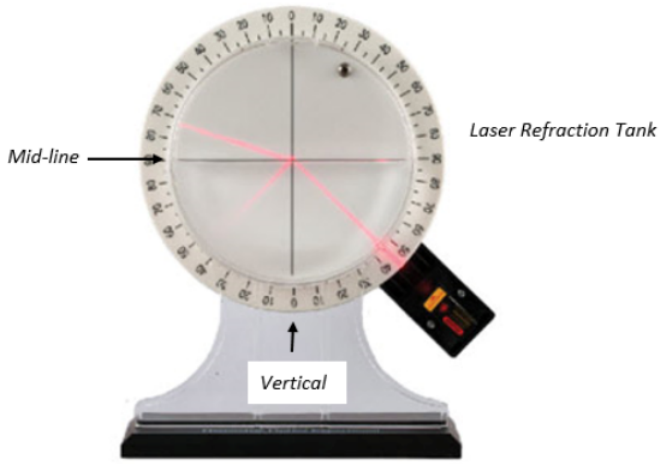

Figure 33.4.6

10. Position the laser at 20º for the angle of incidence. Determine and record the angle of refraction in your *refraction angles* data table. Also record whether any light is reflected (yes or no) back into the water. Choose four additional angles and repeat the process.
11. Determine and record the angle of incidence required for the refraction to send the light beam back into the water, such that no light travels into the air. This is the angle of total internal reflection, for water.

Images with Lenses

12. Draw a table in which to record information about each lens image. Read the instructions for obtaining the data.

Table 33.4.2: Lens Image Data

Lens/Combination	Apparent Size	Orientation
Plano Concave Lens		
Double Concave Lens		
Plano Convex Lens		
Double Convex Lens		

13. Use your aluminum foil to create a candle stand and place your candle on the table. Light the candle with a match. Use each of the hand held lenses and choose two different pairs of lenses, to view an image of the candle; you will need to position the lenses somewhere between you and the candle such that you have a clear, focused image. List the lens combinations you choose, in your table. Record data for each system in your *lens image* data table.
    - Apparent size of image (same, smaller, or larger) compared to the size of candle
    - Orientation of image (same or upside down)

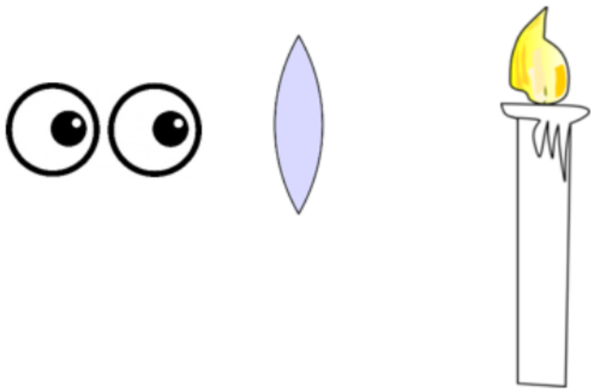

Figure 33.4.7

14. Hold the double convex lens at arm's length and aim it toward a window at some outdoor scene. Hold the blank index card in the other hand, positioned between the lens and your eyes. Move the card back and forth until you can see a clear image on the index card. Describe how the image compares to the outdoor scene.

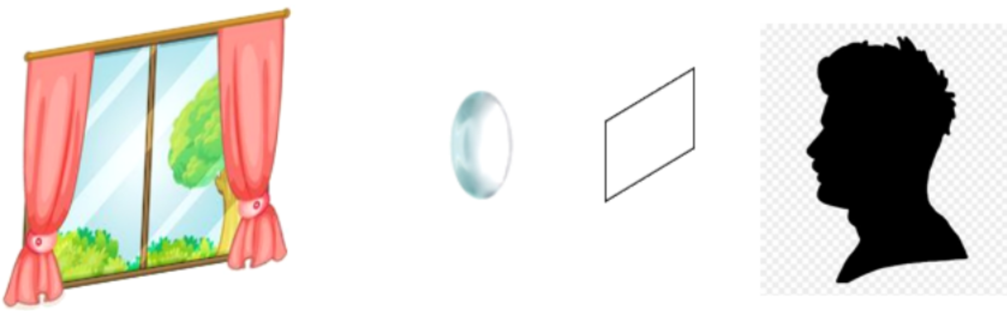

Figure 33.4.8

15. Replace the double convex lens with the double concave lens, while viewing the outdoor scene. Record whether an image appears on the index card. Describe your observations.
16. Place the double convex lens on this written text. Look down through the lens at the text. Continue to look through the lens as you slowly raise the lens from the paper toward your eyes. Describe any changes in the appearance of the letters that occur. Repeat this process with the double concave lens.
17. Draw a circle on the index card that is a little smaller in diameter than the double convex lens. Cut out the circle.

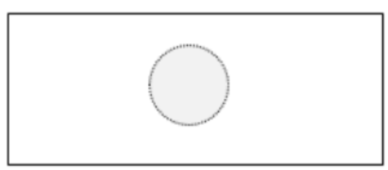

Figure 33.4.9

18. Hold the card at arm's length in front of you and look through the hole at some distant scene (out the window or on the other side of the room). Hold the double convex lens against the hole and look toward same scene. Record whether your field of view (how much you were able to see through the hole) changed; record whether the field of view was the same, smaller, or larger. Repeat the process with the double concave lens.

Clean-up

- Discard water outside (water plants)
- Wash and completely dry your beaker and the plastic tub

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33.5: Analysis

1. Based on your attempt to spear the penny, how should you aim if you are viewing an object that is in water while you are standing in air viewing and the object from an angle?
2. In general, does a small angle or a large angle alter the path of light more? What was your evidence?
3. Sketch a light ray that travels from the penny through water and is transmitted through the side of the beaker, and travels toward you some distance away. Start your line (light ray) from the penny to the side of the beaker, then continue your line from the side of the beaker through air; show how the light changes direction at the water/air boundary. Use your sketch to explain why the penny may disappear as you walk backwards.
4. Use your data from the Laser Refraction Tank to describe, in general, how changes in angle affect the refraction of light.

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33.6: General Questions

1. Does light always travel in a straight path?
2. In general, when light travels from one medium to another, the light always changes ____________ (speed/direction) and may change ____________ (speed/direction). Fill in the blanks.
3. If you see a sea shell in the ocean, and you are viewing it while standing in air on the beach, how should you adjust your aim? Give specific alterations that should be made. You may describe or sketch this.

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CHAPTER OVERVIEW

34: Investigation 33 - The Atomic Spectra of Neon Lights

Learning Objectives

- Compare atomic spectra from various elements, and relate color to wavelength and energy.

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34.1: Materials

- Spectrum Tube Power Supply
- 6-8 Different Gas Emission Tubes
- Heat Gloves
- Diffraction Grating Slides (2-4 per group)
- Hand-held Spectrometers (2-4 per group)
- Colored Pencils

Figure 34.1.1: Spectrum Tube Power Supply and Hand-held Spectrometer

Note

This lab activity must be done in a darkened room.

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34.2: Introduction

As electrons jump from one energy state to another within an atom, the atom absorbs and emits a quantum of energy specific to the jump. The quantum of energy is called a photon. Since light exhibits both particle and wave properties at the same time, each photon is associated with a particular wavelength and energy.

Table 34.2.1

Energy per Photon	h	c
$E = \frac{hc}{\lambda}$	6.626×10^{-34} J s	3×10^{8} m/s

Every atom in the periodic table has unique energy levels, and thus, emits a unique pattern of photons. The pattern of emission lines produced by photons when a gas is excited, is called an atomic spectrum.

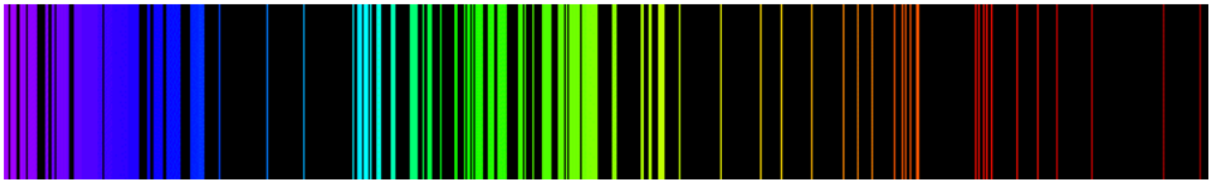

Figure 34.2.1: Example Atomic Spectrum. Emission Spectrum is under public domain

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34.3: Pre-Lab

A. Which has the higher energy, a blue photon or a red photon?

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34.4: Procedures

You will view the atomic spectra of various elements.

Warnings

- Do not touch the high voltage connections on the Spectrum Tube Power Supply
- Gas emission tubes become very hot and can burn the hand if touched
- Overflow light from electronic devices may inhibit observations

1. Start a list in which to record the element, the dominant color, and the pattern of colored lines (atomic spectrum). See example. You may either label the lines or use colored pencils to show the colors.

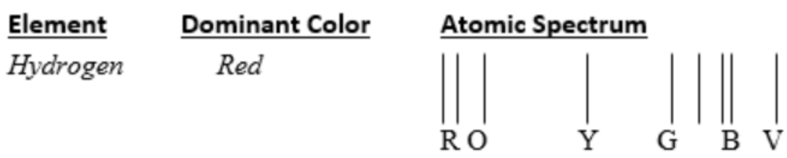

Figure 34.4.1: Atomic Spectrum Observations

2. Make sure the voltage source is off. Place a gas emission tube into the voltage source. Turn on the voltage source and observe the dominant color, the color of the tube you see with your eyes, emitted from the center of the emission tube. Record the element contained in the gas tube and the dominant color you observed. Each person may interpret the dominant color slightly differently (i.e., pink vs red, vs orange).
3. When the lights are turned off, view the atomic spectrum produced through either the diffraction grating slide or the hand-held spectrometer. You may want to alternate devices and determine which the better tool is for you. Observe and remember the pattern of colored lines.
4. Once the lights are turned back on, sketch the pattern of colored lines, labeling each line or set of lines with the color. Attempt to show the relative spacing of the lines in your sketch. Your pattern could go from red to violet or violet to red, depending on how you are holding your observing device. Make sure you orient your observing device so the patterns have the same orientation for each viewing.
5. Observe all available elements and complete your list.

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34.5: Analysis

1. Calculate the energy for each wavelength in the atomic spectrum of hydrogen. Match the wavelengths and energies to the colors you observed when you viewed hydrogen. You will need to convert each wavelength to meters before you calculate the energy in Joules.

Table 34.5.1

Wavelength (nm)	Wavelength (m)	Energy (J)	Color
397			
410			
434			
586			
656			

2. Explain why each element has a different dominant color.
3. Based on your data, is an atomic spectrum unique to the element? Explain.

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34.6: General Questions

1. Hydrogen has one energy level available when it is in the ground state. However, hydrogen is able to emit multiple lines of color when voltage (energy) is added. Explain what must occur for hydrogen to be able to emit multiple colors in the emission line spectrum.
2. In which case must an atom lose more energy, when it emits a color of light that has a shorter wavelength or when it emits a color of light that has a longer wavelength?

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CHAPTER OVERVIEW

35: Investigation 34 - Modeling Radioactive Half-Life

Learning Objectives

- Simulate radioactive decay, and use half-life to determine the age of model samples.

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35.1: Materials

Rolling the Dice

- Graph paper
- Colored Pencils
- 25 small multi-colored cubes per group
- (1 side red, 2 sides black, 3 sides white)

Dating the Beans

- 5 Different Bean Samples

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35.2: Introduction

Radioactive decay is the process of an atom changing into a different type of atom; it is a change in the number of protons. Half-life is the time it takes for one half of a sample of radioactive atoms to decay, so that half of the original number of atoms have decayed. Each radioactive isotope has its own half-life. The half-life of an isotope of carbon may be used to determine the age of a fossil. The amount of a radioactive isotope remaining in a sample indicates the approximate age of the sample.

Table 35.2.1: Radioactive Isotope and Half-life

Radioactive Isotope	Half-life
${}^{239}_{94}\mathrm{Pu}$	24,400 years
${}^{238}_{92}\mathrm{U}$	4.51 x 109 years
${}^{214}_{84}\mathrm{Po}$	0.00016 seconds
${}^{210}_{83}\mathrm{Bi}$	5 days
${}^{210}_{82}\mathrm{Pb}$	20.4 years
${}^{14}_{6}\mathrm{C}$	5,730 years

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35.3: Pre-Lab

A. Based on the half-life, which of the radioactive isotopes in the table above would release the most radiation during a 30 day exposure? Explain.

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35.4: Procedures

You will model the processes of radioactive decay and carbon dating.

Rolling the Cubes

1. The cubes represent atoms. As a color is rolled face-up, it is considered to have decayed into a new type of atom. Assume the 25 blocks start as the same color. Predict and record the number of throws it will take to reach the half-life for each color, to have half of a particular color removed from the set.

Table 35.4.1

Color	Predicted Half-life (Number of Throws)
Red	
Black	
White	

2. You will be making a separate list for each color to track the number of cubes that have decayed such that the color is face-up. Start your first list for red cubes face-up.

Table 35.4.2: Red Cubes Data

Throws	Cubes Remaining	Red Cubes Decayed
0	25	-
1	22	3

3. Assume that all cubes are starting as one isotope. Shake all cubes and roll them onto a table, this counts as throw number 1. Remove and record the number of cubes that are red side up and set them aside (they have decayed). Count and record the number of cubes remaining; the ones that were not red side up. Continue this process until all of the cubes have decayed to red (rolled so red was face-up). Track each throw, including throws for which none of the cubes decayed to red.
4. Repeat the process with the cubes for the black sides.
5. Repeat the process with the cubes for the white sides.

Dating the Beans

6. Draw a table in which to record the number of black beans, red beans, and white beans in each sample. **Do not fill in the data until you have read the instructions for obtaining that data.**

Table 35.4.3: Bean Count Data

Sample	Black Beans	Red Beans	White Beans	Total
1				
2				
3				
4				
5				

2. The colored beans represent atoms. Assume the black beans are carbon atoms and the red beans are nitrogen. Assume the white beans are all of the other types of atoms in the sample. Count and record the number of black beans, red beans, and white beans in each sample. Add and record the total number of beans in each sample. Check the counts with your instructor to ensure that your samples have the correct numbers of beans.

3. Assume that each sample started with 32 black beans, 32 carbon atoms from a live sample, and that each sample is a model of a fossil that has been decaying for a different amount of time with black beans (carbon) decaying into red beans (nitrogen). Determine the fraction of carbon atoms that have not decayed for each of your samples, based on your counts. Record your answers.

Example:

$$\frac{\text{20 not black}}{\text{32 total}} = \frac{20}{32} = \frac{5}{8} \qquad (\text{fraction is } 5/8\text{th})$$

Table 35.4.4

Sample	Fraction Black
1	
2	
3	
4	
5	

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35.5: Analysis

Rolling the Cubes

1. Look at your data for the cubes. You will need to decide whether the number of **throws** or the number of **cubes remaining** is the independent variable. Determine a scale that will allow you to place data for all three colors onto a single graph. Use a different colored pencil for each of the different colors on the cubes. Graph your data for each list (red, black, and white). Include a sketched best fit line for each set of data.
2. Do the graphed sets of data indicate a constant or non-constant rate of decay? How do you know?
3. Determine and record the half-life, in units of throws, for each color (red, black, white), based on your data. This is the approximate number of throws it took to have half of the cubes remaining; this will be a whole number. Record your answers. Compare this information with your predicted half-life for each color. What could account for any differences between your predicted and actual half-life for each color?

Table 35.5.1

Color	Actual Half-life (Number of Throws)
Red	
Black	
White	

Dating the Beans

4. Assume the black beans are carbon-14 atoms and that each sample started with 32 black beans. Complete and document the decay process to track the fractional amount of black beans that would remain out of the original 32, after each decay, and follow the decay process until you have numbers that match your bean samples. Include the time that has passed at each half-life. The process is started below for you.

Table 35.5.2

Amount	Fraction	Time
64	-	-
32	1/2	5730 years

4. Use the decay process for your black beans, and the half-life of carbon-14, to carbon date your fictitious samples.

Table 35.5.3: Age of Fictitious Samples

Sample	Age (Years)
1	
2	
3	
4	
5	

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35.6: General Questions

1. Based on the half-life for each color on the cubes, which of these substances, red, black, or white, do you think would be the most harmful? Why?
2. The abundance of Carbon-14 in our atmosphere is 1 atom of Carbon-14 per Trillion (1012) atoms. Analyze our model of bean samples compared to what is found in nature. Do you think these model samples a good representation of real samples? Explain.
3. Two rocks are found at different levels in the Earth. Both contain the isotope $^{210}_{82}\mathrm{Pb}$. However, one rock contains 1/128th the amount of this isotope as the other rock. What is the difference in the age of these rocks? The half-life of $^{210}_{82}\mathrm{Pb}$ is 20.4 years.

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CHAPTER OVERVIEW

36: Investigation 35 - Identifying Chemical Changes

Learning Objectives

- Identify the indicators of chemical change, and determine whether the reaction was spontaneous.

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36.1: Materials

General Materials Needed

- 4-250 mL Beakers
- 100 mL Graduated Cylinder
- 4 Plastic Spoons
- 2 Thermometers

Red Water

- Red Food Coloring
- 25 mL Bleach
- 25 mL White Vinegar
- Grease Pencil

Inflating Balloon

- 16-18 oz. Empty Plastic Water Bottle
- Balloon (9-12 inch diameter)
- 4 Spoonful's Baking Soda
- 40 mL White Vinegar
- Funnel

Dr. Foamy

- 1 Package Dry Active Yeast
- 400-500 mL Beaker
- 200 mL 12% Hydrogen Peroxide (H2O2)
- Dish Soap

Baking Ingredients

- 1 Spoonful Cream of Tartar
- 1 Spoonful Baking Soda

Professor Flame

- Box of Matches
- Fireplace Lighter

Notes

- Bleach must be new and fresh (chlorine will escape over time)
- Red food coloring must be grocery store grade (other red food colorings will not work)
- 40 volume hydrogen peroxide from a salon is 12% H_2O_2
- Yeast must be fresh each term (aged yeast is no longer active)

Figure 36.1.1:

Graduated Cylinder & Fireplace Lighter. Image used under 3.0 Unported

Safety

- Rubber gloves and safety goggles are recommended for this lab.

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36.2: Introduction

When two substances chemically react, a new substance is formed. The new substance may have a different color or temperature than the original substances, or may be in a different phase. There are several indicators that a chemical change has occurred, and multiple indicators may occur in a single reaction. If no added energy is required to start the reaction, then it is a spontaneous reaction, even if the reaction takes a while to progress. Stirring is not typically regarded as adding energy. A spontaneous chemical reaction does not mean the reaction happens quickly, but rather that the atoms will naturally react when placed into contact.

Warnings

- Bleach and hydrogen peroxide can irritate eyes and skin
- Bleach and food coloring can stain clothing
- Notify your instructor of any spills and/or glass breakage
- It is important to wash glassware, including thermometers, between uses

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36.3: Pre-Lab

A. List indicators of chemical change.

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36.4: Procedures

You will observe indicators of chemical change.

1. Draw a table in which to record your data. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 36.4.1

Reaction	T_i	T_f	ΔT	Spontaneous (yes or no)	Indicator(s)
Red Water (bleach)					
Red Water (vinegar)					
Baking Ingredients					
Inflating Balloon (vinegar)					
Inflating Balloon (water)					
Dr. Foamy					
Prof. Flame (matches)	N/A	N/A	N/A		
Prof. Flame (lighter)	N/A	N/A	N/A		

2. Obtain two 250 mL beakers and measure 100 mL of water in each beaker. Add 25 mL of bleach to one beaker and 25 mL of white vinegar to the 2nd beaker; use the grease pencil to label your beakers. Add 2 drops of red food coloring to each beaker. Stir the contents of each beaker until mixed. Measure and record the initial temperature (T_i) of the contents in each beaker.
3. Occasionally check the contents of the beakers containing red food coloring, for any indication that there has been a chemical change; this may take **30-60 minutes**. If a chemical change occurs, record the temperature of the contents after the change has occurred, and the final temperature (T_f). Calculate and record any change in temperature (ΔT) that was measured. Record whether the reaction is a spontaneous reaction (yes or no), and list any indicator(s) that a chemical change has occurred.

Baking Ingredients

4. Obtain two 250 mL beakers and measure 50 mL of water into each beaker.
5. Add 1 plastic spoonful of baking soda to one beaker and 1 plastic spoonful cream of tartar to the second beaker; be careful that your measurements are equal in amounts. Use the grease pencil to label your beakers. Stir each beaker until the solids are dissolved, or for 2 minutes, whichever comes first. Measure and record the initial temperature (T_i) of the contents in each beaker, listing the baking soda substance in the upper box and the cream of tartar substance in the lower box.
6. Add the baking soda water to the cream of tartar water. Record the temperature of the combined baking soda water and cream of tartar water as the final temperature (T_f) for both. Calculate and record any change in temperature (ΔT) that was measured. Record whether the reaction is a spontaneous reaction (yes or no), and list any indicator(s) that a chemical change has occurred.

Inflating Balloon

8. Use the funnel and a plastic spoon to add 4 spoonful's of baking soda into the balloon. This should be done over a paper towel to minimize the mess.
9. Use the graduated cylinder to measure 40 mL of vinegar into the empty water bottle. Return to your lab table with the water bottle and balloon. Measure and record the initial temperature (T_i) of the vinegar from the outside of the bottle.
10. Carefully, seal the water bottle by stretching the opening of the balloon over the opening of the bottle; make sure it is well sealed and be careful not to allow any baking soda into the bottle yet.

Figure 36.4.1: Water Bottle Balloon

11. Place the bottle with the balloon onto some paper towels. Tip the balloon up and empty the contents of the balloon into the bottle. Measure the temperature (T_f) outside of the bottle after the vinegar and baking soda have been combined. Calculate and record any temperature change (ΔT) that was measured. Record whether the reaction is a spontaneous reaction (yes or no), and list any indicator(s) that a chemical change has occurred.

Dr. Foamy

12. Add 200 mL of hydrogen peroxide to a 250 mL beaker. Add a "squirt" of dish soap to the hydrogen peroxide and gently stir until mixed. Measure and record the initial temperature (T_i) of the contents in the beaker.
13. Set the large (400-500 mL) beaker in a sink. Pour one packet of active dry yeast into the large beaker. Add enough water to dissolve the yeast. Then add the 200 mL of hydrogen peroxide/soap mixture to the large beaker in the sink, and gently stir to mix. Observe the substance in the large beaker for a few seconds. Measure and record the final temperature (T_f) for the combined contents in the large beaker after the few seconds of observation. Calculate and record any temperature change (ΔT) that was measured. Record whether the reaction is a spontaneous reaction (yes or no), and list any indicator(s) that a chemical change has occurred.

Professor Flame

14. Obtain a box of matches, return to your lab table, and strike a match. Record whether the reaction is a spontaneous reaction (yes or no), and list any indicator(s) that a chemical change has occurred.
15. Make the fireplace/BBQ lighter light. Record whether the reaction is a spontaneous reaction (yes or no), and list any indicator(s) that a chemical change has occurred.

Clean-up

- Dispose of bleach, vinegar and hydrogen peroxide substances as directed by your instructor
- Wash, rinse, and completely dry, beakers, spoons, and thermometers
- Wash graduated cylinder and water bottle by shaking with soapy water inside, thoroughly rinse them, and place them on a drying rack
- Rinse the match and discard it
- Discard the balloon in trash
- Thoroughly clean the surface of your lab table

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36.5: Analysis

1. Which substance had the greatest measured temperature change?
2. Explain why some reactions feel cold and some reactions feel hot in terms of heat energy transfer.
3. When a chemical reaction results in a substance feeling cold, is the substance taking heat from your hand or giving heat to your hand?

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36.6: General Questions

1. When bleach removes a stain from clothing, is this a physical or chemical change? How do you know?
2. Vinegar and baking soda may be used as cleaners. What is produced in this reaction that cannot be seen directly?
3. When household cleaners are combined, production of an invisible, odorless gas could result. Why is the practice of combining cleaners dangerous?
4. When heat is added to liquid water, the liquid becomes steam. Is this a physical or chemical change? Explain.
5. What is the basic difference between a physical change and a chemical change?

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CHAPTER OVERVIEW

37: Investigation 36 - Mixing Solids and Liquids

Learning Objectives

- Compare the solubility of different substances under different conditions, and classify mixtures.

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37.1: Materials

General Materials Needed

- 4 3-oz Paper Cups
- 4-250 mL Beakers
- 4 Plastic Spoons
- 4 Thermometers
- 100 mL Graduated Cylinder

Comparing Solutes

- Salt Substitute (KCl)
- Salt ($NaCl$)
- Granulated Sugar ($C_{12}H_{22}O_{11}$)
- Baking Soda ($NaHCO_3$)
- Grease Pencil
- Triple Beam Balance

Comparing Solvents

- Granulated Sugar
- Vegetable Oil
- 91% Isopropyl Alcohol
- Hydrogen Peroxide

Note

Hydrogen Peroxide must be new and fresh (hydrogen will escape over time)

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37.2: Introduction

Solubility is a measure of how well a particular solvent is able to dissolve a particular solute, to break existing chemical bonds. The solubility of a solute depends on several factors. If a solute is successfully dissolved in a solvent to form a stable solution, which has the same appearance throughout, then the solute/solvent combination is classified as a homogeneous solution. If particles of solute remain visible in the solution, then the solute/solvent combination may be classified as a heterogeneous suspension unless the incomplete dissolving is a result of saturation. Saturation occurs when there is too much solute for the solvent to dissolve. A heterogeneous suspension and a saturated solution may have the same appearance. The level of concentration is a ratio of grams of solute to Liters of solvent.

Concentration:

$$\text{Concentration} = \frac{\text{Grams}}{\text{Liter}}$$

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37.3: Pre-Lab

A. How can you determine whether a substance is a heterogeneous suspension or a saturated solution? What would you observe to be different during the process of mixing?

Safety

Rubber gloves and safety goggles are recommended for this lab.

Warning

Salt, salt substitute, hydrogen peroxide, and isopropyl alcohol can irritate eyes and skin.

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37.4: Procedures

You will combine a variety of substances.

Comparing Solutes

1. Record which solid solute you predict will be the most dissolved, and which solid solute you predict will be the least dissolved.
2. Draw a table in which to record your *comparing solutes* data. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 37.4.1: Comparing Solutes

Solid	Initial Temperature	Final Temperature	Classify
KCl			
NaCl			
Sugar			
Baking Soda			

3. Use the grease pencil to label each beaker with the name of the solute you intend to add to the beaker. Add 100 mL of cold water from the graduated cylinder into each of the 250 mL beakers. Measure and record the initial temperature of the water in each beaker.
4. Label the paper cups: "KCl", "$NaCl$", "Sugar", and "Baking Soda". Then add 5 grams of each solid solute into the corresponding paper cups.
5. All 4 team members will be needed in this step. At exactly the same time, add each solid solute to each corresponding beaker of water and begin stirring the contents with a plastic spoon, while holding the thermometer steady; **do not use the thermometer for stirring**. All team members should stir at the same rate. Stir the contents in the beakers for 2 minutes; then stop stirring and allow the contents in the beakers to settle while you measure and record the final temperature of the contents in each beaker.
6. Once the contents in the beakers have been allowed to settle for at least 30 seconds, classify each substance (homogeneous solution, heterogeneous suspension, or saturated solution). Record your answers in your *comparing solutes* data table.

Clean-up

- Pour contents from beakers into a sink and thoroughly flush sink with water
- Wash the beakers, spoons, and thermometers
- Use a dry paper towel to remove any residue from each paper cup

Comparing Liquid Solvents

7. Record which liquid solvent you predict will dissolve the most sugar and which solvent you predict will dissolve the least amount of sugar.
8. Draw a table in which to record your *comparing solvents* data. Read the instructions for obtaining the data.

Table 37.4.2: Comparing Solvents

Liquid	Initial Temperature	Final Temperature	Classify
Vegetable Oil			
91% Isopropyl Alcohol			
Water			
Hydrogen Peroxide			

9. Use the grease pencil to label each 250 mL beaker with the name of the liquid you intend to add to the beaker. Measure 100 mL of each liquid into the corresponding beaker; do not use the graduated cylinder to measure the oil. Measure and record the initial temperature of the liquid in each beaker.
10. Measure 5 grams of granulated sugar into each paper cup.
11. At exactly the same time, add the sugar to each beaker of liquid and begin stirring the contents with a plastic spoon, while holding the thermometer steady; **do not use the thermometer for stirring**. All team members should stir at the same rate. Stir the contents in the beakers for 2 minutes; then stop stirring and allow the contents in the beakers to settle while you measure and record the final temperature of the contents in each beaker.
12. Once the contents in the beakers have been allowed to settle for at least 30 seconds, classify each substance (homogeneous solution, heterogeneous suspension, or saturated solution). Record your answers in your *comparing solvents* data table.

Clean-up

- Dispose of contents in beakers as directed by your instructor
- **Wash, rinse, and completely dry all beakers, thermometers, and plastic spoons**
- **Discard paper cups in trash**
- **Clean your laboratory table top**

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37.5: Analysis

1. Which contents, if any, demonstrated the greatest temperature change in *comparing solutes*?
2. Which solid, if any, <u>decreased</u> the temperature of water the most in *comparing solutes*? Which solid, if any, <u>increased</u> the temperature of water the most?
3. Which contents, if any, demonstrated the greatest temperature change in *comparing solvents*?
4. In each case, you added 5 grams of solute to 100 mL of solvent. Calculate the level of concentration of solute compared to solvent; this will be the same value for each of the combinations.

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37.6: General Questions

1. In chemistry, what does a change in temperature indicate when substances are combined?
2. Does a single solvent (cleanser) remove all solutes (stains)? What is your hypothesis for why this happens?
3. Do you think temperature effects the amount of solute that can be dissolved? What evidence do you have?

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CHAPTER OVERVIEW

38: Investigation 37 - Pattern in the Periodic Table

Learning Objectives

- Practice use of the shell model, and document the patterns in the periodic table.

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38.1: Materials

- Periodic Table
- Drawing Compass (optional)

Figure 38.1.1: Drawing Compass

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38.2: Introduction

The shell model identifies the number of electrons in each main energy shell of an atom, when the atom is in the ground state. Each element in a vertical group of the periodic table has similar physical and chemical characteristics because all elements in a vertical group have the same electron configurations. The electron configuration also determines the reactivity of an element. By accounting for electrons in the main energy levels (shells), and recognizing that electrons begin to pair-up once a shell is half full, this model can be used to predict chemical bonds.

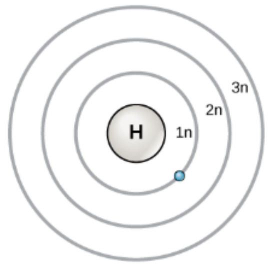

Figure 38.2.1: Shell Model

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38.3: Pre-Lab

A. According to the shell model, what is the maximum number of electrons allowed in each main energy shell?

Table 38.3.1

Shell	Maximum Number Electrons Allowed	Maximum Pairs Electrons Allowed
1		
2		
3		
4		
5		
6		
7		

B. How do we know the number of energy shells elements have available in the ground state?

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38.4: Procedures

You will search for patterns of electron configurations.

1. Choose one Group A set of elements (one of the Group A columns) for which you will be responsible. Each person on the team should have one Group A column, initially.
2. Sketch the number of shells, or orbits, your first element would have in the ground state. Use hash marks to show the correct number of pairs for each inner orbit. Count the number of electrons added to the inner orbits, and calculate the number of electrons remaining.

Example:

- Magnesium (Mg) has atomic number 12, so it will normally have 12 electrons
- (**12** electrons total) − (**10** electrons added to shells) = **2** electrons remaining

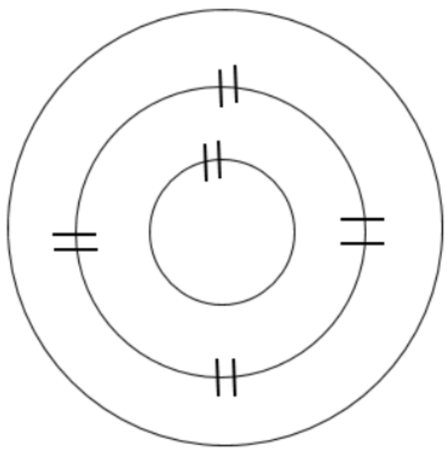

Figure 38.4.1

3. Determine the number of electrons needed to fill the outermost shell half full. Add the remaining electrons as singles, until the shell is half full, and then pair electrons (if needed) until all electrons for that element have been added to the model.

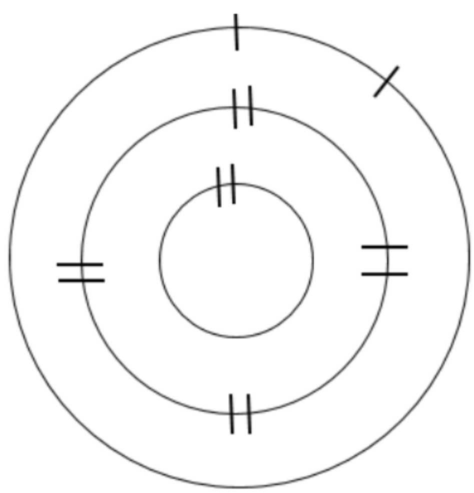

Figure 38.4.2

4. Repeat the process for each element in your first Group A column. Determine and record the number of unpaired electrons in the outermost shell, for your first set of Group A elements; each of these elements should have the same trend (except Group IIIA – the trend changes). Also record whether the outermost shell is mostly full or empty.
5. Choose a 2nd Group A set of elements (another Group A column), and complete the entire process for that set of elements.

6. Draw a table in which to record the trend for each vertical group of elements. Read the instructions for completing the table.

Table 38.4.1: Periodic Table Trends

Group	Unpaired Electrons Trend	Mostly (full/empty)
IA		
IIA		
IIIA		
IVA		
VA		
VIA		
VIIA		
VIIIA		

7. Collaborate with your team to record the trends for each Group A column (IA, IIA, IIIA, IVA, VA, VIA, VIIA, VIIIA). Record the number of unpaired electrons in the outermost shell, and record whether the outermost shell is mostly empty or mostly full.

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38.5: Analysis

1. As you move from left to right along a period (row), what is the change that happens in the outermost shell?
2. Describe how the number of unpaired electrons in the outermost shell is related to the group number, either directly or by the octet rule.
3. Assuming the goal is to be like a noble gas, a Group 8A element, determine the number of electrons that elements in each Group A column would tend to gain or lose in order to have a full outer shell. Record whether the atoms in the group would tend to gain or lose electrons. Record the number of electrons the atoms in the group would tend to gain or lose. Write the charge an atom would tend to have. Complete the *ionization* table.

Table 38.5.1: Ionization Table

Group	Lose/Gain	Number	Charge on Atom
IA	lose	1	+1
IIA			
IIIA			
IVA			
VA			
VIA			
VIIA			
VIIIA			

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38.6: General Questions

1. What makes the noble gases non-reactive?
2. What is periodic in the periodic table?

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CHAPTER OVERVIEW

39: Investigation 38 - Building Models of Molecules

Learning Objectives

- Build models of molecules, and analyze the structure of these molecules for polarity.

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39.1: Materials

- Molecular Models Kit
- Colored Pencils

Figure 39.1.1: Building models

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39.2: Introduction

Atoms are attracted together because they share or exchange electrons in a manner that establishes a chemical bond. In a covalent bond, atoms share 1-3 pairs of electrons. There are specific ways atoms bond within a particular molecule; some molecules have a straight-line structure while others have a more 3-dimensional structure. The structure of the molecule is responsible for some physical and chemical properties of the molecule, and the structure may result in an uneven distribution of electrons (polarity). If electron pairs spend more time around one nucleus than the other, a molecule may have slightly negative and slightly positive ends, the molecule may be polar. If the distribution of atoms is not symmetric, then the molecule may exhibit polarity. In general, if the molecule is symmetric with the same types of atoms in the outer structure, then the molecule will be non-polar.

Molecular Models Kit

- Spheres represent the nucleus of an atom
- Different colors represent different atoms
- Each spring connector represents a pair of shared electrons
- Holes in the spheres represent missing electrons needed by the atom

Table 39.2.1

Element	Symbol	Color of Sphere
Bromine	Br	Orange
Hydrogen	H	Yellow
Carbon	C	Black
Nitrogen	N	Light Blue
Oxygen	O	Red
Chlorine	Cl	Green
Iodine/Fluorine	I or F	Purple

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39.3: Pre-Lab

A. Determine the number of unpaired electrons for each element contained in the kit. Complete the *unpaired electrons* table.

Table 39.3.1: Unpaired Electrons

Element	Symbol	Number Unpaired Electrons
Bromine	Br	
Hydrogen	H	
Carbon	C	
Nitrogen	N	
Oxygen	O	
Chlorine	Cl	
Iodine/Fluorine	I or F	

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39.4: Procedures

You will build and sketch several models of molecules.

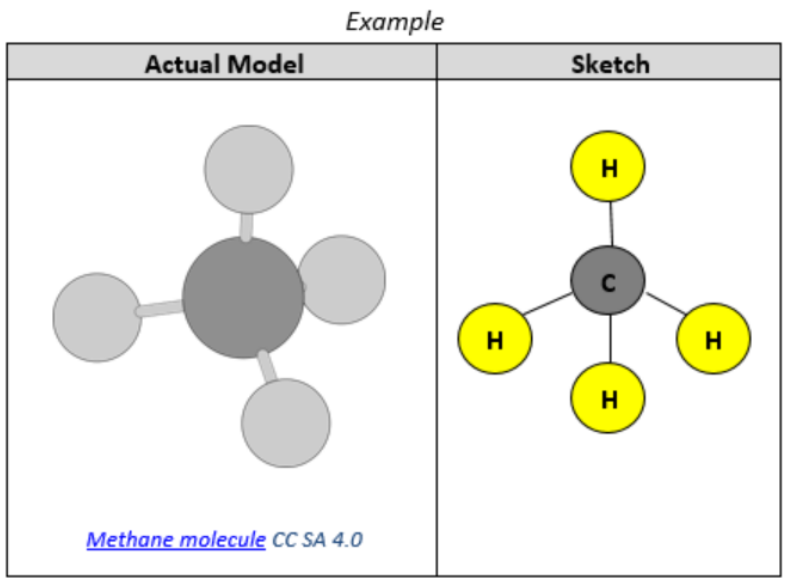
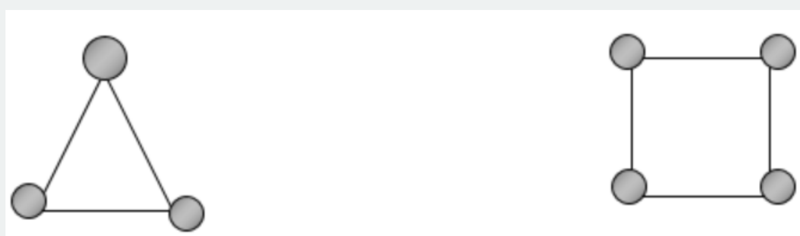


Figure 39.4.1: Sketch of a model of Methane molecule

> **Note**
>
> - Molecules that contain carbon may have more than one structure possible.
> - Triangle and square structures are usually not valid.
>
> 
>
> Figure 39.4.2: Triangle and square structures

1. Draw a table in which to record information about each molecule that contains only single bonds. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 39.4.1: Single Bonds

	Molecule Name	Molecular Formula	Symmetric (yes or no) Polar (yes or no)
a.	Hydrogen	H_2	yes no
b.	Bromine	Br_2	
c.	Water	H_2O	
d.	Hydrogen Chloride	HCl	
e.	Hydrogen Bromide	HBr	
f.	Hydrogen Peroxide	H_2O_2	
g.	Iodine Chloride	ICl	
h.	Methane	CH_4	
i.	Dichloromethane	CH_2Cl_2	

2. Build each molecule in the "Single Bonds" table. Sketch the molecule (remember to label it); attempt to show any three dimensional structure. You may use colored pencils, but you should also include the element symbols in your circles. Look at your model and determine whether it is symmetric (yes or no). Analyze the structure to determine whether the molecule would be polar (yes or no). Record your answers in your *single bonds* data table.
3. Draw a table in which to record information for molecules containing double bonds. Repeat the same process for these molecules as you followed for the single bond molecules.

Table 39.4.2: Double Bonds

	Molecule Name	Molecular Formula	Symmetric (yes or no)	Polar (yes or no)
j.	Oxygen	O_2		
k.	Ethylene	C_2H_4		
l.	Nitroxyl	HNO		
m.	Nitrous Acid	HONO		
n.	Formaldehyde	H_2CO		
o.	Formic Acid	HCOOH		
p.	Chloroethene (vinyl)	C_2H_3Cl		
q.	Carbon Monoxide	CO		
r.	Carbon Dioxide	CO_2		
s.	CycloPropene	C_3H_4		

4. Draw a table in which to record information for molecules containing triple bonds, and repeat the process. Also draw a table in which to record information for some common molecules, and repeat the process.

Table 39.4.3: Triple Bond

	Molecule Name	Molecular Formula	Symmetric (yes or no)	Polar (yes or no)
t.	Nitrogen	N_2		
u.	Acetylene	C_2H_2		
v.	Cyanic Acid	HOCN		

Table 39.4.4: Common Substances

	Molecule Name	Molecular Formula	Symmetric (yes or no)	Polar (yes or no)
w.	Ozone	O_3		
x.	Ammonia	NH_3		
y.	Ethanol	C_2H_6O		
z.	Acetic acid	$C_2H_4O_2$		
	Benzene	C_6H_6		

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39.5: Analysis

1. Look at your sketches for the models of methane and dichloromethane. How are they similar? (choose one)
    a. Same structure
    b. Same elements
    c. Polarity
    d. Same chemical formula
2. Use your data tables to relate symmetry to polarity. Explain the role symmetry plays in polarity.
3. Carbon monoxide is reactive but carbon dioxide is non-reactive. Explain why.
4. Organic compounds are those that contain carbon. What percentage of the models you constructed are organic?

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39.6: General Questions

1. Describe or sketch the different structures possible for C_3H_4. Do you expect these substances to have the same properties or different properties?
2. The structure of a water molecule causes it to be polar. If the water molecule had the structure illustrated below, would it still be polar? Explain.

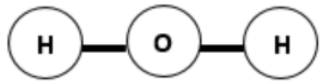

Figure 39.6.1: Water molecule structure illustration

3. The flat structure of the benzene (C6H6) molecule is partly responsible for this molecule being a cancer causing substance. This molecule can slice into the DNA double helix and disrupt the cell's ability to regulate itself. Name a substance that you think may contain the benzene molecule.

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CHAPTER OVERVIEW

40: Investigation 39 - Melting Wax and Cooking Sugar

Learning Objectives

- Observe thermal decomposition of two compounds, and analyze chemical equations to determine the products.

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40.1: Materials

- Paraffin Wax Candle
- Ice Cubes
- 2 Aluminum Pie Tins
- Heat Source (Bunsen burner is preferred)
- Metal Tongs
- Heat Gloves
- Matches
- Aluminum Foil
- Granulated Sugar
- Plastic Spoon

Figure 40.1.1: Metal Tongs

Note

Thermal decomposition of sugar should be performed in a chemistry hood if possible to avoid setting off a fire alarm.

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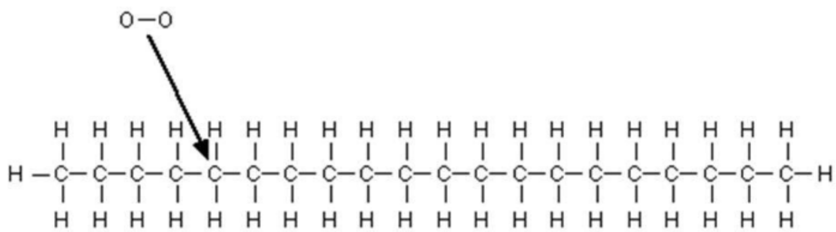
40.2: Introduction

Most of the substances you see around you are a combination of elements; they are compounds. Many compounds contain similar elements, and 90% of compounds contain carbon. When energy is added to a substance, the compounds can be broken into new substances which are the products of the chemical reaction. As a candle ($C_{25}H_{52}$) burns in the oxygen (O_2) provided by air, new substances will result. When sugar ($C_{12}H_{22}O_{11}$) is heated, the molecule will split into three substances. Both wax and sugar decompose into the same products.



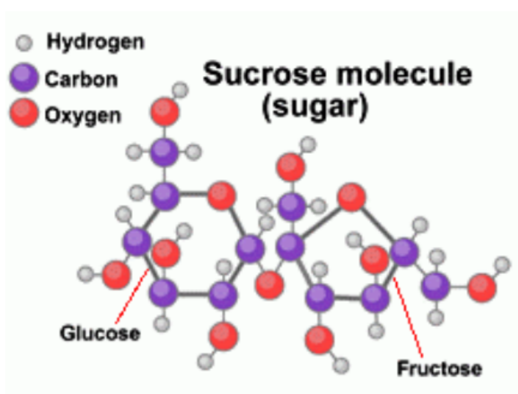


Figure 40.2.1: An oxygen molecule collides with the Paraffin molecule and reacts with that portion of the molecule.

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40.3: Pre-Lab

A. Compare the wax molecule and sugar molecule; describe two differences.

B. Define condensation.

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40.4: Procedures

Warnings

- Heat source and pie tins may become hot enough to cause a thermal burn.
- Always assume the heat source is hot, even when it is off.
- Excessive heating of the sugar may result in a fire alarm.

You will burn a candle and heat sugar.

1. Draw a table in which to record the products you observe in the decomposition reactions. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 40.4.1: Data table

	Moisture	Black Substance
Candle + O_2		
Sugar		

Melting Wax

2. Use the aluminum foil to create a candle stand for your candle.
3. Place 3-4 ice cubes in one aluminum pie tin, and add 2 spoonful's of water to the pie tin. Your goal is to have a little ice water in the pie tin.
4. Light the candle ($C_{25}H_{52}$) and use the metal tongs or heat gloves to hold the pie tin with ice water, such that the pie tin is directly above the flame of the candle; the pie tin should be held about 1 centimeter above the flame. Check the bottom of the pie tin for moisture and a black substance, every few seconds. Once the moisture and the black substance appear, extinguish the candle and analyze the products you have on the bottom of the pie tin. If after 5 minutes only moisture has appeared, end the experiment. Discuss with your team what the substances look like, what they could be. Record what you think the moisture is and what you think the black substance may be, based on the elements in your reactants, in your data table.

Figure 40.4.1: Candle and ice water

5. Clean the bottom of the pie tin, remove all moisture and all of the black substance. Replenish the ice water in the pie tin.

Cooking Sugar

6. Set up and turn on your heat source. Ask your instructor for assistance if your team is uncertain about how to set-up a Bunsen burner.
7. Add 1 spoonful of sugar ($C_{12}H_{22}O_{11}$) to the <u>second</u> aluminum pie tin. Spread the sugar out a little so that it is only a thin layer.
8. Use tongs and/or heat gloves to position the pie tin containing sugar in direct contact with your heat source (in contact with the flame of the Bunsen burner or directly on the hot plate). Once the sugar begins to change color and a gas is observed leaving

the sugar, position the ice water pie tin 1 centimeter above the sugar pie tin, with the pie tins as close together as possible but not touching. Check the bottom of the ice water pie tin for moisture, every few seconds. **Stop the experiment immediately if the sugar begins to burn (turn black)**. Once you see moisture on the bottom of the ice water pie tin, stop the experiment and remove the sugar from the heat source. Prolonged cooking of the sugar may set-off the fire alarm. Turn off the heat source and analyze the products. Discuss with your team what the moisture on the bottom of the ice water pie tin looks like, and what the remnants of the sugar could be. Record what you think the moisture is and what you think the remnants of the sugar may be, in your data table.

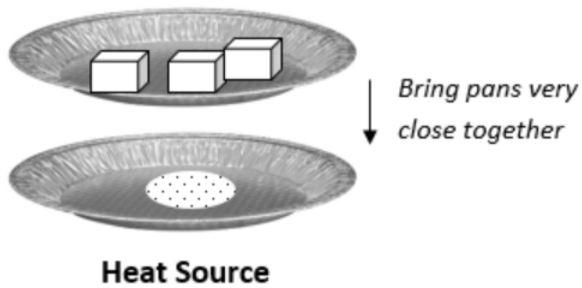

Figure 40.4.2: Heat source and sugar

Clean-up

- Wash and dry both pie tins – discard the sugar pie tin if it will not come clean
- **Clean your laboratory table top**
- Throw away foil used as a candle stand

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40.5: Analysis

1. During the combustion of the wax candle, a gas is released from the candle; the gas is carbon dioxide (CO_2). Analyze the chemical equation and your observations to determine what the liquid was that condensed on the bottom of the ice water pie tin, and to determine what the black substance was. Record your answers.

$$C_{25}H_{52} + 26\,O_2 \rightarrow 12\,C + CO_2 + \text{liquid}$$

2. Analyze the chemical equation and your observations for thermal decomposition of sugar, and determine the products. Record your answers.

$$C_{12}H_{22}O_{11} \rightarrow \text{solid} + \text{liquid}$$

3. List any common products from the two reactions.

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40.6: General Questions

1. If no ice was used, no liquid would condense on the bottom of the ice water pie tin. Why?
2. Explain why energy is required for the compounds (wax and sugar) to become new products. What does the energy do?

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CHAPTER OVERVIEW

41: Investigation 40 - Dozens and Moles

Learning Objectives

- Relate moles to dozens, and practice stoichiometry.

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41.1: Materials

- 36 Small Metal Paperclips
- 36 Large Metal Paperclips
- 36 Small Metal Nuts
- 36 Large Metal Nuts
- Triple Beam Balance

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41.2: Introduction

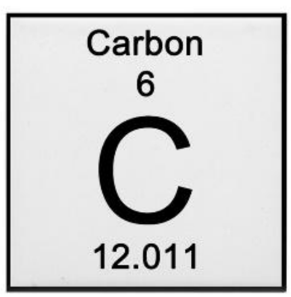
There is a relationship between moles, grams, and the number of molecules that is similar to the relationship between dozens, grams, and the number of pieces. One mole of any substance has the same number of particles (6×10^{23}), just as one dozen of any item has the same number of pieces (12).

Table 41.2.1: Moles and Molecules

Substance	Molecules
1 mole H_2O	6×10^{23}
1 mole CO	6×10^{23}
1 mole H	6×10^{23}
1 mole O_3	6×10^{23}
Item	Pieces
1 dozen Cookies	12
1 dozen Roses	12
1 dozen Eggs	12
1 dozen Paperclips	12

The mole is central to stoichiometry like the meter is central to the metric system. If the number of moles are known, then the amount of grams and the number of particles may be calculated. The atomic mass on the periodic table indicates the amount of grams that one mole of a particular type of atom would contain. Avogadro's number is the number of atoms or molecules that 1 mole of *any* substance would contain.

Table 41.2.1: Example

	$N_A = \dfrac{6 \times 10^{23} \text{ particles}}{1 \text{ mole}}$
1 mole of Carbon has 12.011 grams	1 mole of Carbon has 6×10^{23} atoms

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41.3: Pre-Lab

A. When is the atomic mass measured in amu?

B. When is the atomic mass measured in grams?

C. Define stoichiometry.

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41.4: Procedures

You will use dozens of items to visualize moles of particles (atoms/molecules).

Dozens

1. Draw two tables in which to record your data for dozens, grams, and pieces. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 41.4.1: Dozens

Item	Measured Mass per Dozen	Calculated Dozens in 15 Grams
Small Paperclips		
Large Paperclips		
Small Metal Nuts		
Large Metal Nuts		

Table 41.4.2: Pieces

Item	Calculated Dozens per 36 Pieces	Calculated Mass of 1 Piece	Measured Mass of 1 Piece
Small Paperclips			
Large Paperclips			
Small Metal Nuts			
Large Metal Nuts			

2. Measure and record in your *dozens* data table, the mass in grams of one dozen small paperclips, one dozen large paperclips, one dozen small metal nuts, and one dozen large metal nuts.
3. Calculate how many dozens a 15 gram sample would contain, for each type of item. Record these values in your *dozens* data table.
4. Calculate and record in your *dozens* data table, the mass of 3 dozen for each type of item. Then use the triple beam balance to measure the mass of 3 dozen, for each type of item.
5. Calculate and record in your *pieces* data table, the number of dozens in a 36 piece sample, for each type of item.
6. Calculate and record in your *pieces* data table, the average mass in grams of one piece, for each type of item. Then use the triple beam balance to measure the mass of one piece, for each type of item.

Moles

7. Draw two tables in which to record your data for moles, grams, and particles. Read the instructions for determining the values to enter in these tables. You will be following similar processes as you followed for the metal items, for each column in the data tables.

Table 41.4.3: Moles

Element	Measured Mass per Mole	Calculated Moles in 15 Grams	Calculated Mass of 3 Moles
Aluminum			
Iron			
Helium			
Carbon			

Table 41.4.4: Particles

Element	Calculated Moles per 1.8×10^{24} Atoms	Calculated Mass of 1 Atom
Aluminum		
Iron		
Helium		
Carbon		

8. Use the periodic table to determine the measured mass in grams of one mole of atoms, for each type of atom listed in the table. Record these values in your *moles* data table.
9. Calculate how many moles a 15 gram sample would contain, for each type of atom. Record these values in your *moles* data table.
10. Calculate and record in your *moles* data table, the mass of 3 moles for each type of atom listed.
11. Calculate and record in your *particles* data table, the number of moles in a sample that contains 1.806×10^{24} particles, for each type of atom.
12. Calculate and record in your *particles* data table, the average mass in grams of one particle, for each type of atom.

Clean-up

- Check that none of your paperclips or metal nuts were mixed

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41.5: Analysis

1. Compare the "dozens per 36 pieces" to the "moles per 1.806×10^{24} atoms". Describe any similarity in these sets of numbers.
2. Choose true (T) or false (F) for each statement about dozens, grams, and pieces.
   a. Three dozen small paperclips and three dozen large paperclips have the same amount of mass.
   b. Three dozen small metal nuts and three dozen large metal nuts have the same number of pieces.
   c. A 15 gram sample of anything would contain the same number of pieces.
3. Choose true (T) or false (F) for each statement about moles, grams, and atoms.
   a. Three moles of aluminum atoms and three moles of iron atoms have the same amount of mass.
   b. Three moles of helium atoms and three moles of carbon atoms have the same number of atoms.
   c. A 15 gram sample of any element would contain the same number of atoms.

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41.6: General Questions

1. A typical water bottle contains 16.9 mL of water, which is 16.9 grams of water.
   a. Calculate the number of water bottles you would have if you had 3 dozen water bottles.
   b. Calculate the mass of water you would have if you had 3 dozen water bottles.
   c. Calculate the number of water molecules there would be in a single water bottle.
2. A water molecule (H_2O) contains two hydrogen atoms and one oxygen atom.
   a. Calculate the mass of water in 3 moles of water.
   b. Calculate the number of water molecules in 3 moles of water.
3. How many moles of carbon (C) has the same mass as 6 moles of helium (He)?
4. What mass of sodium (Na) has the same number of atoms as 24 grams of carbon (C)?

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CHAPTER OVERVIEW

42: Investigation 41 - Rates of Reactions

Learning Objectives

- Analyze factors that affect the rate at which chemical reactions progress.

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42.1: Materials

General Materials Needed

- 2 Plastic Spoons
- 6-250 mL Beakers
- 2 Thermometers

Apple & Air

- 1 Fresh Red Delicious Apple (per team)
- 1 Vitamin C Tablet (ascorbic acid)
- Mortar and Pestle
- Petri Dish

Escaping Oxygen

- 200 mL Hydrogen Peroxide (H_2O_2)
- Slice Potato (1/2 inch thick)
- Grease Pencil

Better Faster

- 2 Alka-Seltzer Tablets
- Mortar and Pestle

Making Kool-Aid

- Heat Source
- Beaker Tongs
- Heat Gloves
- Aluminum Foil (for lid)
- 2 Sugar Cubes
- 2 Packages Dry Kool-Aid

Weak or Strong

- 6 Alka-Seltzer Tablets
- 105 mL Vinegar (acetic acid)
- 105 mL D.I. Water
- Grease Pencil
- 100 mL Graduated Cylinder
- Triple Beam Balance
- Splash Goggles (strongly recommended)

Figure 42.1.1: Mortar & Pestle and Petri Dish licensed under CC0

Note

- Hydrogen Peroxide must be new and fresh (hydrogen will escape over time)
- A cutting board and kitchen knife will be needed for apples and for the potato

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42.2: Introduction

Chemical reactions may occur seemingly instantly, or may take some time to progress. There are several factors that determine the rate at which a chemical reaction occurs. In general, the more energetic and numerous collisions are between reactants, the faster reactions occur. Sometimes reaction rates are intentionally slowed or inhibited. Factors that may affect reaction rates include nature of reactants (complexity), temperature, concentration, surface area, and use of a catalyst.

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42.3: Pre-Lab

A. What is a catalyst? What does it do?

B. Which has more surface area, a solid tablet or a crushed one?

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42.4: Procedures

Safety

Rubber gloves and safety goggles are recommended for this lab.

Warnings

- Handle the kitchen knife with caution; it is sharp.
- Hydrogen peroxide can irritate eyes and skin

You will witness a variance in reaction rates related to differing chemical factors.

1. Draw a table in which to list the observations for your first mini-experiments. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 42.4.1: Rates of Reactions Data

Mini-Experiment	Fastest Rate (choose one for each set)	Indicator(s)
Apple & Air (coated)		
Apple & Air (uncoated)		
Escaping Oxygen (with potato)		
Escaping Oxygen (no potato)		
Better Faster (whole)		
Better Faster (crushed)		
Making Kool-Aid (sugar)		
Making Kool-Aid (Kool-Aid)		

Apple & Air

1. Use the mortar and pestle to crush one vitamin C tablet. Transfer the crushed contents to the petri dish and add enough water to make a paste; use the plastic spoon to mix the water with the crushed vitamin C.
2. Cut open an apple, and immediately cover the entire surface of one half of the apple with the vitamin C paste. Leave the other half of the apple uncovered in the open air. Set both halves of the apple aside for **30-60 minutes**, and proceed with the other mini-experiments while you are waiting.
3. After 30-60 minutes have passed, rinse off the vitamin C, and compare the apple halves. Determine which half of the apple exhibited the fastest rate of reaction, and check the appropriate box in your *rates of reactions* data table. List any indicators of chemical change for each half of the apple; if there were no indicators of chemical change then write “none”.

Clean-up

- Wash and dry your mortar and pestle, petri dish, and plastic spoon
- Discard apple halves in trash

Escaping Oxygen

1. Add 100 mL of hydrogen peroxide to each of the 2-250 mL beakers.
2. Add the slice of potato to one of the beakers of hydrogen peroxide. Use the grease pencil to draw a line at the top level of the liquid, on each beaker.

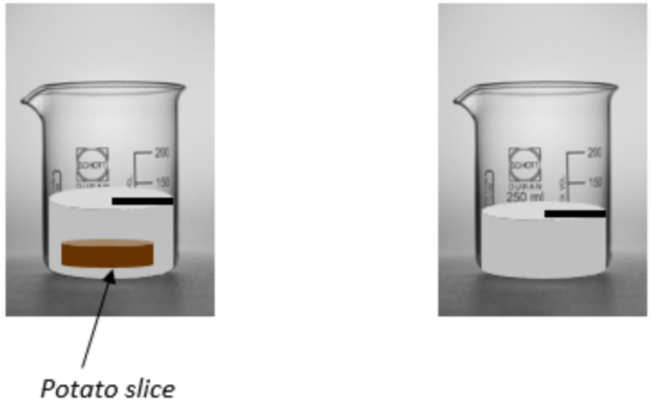

Figure 42.4.1: Slice of potato in hydrogen peroxide

3. Set the beakers side-by-side and view the beakers every few minutes for **30-60 minutes**. Hydrogen peroxide (H_2O_2) will naturally decay to water and oxygen, and your goal is to observe if the potato alters the natural reaction rate. The beaker which shows more gas bubbles is releasing oxygen atoms at the faster rate. Proceed with the other mini-experiments while you continue to check the reaction rates of the hydrogen peroxide.

4. After 30-60 minutes have passed, determine which hydrogen peroxide exhibited the fastest rate of reaction, and check the appropriate box in your *rates of reactions* data table. Check the level of the liquid in each beaker, and note whether there is a change in the level of the liquid compared to the grease pencil line. List any indicators of chemical change; if there were no indicators of chemical change then write “none”.

Clean-up

- Discard potato slice in trash
- Pour liquid contents from beakers into sink
- Wash and dry beakers

Better Faster

5. Fill two 250-mL beakers with 150 mL of cold water, and measure the temperature. Leave the thermometers in each beaker of cold water.

6. Use the mortar and pestle to completely crush one Alka-Seltzer tablet; leave the other tablet whole. At exactly the same time, add the crushed tablet to one beaker and the whole tablet to the other beaker. Stir the contents in each beaker with a plastic spoon until the contents are dissolved, and hold the thermometer steady in the water while you stir; **do not use the thermometer for stirring**.

7. Record whether the crushed tablet or the whole tablet exhibited the fastest rate of reaction; check the appropriate box in your *rates of reactions* data table. Determine whether there was a temperature change. List any indicators of chemical change; if there were no indicators of chemical change then write “none”.

Clean-up

- Pour contents form beakers into sink
- Wash and dry your mortar and pestle, beakers, thermometers, and plastic spoons

Making Kool-Aid

8. Fill two 250-mL beakers with 150 mL of cold water.

9. Place one of the beakers on the heat source and heat the water to nearly boiling; you may use foil as a lid to speed up the heating process. Turn off the heat source once the water is hot, and use beaker tongs or heat gloves to set the hot beaker on the lab table.

10. Simultaneously add one sugar cube to each beaker. Stir the contents of each beaker until all sugar is dissolved. Record whether the hot or cold water exhibited the fastest rate of reaction; check the appropriate box in your *rates of reactions* data table. List

any indicators of chemical change; if there were no indicators of chemical change then write “none”.

11. Simultaneously add one package of Kool-Aid to each of the beakers with sugar water and observe; **do not stir**. Record whether the hot or cold water exhibited the fastest rate of reaction; check the appropriate box in your *rates of reactions* data table. List any indicators of chemical change; if there were no indicators of chemical change then write “none”.

Clean-up

- Wash and dry your beakers and plastic spoons

Weak or Strong

Warning

Alka Seltzer in Vinegar may result in some “spray” of vinegar out of the beakers.

16. Draw a table in which to record your data for the *weak or strong* investigation. Read the instructions for obtaining the data.

Table 42.4.2: Weak or Strong Data

Beaker	Vinegar (mL)	Water (mL)	Mass of Beaker with Liquid (grams)	Mass of Tablet (milligrams)	Final Mass of Beaker contents (grams)	Δ mass
1	5	30				
2	10	25				
3	15	20				
4	20	15				
5	25	10				
6	30	5				

17. Use the grease pencil to label each of your 6 beakers with a number, 1-6.
18. Use the graduated cylinder to fill beakers 1-6 with 5, 10, 15, 20, 25, and 30 mL of vinegar as indicated in the *weak or strong* data table. Rinse the graduated cylinder with water.
19. Use the graduated cylinder to add the appropriate amounts of deionized water (DI) water to each beaker as indicated in the *weak or strong* data table. The beaker may not show that it is filled to the 35 mL level.
20. Measure and record the mass in grams, of each beaker full of liquid. Measure and record the mass of each individual Alka Selter table to the closest milligram (0.000 grams), and place each tablet next to a specific beaker.
21. Add the Alka Seltzer table to beaker #1, gently swirl the contents of the beaker to ensure tablet completely dissolves. Once the reaction has ended, measure and record the final mass of beaker #1. Repeat this process for each beaker. Indicate which beaker seemed to have the fastest rate of reaction.
22. Measure and record the mass in grams, of each beaker with its contents.
23. Calculate the mass loss (Δmass) for each beaker; this is the difference between the final mass of beaker contents and the combined initial mass of the reactants.

Clean-up

- Pour contents from beaker into sink
- Thoroughly wash and completely dry all beakers
- Place graduated cylinder on drying rack
- Clean your lab table

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42.5: Analysis

1. In the reaction *"escaping oxygen"*, what was the purpose of the potato? What is a material called that causes this behavior during a chemical reaction?
2. What is the purpose of crushing the Alka Seltzer tablet? What does crushing the tablet change? Why does crushing a tablet change the reaction rate?
3. Why does hot water change the rate at which contents mix and/or chemically react?
4. How did the dissolving of the sugar cube compare to the Kool-Aid? Why did this happen?
5. Look at your *weak or strong* data table. Is there an amount of vinegar at which the reaction final mass plateaus? What do you think this indicates?
6. In the *weak or strong* reaction, did a higher concentration of vinegar result in a faster rate of reaction? Explain why this may happen?

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42.6: General Questions

1. Some labels on medications warn against breaking and/or crushing tablets. Explain why crushing a medication could be dangerous in terms of chemical reaction rates.
2. Distinguish between a color change that is the result of a chemical reaction and a color change that is the result of mixing.

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CHAPTER OVERVIEW

43: Investigation 42 - Magic Colors

Learning Objectives

- Use color change to determine whether the resulting solution is an acid or a base.

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43.1: Materials

General Materials Needed

- 600 mL Beaker
- 5-250 mL Beakers
- 8 Plastic Small Tip Pipettes
- 115 mL White Vinegar

Looks like Kool-Aid

- 1 mL Phenolphthalein Solution
- 1/8th teaspoon Sodium Carbonate
- Plastic Spoon
- 503 mL D.I. Water

Changing Colors

- 3 mL Universal Indicator Solution
- 3 mL Ammonia
- Grease Pencil
- Graduated Cylinder 3 mL D. I.

Invisible Ink

- 10 mL Phenolphthalein Solution
- 100 mL Beaker
- Q-tip (1 per person)
- Windex/Ammonia (in spray bottle)
- Water White Paper (1 sheet per person)

Notes

- It is very important to use correct glassware
- If measurements are not exact, the process will not work
- Original formula Windex must be used for this experiment (contains ammonia)

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43.2: Introduction

When two substances chemically react, a new substance is produced. One indication that a new substance has been produced is a color change. The universal indicator is a chemical that changes color in the presence of certain levels of acids and bases. *Acids turn the indicator red, pink, orange, and yellow*, while bases turn the indicator green, blue, and purple (fuchsia). The purple color may look more like a deeper pink, as compared to the pink you will see when the solution is acidic. Phenolphthalein solution is also an acid/base indicator; however, this substance will only change color in the presence of a base.

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43.3: Pre-Lab

A. What is the definition of an acid?

B. What is the definition of a base?

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43.4: Procedures

Safety

- Rubber gloves and safety goggles are recommended for this lab.
- Phenolphthalein Solution is harmful if ingested.

Warnings

- Always read the label and make sure you are obtaining the correct chemical.
- The Universal Indicator and the Phenolphthalein are different chemicals; be sure to use the correct one.
- Never obtain chemicals directly from large storage container to avoid cross contamination. Use a beaker.
- Do not re-use pipettes! Pipettes are intended for single use only so chemicals are not mixed unintentionally. Some chemicals used in this experiment can be hazardous if misused!

You will observe color changes as your solution changes acid/base levels.

Changing Colors

Draw a table in which to record your observations. **Do not fill in observations until you have read the instructions.**

Table 43.4.1: Changing Colors

Stage of Experiment	Color	Acidic or Basic
1st Beaker added to 2nd Beaker		
2nd Beaker added to 3rd Beaker		
3rd Beaker added to 4th Beaker		

1. Use the grease pencil to label three 250 mL beakers, 1st, 2nd, and 3rd. Label the 600 mL beaker as 4th.
2. Use a pipette to add 25 drops of the universal indicator into the 1st 250-mL beaker, and then use the graduated cylinder to add 200 mL of DI water to this beaker.
3. Obtain a full pipette of vinegar by squeezing the bulb and then releasing the bulb when the pipette is in the vinegar; note that the pipette will not be completely full. Add the vinegar to the 2nd 250-mL beaker.
4. Obtain a full pipette of ammonia (ideally the same amount in the pipette as compared to the vinegar you obtained in the previous step), and add the ammonia to the 3rd 250-mL beaker.
5. Use the graduated to add 100 mL of vinegar to the 600 mL beaker; this is your 4th beaker.
6. Now it is time to pour.
    a. Slowly pour the contents from the 1st beaker into the 2nd beaker, swirl the contents around to mix, and record the color that results in your *changing colors* data table.
    b. Pour contents from the 2nd beaker into the 3rd beaker, swirl the contents around to mix, and record the color that results.
    c. Pour contents from the 3rd beaker into the 4th beaker, swirl the contents around to mix, and record the color that results.
7. Use the color to analyze whether the contents were acidic or basic, for each pour. Record your answers.

Clean-up

- Pour all liquids down the sink and thoroughly flush sink with water
- Discard all used pipettes in the trash
- Thoroughly wash and dry all beakers
- Thoroughly wash graduated cylinder and place on drying rack to air dry

Looks like Kool-Aid

8. Draw a table in which to record your observations. Read the instructions for obtaining the data.

Table 43.4.2: Looks like Kool-Aid

Stage of Experiment	Color	Basic (yes or no)
4 Beakers		
5 Beakers		

9. Use the grease pencil to label your 250 mL beakers, 1st, 2nd, 3rd, 4th and 5th.
10. Obtain and add exactly 1/8th teaspoon of sodium carbonate into the 1st 250 mL beaker. Use a pipette to add enough DI water to make a paste; use the plastic spoon to mix the water and sodium carbonate until the sodium carbonate is somewhat dissolved and you have a paste like consistency.
11. Use another pipette to add 6 drops of phenolphthalein solution to the 2nd 250 mL beaker.
12. Add 3 full pipettes of vinegar to the 3rd 250 mL beaker
13. Obtain 500 mL of DI water in the 600 mL beaker.
14. Now it is time to pour.
    a. Pour 100 mL of the DI water into each 250 mL beaker, from the 600 mL beaker.
    b. Pour the contents, in order, from the beakers labeled 1st, 2nd, 4th, and 5th into the 600 mL beaker, then pour the liquid from the 600 mL beaker back into the 1st, 2nd, 4th, and 5th beakers, filling each to the 100 mL line.
    c. Record the color of the liquid in the four beakers, in your *Looks like Kool-Aid* table; this is the “4 beakers” stage of the experiment.
15. Now it is time to pour for the next stage of the experiment.
    a. Pour the contents, in order, from all five 250 mL beakers labeled 1st, 2nd, 3rd, 4th, and 5th into the 600 mL beaker, then pour the liquid from the 600 mL beaker back into the five 250 mL beakers, filling each to the 100 mL line.
    b. Record the color of the liquid in the five beakers, in your *Looks like Kool-Aid* table; this is the “5 beakers” stage of the experiment.
16. Use the color to determine in which stage(s) the liquid was basic. Record your answers

Clean-up

- Pour all liquids down the sink and thoroughly flush sink with water
- **Discard all used pipettes in the trash**
- **Thoroughly wash and completely dry all beakers**
- **Clean your laboratory table top**

Invisible Ink

18. Obtain 10 mL of phenolphthalein solution in a clean 100 mL beaker.
19. Dip a Q-tip into the phenolphthalein solution and use it to write a message or make a sketch on your sheet of white paper. Allow your message or sketch to completely dry.
20. After your message or sketch is completely dry, spray the paper with regular formula Windex (or ammonia). Record the color of your message or sketch. Use the color to analyze whether the message/sketch became acidic or basic when sprayed with the Windex. Record your assessment of whether the color indicates an acid or a base.

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43.5: Analysis

1. Compare your observations with what other teams observed. Decide as a team whether to change any of your recorded answers.
2. Use the following scale for the universal indicator to assign pH values to your solutions in the *changing colors* experiment. Record what you think the pH value was for each pour.

Table 43.5.1: Scale for the universal indicator to assign pH values

Red	Pink	Orange	Yellow	Green	Blue	Purple
1	3	5	6	8	12	14

Table 43.5.2: pH value for each pour

Stage of Experiment	pH
1st Beaker added to 2nd Beaker	
2nd Beaker added to 3rd Beaker	
3rd Beaker added to 4th Beaker	

3. What is the evidence that chemical reactions were taking place during these processes?
4. State any errors that may have resulted in the wrong color(s) being observed.

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43.6: General Questions

1. If you were to add the universal indicator to a clear, carbonated beverage, what color would you expect to see? Why?
2. Alkaline water may be purchased in some grocery stores. What color change would you expect if you added a few drops of universal indicator to this water? Why?

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CHAPTER OVERVIEW

44: Investigation 43 - Acids and Bases around the House

Learning Objectives

- Analyze household products for acid/base level, and determine types of products that tend to be acidic/basic.

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44.1: Materials

- pH Test Strips (1 box per team)
- 8 100-mL Beakers
- 2 3-oz Paper Cups
- Household Cleaning Products (2-3 per team)
- Food Items (2-3 per team)
- Bottled Water (2 brands per team)

Figure 44.1.1: pH Test Strip

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44.2: Introduction

Many products that are found in a typical household may be acidic or basic. The pH value indicates the strength of the acid or base. The pH scale ranges from 0 to 14 with 0 being the most acidic and 14 being the most basic. Warnings on certain products may be due to the fact that the product is a relatively strong acid or base. Strong acids and bases completely ionize when brought into contact with water, providing numerous acid ions or base ions to the solution. Many of the products we pour down the sink, that then end up in the ground water, are strong acids or bases. For a substance to be neutral, it must have a pH of exactly 7. Although pure water (pure H_2O) is neutral, some sources of water may have a pH other than 7. In fact, some brands of bottled water have an acid level that would categorize the water as "acid rain".

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44.3: Pre-Lab

A. What is the pH range for an acid?

B. What is the pH range for a base?

C. What is the pH limit for acid rain?

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44.4: Procedures

You will test the pH level of a variety of household items.

1. Draw a table in which to record the data for your lab team's products. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 44.4.1: Data Table

Household Product	pH Value	Acid or Base

2. Obtain a small amount (5-10 mL) of your first item in one of the 100 mL beaker; do not place your pH strip into the original container, so you do not contaminate the contents of the container.
3. Place the multi-colored end of one pH test strip into full contact with your first substance, for a brief moment. The test strip will react immediately upon contact. Match the colors on the strip to the color guide on the box. Record the name of the substance and the pH value according to the test strip. Set aside the used pH test strip; it is trash.

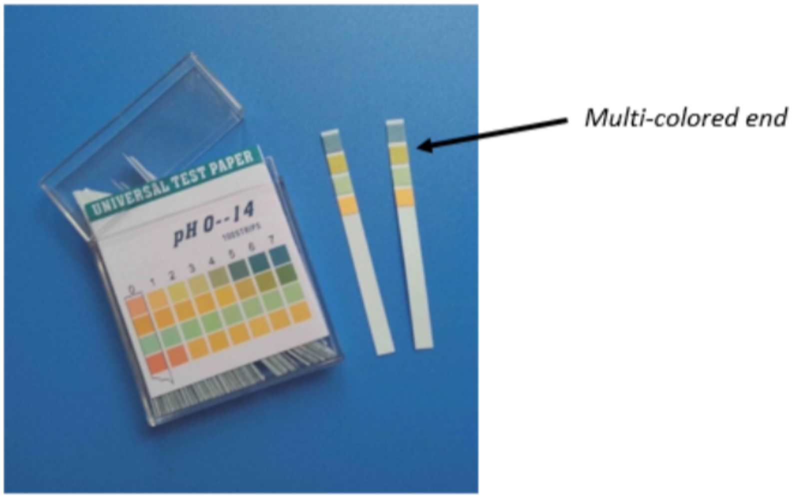

Image by Aliexpress.com

Image by Simplex Health

Figure 44.4.1: pH test strip

4. Complete the pH testing for all of your substances, and record your pH data for each substance.
5. Identify each substance in your data table as an acid or a base, as indicated by the pH value.
6. Label one of the 3-oz paper cups “acid” and fill this cup about 1/4 full with your strongest acid. Label the other 3-oz paper cup “base” and fill this cup about 1/4 full with your strongest base. Place both cups on a paper towel. Allow the cups to set for a few minutes (at least 10 minutes). While you allow time for the substances to interact with your paper cups, write your team’s substances and pH values on the board.
7. Examine each 3-oz paper cup and discuss as a team whether there is any evidence that a chemical reaction between the substance and the cup has taken place. Then walk to the other lab tables and view their 3-oz paper cups. Record your general observations.

Clean-up

- Pour all household substances from beakers and paper cups into sink
- Thoroughly wash and completely dry beakers
- Throw away used pH test strips and paper cups
- Clean your lab table

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44.5: Analysis

1. Discuss any trends your team observes in the data on the board. List any general trends.
2. Which substance tested was the strongest acid?
3. Which substance tested was the strongest base?
4. Are there similarities among the substances that are acids? Explain.
5. Are there similarities among the substance that are bases? Explain.
6. List any food or drink substances that showed a pH level at or below the limit for acid rain.

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44.6: General Questions

1. What do you think something acidic may do to your teeth?
2. If one of your 3-oz paper cups containing an acid or base began to disintegrate, what would this indicate about the substances people may have in their home?
3. In general, what goes together?
    a. Food Items = (acids or bases)
    b. Cleaning Products = (acids or bases)

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CHAPTER OVERVIEW

45: Investigation 44 - Chemistry in a Ziploc Bag

Learning Objectives

- Investigate combinations that result in a reaction, and analyze acid-base reactions.

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45.1: Materials

- Baking Soda ($NaHCO_3$)
- Calcium Chloride ($CaCl_2$) (in 2-3 mm pellets)
- Phenol Red ($C_{19}H_{14}O_5S$) Solution
- 3 Plastic Pipettes (Small Tip)
- 7 Ziploc Bags (Quart Size)
- DI Water

Notes

- There should be a solid waste container for this lab.
- Use appropriately labeled spoons for each substance to avoid cross contamination.

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45.2: Introduction

Acids contribute hydrogen ions (H^+) into a solution during a chemical reaction, making them **proton donors**. Bases contribute hydroxide ions (OH^-) into a solution during a chemical reaction or bond with a proton making them **proton accepters**. Phenol solution turns yellow in acidic solutions and remains red in basic solutions. There are many indicators that a chemical reaction has occurred, including color change.

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45.3: Pre-Lab

A. List indicators that a chemical change has occurred.

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45.4: Procedures

Warnings

- Some chemicals used and produced in this experiment may irritate skin, can damage the eyes, or may be hazardous to your health if inhaled.
- This reaction may form sodium hydroxide ($NaOH$) which can cause severe chemical burns.
- Do not open any Ziploc bag in which a gas is produced, unless you are releasing the gas into an operating chemistry hood!

You will investigate various combinations of the three chemicals.

Safety

- Always read the label and make sure you are obtaining the correct chemical!
- Safety glasses and rubber gloves should be worn for this experiment.

1. Draw a table in which to record your observations. **Do not fill in data until you have read the instructions for obtaining that data; it is very important that you DO NOT COMBINE CHEMICALS until you have read the instructions.**

Table 45.4.1: Data Table

Chemicals Combined	Reaction (yes or no)	Indicators
Baking soda Calcium Chloride		
Baking soda Calcium Chloride Phenol		
Baking Soda Phenol		
Calcium Chloride Phenol		

2. Add 1 spoonful of baking soda ($NaHCO_3$) in your first quart-size Ziploc bag. Add 2 spoonsful of calcium chloride ($CaCl_2$) to the same Ziploc bag. Gently flatten the bag and smooth as much air as possible from the bag, without crushing any calcium chloride pellets, and then seal the bag. Gently mix the two substances being careful not to crush the calcium chloride pellets; the mixing can be accomplished by simply moving the outside of the bag in various directions with your hand. Record whether a chemical reaction occurred, and any indicators of chemical change observed.
3. Use your pipette to obtain phenol red solution from the beaker labeled "phenol"; squeeze the bulb and draw as much liquid as possible into the pipette (note that the pipette will not be completely full). Without allowing any phenol solution to escape the pipette, carefully place the pipette into the Ziploc bag with the solids; no phenol solution should be released into the solid mixture yet. Gently flatten the bag and smooth as much air as possible from the bag, without releasing the phenol solution or crushing any pellets, and then seal the bag.
4. Keep the Ziploc bag sealed. Squeeze the pipette from outside of the sealed Ziploc bag to release the phenol solution. Gently mix the contents in the bag, without crushing the calcium chloride pellets. Record whether a chemical reaction occurred, and any indicators of chemical change observed.

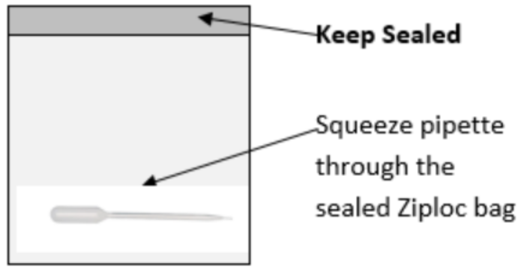

Figure 45.4.1: Chemicals combined in a Ziploc bag

5. If a gas was produced, release the gas from the Ziploc bag into an operating chemistry hood. If there is not a chemistry hood available, then place the sealed Ziploc bag in the container provided by your instructor.
6. Utilizing the same amounts of particular chemicals (1 spoonful baking soda, 2 spoonsful calcium chloride, 1 pipette phenol solution), test various combinations in sealed Ziploc bags; two combinations are listed in the table for you. DI Water may be utilized in place of the phenol solution as a combination, if desired. Write your combinations into the data table. For each combination, record whether a chemical reaction occurred, and any indicators of chemical change observed. **If a gas is produced, do not open the Ziploc bag** unless releasing the gas in a chemistry hood. If there is not a chemistry hood available, then place sealed Ziploc bags in the container provided by your instructor.

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45.5: Analysis

1. Based on your observations, which substances were needed for the specific chemical changes observed?
   a. Color change?
   b. Temperature change?
   c. Gas produced?
2. Which combinations resulted in an acidic product? What was your evidence?

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45.6: General Questions

1. Classify each substance in the chemical equations as an acid or base, by determining for each substance whether it is a proton donor or a proton acceptor.
   a. $NH_3 + H_2O \leftrightarrow NH_4 + OH$
   b. $H_2O + HCO_3 \leftrightarrow H_3O + CO_2$
2. Is there a trend for determining the acid and base when the reaction is reversed? Explain the trend.

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CHAPTER OVERVIEW

46: Investigation 45 - Fruit and Veggie Current

Learning Objectives

- Test fruits and vegetables for production of current.

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46.1: Materials

- Multi-meter
- 3 Produce Items (per team)
- 1 Copper Metal Strip
- 1 Zinc Metal Strip
- pH Test Strips (1 box per team)
- Kitchen Paring Knife (1 per team)
- Work Gloves

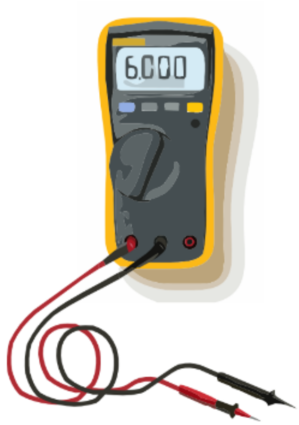

Figure 46.1.1: Multi-meter licensed under CCO

Note

The multi-meter must be able to measure milliamps.

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46.2: Introduction

Copper is a material that easily accepts electrons while zinc is a material that easily gives up electrons. This promotes a flow of electrons. When two different types of metal strips are placed into an acidic solution, a chemical reaction may take place between the solution and the metals. A chemical reaction in which electrons are accepted by one material and given up by another material is called an oxidation-reduction reaction, and results in the flow of electrons. The process of chemical reactions using or producing electricity is electrochemistry.

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46.3: Pre-Lab

A. Calculate the current needed to operate a 60 Watt lightbulb when 110 volts are supplied.

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46.4: Procedures

Warnings

- Please be careful with the knife and be aware at all times of its location.
- The metal strips can cut your hand, so be careful, even while wearing work gloves.
- Juice from produce may squirt, and can irritate the eyes.
- Safety goggles are recommended for this lab.

You will test a variety of produce items for electric current production.

1. Draw a table in which to list your produce items and record your data. **Do not fill in data until you have read the instructions for obtaining that data.**

Table 46.4.1: Data Table

Produce Item	Predicted (Yes or No)	Current (mA)

2. Choose 3 produce items to test, and list these items in your table. Be specific when you list the produce items; there are many varieties of apples.
3. For each piece of produce in your list, predict whether you think there will be any current produced. Record your predictions in your table.
4. Use the knife to make two small cuts about an inch apart, in the outer skin of your first produce item, one for each piece of metal. Insert the copper and zinc strips into the first produce item such that the flat sides are parallel to each other and about 1/3 of the metal strips are submerged inside the produce.

Figure 46.4.1: Fruit and Veggie Circuit construction

5. Turn on your multi-meter, and adjust the dial to measure in milliamps (mA). Attach the accompanying electrical leads (insulated wires) to the appropriate holes in the multi-meter, the ones that will allow you to measure milliamps. Each multi-meter is different.
6. Touch the metal probes at the ends of the electrical leads to the strips of metal, creating a series circuit; you may want to press the probes to the metal strips to ensure good contact. Record the peak current shown by the multi-meter; the reading may fluctuate. Note that a negative reading shows the direction electricity is flowing; it is not a negative amount of current. If you have no reading, try wiggling the metal diodes and make sure the metal ends of the multi-meter leads are in full contact with the metal strips.

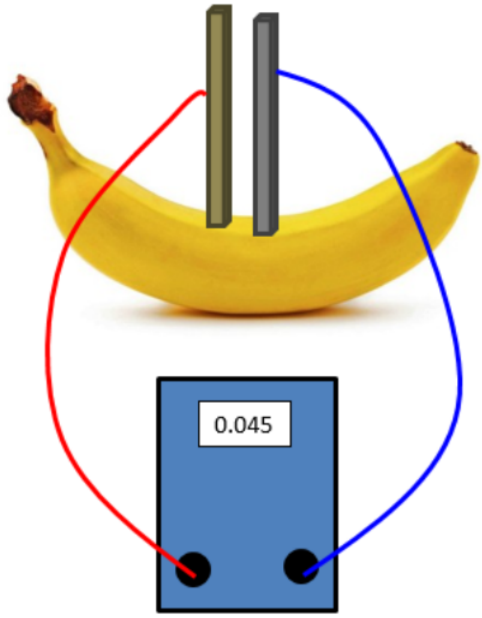

Figure 46.4.2: Measuring current in a Fruit and Veggie circuit

7. Remove the metal strips from your first piece of produce and thoroughly rinse the metal strips before you insert them into your next produce item. Also rinse the paring knife prior to using it for the next produce item. Set your tested produce item aside.
8. Test each of your produce items, recording the peak current for each. Remember to rinse the metal strips and the paring knife each time, prior to testing the next produce item.
9. Use the pH test strips to determine the pH of each produce item. Squeeze some juice from your produce item onto the multi-colored end of a pH test strip or insert the multi-colored end into one of the holes made by the metal strips. The test strip will react immediately upon contact. Match the colors on the strip to the color guide on the box. Record the pH values in your data table.
10. List your data on the board, excluding your predictions.

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46.5: Analysis

1. Did every fruit and vegetable tested in this investigation produce current?
2. Which piece of produce tested in this investigation produced the most current?
3. Which piece of produce tested in this investigation had the highest level of acidity?
4. Are there any general trends that relate properties of the produce tested in this investigation to amount of current? Explain.
5. Add your data to the table below. Use the current you calculated for a 60 Watt lightbulb in the pre-lab and the milliamps (mA) you recorded for each of your produce items, to calculate the number of pieces it would take to operate the 60 Watt lightbulb. Record your answers.

Table 46.5.1: Data Table

Produce Item	Current (mA)	Number of Pieces to Operate 60 Watt Lightbulb

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46.6: General Questions

1. If you were to see a You Tube video of someone powering their cell phone with three pieces of produce (i.e., a lemon, an orange, and a banana), would you believe this was possible? Explain.
2. What type of chemical reaction produces current in a battery? (choose one)
   a. Acid/base reaction
   b. Oxidation-reduction reaction

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CHAPTER OVERVIEW

47: Appendix I - The Physical Science Tool Box of Units

Learning Objectives

- Familiarize yourself with the metric system, and practice converting from one set of units to another set of units.

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47.1: Materials

- Scientific Calculator

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47.2: Introduction

The system of units used in the physical sciences is based on the metric system. Numbers that describe physical quantities range from the very large to the very small, so a set of standard prefixes are used to designate convenient-sized units that differ by multiples of ten. Every step in the metric system is a multiple of 10.

Table 47.2.1: Prefixes to designate convenient-sized units that differ by multiples of ten

Multiple	Prefix	Symbol
10^{24}	yotta	Y
10^{21}	zetta	Z
10^{18}	exa	E
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{1}	deca	da
10^{0}		
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a
10^{-21}	zepto	z
10^{-24}	yocto	y

The United States continues to use English units. Conversion factors utilize equivalent sized measurements, to change from one unit to another. For example, 1 inch and 2.54 centimeters measure the exact same length. Converting from one unit to another requires multiplying by the appropriate conversion factor.

Table 47.2.2: English to Metric conversion

English to Metric
1 inch = 2.54 centimeter
1 mile = 1609 meters
0.2248 lb = 1 Newton

Example*: *[Measurement] x [Conversion Factor] = New Number

$$12 \ \cancel{\text{inches}} \times \frac{2.54 \text{ centimeters}}{1 \ \cancel{\text{inch}}} = 30.48 \text{ centimeters}$$

The inches in the numerator and the inches in the denominator cancel

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47.3: Procedures

Thinking about Prefixes

1. Use the table of prefixes to complete an ordered list of the most common multiples used in physical science: **micro**, **mega**, **nano**, **kilo**, **centi**, and **milli**,. List these prefixes in order by powers of ten, from largest to smallest. Then write the scientific notation and the standard notation for the prefix word.

   Example: **giga = 109 = 1,000,000,000**

2. Think about what the words "Mega Millions Lottery" means. If you won 300 Mega Millions, how many millions of dollars would you have won?

Metric to Metric

3. Utilize differences in powers of ten or a number line to "move" within the metric system of units.
   a. centimeters = ____________________ meters
   b. 2,000 meters = ____________________ kilometers
   c. 650 nanometers = ____________________ meters
   d. 20 millimeters = ____________________ meters
   e. 20 grams = ____________________ kilograms

Time

4. Use your knowledge of seconds minutes and hours.
   a. 1 hour = ____________________ seconds
   b. 1 hour = ____________________ nanoseconds
   c. 1 day = ____________________ seconds
5. There are 365 days in a standard calendar year. Write your current age in years and convert this to seconds.
6. If you were able to blink every nanosecond for an hour, how many times would blink?

English to Metric & Metric to English

7. Use **appropriate** conversion factors to convert from one system of units to another.
   a. 65 mph = ____________________ kph
   b. 65 mph = ____________________ m/s
   c. 60 inches = ____________________ centimeters
   d. 60 inches = ____________________ meters
   e. 20 m/s = ____________________ mph
   f. 20 cm = ____________________ inches

Common American Quantities

8. Write your approximate weight and convert this to Newtons.
9. Cargo ships carry many megatons of consumer products. How many pounds are in 500 Megatons of cargo? (1 ton = 2000 lbs)
10. The length of an American Football field is 100 yards. How many meters are in 100 yards?

Measurements in 2D and 3D

11. An accent rug measures 4 feet by 6 feet.
    a. Calculate the area of the rug in square feet (ft^2), and then convert the units from square feet (ft^2) to square meters (m^2).

b. Convert each of the two given measurements (4 feet and 6 feet) to meters. Then multiply the two measurements in meters to obtain the area in square meters (m^2).

c. Compare the answers you obtained in parts a, and b. Are the numbers the same; did you calculate the same square meters with the two different processes?

12. A gift box measures 12 inches by 8 inches and is 3 inches tall. Calculate the volume, and then convert the volume from cubic inches (in^3) to cubic centimeters (cm^3).

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47.4: Analysis

1. In general, by what factor are mph and m/s different? Is it 2:1, 3:1, etc.?
2. How many times must you move the decimal?
   a. To change between kilometers and meters
   b. To change between kilograms and grams
   c. Explain why the movement of the decimal is the same for the length (meters) measurement and the mass (grams) measurement in parts a, and b.

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47.5: General Questions

1. Explain why using a standard unit is important.
2. Why do you think our country still uses the English system of units? Why do you think we did not change to the metric system?

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CHAPTER OVERVIEW

48: Appendix II - Constructing and Interpreting a Graph

Learning Objectives

- Construct and analyze scientific graphs.

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48.1: Materials

- Ruler
- Graph Paper

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48.2: Introduction

Graphs allow us to visualize the relationship between two sets of numbers. Scientists often graph sets of numbers looking for a correlation, or a mathematical relationship. When constructing a graph of physical quantities, the independent variable is placed on the horizontal (x-axis), and the dependent variable is placed on the vertical (y-axis). A best fit line is utilized to represent the data; it is a smooth line or curve which is the average of the data points. The graph can be used to develop an equation relating the two sets of data, and shows how the two sets of data are related.

Independent & Dependent Variables

Independent variables do not depend on the measurement of another quantity. They are fundamental quantities. A change in location or direction will not affect a fundamental quantity. (*Example: time*)

Dependent variables depend on the measurement of another quantity. A change in location or direction will affect/change this type of quantity. (*Example: acceleration*)

Guidelines for Constructing a Good Graph

- Draw the axes of the graph such that the graph will fill the space provided, leaving just enough room for labeling.
- Determine the independent and the dependent variables, and label your axes accordingly. Include the units in your axes labels.
- Determine the minimum and maximum values for each axis. Then choose a scale with equal increments (like 10, 20, 30, etc.) which will accommodate all of the data; the scale may be different for each axis.
- Plot the data and draw a smooth line or curve that best fits the data points.

Linear or Direct Relationship

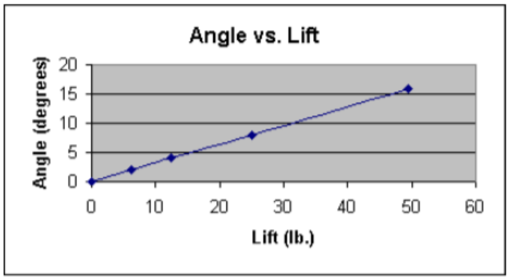

Image Credit: NASA

Figure 48.2.1: Graph shows relationship is $y = x$

Quadratic Relationship

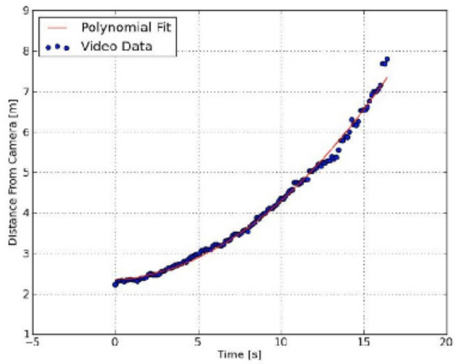

Image Credit: ESA

Figure 48.2.2: Graph shows relationship is $y = x^2$

Inverse Square Relationship

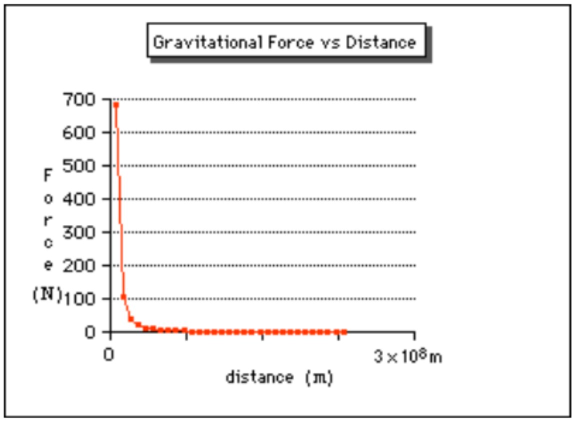

Image Credit: NASA

Figure 48.2.3: Graph shows relationship is $y=\frac{1}{x^2}$

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48.3: Procedures

1. Construct a graph using the distance and time data in Table 48.3.1.

Table 48.3.1

Distance (meters)	Time (seconds)
7.06	1.2
19.62	2.0
47.13	3.1
90.69	4.3
122.62	5.0
188.50	6.2
240.35	7.0

2. Construct a graph using the speed and time data in Table 48.3.2.

Table 48.3.2

Speed (m/s)	Time (seconds)
5.9	1.2
15.7	2.0
25.0	3.1
51.4	4.3
45.6	5.0
54.9	6.2
64.8	7.0

3. Look at the data table containing football player statistics. Determine which data set is the independent variable and which data set is the dependent variable. Construct a graph using the football player data.

Table 48.3.3

Football Player Height	Football Player Weight (pounds)
5 ft 8 in	168
5 ft 9 in	178
5 ft 10 in	186
5 ft 11 in	177
6 ft	201
6 ft 1 in	196
6 ft 2 in	230
6 ft 3 in	205
6 ft 4 in	222
6 ft 5 in	228

Football Player Height	Football Player Weight (pounds)
6 ft 7 in	259

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48.4: Analysis

1. Determine whether the graph for Table 48.3.1 data shows a linear, quadratic, or inverse square relationship. Describe the motion shown by this graph.
2. Determine whether the graph for Table 48.3.2 data shows a linear, quadratic, or inverse square relationship. Describe the motion shown by this graph.
3. Determine whether the graph for football player data shows a linear, quadratic, or inverse square relationship. Interpret the "Football Player" graph by describing how height and weight are related to each other.

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48.5: General Questions

1. Does a quadratic relationship, a curved line, indicate a static or changing system?
2. What does a lot of scatter in data points, variations from the best fit line or curve, indicate?

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CHAPTER OVERVIEW

49: Appendix III - Manipulating Numbers in Scientific Notation

Learning Objectives

- Practice with scientific notation.

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49.1: Materials

- Scientific Calculator

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49.2: Introduction

Scientific notation indicates the number of 10's by which a coefficient is multiplied or divided. A negative exponent indicates the coefficient is divided by 10's, which means the decimal would move to the left for each negative power. A positive exponent indicates the coefficient is multiplied by 10's, which means the decimal would move to the right for each positive power. Numbers in the physical sciences can be very large or very small, making it cumbersome to write the entire number in standard notation, so powers of ten are used as a shorthand. When two numbers with powers of 10 are multiplied, the coefficients are multiplied, and then the powers of 10 exponents are added. When two numbers with powers of 10 are divided, the coefficients are divided, and then the powers of 10 exponents are subtracted.

The Meaning of Powers of 10

Table 49.2.1

Standard	Scientific	Powers of Ten
$540,000,000,000$	5.4×10^{11}	$5.4 \times (10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times$
0.00000101	1.01×10^{-6}	$\frac{1.01}{(10 \times 10 \times 10 \times 10 \times 10 \times 10)}$

Table 49.2.2

Standard	Scientific	Decimal Places
$540,000,000,000$	5.4×10^{11}	move decimal 11 places to the right
0.00000101	1.01×10^{-6}	move decimal 6 places to the left

Examples

Table 49.2.3: Multiply & Divide Powers of 10

$10^6 \times 10^2 = 10^8$	exponents: 6 + 2 = 8
$10^6 \times 10^{-2} = 10^4$	exponents: 6 + (−2) = 4
$10^6 \div 10^2 = 10^4$	exponents: 6 – 2 = 4
$10^6 \div 10^{-2} = 10^8$	exponents: 6 – (−2) = 8

Table 49.2.4: Multiply & Divide with Coefficients

$(2 \times 10^3) \times (4 \times 10^5)$	$(2 \times 4) \times 10^{3+5} = 8 \times 10^8$
$(2 \times 10^3) \div (4 \times 10^5)$	$(2 \div 4) \times 10^{3-5} = 0.5 \times 10^{-2}$

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49.3: Procedures

Practicing with Scientific Notation

1. Write the following numbers in scientific notation; keep only 3 significant figures.
   a. 9,876,543
   b. 1,000
   c. 1,000,000,000
   d. 0.000009876543
   e. 0.000000001000
2. Multiply and divide the following numbers. Write the answer in scientific notation, and then in standard notation.
   a. 10^8 times 10^{-3}
   b. 10^8 divided by 10^{-3}
   c. 14×10^{15} times 2×10^{-12}
   d. 14×10^{15} divided by 2×10^{-12}
   e. $(9 \times 10^9)(1.6 \times 10^{-19})(1.6 \times 10^{-19})$ divided by (5×10^{-5})

Metric System

3. Write the number of kilograms in a 1,000 grams, in scientific notation. How many places do you need to move the decimal? Explain why the decimal this moved this many places.
4. Write the number of meters in 100 centimeters, in scientific notation. How many places do you need to move the decimal? Explain why the decimal this moved this many places.

Real Measurements

5. A wavelength of blue light is 450 nanometers or 450×10^{-9} meters. What is this wavelength in standard notation?
6. Our sister galaxy, the Andromeda galaxy is 250 Million light years, or 250×10^6 light years from us, and 1 light year is 9.46×10^{15} meters. Calculate the total distance in meters to the Andromeda Galaxy, in standard notation.

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49.5: Analysis

1. Explain when the decimal would move to the left if changing from scientific notation to standard notation.
2. Explain when the decimal would move to the right if changing from scientific notation to standard notation.

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49.6: General Questions

1. What does scientific notation indicate?
2. Why is scientific notation useful?

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