



2015-2016 SJP Physics Laboratory Manual

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ST. JOSEPH'S PREPARATORY SCHOOL

LABORATORY SAFETY CONTRACT

IT IS IMPORTANT THAT YOU FOLLOW SOME COMMON SENSE RULES IN LAB. THIS WILL FOSTER A SAFER LAB INVESTIGATIVE ENVIRONMENT FOR YOURSELF AND FOR EVERYONE ELSE IN THE LAB.

1. Never work in the lab unless a teacher is present and aware of what you are doing.
2. Prepare for the lab activity or experiment by reading it over first. Ask questions about anything that is unclear to you. Note any cautions that are stated.
3. Wear lab apron and safety goggles/glasses when working with flames, heated liquids, or heated glassware. In the chemistry laboratory, safety goggles and aprons are required at all times.
4. Keep the work area free of any books and materials not needed for what you are working on.
5. Do not touch any equipment, chemicals or other materials in the lab area until you are instructed to do so.
6. Use the lab equipment only as instructed in the lab manual or by your teacher.
7. Keep hands away from your face, eyes, mouth and body while using chemicals or preserved specimens. Wash your hands with soap and water after performing all experiments. Clean all work surfaces and equipment at the end of each experiment.
8. All chemicals in the lab are to be considered dangerous. Do NOT touch, taste, or smell any chemicals unless specifically instructed to do so. The proper technique for smelling chemical fumes will be demonstrated to you.
9. If a thermometer breaks, inform your teacher immediately.
10. Do not force glass tubing or a thermometer into a dry rubber stopper. The hole and the glass should both be lubricated with glycerine (glycerol) or soapy water, and the glass should be gripped with paper towels sufficiently thick to protect the hands.
11. Do not touch anything that may be hot such as burners, hot plates, beakers, electric bulbs. If you must pick up something that is hot, use damp paper towels sufficiently thick to protect the hands.
12. When working with electric circuits, be sure that the current is turned off before making adjustments in the circuit.
13. Never return unused chemicals to their original containers.
14. Report any injuries, accidents, or breakages to your teacher immediately. Also report anything that you suspect may be malfunctioning.
15. Work quietly so that you can hear any announcements concerning cautions and safety.
16. Know the location of fire extinguishers, fire blankets, eye wash stations, and the nearest exit.
17. When you have finished your work, check that water and gas are turned off and that electric circuits are disconnected. Return all materials and equipment to a place designated by your teacher.

Student: I acknowledge that I have read, understand and agree to abide by these safety guidelines as reviewed in class on (date) _____.

Student's Name (printed): _____ Date: _____

Student's Signature: _____ Period: _____

Parent: I acknowledge that I have read and reviewed this safety contract with my son.

Parent's Signature: _____ Date: _____

DATA ACQUISITION AND ANALYSIS

"A measurement whose accuracy is unknown has no use whatever. It is therefore necessary to know how to estimate the reliability of experimental data and how to convey this information to others."

-E. Bright Wilson, Jr., *An Introduction to Scientific Research*

Throughout this year you will engage in experiments, collect data, and analyze the data. It is important to understand how to collect data to proper significant figures and understand how to find relationships between the data. The foundation of Physics is understanding the relationships between physical quantities.

Initial setup

1. Ensure you have the following materials:
 - Ticker timer
 - Ticker tape (2-m strips, one per person)
 - A new carbon circle
 - Masking tape
 - Meter stick
 - Dynamics cart
2. Clamp the timer to the table 2-m away from the seam in the table. Ensure the clamp is only tight enough to keep the timer from moving during the experiment.
3. Plug the timer into the **electrical outlet**, not in the power supply.
4. **Practice.** Give the cart a push and release it quickly so that it travels along the lab table. Practice pushing the cart along the table so that a 1.5 – 2.0 m trip takes about 2 seconds.

Investigation (Data Acquisition)

5. Attach a piece of "ticker tape" to the dynamics cart with masking tape and feed the tape through the timer. Make sure that the cart, the ticker tape and the recording timer all arranged along a straight line.
6. Turn on the recording timer and push the cart as practiced.
7. Run enough trials so that each member of the team has his own ticker tape record of a trial.

Each student must do the rest of the steps on his own.

8. Count the dots on the tape from the initial blur to the end of the tape. If there are fewer than 80 dots, the trial must be repeated.
9. Divide the number of dots on the tape by twenty and round the result to an integer. This is the number of spaces per time interval that will be used.
 - Each space on the tape identifies 1/60th a second. This is the smallest time interval that you can measure. The interval to be measured is an integer multiple of 1/60-s.
 - The values in the time column must increase uniformly by the decimal equivalent of this fraction.
 - The values in the Δt column must all be equal to the decimal equivalent of this fraction.
10. Attach the ticker tape to a flat surface with the dots facing up so that measurements can be made easily.
11. Measure the distance **from the blur** to the end of each interval and enter these values in the table. This is the only complete set of values that must be entered by hand.

DATA ACQUISITION AND ANALYSIS

Data Organization and Graphs

12. Make a table like the one shown using a readily available spreadsheet program, enter the measured values for x in the appropriate column
13. Enter formulas into the other cells on the spreadsheet so that the computer can calculate all of the other values in the table for you.
14. Have your data checked by the instructor before proceeding to the graph.
15. Use the spreadsheet to generate two "x-y scatter" graphs of **displacement vs. time** and **velocity vs. time**. Time must be the horizontal axis for both graphs.

Analysis

Note: Answer these questions in the **Analysis** part of your lab report!

1. What formula or method did you use to put the times in column B?
2. What formula or method did you use to put the Δx values in column D?
3. What formula or method did you use to put the velocity values in column F?
4. How many dots per second does the ticker timer make?
5. What increment of time is represented by a single dot?
6. What increment of time is represented by the space between two dots?
7. What physical quantity is represented by the slope of the displacement vs. time graph?
8. What physical quantity is represented by the slope of the velocity vs. time graph?

UNIFORM ACCELERATION

As objects speed up or slow down the rate at which the change in speed occurs may not always be uniform (constant). The acceleration an object experiences will change if the net force acting on the object changes. It is up to you to determine whether or not uniform acceleration has occurred.

Initial setup

1. Ensure a 2x4 is clamped along the seam on the table.
2. Choose an appropriate length of ticker tape (distance the hanging mass will fall. ~80-90cm) **Reminder:** plug the timers into the **electrical outlet**, not the power supply.
3. Ensure the pulleys are clamped to the short edge of the tables on the opposite side of the 2x4 from the timer.
4. Place a numbered foam pad on the floor below the pulley.
5. **Place an S-hook in the hole on the cart and hook the string to the cart. DO NOT TIE STRING TO THE CART**
6. Place 50-300g of the slotted weights onto the hanger and hook it to the other end of the string, carefully aligning the string with the pulley. Record the mass used (the hanger itself is 50 g). **Each member of the group must use a different mass on the hook.**
7. Adjust the pulley and the cart so that the pulley, the string and the ticker tape are all in line with the ticker timer.

Investigation 1: Weight and Pulley

8. While one group member holds the cart such that the hanger is just below the pulley wheel, attach the ticker tape to the car and feed it through the timer.
9. Move the cart until the hanging mass is just touching the ground and there is no slack in the string or the ticker tape. Make a mark just next to the pin of the timer on the ticker tape. This will mark the end of **useful dots** on the tape. Pull the cart back to its starting position.
10. Turn on the ticker timer, and immediately release the cart.
11. Repeat with different masses for the other members of the group.
12. Count the total number of useful dots on your ticker tape, record. Divide by 20 and round to nearest integer to determine your interval, record.
13. Measure the distance (in meters) **from zero** to the end of each interval and record in the data table.
14. Remove the hanging masses and string from the cart.

UNIFORM ACCELERATION

Investigation 2: Rubber bands

15. Attach a chain of rubber bands to the S-hook.
16. One team member will hold the other end of the rubber bands with a finger on the back side of the 2x4. Attach the ticker tape to the cart and feed it through the ticker timer.
17. Move the cart to the position just before the rubber bands go completely slack. Make a mark on the ticker tape next to the timer's pin. This will indicate the end of the useful data.
18. Pull the cart, stretching the rubber bands, towards the timer. Turn on the timer and release the cart. Repeat for each group member.
19. Count the total number of useful dots, record. Determine the interval, record.
20. Measure from zero to the end of each interval and record in the data table.

Graphs

- **Distance vs. time for the weight and pulley data.**
- **Distance vs. time squared for the weight and pulley data.**
- **Distance vs. time for the rubber band data.**
- **Distance vs. time squared for the rubber band data.**

Analysis

Note: Answer these questions in the **Analysis** part of your lab report!

1. Determine whether either or both of the data sets demonstrates a quadratic function of time. Explain your reasoning.
2. Determine (from the data) whether either or both of the motions represent uniform acceleration. Explain your reasoning.
3. Give an example of another form of uniform acceleration.

VECTORS

Vectors are physical quantities that have both magnitude and direction. The motion of objects is hardly ever one dimensional but two or three dimensional. Performing calculations and describing the motion of objects with two dimensional motion can be tricky. There are two methods used for vector addition; graphing and analytical. You will be practicing and comparing both methods in this experiment. The vectors you will be working with will be distributed to you.

Investigation 1: Graphical Method

Use the graphical method **only** during this investigation. Use different colors to represent vectors and the components. When graphically adding vectors, use different colors for the two vectors, the resultants, and the components of the resultants.

1. On the graph paper provided draw the vectors and components of **A, B, C, D**. Record the vector measurement of the x, y components in the data table.
2. Draw **-A, -B, -C**. Record the vector measurement of the x, y components and the vector in the data table.
3. Graph **(A+B)**. Record the vector measurements of the resultant and its components in the table.
4. Graph **(C+D)**. Record the vector measurements of the resultant and its components in the table.
5. Graph **(A-D)**. Record the vector measurements of the resultant and its components in the table.
6. Graph **(A-B)**. Record the vector measurements of the resultant and its components in the table.
7. Graph **(A+B+C)**. Also, draw the equilibrant of **(A+B+C)**. Record the vector measurements of the resultant and its components in the table.

Investigation 2: Analytical Method

Use the analytical method **only** during this investigation. Include all work and calculations in the lab report. Complete the table with all necessary information.

1. Determine the magnitudes and directions of **E, F, G, and H**.
2. **(E+F)**.
3. **(G+H)**
4. **(E-H)**
5. **(E+F+G)**
6. **(-E)**
7. **(-F)**
8. **(-G)**
9. *Equilibrant of **(E+F+G)***

VECTORS

ANALYSIS

Write a **SHORT** essay describing these things:

- The method(s) used to add and subtract vectors graphically.
- Any facts about vector addition that were observed while adding graphically.
- A value judgment regarding the possible precision in graphical addition and subtraction.
- The method(s) used to add and subtract vectors analytically.
- An analysis of the circumstances under which one method would be preferred to the other.

WASHER DROP

Six washers are to be attached to 5 m of string in such a way that when the entire length of string is held vertically and dropped, the time between impacts is equal. Video analysis will be used to determine the equivalence between time intervals instead of relying on our inaccurate ears or stop watches.

Investigation

1. Determine the positions of the washers on the string. Make note of the method your group used and reasoning. This will be included in the analysis section of your lab report.
2. . **The top washer must fall 5 meters.**
3. The string will be held by the top washer and will hang vertically down
4. The washers are to be firmly attached to the string and colored masking tape must be wrapped around the washers after they have been attached so that they can easily be identified in a video recording. Each washer will have a **different** color.
5. Experimenters are expected to make a value judgment regarding the sound of the washers hitting the pie plate.
6. **No practice is allowed.** Each group gets only **one** drop.
7. Carefully analyze the video recording:
 - a. Determine which frame the string appears to begin to fall. Count this as frame 1.
 - b. Count frames until the first washer hits the ground.
 - c. Continue counting (do not start over at 1) until the next washer hits. Repeat.

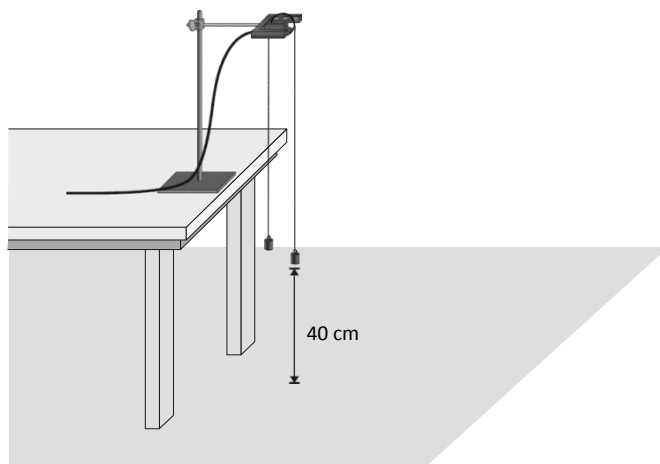
Analysis:

1. Explain how the distances for washer placement were determined/calculated.
2. Explain how the time was measured from the video.
3. How does the initial height of the highest washers affect the outcome of the experiment?
4. Do the washers placed lower on the string effect how the washers higher on the string fall?
5. Is it reasonable to consider the washers to be in free fall even though they are all tied together?
6. If your washers did not hit at equal time intervals, explain the errors that occurred to contribute to this.

ATWOOD'S MACHINE

A classic experiment in physics is the *Atwood's machine*: Two masses on either side of a pulley connected by a light string. When released, the heavier mass will accelerate downward while the lighter one accelerates upward at the same rate. The acceleration depends on the difference in the two masses as well as the total mass.

In this lab, you will determine the relationship between the two factors which influence the acceleration of an Atwood's machine using a Photogate for measuring acceleration.



Investigation 1: Constant Total Mass

For this part of the experiment you will keep the total mass used constant, but move weights from one side to the other; the difference in masses changes.

1. Set up the Atwood's machine apparatus as shown in Figure 1. Be sure the heavier mass can move at least 40 cm before striking the floor.
2. Connect the Photogate with Super Pulley to DIG/SONIC1 of the interface.
3. Open the file "10 Atwoods Machine" in the *Physics with Vernier* folder. A graph of velocity vs. Time will be displayed.
4. Arrange a collection of masses totaling 200 g on m_2 and a 200 g mass on m_1 . What is the acceleration of this combination? Record your values for mass and acceleration in the data table.
5. Move 5 g from m_2 to m_1 . Record the new masses in the data table.
6. Position m_1 as high up as it can go. Click to begin data collection. Steady the masses so they are not swinging. Wait one second and release the masses. Catch the falling mass before it strikes the floor or the other mass strikes the pulley.
7. Click the Examine button and select the region of the graph where the velocity was increasing at a steady rate. Click the Linear Fit button to fit the line $y=mt+b$ to the data. Record the slope, which is the acceleration, in the data table.
8. Continue to move masses from m_2 to m_1 in 5 g increments, changing the difference between the masses, but keeping the total constant. Repeat Steps 6–7 for each mass combination. Repeat this step until you get at least five different combinations.

ATWOOD'S MACHINE

Investigation 2: Constant Mass Difference

For this part of the experiment you will keep the difference in mass between the two sides of the Atwood's machine constant and increase the total mass.

9. Put 120 g on m_1 and 100 g on m_2 .
10. Repeat Steps 6–7 to collect data and determine the acceleration.
11. Add mass in 20 g increments to both sides, keeping a constant difference of 20 grams. Record the resulting mass for each combination in the data table. Repeat Steps 6–7 for each combination. Repeat the procedure until you get at least five different combinations.

Graphs

1. Acceleration vs. Δm
2. Acceleration vs. Total mass (investigation 2 data)

Analysis

1. Analyze the graph of Acceleration vs. Δm , what is the relationship between the mass difference and the acceleration of an Atwood's machine?
2. Analyze the graph of acceleration vs. total mass, what is the relationship between total mass and the acceleration of an Atwood's machine?
3. Develop a single expression for the acceleration of an Atwood's machine, combining the results of the previous two steps in the analysis.
4. Draw a free body diagram of m_1 and another free body diagram of m_2 . Using these diagrams, apply Newton's second law to each mass. Assume that the tension is the same on each mass and that they have the same acceleration. From these two equations, find an expression for the acceleration of m_1 in terms of m_1 , m_2 , and g . Compare the expression to your result in #3 of Analysis.
5. For each of the experimental runs you made, calculate the expected acceleration using the expression you found with Newton's second law of motion and the specific masses used. Compare these figures with your experimental results. Are the experimental acceleration values low or high? Why?

STATIC AND KINETIC FRICTION

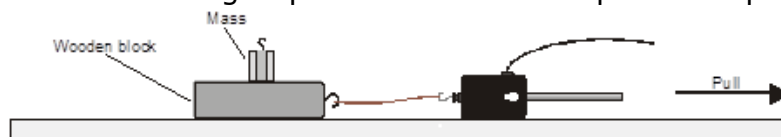
If you try to slide a heavy box resting on the floor, you may find it difficult to get the box moving. *Static friction* is the force that is acting against the box. If you apply a light horizontal push that does not move the box, the static friction force is also small and directly opposite to your push. If you push harder, the friction force increases to match the magnitude of your push. There is a limit to the magnitude of static friction, so eventually you may be able to apply a force larger than the maximum static force, and the box will move. The maximum static friction force is sometimes referred to as *static friction*. We model static friction, F_{static} , with the inequality $F_{static} \leq \mu_s F_N$ where μ_s is the coefficient of static friction and F_N the *normal* force exerted by a surface on the object. The normal force is defined as the perpendicular component of the force exerted by the surface. In this case, the normal force is equal to the weight of the object.

Once the box starts to slide, you must continue to exert a force to keep the object moving, or friction will slow it to a stop. The friction acting on the box while it is moving is called *kinetic friction*. In order to slide the box with a constant velocity, a force equivalent to the force of kinetic friction must be applied. Kinetic friction is sometimes referred to as *sliding friction*. Both static and kinetic friction depend on the surfaces of the box and the floor, and on how hard the box and floor are pressed together. We model kinetic friction with $F_{kinetic} = \mu_k F_N$, where μ_k is the coefficient of kinetic friction.

In this experiment, you will use a Force Sensor to study static friction and kinetic friction on a wooden block. A Motion Detector will also be used to analyze the kinetic friction acting on a sliding block.



Initial Setup

1. Measure the masses of the block, brick and other appropriate objects and record them in the data table.
2. Open LoggerPro and open the file *12a – Static and Kinetic Friction* in the *Physics with Vernier*
3. Connect one end of a string to the hook on the Force Sensor and the other end to the hook on the wooden block.
4. Place a total of 1 kg mass on top of the block, fastened so the masses cannot shift.
5. Practice pulling the block and masses with the Force Sensor using this straight-line motion: Slowly and gently pull horizontally with a small force. Very gradually, taking one full second, increase the force until the block starts to slide, and then keep the block moving at a constant speed for another second. If it seems appropriate, a brick can be placed on the block of wood to increase the normal force. When the brick is used, it will probably be necessary to put the Force Sensor on the 50 N setting.
6. Hold the Force Sensor in position, ready to pull the block, but with no tension in the string. Click on at the top of the graph to set the Force Sensor to zero.
7. Click to begin collecting data. Pull the block as before, taking care to increase the force gradually. Repeat the process as needed until you have a graph that reflects the desired motion, including pulling the block at constant speed once it begins moving.
8. Print the graph; add the names of all the group members to the caption and print a copy of each member.





STATIC AND KINETIC FRICTION

Investigation 1: Peak Static and Kinetic Friction

9. Remove all masses from the block.
10. Click  to begin collecting data and pull as before to gather force vs. time data.
11. Examine the data by clicking the Statistics button, . The maximum value of the force occurs when the block started to slide. Read this value of the *maximum* force of static friction from the floating box and record the number in your data table.
12. Drag across the region of the graph corresponding to the block moving at constant velocity. Click on the Statistics button again and read the average force during the time interval. This force is the magnitude of the kinetic frictional force.
13. Repeat Steps 9-11 for two more measurements and average the results to determine the reliability of your measurements. Record the values in the data table.
14. Add masses in approximately 250 g increments to the block. Repeat Steps 9 – 12, recording values in the data table.
15. Repeat for additional masses of 500, 750, and 1000 g. Record values in your data table.

Investigation 2: Kinetic Friction again



16. Connect the Motion Detector to DIG/SONIC 1 port of the LoggerPro interface.
17. Open the file *12b Static Kinetic Frict* in the *hawk/science files* folder
18. Place the Motion Detector on the lab table 2–3 m from a block of wood, as shown. Position the Motion Detector so that it will detect the motion of the block as it slides toward the detector.
19. Practice sliding the block toward the Motion Detector so that the block leaves your hand and slides to a stop. Minimize the rotation of the block. After it leaves your hand, the block should slide about 1 m before it stops and it must not come any closer to the Motion Detector than 0.4 m.
20. Click  to start collecting data and give the block a push so that it slides toward the Motion Detector. The velocity graph should have a portion with a linearly decreasing section corresponding to the freely sliding motion of the block. Repeat if needed.
21. Select a region of the velocity vs. time graph that shows the decreasing speed of the block.
22. Drag the mouse over this section and determine the slope by clicking the Linear Fit button, . Record this value of acceleration in your data table.
23. Repeat Steps 19–20 four more times.
24. Place masses totaling 500 g on the block. Fasten the masses so they will not move. Repeat Steps 19–20 five times for the block with masses. Record acceleration values in your data table.
25. Calculate the kinetic friction and coefficient of friction for each trial.

STATIC AND KINETIC FRICTION

Graphs

1. On the printout from the initial setup label: the portion of the graph corresponding to the block at rest, the time when the block starts to move, and the time when the block is moving at constant speed.
2. Plot a graph of the **average static friction force vs. normal force**.
3. Plot a graph of **average kinetic friction vs. normal force**

Analysis

4. Using the force vs. time graph from the initial setup, compare the force necessary to keep the block sliding compared to the force necessary to start the slide.
5. The *coefficient of friction* is a constant that relates the normal force between two objects (blocks and table) and the force of friction. Based on your graph from Investigation I, would you expect the coefficient of static friction to be greater than, less than, or the same as the coefficient of kinetic friction?
6. What physical property does the slope of friction force vs. normal force represent?
7. What are the coefficients of static and kinetic friction for investigation 1?
10. Does the coefficient of kinetic friction depend on speed? Explain, using your experimental data.
11. Does the force of kinetic friction depend on the weight of the block? Explain.
12. Does the coefficient of kinetic friction depend on the weight of the block?

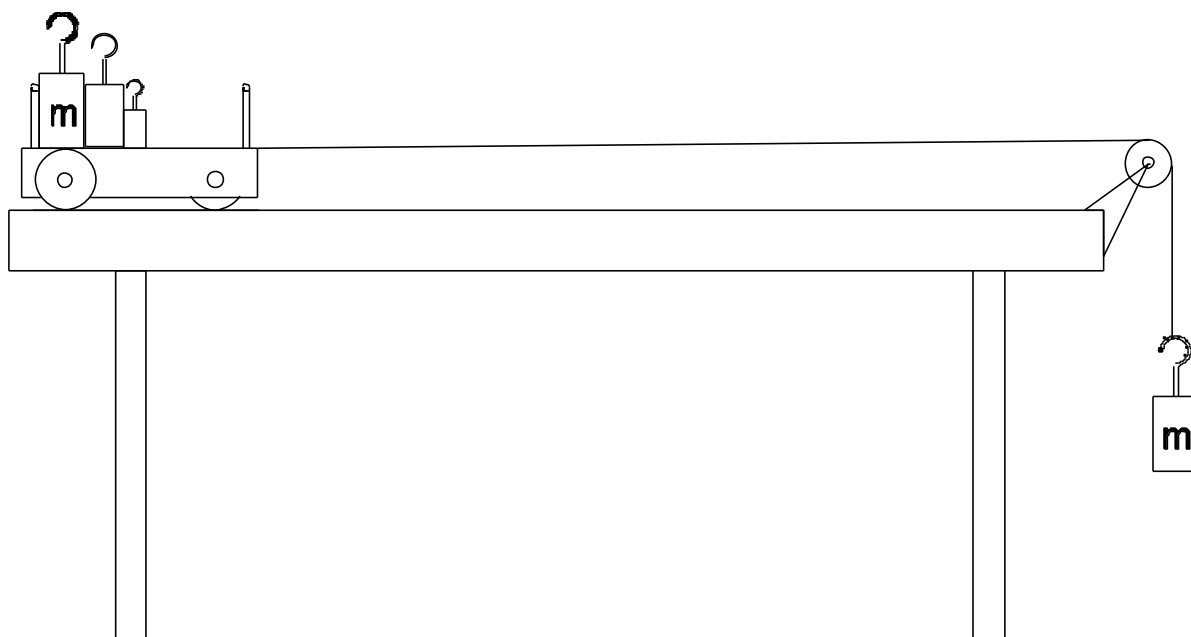
Newton's Second Law of Motion (Part One)

We will be attempting to verify that $a \propto \Sigma F$. This is one part of Newton's Second Law of Motion. Each group will run **eight** trials with different accelerating forces but the **same total mass of the system**.

Set up the equipment and add weights to the cart as instructed in the lab.

Investigation

1. Find the mass of the cart, slotted mass holder and all the slotted masses and hanger you will be using during this experiment. Record in data table.
2. Make sure the ticker timer, 2x4, and pulley are secure (as in the previous labs).
3. Place the hanger and a small mass on the pulley, all the rest of the slotted masses must be placed on the cart. Refer to image below. Ensure a numbered foam pad is below the pulley.



4. Choose an appropriate length of ticker table (distance mass falls to the floor). Make a mark on the ticker tape where the hanging mass makes contact with the floor. Reminder: this marks your useful data.
5. Pull the cart back to its starting position. Turn on the timer and release the cart.
6. Write on the Ticker tape in the space before the blur the amount of mass that was hung from the string. Also record this as your accelerating mass in the data table.
7. Repeat steps 3-6, taking mass off the cart and adding it to the hanger. **It is important that the total mass of the cart, weights on the cart, weight on the string, be a constant for all eight trials.**
8. Each student should take at least two of the ticker tapes to record the data then share with his collaborators.

Newton's Second Law of Motion (Part One)

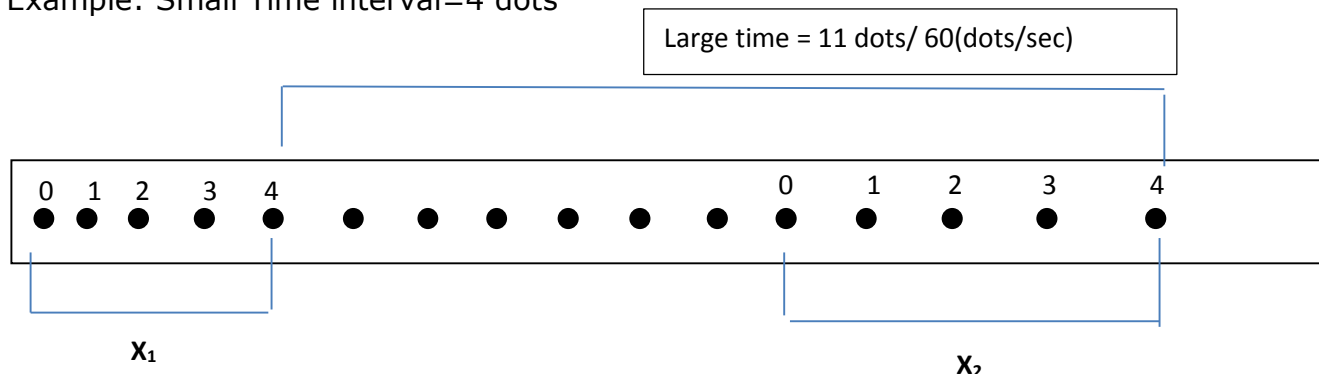
9. Choose a smallest number of dots (3-6 dots) that will be easy to measure at the beginning of the tape. Divide this small number of dots by 60 and record under **Small Time Interval**.

Note: The small time interval will not be the same for all trials.

See diagram below

10. Measure the distance.
11. Count the same number of dots at the end of the useful dots and measure the distance.
12. Count the number dots from the end of the first measurement to the end of the second measurement. Divide your total number of dots by 60 and record the time under **Large Time Interval**. Note: The large time interval will not be the same for all trials.
13. Share your measurements with your collaborators to complete these columns. Use Excel to fill in the rest. Note the initials for the student who measures the different ticker tapes.

Example: Small Time interval=4 dots



Graphs

Produce a graph of **acceleration vs. force**.

Analysis

1. Discuss whether the acceleration of the cart is proportional to the force on the cart. Discussion must include the graph you produced.
2. What physical quantity does the slope of your graph represent? (Hint: what are the units of the slope?)
3. Compare the slope of your graph to the mass of the object being accelerated. Discuss.

Newton's Second Law of Motion (Part Two)

We will be attempting to verify $a \propto \frac{1}{m}$. This is one part of the second law of motion. This experiment will use a constant accelerating force and a changing mass of the system.

Investigation

1. Based on instructor's instructions repeat steps from Newton's Law Part 1 **except keep the accelerating mass constant and change the mass on the cart (thus a changing system mass)**

-OR-

2. Each group will run **ten** trials with different total masses and the same accelerating force. It is important that the weight on the string be a constant for all eight trials. The total mass of the system will be varied in this experiment while the accelerating force will remain constant.
3. Clamp the 2x4 along the seam on the table.
4. Attach the smart pulley system to the pulley clamps and clamp to the table. Ensure the cable from the Photogate is plugged into the dig/sonic 1 port of the LabPro and the LabPro is connected to the computer. Log onto the computer using your student account and open LoggerPro (located on the desktop). Note: make sure none of the cables will interfere with the motion of the cart.
5. Now you need to tell the computer what sensor you are using. Click on the EXPERIMENT menu, click SET UP SENSORS, click SHOW ALL INTERFACES, **right** click on the picture of the Photogate, SET DISTANCE OR LENGTH, ULTRA PULLEY (10 SPOKE) IN GROOVE, click ok and close the window.
6. Hang your chosen constant accelerating mass on the string, placing the string over the pulley and attaching the string to the cart.
7. Move the cart forward until the hanging mass is touching the foam cushion, ensure the string is not slack, place a piece of masking tape on the table marking the front of the car at this point.
8. Pull the cart back. Click the collect button wait until you hear the clicking or the button turns red, then release the cart, click the stop button when the cart has reached the masking tape mark.
9. Examine the acceleration vs. time graph generated on the computer. Highlight the portion of the graph representing when the cart was accelerating under the influence of the hanging mass. Click on the STAT button. Record the mean value in the data table under acceleration.
10. Record the total mass of the system for that run in the data table.
11. Repeat 9 more times adding mass to the cart only each time.

Graph

1. Produce a graph of **acceleration vs. mass**
2. Produce a graph of **acceleration vs. 1/mass**

Newton's Second Law of Motion (Part Two)

Analysis

1. Does the graph of acceleration vs. mass demonstrate whether or not acceleration is proportional to mass? Discuss.
2. Does the graph of acceleration vs. $1/\text{mass}$ demonstrate whether or not acceleration is proportional to $1/\text{mass}$? Discuss.
3. What physical quantity is represented by the slope of the line of the acceleration vs. $1/\text{mass}$ graph?
4. Compare the slope of your graph to your accelerating Force.

BOWLING BALLS AND BROOM STICKS

You will be investigating the nature of circular motion. The effects of mass, velocity, and radius of curvature have on circular motion. Using a broom you will push several bowling balls around circles and around a track of the instructors design. At all times the broom must be kept perpendicular to the floor and the speed of the ball must be kept constant.

Investigation 1

Rank the amount of force needed to move the ball in circular motion on a scale of 1-3; 1 being the greatest force necessary and 3 being the least force necessary. Assume the other two variables are constant in each case.

Investigation 2

Using brooms you will need to navigate the path around the obstacles designated by your instructor as fast as you can. A time penalty will be added for leaving the designated path, penalties will be assessed by the official time keepers. Sketch the track on the back ensure to not the direction the ball must be moving in the various parts.

As part of your conclusion please include a discussion about the following

1. What observations did you make about circular motion?
2. Where on the ball did you have to place the broom compared to the motion of the bowling ball to achieve circular motion?
3. Are your results from Investigation 1 consistent with the formula for centripetal force?
4. What was your total time in Investigation 2?
5. How many times did you stray from the designated path?
6. What you would do differently to navigate the path faster, with fewer penalties.

SPINNING STOPPERS

You will be investigating the relationship between centripetal force, speed of the mass, and radius.

Safety: Be especially careful when spinning the mass. Make sure you have enough space and that a partner is watching for problems.

Investigation

1. Assemble the equipment completely as shown by your instructor.
2. Find the mass of the stopper and washer assembly using the triple beam balance and record under data.
3. Set the radius to 0.3 m and attach a piece of masking tape(that can be easily removed) or paper clip as a marker under the tube.
4. Whirl the mass around until the radius is 0.3 m. Have your partner start the timer and record the time for 10 revolutions. (Remember starting the timer is not the first revolution.)
5. Record the time and repeat for 2 additional trials at this radius. (You may want to alternate people spinning and timing for better results.)
6. Repeat steps 3-5 for radii equal to 0.4 m, 0.5 m, and 0.6.

Analysis

1. Determine the percent error in the centripetal force.
2. If the string that holds a whirling mass in its circular path breaks, what causes the mass to move in a straight path? What law of physics supports your answer?
3. If you lose your grip on a rapidly spinning merry-go-round and fall off, in which direction will you fly and why?
4. If the mass of the whirling stopper were doubled while the radius remained at 0.3m, what would happen to the following:
 5. the tangential velocity
 6. the centripetal acceleration
 7. the centripetal force
 - a. Justify your answer with qualitatively or quantitatively.

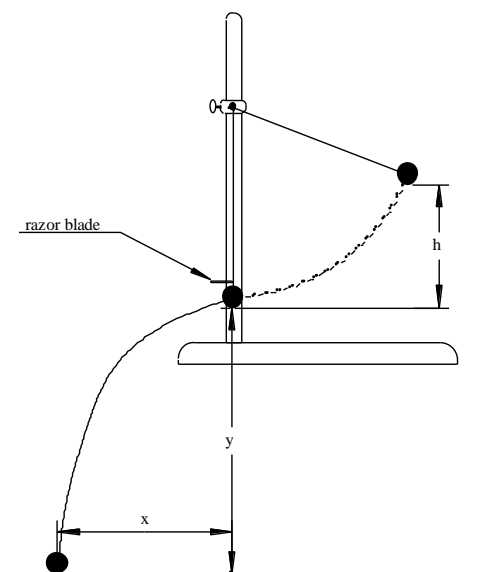
CONSERVATION OF ENERGY

This experiment attempts to verify conservation of energy indirectly. By making three linear measurements, and without resorting to the measurement of speed, the relationship between gravitational potential energy and the maximum speed of a pendulum can be determined.

When a pendulum is released from rest, the gravitational potential energy is converted to kinetic energy as it falls and, since the string supporting the pendulum does no work, the kinetic energy the pendulum has at the lowest point in its path, is exactly equal to the work done by gravity. The speed it has at this point is, therefore, related to the height from which it is released. If the string of the pendulum is cut at the moment that it is moving horizontally, the pendulum becomes a projectile with an initial velocity that is horizontal. This initial velocity together with the height from the floor will determine where it lands. As a result, the spot where the pendulum 'bob' lands is determined by the height from which it is released.

Investigation

1. Derive a single formula using conservation of energy and free fall that will predict the horizontal distance (x) of the brass ball. The formula should be only in terms of h and y .
2. Verify the formula with your instructor to receive the razor blades, string, and brass ball.
3. **Create a table to record the necessary measurements, predicted x and actual x and percent difference.**
4. Clamp the two razor blades to the bottom pendulum clamp so that they form a V cutting edge.
5. Tie the string to the ball and clamp the string to the top, the excess string should be placed out of the way but not cut.
6. Choose **four** heights (h) that the pendulum will be released from. These heights should not cause the string go beyond the horizontal position.
7. Using your derived formula to **predict** where the brass ball will land for each of height.
8. Use a dry erase marker to coat the bottom of the ball. This will cause the ball to make a mark on the floor where it lands. Be sure to watch carefully as more than one mark may be made due to bouncing.
9. Measure the distance to where the ball actually landed
10. Calculate the percent difference for each trial.



Analysis

1. Discuss qualitatively the accuracy of your predicted distance for each trial.
2. Was energy conserved throughout the entire motion of the ball?

CONSERVATION OF MOMENTUM

Two dynamics carts at rest on the table have zero momentum. If they are arranged so that they can be forced apart by releasing a spring compressed between them, the momentum of each will change but the total momentum will remain zero.

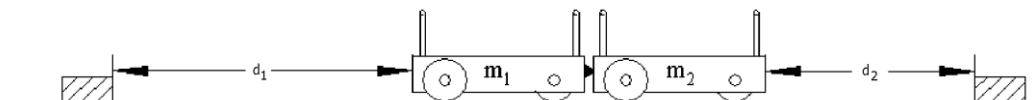
This experiment is designed to find evidence to support the Law of Conservation of Linear Momentum. This will be done indirectly in order to eliminate the need for measuring time or velocity. It remains necessary to measure mass and distance.

Investigation

1. Measure the mass of each dynamics cart and each brick. Carts are identified by type. Use masking tape to on the bricks if needed for identification.
2. Make certain that the 2 x 4's are parallel and 2.0 m apart.
3. Make certain that the spring trigger works properly.
4. Position the carts so that they will go in opposite directions and hit the 2 x 4's when the spring is released. The carts should be touching each other.
5. By trial and error, find the location of the two carts that result in them hitting the boards simultaneously. Record the distance each travels before hitting the boards.
6. Reverse the directions of the two carts and repeat the trial.
7. Load the carts with different combinations of bricks making careful note of the total mass traveling in each direction. Repeat the measurements for each combination. **Make sure that each combination of bricks is run in both directions.**
8. The experiment must be run for at least four different combinations of bricks and carts. **Fill in the data table completely.**

Analysis

1. Derive a formula to analyze the data in reference to conservation of momentum that eliminates the need to know the velocity of the carts. **Include the derivation in the analysis section of your report.**
2. If you believe that your data suggest that linear momentum is conserved, explain why. If your data do not support the Law of Conservation of Momentum, explain what leads you to this conclusion and list some reasons why the experiment might have lacked accuracy.



TORQUE and BALANCES

Balances are used to measure mass by comparing two things and adjusting one of them until they are equal. At first, it seems that masses are compared since that is what is measured. Equal arm balances do, in fact, require that the masses on each pan be the same in most cases. Triple beam balances clearly do not use equal masses to produce equilibrium (balance). It might seem that weight is what is compared since most balances do not work without gravity. This, however, still does not explain the triple beam balance.

In fact, a balance balances torque. The unknown mass has weight that produces torque acting on the beam of the balance. The known weights are moved until the torques that they produce cause **rotational equilibrium**.

In this exercise, you will make a balance and use it to measure the mass of an unknown object. In addition, you will use the same principals to find the center of mass of a non-uniform object that you will construct.

Investigation 1: Center of Mass

1. With nothing hanging on the meter stick, balance it and determine the location of its center of mass (gravity) measured from end of the meter stick with the lowest markings. Record the distance from the end of the meter stick.

Investigation 2: Creating a Balance

2. Leave the meter stick supported at its center of mass from investigation 1.
3. Hang an unknown mass at the 90 cm mark. Record the lever arm distance.
4. Choose a known mass. Record the mass (including the hanger). Move the known mass around until the meter stick is in rotational equilibrium. Record the lever arm distance.
5. Calculate the mass of the unknown and its hanger.
6. Measure the mass of the unknown on a triple beam balance.
7. Calculate the percent error.

Investigation 3: Mass of the Meter Stick

8. Move the meter stick support so that it is 15 cm from one of the ends.
9. Choose a known mass. Record.
10. Balance the meter stick with the known mass on the short side of the meter stick (within the 15 cm between the support and the meter stick end).
11. Calculate the mass of the meter stick using the location of its center of mass from investigation 1.
12. Measure the mass of the meter stick
13. Calculate the percent error of the calculated value.

TORQUE and BALANCES

Investigation 4: Complex Object

1. Combine the meter stick with one or two small C-clamps to produce a new object with a new center of mass. Place the C-Clamps between zero end and the 50 cm mark.
2. Measure the mass of this "object" on the balance. Record.
3. Support the new object at the 60 cm mark.
4. Choose a known mass. Record.
5. Use a known mass to find the rotational equilibrium of the new objects.
6. Calculate the lever arm distance of the new center of mass. Record.
7. Calculate the new center of mass from the zero end. Record.
8. Support the object at the new center of mass and verify your determination.

Analysis

1. Observe the zero adjust on a triple beam balance and use it to adjust the balance properly. Describe how the zero adjust works on the triple beam balances in the lab.
2. Is it necessary for the meter stick to be horizontal when it is in equilibrium? Explain.
3. Discuss each investigation and the observations on torque. Each investigation must be addressed individually and there must be a single conclusion that ties the parts together. **All analysis must be done in the context of torque and the physical quantities that affect torque.**

ROTATIONAL MECHANICS

As a car rolls along the floor, the wheels travel in circular paths without skidding. A point on the edge of the wheel turns through a given angle (measured in radians). The purpose of this experiment is to determine the relationship between the angular velocity of the wheel and the linear velocity of the car. Linear and angular velocities are defined to be:

$$V_{avg} = \frac{\Delta d}{\Delta t} \qquad \omega_{avg} = \frac{\Delta \theta}{\Delta t}$$

Investigation 1: Linear and Rotational Velocity

1. Place a piece of blue tape on the floor as a starting line. Measure a sufficient linear distance for the car to travel so that the error in using the stop watch is minimal. Record the linear distance traveled.
2. Time the car traveling across the floor for the given distance. Repeat the process enough times to ensure a high degree of accuracy and record the times. Calculate the average of the times.
3. Place a piece of blue tape on the edge of the constant velocity buggy's wheel so that it can be seen while rolling.
4. Run the car across the floor. Decide how many full rotations of the wheel are needed to be able to measure time with a stop watch and have a low error due to human reaction and sighting the wheel.
5. Record the rotation in radians. Measure the time required for the car's wheel to complete the given rotation and record the time. Repeat the experiment until you have enough data to accurately analyze. Calculate the average of the times.
6. Measure the radius of the wheel on the buggy.

Investigation 2: Free Spinning Wheels

7. Turn the physics buggy on upside down. Once again measure the time for the same number of rotations of the wheel as measured in table 2.
8. Calculate an average time.

Analysis

1. Scientifically compare the radius of the wheel to the ratio of the two velocities.
2. What generalization can be made?
3. Scientifically compare the average time of the loaded wheels to the unloaded wheels. Is there a significant difference?

Average Time: _____

Average Linear Velocity _____

Average Time: _____

Average Angular Velocity _____

Spring Constants – Simple Harmonic Motion – Hooke's Law

In this exercise, you are to determine a spring's constant in two ways:

Directly, by hanging weights on the spring using Hooke's Law and indirectly by measuring the period of an oscillating spring in simple harmonic motion.

Investigation 1: Hooke's Law

1. Place the 50 g brass hanger onto your spring. Note the length of the spring.
2. Add a mass to the hanger. Record the total hanging mass.
3. Measure the new length of the spring. Record the change in length.

Investigation 2: Simple Harmonic Motion

1. Place a small amount of mass onto spring.
2. Practice: pull the mass down a small amount and release. The mass should be oscillating up and down in a smooth manner. There should be no back and forth motion. If the motion is violent then stop the motion and try again.
3. Pull the mass down a small amount. Measure the time it takes the mass to complete 10 cycles. Allow the mass to bounce once or twice before beginning timing.
4. Repeat with 6 new masses.

Investigation 3: Pendulums

1. Using at least two (2) different weights measure the period of a swinging pendulum. Keep the length constant. Use the method from investigation 2 for timing.
2. Repeat step 1 but keep the weight constant and use at least two lengths, measure the period of the swinging pendulum.
3. Calculate g for each trial.

Investigation 4: g in Philadelphia

1. Use the large pendulum hanging from the ceiling.
2. Measure the period of the swinging pendulum.
3. Calculate the acceleration due to gravity of Philadelphia.

Graphs

1. **force (weight) vs. distance;** investigation 1

Spring Constants – Simple Harmonic Motion – Hooke's Law

Analysis

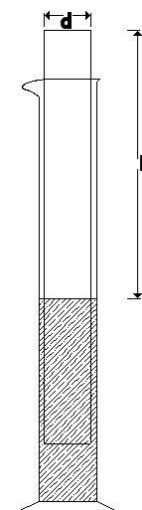
1. Does the amount of mass on the spring affect the period of oscillation? Explain your reasoning using your observations during the trial.
2. Does the amount of mass on the pendulum affect the period of the swing? Explain your reasoning using your observations during the trial.
3. Does the length of the pendulum affect the period of the swing? Explain your reasoning using your observations during the trial.
4. What physical quantity is represented by the slope of the force vs. distance graph from investigation 1?
5. What is the spring constant found in investigation 1?
6. What is the average spring constant found in investigation 2?
7. Compare the spring constants from both investigations. Calculate the Percent difference of the two values. Is this what you would expect?
8. Compare your calculated g value from investigation 3 to the accepted value of g for Earth.

SPEED OF SOUND IN AIR

Sound waves travel very fast through air. It is fast enough that measuring the speed of sound is a technical challenge. This experiment will use resonance and echoes to compute the speed of sound in air at room temperature.

Resonance

The speed of sound in air can be measured indirectly. If a way can be found to determine both the frequency and the wavelength of a particular sound wave, then the equation $v = f\lambda$ can be used to calculate the velocity. In this experiment, an apparatus similar to what is shown in the picture will be used. Several important characteristics of wave behavior are necessary for this measurement to work. A standing wave will be produced in the column of air in the apparatus. The presence of real but invisible nodes and anti-nodes in the column of air will make it possible to measure the wavelength of a sound even though it cannot be seen.



Investigation 2



Another method you could use would be to time an echo. For example, if you were in an open field with a large building a quarter of a kilometer away, you could start a stop watch when a loud noise was made and stop it when you heard the echo. You could then calculate the speed of sound. To use the same technique over short distances, you need a faster timing system, such as a computer. In this experiment you will use this technique with a Microphone connected to a computer to determine the speed of sound at room temperature.

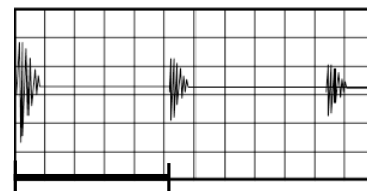
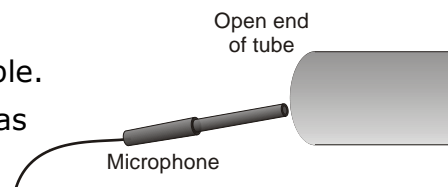
Investigation 1: Resonance

1. Measure the **inner diameter** (i.e.) of the PVC pipe.
2. Place the PVC pipe into the graduated cylinder. Fill the graduated cylinder with water until the water reaches the bottom of the spout.
3. Determine the **shortest** column of air with which the tuning fork resonates.
4. Calculate the wavelength from this equation: $\lambda = 4(L + 0.3d)$. (Since the actual vibration of air in a cylinder is complicated by the three dimensional nature of the cylinder, it is necessary to correct for the diameter of the air column.)
5. Record the temperature of the room.
6. Repeat the measurement with several different tuning forks.
7. Calculate the speed of sound for each frequency.

SPEED OF SOUND IN AIR

Investigation 2: Echoes

1. Ensure the Vernier Microphone is connected to Channel 1 of the interface. Open LoggerPro on the computer.
2. Open the *Sound.cmbl* file in *hawk/science files*
3. Measure and record the length of the tube in your data table.
4. Place the Microphone as close to the end of the long tube as possible, as shown. Position it so that it can detect the initial sound and the echo coming back down the tube.
5. Click  Collect to begin data collection. Data collection will start when a sound triggers the sensor. Snap your fingers, clap, or hit two pieces of wood together near the opening of the tube to trigger data collection.
6. You should see a graph similar to the one to the right. If your graph does not appear like this one you must redo the trial until it does.
7. The second set of vibrations with appreciable amplitude marks the echo. Click the Examine button, . Move the mouse and determine the time interval between the start of the first vibration and the start of the echo vibration. Record this time interval in the data table.
8. Repeat the measurement for a total of five trials and determine the average time interval.
9. Calculate the speed of sound. Remember that your time interval represents the time for sound to travel down the tube and back.



Analysis

1. Assuming that the speed of sound in air in m/s can be determined from the equation $v = 331.5 + 0.607C$ where C is the temperature of the air in degrees Celsius, calculate the accepted value of the speed of sound at the temperature recorded in lab.
2. Calculate your percent error for both investigations using the accepted value calculated in #4.
3. On the particle level, describe the motion of the air particles as the sound wave travels through the air.
4. How could this experiment be adjusted to determine whether the speed of sound is dependent on atmospheric pressure?
5. How can the experiment be adjusted to determine the frequency of an unmarked tuning fork?

OHM'S LAW

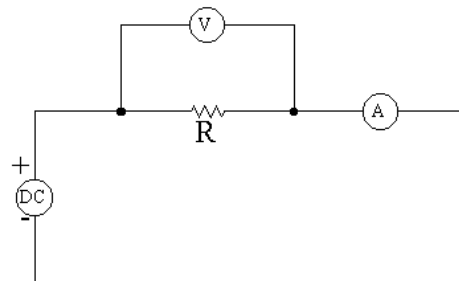
In this experiment, you will study the relationships among voltage, current and resistance. Be sure to make careful diagrams of the circuits to include in your lab report.

Investigation 1

1. Connect the voltmeter to the power supply as instructed and determine the range of voltages available from the power supply

Investigation 2

1. Obtain a set of six different resistors. Read the color codes and measure the resistances with the electronic meter.
2. Set up the circuit as shown in the diagram that contains one resistor, an ammeter, and a voltmeter.
3. Slowly turn on the voltage until the voltmeter reads 5.0 V. Record the current in the circuit (ensure you have read the correct dimension for current and convert appropriately).
4. Turn off the voltage and replace the resistor with another, set the voltage to 5.0 v again and record the current. Repeat this step for each resistor.



Investigation 3

1. Keep the same set up as in *Investigation 2* but this time use only one resistor and measure the current through the resistor for each of several voltages. (e.g.: 0 through 10 volts in 2 volt increments.)

Investigation 4

1. Replace the resistor with a light bulb and repeat part three.

Graphs

Investigation 2: Current vs. Resistance **AND** Current vs. 1/Resistance

Investigation 3: Current vs. Voltage

Investigation 4: Current vs. voltage

OHM'S LAW

Analysis

1. What quantity is represented by the graphs of part 2?
2. What quantity is represented by the graph of part 3?
3. Compare the slope of the line in part 2 to the voltage used in part 2.
4. Compare the slope of the line in part 3 to the resistor used in part 3.
5. What is the shape of the graph in part 4? Explain why this occurs.

SERIES AND PARALLEL CIRCUITS

How devices are wired together can change the voltage, current, and resistance in the circuit. In this experiment you will be investigating the different ways a circuit can be wired and how that affects the internal processes.

Investigation 1: Series Circuits

1. Set the power supply to zero volts.
2. Set up a series circuit using three of the six resistors available.
3. Without connecting the power supply measure the resistance of each resistor and the total resistance of the series circuit.
4. Connect the ammeter into the circuit. (see figure 1)
5. Adjust the power supply so that the total voltage across the resistors is 15 V.
6. Measure the voltage across and the current through each resistor and the entire circuit. You will need to change the positions of both meters for each measurement.
7. Verify that the circuit behaves as described in class and the text book. Not any discrepancies.

Draw a diagram of each circuit before making the connections.
Be sure to have each circuit checked before connecting the power.

Investigation 2: Parallel Circuits

8. Set up a parallel circuit using three of the six resistors available.
9. Repeat the procedure from *investigation 1* for this circuit. Take note of the correct connection for the ammeter. (see figure 2)

Investigation 3: Complex Circuits

10. Repeat the previous procedure for two complex circuits and verify that the results are consistent with theory. (see figures 3 and 4)

Graphs

Graphs for this lab will be the circuit diagrams. You will need one diagram for each circuit.

*Your diagrams should be of your circuits, not simply copied from the sample figures.

Analysis

Series Circuits

1. Compare the voltage across each resistor. How does the voltage across the resistors compare to the total voltage of the circuit?
2. Compare the current in each resistor. How does the current in the resistors compare to the total current in the circuit?

Parallel Circuits

1. Compare the voltage across each resistor. How does the voltage across the resistors compare to the total voltage of the circuit?
2. Compare the current in each resistor. How does the current in the resistors compare to the total current in the circuit?

SERIES AND PARALLEL CIRCUITS

Sample Diagrams

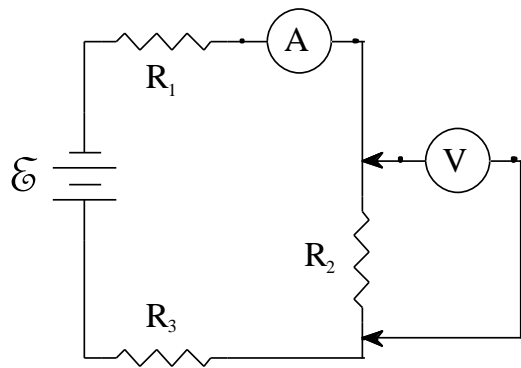


Figure 1

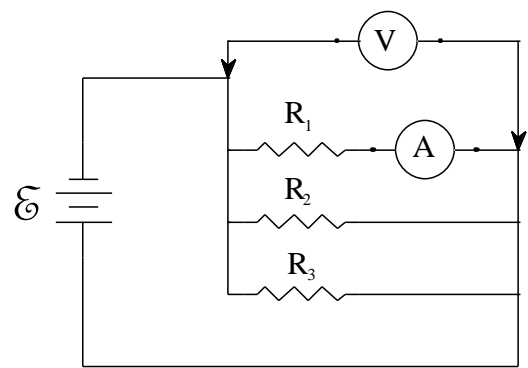


Figure 2

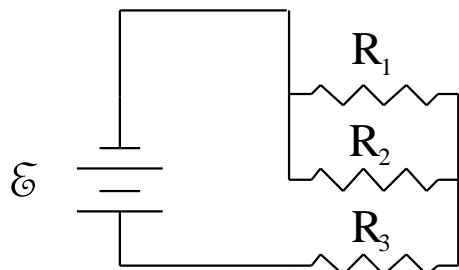


Figure 3

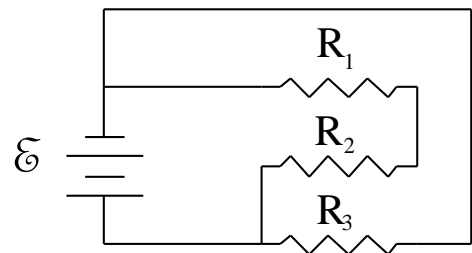


Figure 4

MAGNETISM

In this experiment, you will study magnetism and magnetic fields. Be sure to make careful diagrams of the magnetic fields. **AT NO TIME SHOULD ANY TWO MAGNETS TOUCH OR COME WITHIN 4 CM OF EACH OTHER.**

Investigation 1: Field Surrounding a Bar Magnet

1. Place your bar magnet on a sheet of paper and cover it with the plastic overhead sheet.
2. Sprinkle the iron filings from a height of about 10 cm. Keep sprinkling until a distinct pattern emerges.
3. Draw a simplified version of the field pattern that emerged, show the shape of the field. Be sure to describe the shape and the most unique characteristics of the field.

Investigation 2: Compass Directions around a Bar Magnet

1. Place your bar magnet on the sheet as indicated. Place your compass on each circle then draw an arrow indicating the direction of the north pole of your compass in the field.

Investigation 3: Field between Magnets

1. Place the north end of a bar magnet about 4 cm from the south end of another bar magnet. Place a piece of plastic over top the magnets. Sprinkle iron filings in the region between the magnets.
2. Draw a simplified version of the pattern that emerges.
3. Use the north pole of your compass to determine the direction of the magnetic field lines. Add arrows to your picture showing only the direction of the magnetic field between the magnets.
4. Place the south poles of the two bar magnets 4 cm apart, repeat the previous steps.

Part 4: Unknown Pole

1. Determine which pole of the unknown magnet is north and south using the methods in the previous parts. Be sure to include a drawing of the magnet orientations and the patterns of the iron filings and direction of the field lines. Include the letters of your unknown poles on your drawings.

Analysis

1. Describe the pattern that emerged from sprinkling the iron filings in part 1. Look closely at the filings from part 1. Where on the bar magnet is the magnetic field strength the strongest? How can you tell?
2. How do the magnetic field line patterns between the magnets in part 3 differ?
3. Which color of the unknown magnet represents the North Pole and which color represents the South Pole?

REFLECTION AND SNELL'S LAW

This lab will investigate the behavior of light during reflection and refraction.

When a light ray strikes a reflecting surface, the angle of reflection is equal to the angle of incidence. Both angles are measured from the normal, an imaginary line perpendicular to the surface at the point where the ray is reflected. In this laboratory activity, you will investigate and measure light rays reflected from the smooth, flat surface of a plane mirror in order to determine the apparent location of an image. This type of reflection is called regular reflection. The image of an object viewed in a plane mirror is a virtual image. By tracing the direction of the incident rays of light, you will be able to construct a ray diagram that locates the image formed by a plane mirror.

Light travels at different speeds in different media. When light rays pass at an angle from one medium to another, they are **refracted** or bent at the boundary between the two media. If a ray of light enters a medium in which it moves less quickly and at an angle, it is bent toward the normal line. If a ray of light enters a medium in which it moves more quickly and at an angle, it is bent away from the normal line. This change in direction or bending of light at the boundary at two media is called **refraction**. Refraction is one of the wave characteristics of light and does not involve an energy change.

The *index of refraction* of a substance, n_s , is defined as the ratio of the speed of light in a vacuum, c , to its speed in the substance, v_s :

$$n_s = \frac{c}{v_s}$$

All indices of refraction are greater than one, because light always travels slower through matter than through a vacuum. The index of refraction can be measured by using Snell's law, which states that a ray of light passing from one medium to another bends in such a way that the ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant for any two media. Snell's law can be written:

$$n = \frac{\sin \theta_i}{\sin \theta_r} = \frac{v_i}{v_r}$$

It is more useful to write Snell's law as:

$$n_i \sin \theta_i = n_r \sin \theta_r$$

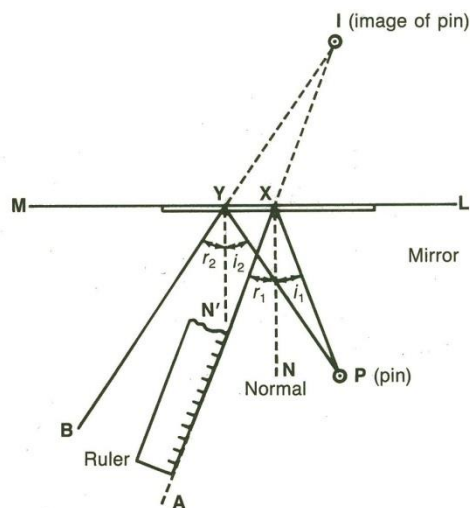
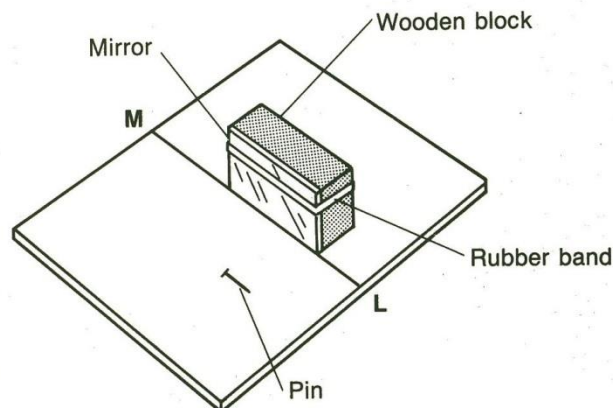
where n_i is the index of refraction of the first medium and n_r is the index of refraction of the second medium. The angle of incidence is θ_i , and the angle of refraction is θ_r .

You are to construct ray diagrams to analyze the path of light as it passes through plate glass. For each angle of incidence, you will measure the angle of refraction to find the index of refraction of plate glass and or transparent plastic. The results of this exercise depend on the fact that the difference between the speed of light in air and its speed in a vacuum is negligible.

REFLECTION AND SNELL'S LAW

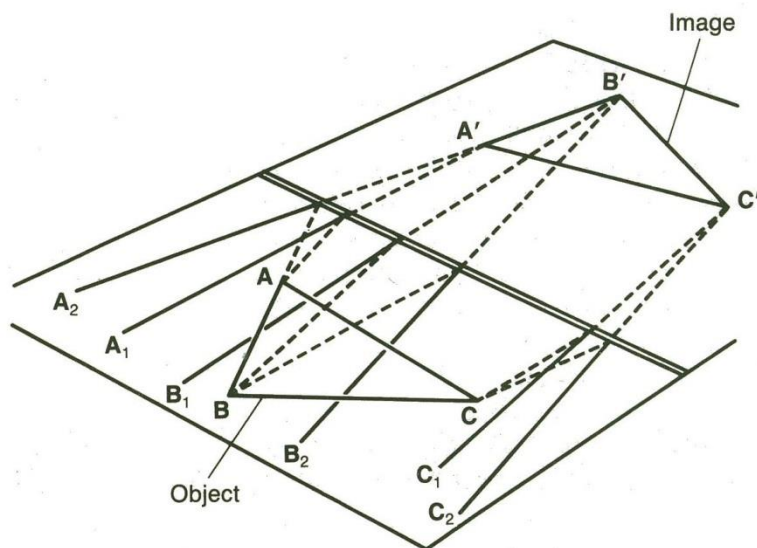
Investigation 1: Reflection

1. Draw a line across the middle of the paper.
2. Label it **ML (Mirror line)**
3. Attach the small block of wood to the back of the mirror with a rubber band. Place the mirror with the silvered surface (normally the back side) of the mirror along the line, **ML**, as shown in Figure 1.
4. Make a dot on the paper in front of you mirror and label it **p (pin)**. Place a pin at the dot. This will hold your paper in place.
5. Place your ruler on the paper about 5 cm to the left of the pin. **Do not allow the ruler to touch the mirror.**
6. Sight along the edge of the ruler at the image of the pin in the mirror. When the edge of the ruler is lined up on the image, draw a line along the ruler toward, but not touching, the mirror. Label this line **A**.
7. Move the ruler another 3 or 4 cm to the left and sight along it at the image of the pin in the mirror. Draw a line along the edge of the ruler toward, but not touching, the mirror. Label it line **B**.
8. Remove the pin and the mirror from the paper. Extend lines A and B to line **ML**. Where line **A** intersects with line **ML** Label this **X**, where line **B** intersects with line **ML** label this **Y**
9. Using dotted lines, extend each of these lines beyond line ML until they intersect. Label the point of intersection **point I (image)**. This is the position of the image. Measure the object distance from point **P** to line **ML** and the image distance from point **I** to line **ML**. Record these distances on the paper.
10. Draw a line from point **P** to point **X**, as shown. Using your protractor, construct a normal at **X** and measure the angle of incidence, θ_{i1} , and the angle of reflection, θ_{r1} . Record the values of these angles on the paper. In a similar manner, draw line from point **P** to point **Y**. Construct the normal at point **Y**. Measure the angle of incidence, θ_{i2} , and the angle of reflection, θ_{r2} . Record the values of these angles. A line path such as **PXA** or **PYB** is the path followed by a ray of light as it is transmitted from the pin (object) to the mirror, and reflected from the mirror to your eye. Drawing many such rays enables you to locate and recognize images in a mirror.



REFLECTION AND SNELL'S LAW

11. On the back of the paper, draw a new line, **ML**, across middle of the paper. Draw an triangle in front of the line, as shown in Figure 3, and **label the vertices A, B, and C**. Place the pin at vertex **A** place the mirror and block along line **ML**, as you did in Part A.
12. Sight twice along the ruler to obtain two different light paths from the location of the pin at vertex **A** to line **ML**, as you did in Part A. Label these lines **A1**, and **A2**
13. Remove the pin from vertex **A** and place it at vertex **B**. Again, sight along the ruler to obtain two lines from the location of the pin at **B** to **ML** and label these lines **B**, and **B2**.
14. Remove the pin from vertex **B** and place it at vertex **C**. Repeat the procedure and draw lines **C**, and **C2**.
15. Remove the mirror and the pin. Extend the pairs of lines, **A**, and **A2**, **B**, and **B2**, and **C**, and **C2**, beyond the mirror and locate points **A'**, **B'**, and **C'**, as shown in Figure 3. Construct the image of the triangle. Measure and record the distances from points A, B, C, A', B', and C' perpendicular to the mirror line ML. Record on the paper.



REFLECTION AND SNELL'S LAW

Investigation 2: Snell's Law

1. Place the glass plate in the center of a sheet of plain white paper. Use a pencil to trace an outline of the plate.
2. Remove the glass plate and construct a normal $\mathbf{N_1B}$ at the top left of the outline, as shown in Figure 1 on the next page.
3. Use your ruler and protractor to draw a heavy line \mathbf{AB} at an angle of between 20° and 80° with the normal. Record this angle on the paper. Angle \mathbf{ABN} , is the angle of incidence, θ_i .
4. Replace the glass plate over the outline on the paper. With your eyes on a level with the glass plate, sight along the edge of the glass plate opposite the line \mathbf{AB} until you locate the heavy line through the glass as shown in Figure 2. Sight your ruler at the line until its edge appears to be a continuation of the line. **DO NOT MOVE THE GLASS!** Draw the line \mathbf{CD} as shown in Figure 1.
5. Remove the glass plate and draw another line \mathbf{CB} connecting lines \mathbf{CD} and \mathbf{AB} . Extend the normal $\mathbf{N_1B}$ through the rectangle, forming a new line $\mathbf{N_1BN_1'}$.
6. Use a protractor to measure angle $\mathbf{CBN_1'}$. This is the angle of refraction, θ_r . Record the value of this angle.
7. Record the sines corresponding to the measured angles of incidence and refraction.
Determine and record the ratio of $\frac{\sin \theta_i}{\sin \theta_r}$. This is the index of refraction, n of the glass or plastic.
8. Construct a normal $\mathbf{N_2}$ at point \mathbf{C} . Measure angle $\mathbf{DCN_2}$, which will be called θ_r , and record this value.
9. Turn the paper over and repeat Steps 1 through 7, using a **new angle of incidence**. Again, determine the index of refraction from your data.

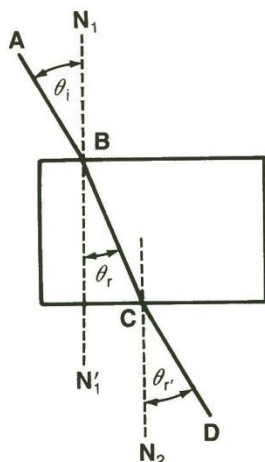


Figure 1: Construct normal lines at points **B** and **C**.

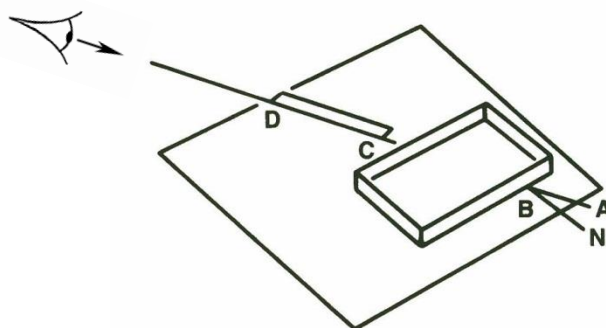


Figure 2: Sight through the glass or plastic and align the ruler with line **AB**.

REFLECTION AND SNELL'S LAW

Analysis

1. Using your observations from Investigation 1, what can you conclude about the angle of incidence and the angle of reflection?
2. How far behind a plane mirror is the image of an object that is located in front of the mirror?
3. Using your observations from the image of the triangle, compare the size and orientation of your constructed image with those of the triangle object.
4. From your observations in this experiment, summarize the general characteristics of images formed by plane mirrors.
5. Why is the image formed by a plane mirror is called virtual rather than real?
6. Is there good agreement between the two values for the index of refraction of plate glass?
7. According to your diagrams, are light rays refracted away from or toward the normal as they pass at an angle from an optically less dense medium into an optically more dense medium?
8. According to your diagrams, are light rays refracted away from or toward the normal as they pass from an optically denser medium into an optically less dense medium?
9. Compare θ_i and θ_r . Is the measure of θ_r what you should expect? Explain.
10. Use your results to determine the approximate speed of light as it travels through glass. By what percent is the speed of light traveling in a vacuum faster than the speed of light traveling in glass?

DIFFRACTION

Light from a single source can pass through a barrier divided by two or more narrow openings. The light emerging from each of the openings acts as a single point source and the light spreads out in waves that interfere with each other. The interfering waves will create an interference pattern that might look something like this:

* * * or * * * or * * *

In a transmission diffraction grating there are many tiny parallel grooves or lines scratched into a transparent film. The light scattered by even a few grooves interferes to form a pattern of closely spaced bright and dim patches called fringes. As we add more closely spaced grooves the bright fringes get farther and farther apart. Depending on the spacing of the grooves and the wavelength of light, each bright fringe appears at a specific, predictable angle. Using these relationships and measuring the angle of deflection of the light, the wavelength of the laser light can be determined.

$$d \sin \theta = \pm n \lambda$$

Where:

d: the spacing between lines of the diffraction grating (m)

θ : the angle of deflection

n: the order of the fringe

$$\theta = \tan^{-1} \left(\frac{x}{L} \right)$$

λ : wavelength of light (m)

x: the distance between fringes (m)

L: the distance from the diffraction grating to the screen (m)

Reflection gratings differ from transmission gratings in that there is a mirror surface behind the scratched grooves. Light is reflected off of the grooves instead of passing through them. Reflection gratings will produce a similar predictable pattern that transmission gratings do. A CD and a DVD are close representations of a reflection grating, over a small area the grooves act like parallel lines. It has a single line of data written in a tightly wound spiral. One side of a disc can hold more music than two sides of a vinyl record. How close are the grooves on a CD and a DVD?

DO NOT TURN THE POWER SUPPLY PAST THE NUMBER 2.

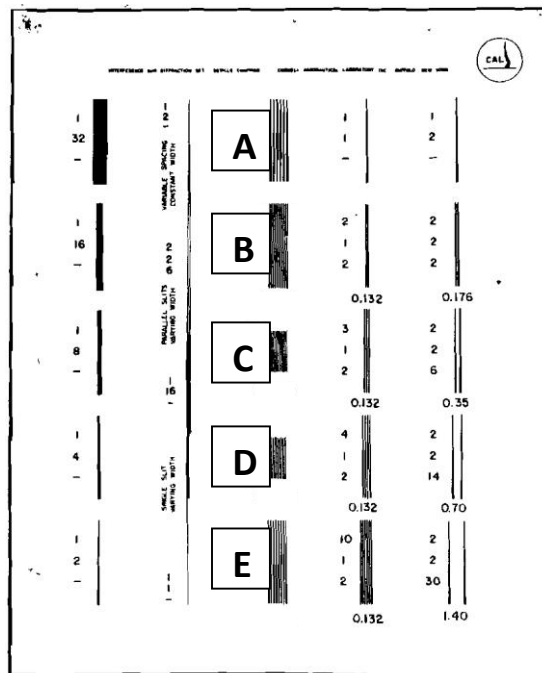
Investigation 1: Laser Wavelength

1. Set up the apparatus as directed.
2. Record the grooves per unit length of the diffraction grating in the data table.
3. Measure the distance from the diffraction grating to the screen
4. Make a mark in pencil where you see the fringes appear on the screen
5. Measure the distance between the 0th order and the 1st order fringes
6. Calculate the wavelength of the laser

DIFFRACTION

Investigation 2: Unknown Separation of Slits

- Set up the laser to pass through the glass slit film demonstrator shown in the figure to the right.
- Choose one of the sets of slits in the middle column. Record the corresponding letter in the data table.
- Record all necessary measurements and calculations to find the separation between the slits.



Investigation 3: CD and DVD Track Spacing

- Set up the apparatus with the CD's reflective data side facing the screen. The laser should point towards the CD and reflect back towards the screen.
- Measure the distance from the CD to the screen
- Make a mark in pencil where you see the 0th order and fringes appear on the screen
- Measure the distance between the 0th order and the 1st order fringes
- Calculate the distance between grooves on the CD
- Repeat for the DVD

Analysis

- Include all calculations necessary in the lab. Be mindful of the dimensions of the units.
- Describe the pattern of fringes you saw in both parts.
- Does the wavelength you calculated for the red laser make sense? (hint: electromagnetic spectrum)
- What was the separation between slits calculated in investigation 2?
- Calculate the number of slits per cm your chosen set from investigation 2.
- What is the percent error for spacing on the CD and DVD? (you will have to look up the accepted value for this)
- How many more lines are there on a DVD than a CD?
- Given that a Blue Ray laser uses light whose λ is 405 nm, how much more data (proportionately) can a Blue Ray Disc hold as compared to a DVD?

Appendix A

Error Analysis

Percent Error

Applied when comparing an experimental quantity, E , with a theoretical quantity, T , which is considered the “correct” value.

$$\% \text{ error} = \left| \frac{T - E}{T} \right| * 100$$

Percent Difference

Applied when comparing two experimental quantities, E_1 and E_2 , neither of which can be considered the “correct” value.

$$\% \text{ Difference} = \frac{|E_1 - E_2|}{\frac{1}{2}(E_1 + E_2)} * 100$$

Error range for error bars on graphs:

Applied to data points graphed to show the possible range of error on any of the collected data.

$$\frac{(E_{\text{high}} - E_{\text{low}})}{2}$$

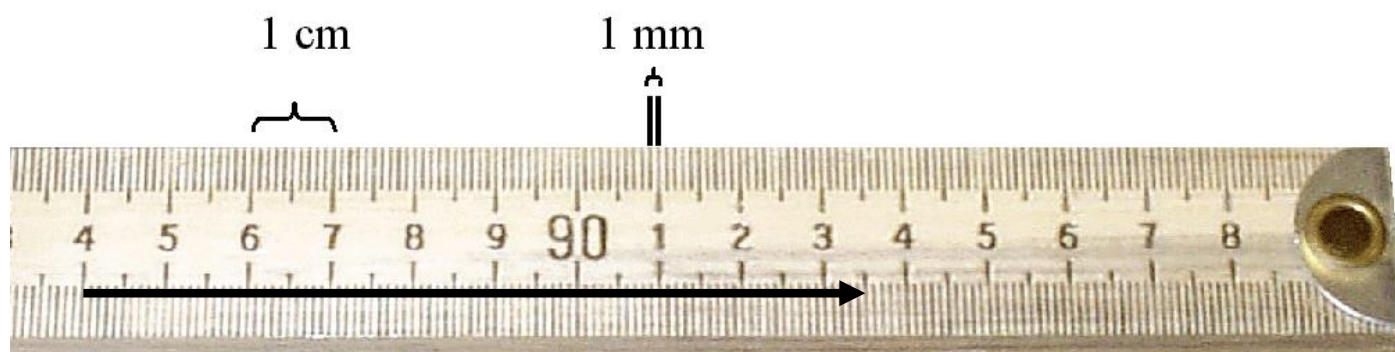
Appendix B

Making to Most of your Measurements (Significant Figures)

Recording Measurements:

- An instrument must be used to the best of its ability
- Measurements must be recorded to that end.
 - Must include an estimated digit (estimated $1/10^{\text{th}}$ of the smallest marked increment)
 - Record all digits any digital instrument displays
 - The number of digits may vary for different instruments

Example:



This meter stick contains centimeter and millimeter marks. All measurements taken with this instrument must be taken to a tenth of a millimeter.

The length of the arrow would be recorded as 9.50 cm or .0950 m.

Measurement Errors:

The accepted error of an instrument is ± 0.5 the smallest increment.

The meter stick pictured above would have an error of $\pm 0.5\text{mm}$.