Laboratory Exercises for Physics 101

Mechanics, Heat, Electricity, and Optics
(Physics 101 LB)

Contents

These laboratory exercises are designed to accompany and supplement the lectures in Physics 101, Concepts of Physics. The exercises are the product of much work by the physics faculty. In particular, extensive revisions and updates by Professor Robert A. Marino a few years ago substantially improved this lab series with the introduction of new exercises and the use of modern equipment. We are indebted to his work and that of the many other faculty members, staff, and students who have contributed to these labs over the years.

Physics Faculty
Hunter College
1998 July

How to Succeed in Physics Lab

Read the lab manual before coming to class to become familiar with the experiment. Lecture and Lab are NOT in perfect synch, so you may have to give the textbook a look also.

You should take responsibility to learn safe operating procedures from the lab instructor. The lab manual is also occasionally a good source of safety tips. With electrical circuits, no power is to be supplied unless OK'd by instructor or lab tech. *Report any accidents immediately!*

You will work with a lab partner to take data, but you are individually responsible for your own data. All subsequent calculations, graphs, etc. are also your own individual responsibility.
Original data MUST be in ink. If you change your mind, cross out with a single stroke, and enter new datum nearby.

Do not leave the lab room without obtaining the instructor's signature on your original data sheet. Without it, your lab report will not be accepted. No exceptions.

The lab has been designed to be a "low pressure" experience. We hope it is an enjoyable one as you take the time to become familiar with new equipment and experiences. Still, you should aim to complete all data-taking, all necessary calculations, reach all conclusions, and at least *sketch* all graphs before you leave. It's well known (to those who know it well) that once you walk out that door, all work on lab reports will take longer. Besides, most of the grade for the course will come from the lecture part, so spend your time accordingly.

Before taking good data, run through the experiment once or twice to see how it goes. It is often good technique to sketch data as you go along, whenever appropriate.

The Report: Your Lab Report should be self-contained: It should still make sense to you when you pass it on to your grandchildren. It should include:
a) Front page: your original data sheet with your name, partners and date. The original data MUST be in ink. A lab report is not acceptable if the original data is in pencil or if the data sheet was not signed by your instructor. (So... don't leave the lab room without it.)
b) Additional pages with data and calculations in neat tabular form. If the original came out messy, you should rewrite your data before continuing with calculations.
c) Any graphs. Neatness counts! It's one of the aims of this lab to produce students that know how to produce a decent graph.
d) Answers to any Questions
e) An Appendix made up of the pages from the lab manual that describes the experiment. Including them relieves you from having to rewrite the essential points of the procedure, description of equipment, etc.

Lab reports are due the next time the lab meets. *At the beginning of the period!* It is department policy to penalize you for lateness in handing in lab reports. This is to discourage you from working on stale data with the lab experience no longer fresh in your mind. A schedule will be announced.

Laboratory Grade: The lab instructor will make up a grade 90% based on the average of your lab reports, and 10% on his/her personal evaluation of your performance in the laboratory. This grade is then reported to your lecturer for inclusion in the final course grade (15% weight factor). The list below will give you an idea of the criteria used by your lab instructor in grading your lab report:

1. Quality of measurements. Logical presentation of report contents.
2. Accuracy and correctness of calculations resulting from proper use of data and completion of calculations.
3. Orderly and logical presentation of data in tabular form, where appropriate.
4. Good-looking graphs, easy readability, good choice of scales and labels.
5. Comparison with theory.
6. Answers to Questions; Conclusions.
7. Clarity, Neatness, Promptness.

On Errors and Significant Figures

Errors

We could distinguish among three different kinds of "errors" in your lab measurements:

1. *Mistakes or blunders.* We all make these. But with any kind of luck, and some care, we catch them and then repeat the measurement.

2. *Systematic Errors*. These are due either to a faulty instrument (a meter stick that shrank) or by an observer with a consistent bias in reading an instrument.

3. *Random Errors*. Small accidental errors present in every measurement we make at the limit of the instrument's precision.

After blunders are eliminated, the *precision* of a measurement can be improved by reducing random errors (by statistical means or by substituting a more precise instrument, i.e., one that yields more significant figures for the same measurement.) *Accuracy* is increased by reducing systematic errors and increasing precision.

Significant Figures

No measurement of a physical quantity can ever be made with infinite accuracy. As an honest experimentalist, you should relay to the reader just how good *you* think your measurement is. One simple way to relay this information is by the number of *significant figures* you quote. For example, 3.4 cm says one thing, 3.40 cm tells a different story. The last digit you write down can be your best estimate made between the markings of a scale, but it still represents a willfully reported number, it still is a *significant* figure.

The placement of the decimal point does not change the number of significant figures. For example, 20.8 grams and 0.00208 grams each have three significant figures; each is assumed to be uncertain by at least ±1 in the last figure, i.e., ±1 part in 208, which is about ½ %.

Normally, figuring out how many significant figures are in a stated number gives no problems, except when zeros are involved. For example, is it obvious how many significant figures are expressed in 5500 feet, 250 years, or $1,300,000 ? A good way to tell the reader which is, in fact, the last significant figure is by using *scientific notation*. For example, 5.50×10^3 feet, 2.5×10^2 years, and 1.300 Megabucks, telegraph that the number of digits in which any confidence can be placed was three, two, and four, respectively.

Computations using raw data

How do you combine your carefully gathered data with other numbers in an expression? With a little common sense, and a hand calculator, you can verify that the following rules should be followed:

Multiplication and Division:

Report only as many significant figures in your final answer as there were in the *least precise* value. For example,

3.481 x 1.75 gets reported as 6.09, not 6.092.

Of course, you should only round off the *final* answer. If a number is used again in another computation, you should not round it off in between, or you may make a small but significant error.

Addition and Subtraction:

Again, common sense rules: $1.11 \times 10^3 + 3.33 \times 10^4$ is, unfortunately, just 3.44×10^4.

Note: To see this you have to write it out in ordinary notation (even better: line-up one under the other):

1,110 + 33,300 = 34,410 mathematically

but the *tens* position is not significant in one of the terms, so it cannot be significant in the final sum. The answer is 34,400, or 3.44×10^4.

Making a Good Graph by Hand

Start thinking about a nice title. For example, " The Square of the Period (T^2) of a Simple Pendulum vs. its Length (L)" [A shorter title would have been even better].

Keep your axes straight: If you need to plot "A vs B", or "A as a function of B", then A is on the vertical axis and B is on the horizontal axis.

vertical axis = y-axis = the "ordinate"
horizontal axis = x-axis = the "abscissa"

The crucial part is choosing the range and scale for each axis. Two examples:

a) 0 to 5 sec; 5 graph boxes =1 sec.
b) -300 to +200 degrees; 2 boxes =100 degrees

The range must be just large enough to accommodate all your data and small enough that the scale is *readable*.
The scale should be spread out enough so your data take up most of the graph area, and *labeled so plotting (and reading) is easy.*

Label the x and y-axis with the appropriate magnitudes. These should be round numbers which cover the entire range of values that you will be plotting. A common mistake is to label too many boxes. If you are trying to show that one quantity is proportional to another, or if you are not told otherwise, zero is part of the range and must be located at the Origin. The numbers should be evenly spaced with the same number of boxes between the same increase in numbers including the space from zero to the first non-zero number. Choose an appropriate number of boxes between numbers. It is better to have 5 boxes between numbers than 4 since it is easier to interpolate in the first case than in the second. (Similarly, 10 is better than 8, and 2 is better than 3.)

Plot the results of your measurements on this graph. Where appropriate, you should include error bars to indicate the uncertainty in your measurements. These error bars *are not* of arbitrary size but should be of the size of your uncertainty on the scale dictated by the numbers on the axis of your graph.

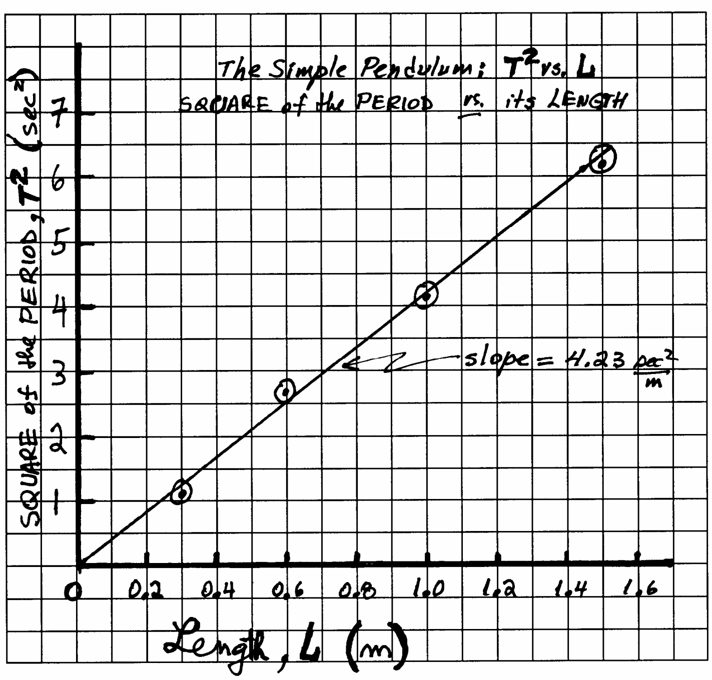
When you draw the line that best fits your data, the line should be a smooth one that need not go through any points. In general, there should be as many points on one side of the line as on the other. If you have done your work properly, the line should pass inside of the error bars for each point. (If it does not, that may be an indication that there is something wrong with the point in question. Perhaps you miss-recorded a measurement, or your estimate of the error was too small, or there was something wrong with the apparatus, or with the technique you applied, etc.) If your graph shows that one quantity is proportional to another, it should be a *straight line* that starts at the origin and passes through the plotted data with as many points on one side as the other.

If you are asked to find the *slope of the line*, choose two points *on the line* that are as *far apart as possible.* This will minimize the error that is introduced in reading the value of those points. The slope is the difference between the vertical values of those points divided by the difference in the horizontal values of those points.

A common mistake is to measure the slope of *the segment connecting two actual data points*: this does not yield the slope of the straight line you fitted to your data!

Note: Normally, the slope of your graphs has its own units, e.g., the slope of graph of velocity vs. time has units of (m/s)/(s) = m/s^2.

Here is a graph so messy, one can surely do better with a little practice.



LAB 1: DENSITY

1.1 INTRODUCTION

The MASS DENSITY of a body measures the amount of mass per unit volume of that body.

Definition: (Density of a body) = (body's mass)/(body's volume) **or D = M / V**

The density of a substance is independent of the shape or the particular amount of that substance. For example, the density of a small gold ring and the density of a large gold brick should be the same number, i.e., the density of gold.

In this lab you will measure the density of several different substances. As you do this, I hope you will develop an appreciation for the concept of SIGNIFICANT FIGURES. *You need to master the concept of significant figures in order to succeed in this laboratory course.*

As part of your density calculations you will need to compute the *volume* of a regular solid from its linear dimensions. The quality of your volume measurements will thus depend on how precisely you can measure lengths. You will use three progressively more precise instruments: a wooden "meter stick," vernier calipers, and a micrometer. Your instructor will demonstrate how to use each one. In each case, read the instrument to the smallest division plus one more digit by estimation. So, a meter stick with millimeter markings can be used to estimate a length to the nearest tenth of a millimeter, e.g., 12.4 mm, or 1.24 cm. This estimate by "eye" is often good only to ±2 or 3, as you can verify by repeating the measurement or asking your partner to do the estimating. A *vernier* is an invention that removes the uncertainty in reading to the nearest tenth between adjacent markings, thus increasing the *precision* of the final measurement. Your instructor will demonstrate how this is done with the vernier model, prominently displayed in the front of the laboratory room.

On Errors and Uncertainty in a measurement:

When you work out a *math* computation, the numbers are usually considered exact, e.g., 1.1 x 1.2 x 1.3 = 1.716. But when a number represents a *physical measurement* it is **never** exact because of the limitations of the instrument used, or the way it was employed, etc. It is essential, therefore, that each experimental result be presented in a way that indicates its reliability. A very simple way to do this is by the use of *significant figures.* (See Tutorial #1, on Significant Figures)

As an example, consider how different the following three cases are, even though they refer to exactly the same steel block:

a) 1.1 cm x 1.2 cm x 1.3 cm = 1.7 cm^3

b) 1.13 cm x 1.20 cm x 1.29 cm = 1.75 cm^3

c) 1.127 cm x 1.195 cm x 1.293 cm = 1.741 cm^3

What is different about these three reports is the *precision* with which the data was measured. (By the way, all three workers used significant figures correctly.)

Now, how *accurate* are the results? This concept reports on how close the reported answer is to the "accepted answer". What determines accuracy? Examples are the calibration of the measuring instruments or systematic errors on the part of whoever is taking the data. The following somewhat oversimplified table may be useful in thinking about these concepts:

Problem	Remedy
Mistakes and blunders	Repeat measurements several times to check yourself
Systematic errors	Use calibrated instruments properly and carefully
Random errors	Treat data statistically and report on the average magnitude of errors

1.2 PRELAB ASSIGNMENT

After your lab instructor explains the concept of significant figures, complete the problems on the page entitled, LAB 1: PRELAB ASSIGNMENT. Hand in your solutions before proceeding with the experiment.

1.3 PURPOSE

The objective of this laboratory exercise is to learn the concept of mass density and practice proper use of significant figures. Another aim is to become familiar with instruments to measure length (meter stick, vernier calipers, micrometer) and to appreciate the difference between accuracy and precision of experimental measurements.

1.4 EQUIPMENT AND SUPPLIES

Balance, metric ruler, wood blocks, metal blocks and cylinders, an aluminum block marked with identifying letter, liquid samples and a graduated cylinder.

1.5 PROCEDURE

Measuring the density of a block of maple wood.

Al. Familiarize yourself with the balance as you measure the mass of a maple wood block. Record the mass of the block on the page labeled **LAB 1: DATA SHEET.**

A2. Measure the dimensions (length, width, thickness) of the maple wood block. Estimate to nearest 0.01cm by interpolating between millimeter markings. Record your data on the data sheet.

A3. Repeat the measurements carried out in **A2** and record your data on the data sheet. Repeat the measurements again and record. Do not forget units and the use of significant figures.

A4. Perform the computations required on the data sheet and obtain the best (or average) dimensions, volume, density and percent deviation.

A5. Write your result for the density on the blackboard under the heading "Density of Maple Wood" in a column of results provided by your classmates. Initial your own record.

Density of other solids.

Bl. You should be getting good by now at extracting maximum precision from the platform balance and the metric scale. Follow the Data Sheet and make the necessary measurements in order to compute the density of an aluminum block and cylinder. If time permits, continue with a brass block or cylinder and an iron block. In each case, compute the percent deviation from the expected value.

B2. Attempt your most careful measurement on a block of aluminum. The aluminum block will be marked with an identifying letter (A to Z). For this part of the lab exercise, do the work individually (without a partner).

Density of liquids.

Cl. Obtain the density of water by the following procedure. Determine the mass of the DRY graduated cylinder and record. Add about 50 cc (cubic cm) of tap water. Read and record the actual volume of water in the graduated cylinder as precisely as you can, using the bottom of the meniscus as your reference level. Obtain the combined mass of the graduated cylinder and water. From these data compute the net mass of the water and, finally, the density of the water.

C2. Use the same procedure as in C1 to obtain the density of the colored alcohol solution that is provided. CAUTION: Return all liquids to their proper containers.

DENSITY OF SOME SUBSTANCES (grams/cubic centimeter)

aluminum	2.70	brass	8.90
water	1.00	lignum vitae	1.17 to 1.33
maple	0.62 to 0.68	balsa	0.12 to 0.20
iron	7.87	alcohol solution	0.80
lead	11.34	mercury	13.6
gold	19.3		

LAB 2: ARCHIMEDES' PRINCIPLE

INTRODUCTION

Archimedes' problem is said to have been the following: Determine (nondestructively!) if the king's new gold crown contained within it baser metals. Whether or not the solution came to Archie in the bathtub, the concepts of BUOYANCY and of SPECIFIC GRAVITY can provide the answer.

ARCHIMEDES' PRINCIPLE states that a body, partially or completely submerged in a fluid, is buoyed up by a force equal to the weight of the fluid it displaces. The buoyant force B is then expressed as the body's apparent loss of weight.

SPECIFIC GRAVITY is defined as the ratio of the density of a substance to the density of water. An equivalent definition of this dimensionless quantity is: the ratio of the weight of a body to the weight of an equal volume of water.

SPECIFIC GRAVITY of a chunk = Weight in air / Weight of water displaced

= Weight in air / Buoyant force

= Density of substance / Density of water

NOTE: The specific gravity of different substances is, in general, different. Thus, measuring the specific gravity would help differentiate gold from lead. This was the brilliant idea that led Archimedes to shout "*Eureka!* "

PURPOSE

The purpose of this experiment is to verify Archimedes' Principle and to determine the specific gravity of certain substances.

EQUIPMENT AND SUPPLIES

Test samples made of marble, metal and wood; balance, overflow can with spout, beaker, metal can, 1000 cc (cm^3) graduated cylinder, metric ruler and some thread.

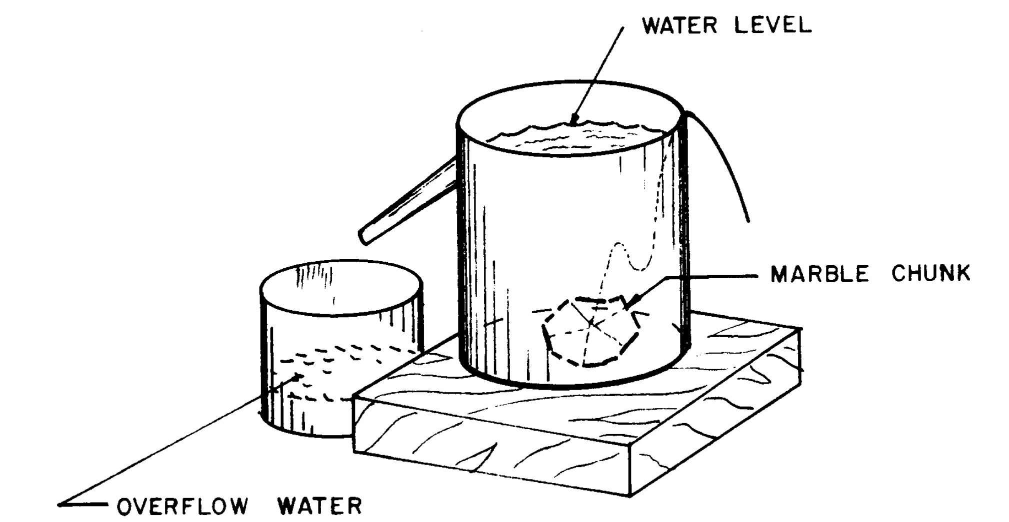
PROCEDURE

A. Measuring the specific gravity of an odd-shaped chunk of marble

Al. Measure and record the weight of a dry chunk of marble. If marble is wet, dry it with paper towels.

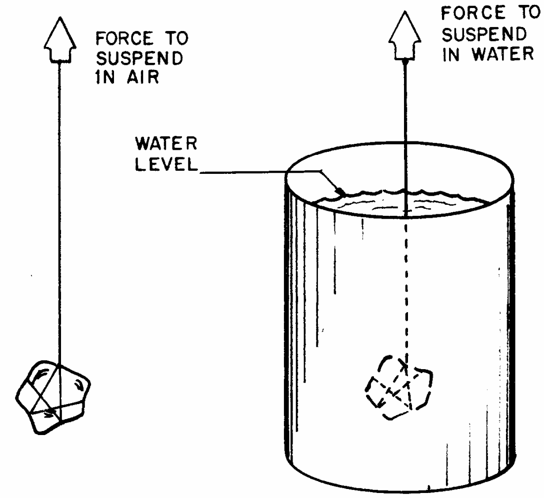
NOTE: To obtain the weight of an object in the proper units (i.e., units of force) simply multiply the mass by g, the constant acceleration due to gravity (w=mg, where m represents mass and g is a constant equal to 9.8 m/s^2).

A2. Measure the volume of the marble chunk by the following method. Fill the 'overflow can with spout' so that an initial overflow runs out into the beaker. When the spout stops dripping, measure and record the weight of the beaker containing the initial overflow water. Now, replace this same beaker and gently lower the marble chunk into the overflow can. By doing so you will have collected the additional water displaced by the chunk. The thread comes in handy in gently lowering the marble; if you had thought of using your fingers, think again. Record the weight of the beaker with the additional overflow water. Compute the net weight of water displaced by the chunk of marble. From the known density of water, you can now compute the volume of the displaced water, and thus, the volume of the marble chunk. Finally, compute the specific gravity of the marble chunk and record the result on the DATA SHEET.



Measuring the buoyant force on a submerged object

Bl. Pick a metal sample and record the weight and type of metal. Ask for help if you cannot distinguish the various materials from each other.
B2. Determine the apparent weight of the metal when completely immersed in water. Do this by suspending it with thread under the left-hand side of the platform balance, while it dangles fully immersed in the water can.
B3. Use paper towels to dry both the metal sample and your can. Now repeat procedure **B2** using the *alcohol solution instead of water*.



Specific gravity of a floating object (wood, in this case)

C1. Measure and record the weight and length of the block of wood.
C2. Fill the graduated cylinder with enough water so the block will float upright. Record the water level before immersing the block.
C3. Place the block upright in the cylinder and record the water level. You can now compute the volume and the weight of water displaced by the block.
C4. Measure the average length of the part of the block remaining ABOVE the water level and determine the length that is submerged.
C5. You can now compute the volume of the whole block using the following proportion: Total volume divided by submerged volume equals the total length divided by the submerged length.
C6. What is the weight of water that has a volume equal to the volume of the block; i.e. how much water is displaced?
C7. The specific gravity of the wooden block is now just the ratio of its weight in air to the weight of an equal volume of water.

LAB 3: MOTION ON AN INCLINED PLANE

INTRODUCTION

The distance d traveled by an object accelerating from rest is given by the expression

$$d=1/2at^2$$

where a is the acceleration and t is the time required for the object to travel a distance d starting from rest.

In this experiment you will measure the time it takes an object to roll 20, 40, 60, 80 and 100 cm for two slightly different inclined plane angles. Each measurement of the time will enable you to compute a value of the acceleration. Then, for each inclined plane, you will present all your data on a graph of d versus the square of t. The equation above predicts that the points will fall on a straight line of slope (a/2).

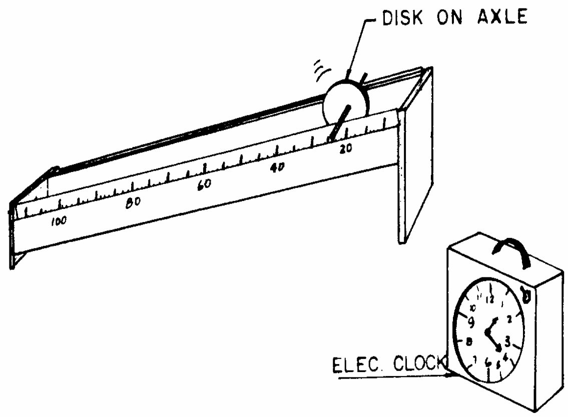
The apparatus provided is designed to generate small accelerations, so that the times for trips of a distance of a meter or so are sufficiently long to be measured by a hand-operated clock. The effect of gravity is decreased by using the inclined plane and by allowing the disks to roll on a thin axle. (This trick was first realized by Galileo.)

PURPOSE

The purpose of this laboratory exercise is to verify the constancy of acceleration of a disc rolling down an inclined plane and to experimentally verify the equation displayed above.

EQUIPMENT AND SUPPLIES

Inclined plane, disk mounted on axle, timer.



PROCEDURE

l. Using the inclined plane with both supports on the lab bench, make 3 determinations of the time required for the disk to roll a distance of 20 cm starting from rest. Practice first until you can start the disk in a repeatedly uniform fashion. Calculate the *average time* required for the three determinations, the *square of this time* and the *average acceleration*. Make proper use of significant figures and record your results on the data sheet provided.

2. Repeat for trips of 40 cm, 60 cm, 80 cm and 100 cm. Compute the average of the five values of acceleration and the average of the percent deviations.

3. Increase the angle of inclination by letting the lower support of the plane extend over the edge of the bench. Then repeat Procedures **l** and **2.**

LAB 4: THE SIMPLE PENDULUM

INTRODUCTION

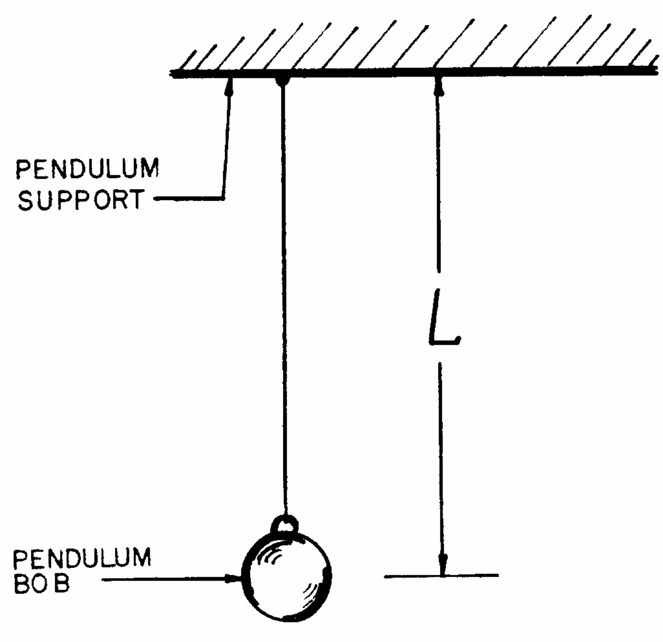
A pendulum is called simple if all the mass is concentrated at a point at the end of a massless string. We get a good approximation of a simple pendulum by using a heavy "bob" of mass m suspended by a light string. The pendulum length L is taken to be the distance from the support to the center of the pendulum bob.

The period T of a simple pendulum of length L oscillating with small amplitude is given as

$$T^2 = 4\pi^2 \frac{L}{g}$$

where g is the acceleration due to gravity. Note that the mass of the bob does not appear in the equation. For our purposes, "small amplitude" means an angular displacement of less than 10°. Solving the above equation for g, we find

$$g = 4\pi^2 \frac{L}{T^2}$$



PURPOSE

The objective of this Laboratory Exercise is to measure the acceleration due to gravity in this room using the simple pendulum as a gravity sensor.

EQUIPMENT AND SUPPLIES

Pendulum bob and string, sturdy support, vernier calipers, metric ruler, and electric clock.

PROCEDURE

1. Set up the pendulum with a length of about 50 cm. On the data sheet provided record your measured value of L. Note that *L*, the length of the pendulum, is the sum of the length of the string plus the length of the hook on the bob plus the radius of the bob. You may find the vernier calipers useful in measuring the radius of the bob.

2. Set the pendulum swinging through small angles, and check that the pendulum support point from which you measured L is in fact the one that the pendulum uses. If not, correct your measurement of L in Procedure 1.

3. Measure the time required for 50 complete oscillations (oscillation is complete when the pendulum has returned to its starting point). Then repeat this measurement of the time required for 50 oscillations twice more. Enter the results of your three measurements on the data sheet.

4. Repeat Procedure 3 for pendulums with lengths of about 1meter and 2 meters. If the support is not tall enough to allow for a 2 meter length, get as close to 2 meters as possible. On the data sheet, record the actual length, L, measured for each pendulum.

5. For each pendulum length, compute the average period, T, for the oscillations. Then complete the remaining columns on data sheet for each pendulum length.

6. *Average* the three determinations of g that you have now completed. Write this value in the table on the blackboard, along with your initials. To within what percent is your result in agreement with the accepted value?

7. Prepare a separate graph of $4\pi^2 L$ *vs.* T^2, where you summarize your results by plotting three points as follows. Plot the values of $4\pi^2 L$ on the vertical axis and the corresponding values of T^2 on the horizontal axis. Draw the best straight line fit to the data points that passes through the origin. Compare the value of g deduced from the graph with the value of *g* you obtained in Procedure 6. Why is the line drawn through the origin of the graph?

LAB 5: GAS LAWS

INTRODUCTION

When far from their liquefying points, most gases behave like ideal gases. The ideal gas law states that there is a relationship between the pressure P, volume V, and absolute temperature T. This relationship requires that the combination PV/T remains constant even as the individual variables P, V, and T each take on different values. Thus the ideal gas law is expressed by the equation,

$$\frac{PV}{T} = constant.$$

In this Laboratory exercise you will study two special cases of the ideal gas law given above.

The first case, called Boyle's law, states that if the temperature is not allowed to change, then the volume of the gas varies inversely as the pressure.

V = constant / P or equivalently, PV = constant.

The second case, called Charles' law, states that if the pressure is not allowed to change, then the volume of the gas is directly proportional to the absolute temperature.

V = constant T or equivalently, V / T = constant.

PURPOSE

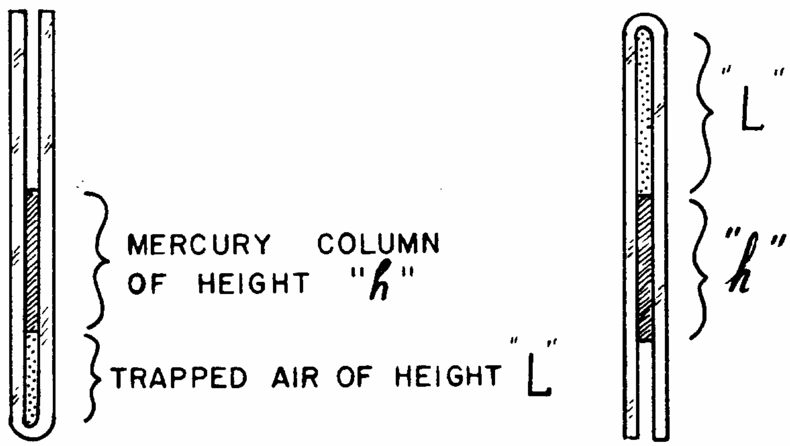
The purpose of this Laboratory exercise is to study the relationship between the volume, pressure, and temperature of a gas. We will also determine graphically the temperature that corresponds to absolute zero on the Celsius scale.

EQUIPMENT AND SUPPLIES

Air thermometer, large metal can, Bunsen burner, mercury thermometer, stirrer, metric ruler.

The air thermometer is illustrated in the figure on the next page. In the air thermometer, the length of the trapped air column varies as the air thermometer is gently rotated. Since the cross-sectional area of the glass tube is constant, this length is proportional to the volume of the trapped air. The mercury column has a length which does not vary during the experiment. By changing the orientation of the mercury column, from right-side-up to upside-down, we can increase or decrease the pressure in the air column relative to atmospheric pressure.

Note: The air thermometer must be handled gently, or the mercury may spill. Do not attempt to clean up spilled mercury. Call your instructor immediately.



PROCEDURE

A. Boyle's Law

Al. Place the air thermometer in an upright position (open end up) and the vertically mounted meter stick next to the air thermometer. Measure the length of the air column, *L*, and the height of the mercury, *h*. Also record the room temperature.

A2. Measure *L* when the air thermometer is horizontal.

A3. Measure *L* when the air thermometer is vertical with the open end down.

A4. Read the laboratory barometer and record the atmospheric pressure. Then complete the required computations on the data sheet provided. Note that if barometric pressure is 760 mm of mercury (mm Hg), the three pressures you would obtain in **A1**, **A2** and **A3** are (760 + *h*) mm Hg, 760 mm Hg, and (760 - *h*) mm Hg, respectively, where *h* is the length of the mercury column in millimeters.

B. Charles' Law

B1. Return the air thermometer to its original upright position and immerse it in a mixture of ice and water to a level well above the enclosed air. Stir ice bath thoroughly. Record the length *L* and the temperature of the ice bath water.

B2. Replace the ice bath with hot water from the tap. Insert the air thermometer as before, and heat the water to a boil. Record the length *L* and the temperature of the hot water.

LAB 6: HEAT EXCHANGE

INTRODUCTION

When bodies at different temperatures are placed in contact, heat energy is transferred until a common, or equilibrium, temperature is reached. Since heat is a form of energy, it can be neither created nor destroyed in the process. The total heat of a system remains constant, but it may take on different forms. This principle of heat energy transfer can be stated as follows:

THE AMOUNT OF HEAT **GAINED** BY THE INITIALLY COLDER BODY IS EQUAL TO THE AMOUNT OF HEAT **LOST** BY THE INITIALLY HOTTER BODY.

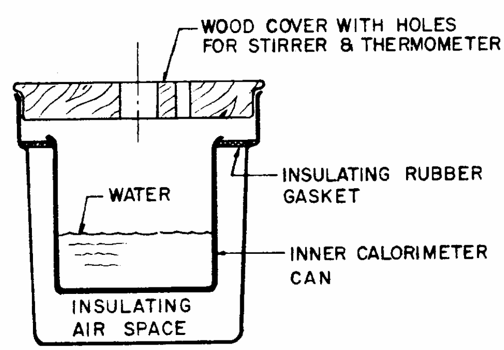
We introduce a quantity called *the specific heat capacity*, c. The specific heat of a substance is the amount of heat required to raise the temperature of a unit mass one degree Celsius. The amount of heat (Q) required to raise the temperature of a substance of mass m and specific heat c through a temperature difference ΔT is given by the equation:

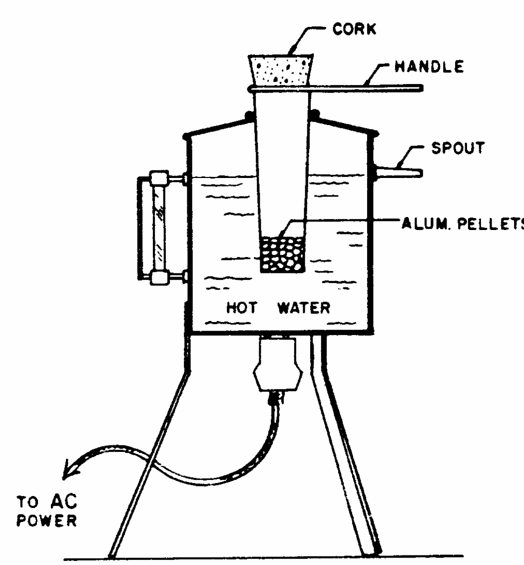
$$Q = mc\,\Delta T.$$

The specific heat capacity of a substance is in fact fairly specific to that substance, and is independent of its temperature. For instance, the specific heat capacity of water is 1.00 calorie/gram °C.

PURPOSE

The object of this Laboratory Exercise is to study the law of heat exchange by the method of mixtures and to apply the law of heat exchange to determine the specific heat capacity of a metal.





EQUIPMENT AND SUPPLIES

Two thermometers, calorimeter, glass beaker, hot and cold running water, double boiler, metal pellets and platform balance with weights.

PROCEDURE

When taking the temperature of a liquid, first stir thoroughly, then read the thermometer carefully to the nearest tenth of a degree.

A1. Record the mass and specific heat capacity of the inner calorimeter can and stirrer on the LAB 7: DATA SHEET. Fill this can about one-third full of cold tap water. Measure the total mass of the inner calorimeter can, stirrer and water. Determine the mass of the cold water. Now, reassemble the calorimeter and insert the thermometer and the stirrer into the calorimeter.

A2. Fill the glass beaker half full of hot tap water. Let the tap run a while so you get really hot water. **Warning: Hot water burns are dangerous.**

A3. Stir the cold water in the calorimeter thoroughly, and record its temperature. Stir the hot water in the beaker well and record its temperature. Immediately after recording these temperatures, pour the hot water into the calorimeter until it is about two thirds full. Cover at once, stir vigorously for about 15 seconds and read the temperature of the mixture within the next few seconds. The idea is to read the temperatures before heat loss to the environment becomes a factor that will affect the accuracy of your data and computation.

A4. Determine the mass of the calorimeter (with stirrer) and water whose final temperature you obtained in **A3**.

A5. Perform the computations requested on the data sheet. Note that in determining the heat gained, you need to do two computations - one for the cold water, and one for the calorimeter can and stirrer.

B1. Begin heating the water in the double boiler. Fill the boiler cup about two-thirds full with dry aluminum pellets. Insert a thermometer in contact with the pellets and cork the opening closed. You will have to heat up the dry aluminum pellets to about 95 °C.

B2. While the metal is heating, prepare the inner calorimeter can by filling it about two-thirds full of cold tap water. Try to get a water temperature several degrees below room temperature, using ice if necessary. The outside of the can should be dry, or that extra water will introduce an error.

B3. When the aluminum pellets are close to 95 °C, record the actual temperature of the pellets and the temperature of the cold water. Then, carefully add the pellets to the calorimeter water. (Be careful not to splash.) Replace the calorimeter cover, stir well, and record the highest temperature to which the water and pellet mixture rises.

B4. Measure the mass of the calorimeter can with stirrer and all contents. Record the value on the data sheet. Complete all the required computations.

LAB 7: MECHANICAL EQUIVALENT OF HEAT

INTRODUCTION

Heat is a form of energy. An increase (decrease) in mechanical energy in a system always accompanies an equal decrease (increase) of heat because the total amount of energy is conserved.

Mechanical work, which for linear motion is simply (perpendicular) force times distance, takes on the following expression for circular motion:

W = (Torque) x angle,
W = (Tangential force x Radius) x angle,
W = F x R x θ, where θ is in radians.

For example, a force of 2.00 N acting for one complete revolution (2π radians) around a circle of radius 1.00 meter does an amount of work given by,

$$W = FR\theta = (2.00\ \text{N})(1.00\ \text{m})(2\pi\ \text{radians}) = 4\pi\ \text{J} = 12.6\ \text{Joules}.$$

The heat energy Q transferred to a body of mass m and heat capacity c will raise its temperature by an amount ΔT degrees, where

$$Q = mc\Delta T$$

For example, if the temperature of 0.10 kg of Aluminum (c = 0.220 kcal/kg °C) is increased from 21.5 °C to 38.5°C, we can conclude that an amount of heat Q must have been added to the aluminum, where

$$Q = mc\Delta T = (0.10\ \text{kg})(0.220\ \text{kcal/kg°C})(38.5°\text{C} - 21.5°\text{C}) = 0.38\ \text{kcal}.$$

PURPOSE

The purpose of this Laboratory exercise is to prove the mechanical equivalence of heat and to verify that 1 kcal = 4186 Joules.

EQUIPMENT AND SUPPLIES

Commercial apparatus is provided which consists of the following:

1. An aluminum cylinder whose specific heat you know, whose mass you will soon measure, and whose temperature is conveniently sensed by a built-in thermistor. [A *thermistor* is a resistor whose resistance varies with temperature. You are provided with a digital ohmmeter and a table (see below) to tell you what temperature corresponds to what resistance. This often requires *interpolation*. If you are rusty on interpolation, ask your instructor.

2. A hand-crank and digital counter to record the number of revolutions.

3. A nylon rope with a "10 kg" weight at one end. The rope is wrapped a few times around the aluminum cylinder so that tangential functional forces are set up between rope and aluminum cylinder when you turn the crank. **CAUTION: Allowing the 10 kg weight to rise more than a few inches off the floor is dangerous both to student feet and to the delicate one-way digital counter.**

> **CAUTION**: THE PROPER PROCEDURE FOR TURNING AND STOPPING THE CRANK WILL BE DEMONSTRATED BY YOUR INSTRUCTOR. IT MAY LOOK SIMPLE ENOUGH, BUT IN FACT IT'S EASY TO HURT YOURSELF OR DAMAGE THE EQUIPMENT.

PROCEDURE

A. Introduction:

A1. Familiarize yourself with the apparatus. Find all the parts in the diagram below.

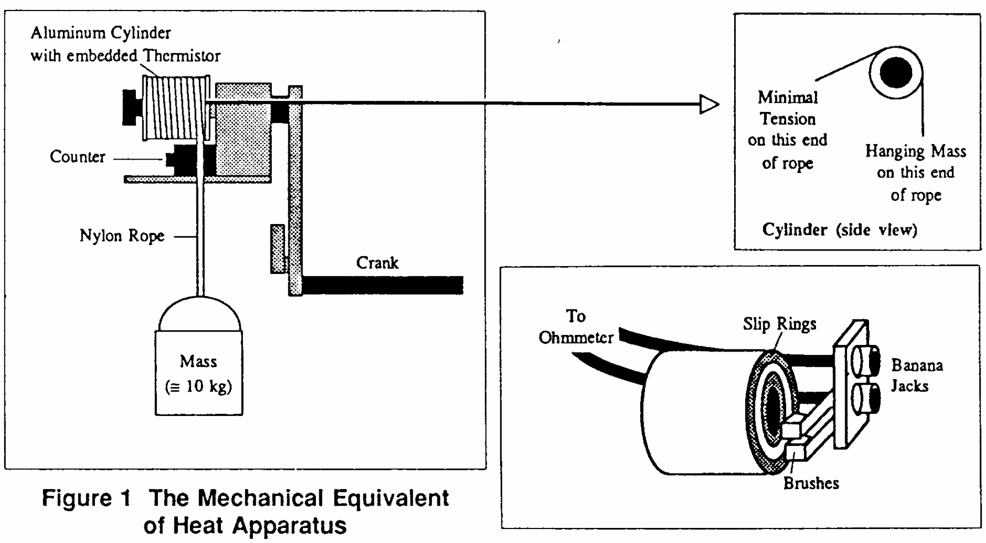


Figure 1 The Mechanical Equivalent of Heat Apparatus

A2. Note how sensitive the thermistor resistance is to the touch of your hot little hands, and how quickly or slowly thermal equilibrium is approached. Now you know the timescale of the response of this equipment.

A3. When confident, unscrew the black knob that holds the aluminum cylinder in place and weigh it. Measure its diameter alone, and the diameter of the cylinder plus rope, when tightly wound.

A4. Weigh the "10 kg" mass to 3 significant figures.

B. “Quick and Dirty” Run

B1. Note the approximate initial temperature of the aluminum cylinder. Look up what thermistor resistance corresponds to a "target" final temperature of about 8 degrees Celsius higher. Your aim is to do enough mechanical work to heat up the aluminum cylinder to the target temperature.

B2. Reset the counter. Enter the actual initial temperature in your data sheet and start cranking vigorously!

B3. When you get to your target temperature, stop cranking BUT DO NOT LET GO OF THE CRANK. Allow the "10 kg" weight to drift to the floor before slowly returning the crank to its equilibrium position. **Do not let go prematurely** or the crank will snap back, possibly damaging the plastic clicker and invaluable body parts.

Continue to watch the thermistor resistance carefully and enter in your data sheet the lowest value (highest temperature) to which it drifts.

B4. Record the total number of turns and complete the calculations called for in your data sheet.

C. Serious Run

Even when done by an expert student, one of the major sources of error in Procedure B is that some of the heat generated will go to heat up the surroundings rather than the aluminum cylinder. To counteract this, in this procedure you will pre-cool the cylinder so that during your run the temperature of the block will be as much below room temperature as above it. Then there should be as much heat gained from the surroundings as lost to them. It is by tricks of this nature that successful experiments are accomplished.

C1. Note the temperature of the room. Plan your target initial and final temperatures to be about 8°C below and above room temperature, respectively.

C2. Remove the aluminum cylinder and cool it in the ice chest provided. Use plastic bags, if available, to prevent wetting. You may not need to cool it all the way to 0°C. In any event, the heat from your hands can now be skillfully used to compensate for too much pre-cooling.

NOTE: Carefully dry any condensed water from the aluminum cylinder with the tissue paper provided. Do this before re-wrapping the friction rope. Evaporating water could carry away a considerable amount of heat; heat that would otherwise go to warm up the aluminum.

Now, reassemble the apparatus, reset the counter and get ready. Watch the ohmmeter carefully as the thermistor resistance drifts toward your pre-designated "target" for the initial temperature. When it gets there, start cranking vigorously.

Crank until the temperature reaches approximately one degree short of your designated final temperature. Then crank slowly until you reach your target. Record the actual maximum temperature (minimum resistance) reached. Record the total number of turns.

REMEMBER THE SAFE STOPPING PROCEDURE. A MISTAKE CAN RESULT IN INJURY!

C3. Compute the work done, the heat input, and the mechanical equivalent of heat as instructed by your data sheet. Compute the percent deviation from the accepted value.

D. Consider the possible reasons (mechanisms) why your answer is different from the accepted value. Do you have any suggestions to improve this experiment?

Resistance versus temperature for your thermistor:

Res. (Ω)	T (°C)	Res. (Ω)	T (°C)	Res. (Ω)	T (°C)	Res. (Ω)	T (°C)
351,020	0	95,447	26	30,976	52	11,625	78
332,640	1	91,126	27	29,756	53	11,223	79
315,320	2	87,022	28	28,590	54	10,837	80
298,990	3	83,124	29	27,475	55	10,467	81
283,600	4	79,422	30	26,409	56	10,110	82
269,080	5	75,903	31	25,390	57	9,767.2	83
255,380	6	72,560	32	24,415	58	9,437.7	84
242,460	7	69,380	33	23,483	59	9,120.8	85
230,260	8	66,356	34	22,590	60	8,816.0	86
218,730	9	63,480	35	21,736	61	8,522.7	87
207,850	10	60,743	36	20,919	62	8,240.6	88
197,560	11	58,138	37	20,136	63	7,969.1	89
187,840	12	55,658	38	19,386	64	7,707.7	90
178,650	13	53,297	39	18,668	65	7,456.2	91
169,950	14	51,048	40	17,980	66	7,214.0	92
161,730	15	48,905	41	17,321	67	6,980.6	93
153,950	16	46,863	42	16,689	68	6,755.9	94
146,580	17	44,917	43	16,083	69	6,539.4	95
139,610	18	43,062	44	15,502	70	6,330.8	96
133,000	19	41,292	45	14,945	71	6,129.8	97
126,740	20	39,605	46	14,410	72	5,936.1	98
120,810	21	37,995	47	13,897	73	5,749.3	99
115,190	22	36,458	48	13,405	74	5,569.3	100
109,850	23	34,991	49	12,932	75		
104,800	24	33,591	50	12,479	76		
100,000	25	32,253	51	12,043	77		

LAB 8: CIRCUITS

INTRODUCTION

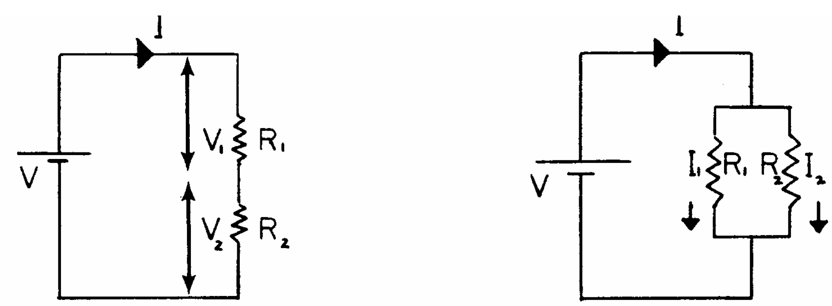
Ohm's Law states that the voltage drop across a resistor equals the product of the current through a resistor and the resistance. Thus Ohm's Law can be written:

$$V = IR.$$

where the voltage V is measured in volts, the current I, in amperes and resistance R, in ohms. This relation can be used to determine the resistance when the voltage and current are known:

$$R = V / I.$$

In the figure on the left below, two resistors, R_1 and R_2, are connected to a battery in *series*. In the figure on the right the resistors, R_1 and R2, are connected in *parallel*.



In the series circuit, the same current flows through each resistor, and the sum of the voltages across each resistor is equal to the battery voltage. That is, applying Ohm's Law, we find

$$V = V_1 + V_2 = I\ R_1 + I\ R_2$$

with the larger voltage appearing across the larger resistor.

In the parallel circuit the voltage across each resistor is the same, and the sum of the currents is equal to the total current supplied by the battery. Again, applying Ohm's Law we find

$$I = I_1 + I_2 = \frac{V}{R_1} + \frac{V}{I_2}$$

with the larger current flowing through the smaller resistor.

PURPOSE

The purpose of this laboratory exercise is to learn to wire simple circuits and to measure resistance by the voltmeter-ammeter method.

EQUIPMENT AND SUPPLIES

Voltmeter, ammeter, resistor, rheostat (variable resistor), two lamp bases, two lamps, connecting wires, switch and a 20-volt DC source.

PROCEDURE

A1. Study the circuit diagram in the figure below, and absorb the following points:

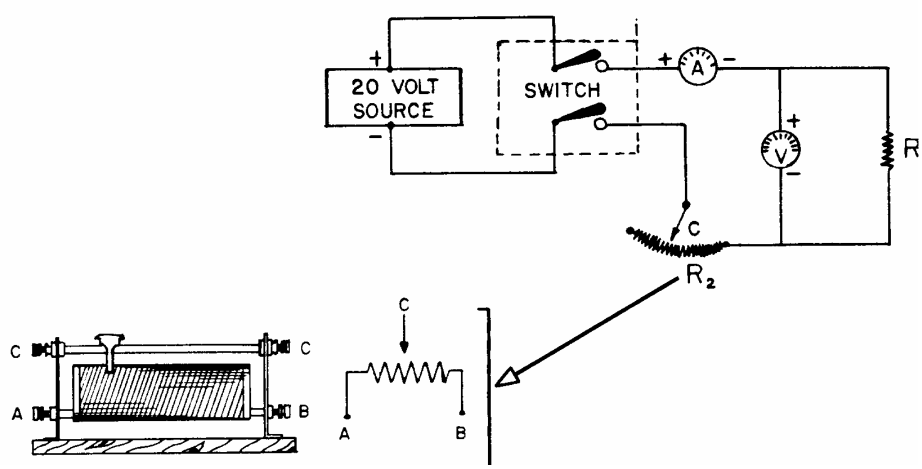
A voltage source is connected in series with a fixed resistor R_1 (a 2-terminal device) and a variable resistor R_2 (a 3-terminal device).

A switch is included to facilitate connecting and disconnecting the power supply.

An ammeter is connected in series with the fixed resistance R_1 so it will indicate the current passing through R_1.

A voltmeter is connected in parallel with R_1, so it will indicate the voltage across R_1.

A convenient variable resistance is obtained by wiring the three-terminal rheostat as shown.



Now connect a circuit as shown in the circuit diagram using the supplies provided. Observe the correct polarities where polarity matters. Leave the switch open. Do not proceed until you **ASK YOUR INSTRUCTOR TO CHECK THE CIRCUIT.**

A2. Close the switch and observe the ammeter and the voltmeter readings. Also observe the effect on these readings that results from moving the sliding contact (c) of the rheostat.

A3. Record on the data sheet provided the smallest reading of the ammeter and the corresponding voltmeter reading.

A4. Increase the ammeter reading by adjusting the rheostat. Record the new reading of the ammeter and the corresponding voltmeter reading.

A5. Repeat to obtain three more sets of readings and record these on the data sheet.

A6. Obtain the value of R_1, from your instructor.

B1. Open the switch and substitute a lamp base (with lamp) for the resistor R_1 in the circuit. **Do not proceed until you ASK YOUR INSTRUCTOR TO CHECK THE CIRCUIT.**

B2. Close the switch and observe the possible variations of the current in the lamp as R_2 is varied.

B3. Take a series of five voltmeter-ammeter readings over as wide a range as possible and record these on the data sheet.

C1. On the data sheet, draw a diagram of a new circuit in which you include an extra lamp base in series with the one used in the circuit in **B1**. (The new lamp base replaces the rheostat, R_2.)

C2. Wire the circuit leaving the switch open and using two lamps of equal rating. **Do not proceed until you ASK YOUR INSTRUCTOR TO CHECK THE CIRCUIT.**

C3. Close the switch and record the reading on both meters.

C4. Open the switch and change connections so that the voltmeter will now be reading the voltage across the other lamp.

C5. Close the switch and record the reading on both meters.

C6. Open the switch and change connections so that the voltmeter will now be reading the voltage across both lamps.

C7. Close the switch and record the readings on both meters.
C8. Open the switch and remove the voltmeter from the circuit.

C9. Remove one lamp from its socket and read the ammeter.

C10. Record what happens to the other lamp.

D1. Draw a diagram of a circuit with the two lamps in parallel. Show an ammeter connected to read the combined current and a voltmeter connected to read the voltage across the lamps.

D2. Wire the circuit leaving the switch open. **Do not proceed until you ASK YOUR INSTRUCTOR TO CHECK THE CIRCUIT.**

D3. Close the switch and record the meter reading on the data sheet.

D4. Remove one lamp from its base and record the meter readings.

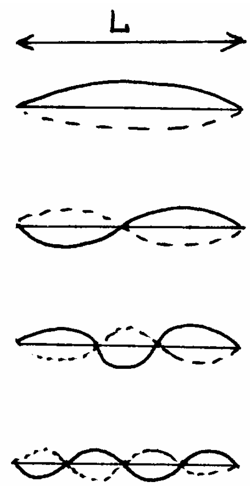
D5. Record what happens to the other lamp.

LAB 9: VIBRATIONS OF A TAUT STRING
"The Sonometer"

INTRODUCTION

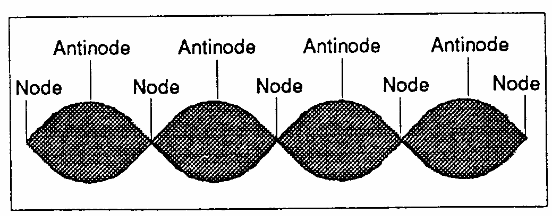
When you pluck a taut fixed string of length L, the resultant vibrations are a superposition of many simpler "standing wave" patterns as depicted below:

Mode	Wavelength	Frequency
$n = 1$	$\lambda_1 = 2L$	$f_1 = \frac{v_0}{\lambda_1}$
$n = 2$	$\lambda_2 = L$	$f_2 = \frac{v_0}{\lambda_2} = \frac{\lambda_1 f_1}{\lambda_2} = 2f_1$
$n = 3$	$\lambda_3 = \frac{2L}{3}$	$f_3 = \frac{v_0}{\lambda_3} = \frac{\lambda_1 f_1}{\lambda_3} = 3f_1$
$n = 4$	$\lambda_4 = \frac{L}{2}$	$f_4 = \frac{v_0}{\lambda_4} = \frac{\lambda_1 f_1}{\lambda_4} = 4f_1$



etc. for $n = 5, 6, 7, \ldots$

In general, $\lambda_n = 2L / n$, and $f_n = n f_1$, meaning that all harmonics are an integer multiple of a fundamental frequency f_1. Also note that points on a standing wave where there is no vibration are called **nodes** and points where there is maximum amplitude are called **antinodes.** For example, in the table above, for n = 3 there are two nodes and three antinodes. These nodes and antinodes are also depicted below:

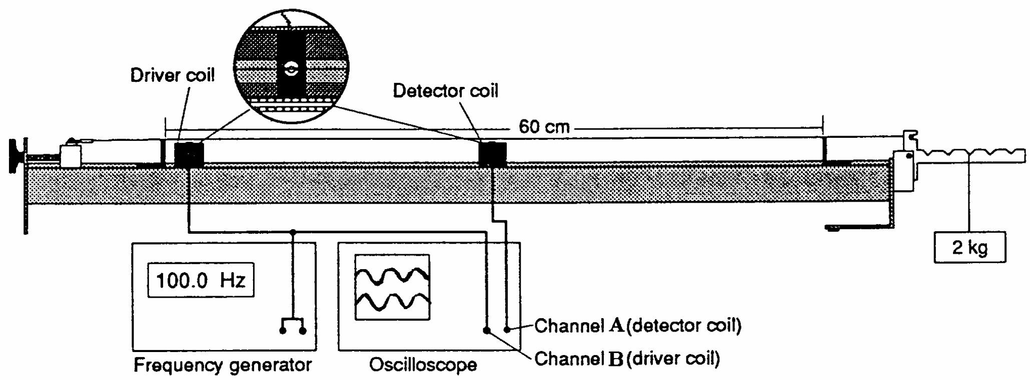


PURPOSE

In this exercise you will excite and study the first few vibrational modes of a taut string (a wire, really). You will use a *sonometer*, a single-string "musical" instrument described below.

EQUIPMENT AND SUPPLIES

1. Sonometer from Pasco Scientific. This instrument, shown below, allows a known tension to be placed on a guitar string whose vibrating length can be varied by movable "bridges."



2. A function generator. This can "drive" an electromagnet with AC current in the lower audio range. Note: The guitar string win be attracted to the AC electromagnet twice each AC cycle, because both the North and South poles are equally good at attracting the steel string.

3. "Detector" coils capable of detecting the AC motion of a steel string.

4. A dual-trace oscilloscope to display both the driving frequency and the detected string vibrational frequency.

5. A digital voltmeter (DVM) to obtain a 3-digit direct reading of the driving frequency. (The function generator dial can only be read to two significant figures, and we need the extra precision.)

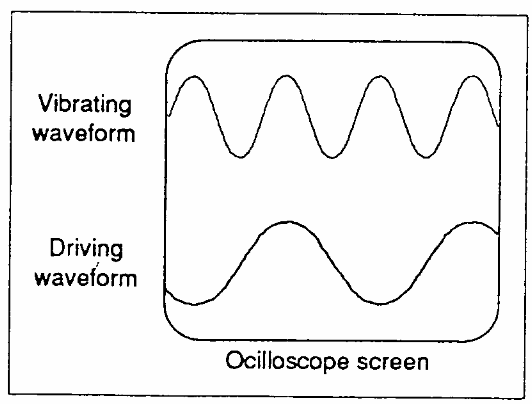


Figure 2. String vibrations at twice the driving frequency

PROCEDURE

A1. Set up the sonometer system. Set the bridges 60 cm apart. Hang a 2 kg mass from the tensioning lever. Adjust the string tensioning knob so the tensioning lever is horizontal.

A2. Position the driver coil about 5 cm from one of the bridges and the detector about 35 cm away from the same bridge.

A3. Gently pluck the string with a fingertip. The detector coil will pick up an induced voltage which you can see displayed on the oscilloscope. You can excite different waveforms by plucking in different places or with a different technique.

Play with this a while. You are seeing various mixes of harmonics (another name for the different modes corresponding to different values of n) being induced “excited” in the string.
Note: If the oscilloscope does not display, adjust the TRIGGERING: all three levers in the upper right corner should be flipped up, and the level knob pulled out (auto mode.) Also, adjust the trace position knobs as necessary.

A4. Set the signal generator to produce a sine wave and set the gain of the oscilloscope of channel B to 5 mvolts/cm.

A5. With the function generator amplitude set at about 12 o'clock slowly increase the frequency of the signal to the driver coils, starting from about 5 Hz.

Listen for an increase in sound from the sonometer and/or an increase in size of the detector signal on the oscilloscope screen. Frequencies that result in maximum string vibrations are the resonant frequencies. Determine the lowest frequency at which resonance occurs. This is the first or fundamental mode (n = 1). Measure this frequency and record it on the data sheet provided. Note: Because of the effect noted in the equipment section, the resonant frequency is twice the driving frequency.

Note: For the $n = 1$ mode, you should actually hear the sonometer hum and produce enough amplitude vibration to clearly see the central antinode and the node at the bridges.

A6. Continue increasing the frequency to find successive resonant frequencies for each mode - at least five or six. For each resonant mode you find, locate all the nodes, and record the distance between adjacent nodes. There are two ways to locate notes:

1. Use the "detector" provided as follows: Start with the detector as close as you can to the free bridge. Watch the oscilloscope display as you slide the detector slowly along the vibrating string. When you reach a node, the amplitude on the scope will drop to a minimum. (This method breaks down when you get too close to the "driver" and start to pick up its field directly.)

2. Use your fingers. Watch the oscilloscope display as you slide your fleshy fingertips along the vibrating string. Even a light touch will kill the vibrations everywhere except when you touch a node, where there is no vibration to kill, in any case. (Make sure that the detector is not accidentally left under a node or this won't work.)

A7. From your results, determine and record the wavelength of each resonant mode you find. Make use of the fact that the wavelength is twice the distance between adjacent nodes.

B1. Repeat the experimental procedure A for a string length of 50 cm, obtained by moving one or both of the bridges.

LAB 10: REFLECTION OF LIGHT

INTRODUCTION

The Law of Reflection is: angle of incidence = angle of reflection.

Each angle is measured between the ray and a line perpendicular (normal) to the surface. It is usually convenient to place the perpendicular to the surface at the point that the ray strikes and reflects from the surface.

Curved mirrors are portions of spheres or cylinders. If the mirror is the outside of such a surface, it is convex; if it is the inside surface, it is concave. The center of curvature of a curved mirror is the center of the sphere or cylinder of which it is a part. A line drawn from the center of the curvature to the center of the mirror is called the principal axis. A beam of rays parallel to the principal axis of a concave mirror can be shown to converge to one point after reflection, if the angle of incidence is small. This point is called the principal focus (focal point) and the distance from the mirror to this point is called the focal length. For a convex mirror, the principal focus is the point from which the reflected rays diverge.

PURPOSE

In this laboratory exercise the validity of the law of reflection is demonstrated and the effects of curved mirrors on rays of light are studied.

EQUIPMENT AND SUPPLIES

Ray board with converging lens, source of light, plane mirror, convex cylindrical mirror, concave cylindrical mirror, ruler, protractor, unlined white paper, and a well-sharpened hard pencil (to be supplied by student).

PROCEDURE

A1. Set up the ray board and light source, placing the converging lens in the wire holder and adjusting the metal shutter so that a single slit will be uncovered. See the diagram at the end of the procedure section. Move the light source or ray board until the ray is as narrow as possible. Place a plane mirror on edge on a piece of unruled white paper on the ray board. Allow the narrow ray to strike the mirror. Observe the path of the reflected ray.

A2. Rotate the mirror until the angle between the reflected ray and the incident ray is approximately 70 degrees. Judge "by eye" after studying a protractor. On the paper, carefully place a dot at each end of the reflecting surface of the mirror. Then place two dots, widely spaced, on the incident ray, and two dots, widely spaced, on the reflected ray. (Note, use a well sharpened pencil and be as accurate as you can in the placement of the dots. Poor attention to detail in your diagram will affect the accuracy of your data.)

A3. Remove the mirror. Use a straight edge to connect the dots in order to represent the mirror surface, the incident ray, and the reflected ray. Indicate the direction of each ray with an arrow. Use the protractor to draw a line perpendicular to the line representing the mirror at the point of incidence of the incident ray. Label this figure *Diagram 1.*

A4. Measure on Diagram 1 the angle of incidence and the angle of reflection. Record the result on the data sheet provided.

B1. Repeat Procedure A with the angle between the reflected ray and the incident ray approximately 60 degrees. After completing your diagram label it *Diagram 2.*

C1. Place the cylindrical mirror well above the middle of a sheet of unruled white paper. The convex surface of the mirror should face the top of the sheet. Draw a sharp fine line along this convex surface (from end to end). Remove the mirror and draw a line connecting the ends of the arc. Draw a dashed perpendicular at the midpoint of this chord, extending it through the arc. (Use your ruler to determine accurately the midpoint.) This line is perpendicular to the arc at its center.

C2. Reposition the mirror on its line. Allow a narrow ray to strike the center of the convex surface. KEEP THE MIRROR ON ITS TRACING and adjust the position of the light source until the angle between the incident ray and the reflected ray is approximately 70 degrees.

C3. Place two dots widely spaced on the incident ray and two dots widely spaced on the reflected ray.

C4. Remove the mirror. Connect the dots to represent the incident ray and the reflected ray. Indicate the direction of each ray by an arrow. Label this figure *Diagram 3.*

C5. On Diagram 3, measure the angle of incidence and the angle of reflection. Record the result on the data sheet.

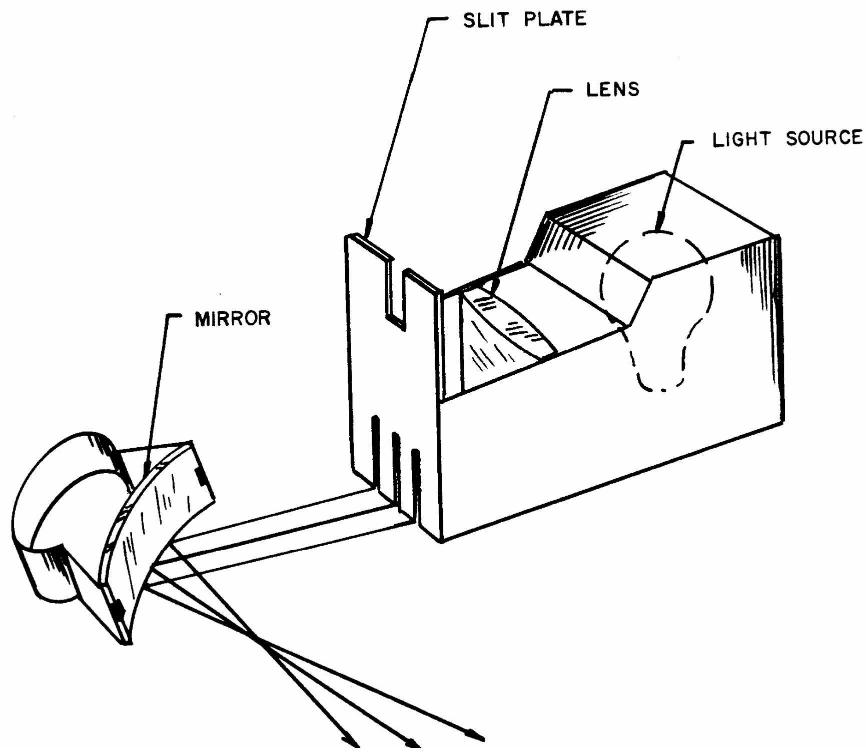
D1. Repeat Procedure C using the concave side of the cylindrical mirror. Label the diagram obtained in Procedure C, *Diagram 4.*

E1. Adjust the shutter so that three slits will be uncovered. Allow three parallel rays to strike the concave cylindrical mirror so that the reflected rays intersect on the middle ray. Trace the mirror and all the incident and reflected rays. Use the same technique as used above to include all the rays in your diagram. Label the figure *Diagram 5.*

E2. Measure the distance between the point of intersection of the reflected rays and the point where the middle ray is incident on the mirror. Record the result on the data sheet.

F1. Allow three parallel rays to strike the convex cylindrical mirror so that the middle ray is reflected back along itself. Trace the mirror and all the incident and reflected rays. Label the sheet *Diagram 6.*

F2. Use a dashed line to locate the point from which the reflected rays appear to be diverging. Measure the distance between this point and the reflecting surface of the mirror. Record the result on the data sheet.


SLIT PLATE
LENS
LIGHT SOURCE
MIRROR

LAB 11: REFRACTION OF LIGHT

INTRODUCTION

Objectives

In this laboratory exercise, we study the law of refraction and the formation of images by refraction.

Equipment and supplies

Light box, slits, plexiglass semicircular lens, semicircular water cell, ruler, protractor, white tracing paper.

Refraction

When light strikes the boundary between two media it may be reflected, transmitted, or absorbed. Often all these three processes occur simultaneously. If the velocities of light in two transparent media are different and if an incident ray is not normal (perpendicular) to the boundary separating the two media, the direction of the ray will be changed as it passes from one medium to the other. This bending of light is called refraction.
The **law of refraction of light**, discovered by Snell, is

$$\frac{\sin\theta_i}{\sin\theta_r} = n \qquad (1)$$

where θ_i = the angle between the incident ray and the normal to the surface separating the two media, θ_r = the angle between the refracted ray and the normal to the surface separating the two media, n = a constant depending on the two media called the index of refraction of the second medium (where the angle with the normal is θ_r) relative to the first medium (where the angle with the normal is θ_i).

The **index of refraction, *n***, is equal to the ratio of the speed of light in the first medium to the speed of light in the second medium and varies with the wavelength of the light.

$$n = \frac{v_1}{v_2}$$

The critical angle

When light with velocity v_1 passes from medium 1 into medium 2, where its velocity is v_2, it will bend away from the normal if v_2 is larger than v_1 (See Figure 1). As angle θ_i is increased, angle θ_r will increase to its maximum value of 90 degrees. The value of θ_i for which θ_r is 90 is called the critical angle. If θ_i is greater than θ_c, total internal reflection will occur and the light will not pass into the second medium. The index of refraction of medium 2 (n2) relative to that of medium 1 (n_1) is equal to sin θ_c since sin θ_r =1 (θ_r=90 degrees); i.e., the index of refraction of medium 1 relative to medium 2 is

$$n = \frac{1}{\sin\theta_c} \qquad (3)$$

If medium 2 is air (n=1), the index of refraction of medium 1 may be found by measuring θ_c and applying equation (3).

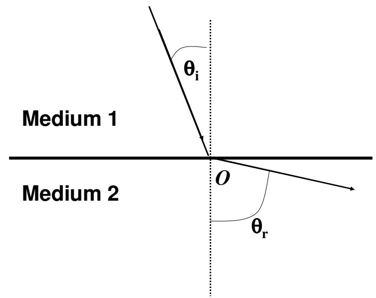


Figure 1. The light bends away from the normal when it enters Medium 2 in which the speed of light is larger.

Thus, the ratio of the speed of light in two media determines the amount of bending, or refraction, when light travels from one medium to another.

Rays of light parallel to the principal axis of a thin lens, thicker in the center than at its edges, converge after passing through the lens. The rays converge to a point whose location is determined by the radii of curvature of the surfaces of the lens and the index of refraction of the glass. These points (one on each side of the lens) are called the *principal foci*. The distance between a focus point and the lens is called the focal length, *f*. The object distance d_o (that is, the distance between the object and the lens), the image distance d_i (the distance between the image and the lens), and the focal length are related by the equation

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

The ratio of the size of the image to the size of the object is equal to the ratio of the image distance to the object distance, i.e.,

$$\frac{image\ \ size}{object\ \ size} = \frac{d_i}{d_o}$$

EQUIPMENT AND SUPPLIES

Ray board with converging lens, glass segments, convex spherical lens, source of light, ground glass plate, metal stencil, screen, meter stick, ruler, protractor, and sharp pencil (to be supplied by the student).

PROCEDURE

A1. Place the converging lens in the wire holder and adjust the metal shutter so that a single slit is uncovered. Move the light source or ray board until the ray is as narrow as possible. Place a sheet of paper on the ray board. Allow the narrow ray to strike one surface of the triangular glass segment provided. Rotate the prism until the ray bends appreciably when it enters the glass and again when it emerges from the glass. (Do not allow the ray to strike any corners.)

A2. Trace the glass prism. Use two widely spaced dots to indicate the direction of the entering ray and two dots to indicate the emerging ray.

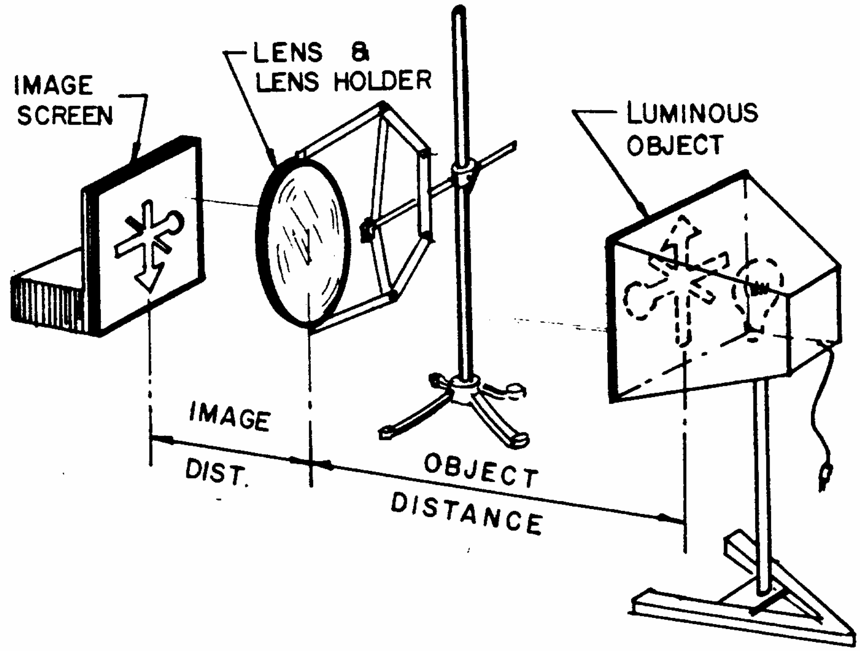
A3. Remove the prism. Draw lines to indicate the paths of the incident and emergent rays in air and a third line to indicate the path of the light through the glass.

A4. Construct dotted "normals" at the points of incidence and emergence. Measure and record on your diagram, and on the data sheet provided, the angle of incidence and the angle of refraction both when the ray enters the prism as well as when it leaves the prism. (These angles are measured from the normal). Label this figure *Diagram 1*. Remember to write your name and the date at the top of each sheet containing diagrams.

B1. Repeat Procedure A allowing the narrow ray to strike the curved surface of the semi-circular glass segment at an angle of incidence of at least 30 degrees. Label this figure *Diagram 2*.

C1 Arrange three parallel rays perpendicularly incident on the plane surface of the semi-circular glass segment so that the middle ray hits the midpoint. Trace the segment, the incident rays, the refracted rays in glass, and the reflected rays in air. Label this figure *Diagram 3*.

D1. Arrange three parallel rays to strike the circular glass segment so that the middle ray travels along a diameter inside the glass. Trace the segment and rays as in Procedure C. Label this figure *Diagram 4*.



E1. Arrange three parallel rays to strike the double convex glass segment symmetrically. Again, trace the segment and rays as in Procedures C and D. Label this figure *Diagram 5.*

F1. Use the double concave glass segment and repeat Procedure E. Leave enough space on the paper so that you can, by means of dotted fines, locate the point from which the emerging rays appear to come. Label this figure, *Diagram 6.*

For Procedures G1 to G4, record on the data sheet the object distance, the image distance, the size of object and the size of the image.

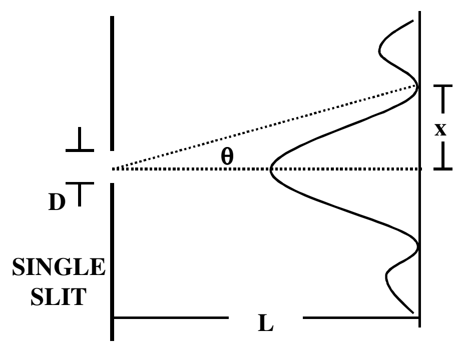
G1. By trial and error arrange a converging lens, object and screen so that when the image is in sharp focus on the screen, the image distance equals the object distance.
G2. Choose an object distance that is 10 cm longer than the object distance in Procedure Gl. Move the screen until a sharp image is formed.
G3. Choose an object distance equal to the image distance obtained in Procedure G2. Move the screen until a sharp image is formed.
G4. Choose an object distance of 200 cm. Move the screen until a sharp image is formed.
G5. Obtain a sharp image of the skyline. Since the object distance is effectively infinite, the image distance equals the focal length of the lens.

LAB 12: THE WAVELENGTH OF LIGHT

INTRODUCTION

Diffraction

When plane waves of light of a single wavelength illuminate a narrow slit, light can diffract around the edges, giving rise to bright and dark fringes. To see how a diffraction pattern arises, parallel rays fall on the slit of width *D* as shown in Figure 2.



A beam of light perpendicularly incident on a system of evenly spaced slits (a diffraction grating) results in constructive and destructive interference. By knowing the angle between the direction from the eye to the regions of constructive interference (bright images) and the direction from the eye to the light source and by knowing the number of grating lines per unit length, one can determine the wavelength of the light that is producing the interference pattern. These quantities are related by the equation,

$$n\, k\, \lambda = \sin \theta$$

where n is the order of the image (the first image is order one, the second image is order 2, etc.), λ is the wavelength, k is the number of grating lines per unit length and θ is the angle between the direction to the light source and the direction to the image. In this Laboratory Exercise, we utilize the bending of light produced by a diffraction grating to measure the wavelength of light.

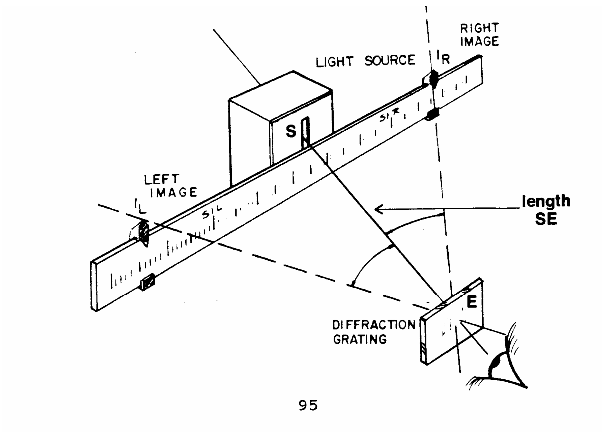
PURPOSE

In this Laboratory Exercise, we observe various spectra and measure some wavelengths of visible light.

EQUIPMENT AND SUPPLIES

Light sources, meter stick and diffraction grating which is a replica made from an original grating scratched on metal by means of a precise ruling engine - the number of lines per centimeter (or inch) is marked on the replica.

PROCEDURE



A1. On the data sheet provided, record the number of lines per centimeter marked on the grating. Look through the grating at a vertical slit illuminated by a sodium arc. If the grating is held correctly, you can observe that in addition to the image of the original slit, S, you see at least one image of the slit to the right, I_L and one image to the left, I_R . These images are the backward extension of the rays bent by the grating. Observe that the side images are fainter than the image of the original slit. Look for images farther to the right and to the left. (The first image to the right or to the left is called an image of the first order; the second image is called an image of the second order and so on.) The sodium arc is used first because it produces most of its intensity as nearly monochromatic yellow light with wavelength λ = 589.3 nm (nanometer). Note that 1 nm = 1 x 10^{-9} m.

B1. Look through the grating at the slit illuminated by a sodium arc. Have your partner place a marker on the meter stick above the apparent position of the first order image on the right, i.e., above I_R.

B2. Measure and record the distances SE and SI_R for the first order image. Note that the tangent of the angle between SE and SI_R equals SI_R/SE.

B3. Repeat Procedures Bl and B2 for the image on the left keeping SE constant. Record SE and SI_L on the data sheet.

B4. Repeat Procedures BI, B2 and B3 with a different value of SE.

C1. Look through the grating at the slit illuminated by "white" light produced by the tungsten lamp (an ordinary filament bulb whose light is produced by a glowing white hot metal wire in an evacuated glass bulb). Observe that instead of a simple image there is a continuous spectrum on either side of the original slit. This is because there is a separate image for each wavelength of light but each image blends into the next one. Select a particular blue region in the spectrum in the right image and direct your partner to mark it with the marker. Then, after locating the same blue region in the spectrum in the left image, again have your partner mark the location. The wavelength for blue light is roughly 470 ± 20 nm.

C2. Measure and record SE, $(SI_R)_{blue}$ and $(SI_L)_{blue}$.

C3. Repeat Procedures Cl and C2 using a particular region in the red portion instead of the blue portion of the spectrum. Again measure and record SE, $(SI_R)_{red}$ and $(SI_L)_{red}$. The wavelength for red light is roughly 650 ± 20 nm.

D1. Obtain a second set of data by repeating Procedure C after changing places with your partner.

E1. Look through the slot illuminated by the mercury source, and observe the discrete colored images of the slit. Locate and mark the position of a green image on the right and on the left. Note, the wavelength for the green mercury light is 546.0 nm.

E2. Measure and record SE, $(SI_R)_{green}$ and $(SI_L)_{green}$.

LAB 1. PRELAB ASSIGNMENT

Name _______________________Date completed_______________________________

Complete the homework problems on this sheet and give the sheet to your instructor at the beginning of the laboratory session.

Problem 1.

A block of wood has dimensions 10.20 cm by 10.15 cm by 2.45 cm. What is the volume of this block in units of cubic centimeters? (By all means, use your calculator.)

a) 253.6485
b) 253.65 Answer:___________________
c) 253.7
d) 254

Now, if the mass of the block is 175.2 g, find the density.

Density = _________________g/cm^3

Assume that the accepted value is 0.665 g/cm^3. Determine the percent deviation of your result from the expected value.

Percent Deviation:_____________________%

Note: Percent Deviation is (the difference between your value and the accepted value) times 100, then divided by the accepted value. In this course we shall report percent deviations to one significant figure.

Problem 2.

A student measures the mass of 49.4 cm^3 of water and finds the mass to be 50.2 g. Assume that the accepted value is 1.00 g/cm^3. Compute the density of the water and the percent deviation.

Density = ____________________ Percent Deviation = ________________%

Remember to include the units with the density.

Note: If you did these problems correctly, your value of density should have agreed with the expected value to within four percent, in Problem 1. In Problem 2, on the other hand, agreement is good to within two percent.

LAB 1. DATA SHEET Name________________ Date:____________

Instructor:__________________________**Partners:**__________________________

A)Density of wood block.

Mass of block	

length (*l*)	width (*w*)	thickness (*t*)

average *l*	average *w*	average *t*	Volume	computed density (*D*)	accepted value of *D*	percent deviation

B) Density of other solids. Take all necessary data, and present both data and computed results in tabular form below. Think about the layout of your tables, perhaps guided by the above example.
C) Density of liquids.

Mass of DRY grad cylinder	mass of water plus cylinder	net mass of water	volume of water	computed density	% deviation
a)					
b)					

Mass of graduated cylinder + alcohol	net mass of alcohol solution	volume of alcohol solution	computed density
a)			
b)			

Class average of Procedure A5, from blackboard:

____

Questions

1. To within what percent did you show that the density of aluminum is a constant and is independent of the shape of the sample?

2. How do substances that float in water differ from those that do not? (Hint: Name the property of the substance you will use for the comparison.)

3. Compare your result for the density of maple wood to the average value of the density obtained by your classmates. Refer to the blackboard. Your answer should be expressed as a percent deviation. Is the spread in values on the blackboard consistent with the number of significant figures each has reported? Give the criteria you used to answer this last question.

LAB 2. PRELAB ASSIGNMENT

Your name:_______________________ Date completed:____________________________

Read the section in your Physics text that discusses buoyancy and Archimedes' Principle. Then complete the homework problems on this sheet and give the sheet to your instructor at the beginning of the laboratory session.

1. An object weighs 230 N (kg-m/sec$^{2)}$ in air. If it displaces 92 N of water (92 cm^3), what is the specific gravity of the object?

2. It takes only 9.12 N of force to hold up a one-kilogram metal crown in water. Compute the specific gravity of this metal, and guess what element it might be. (See table of densities in the preceding **Density** lab.) Justify your guess. If you were the monarch how would you reward the goldsmith? (No need to justify this answer.)

3. Deduce the specific gravity of polar ice from the observation that “the tip of the iceberg that shows above water is only 10% (by volume) of the total.”

LAB 2. DATA SHEET Name: ___________ Date: ________________

Instructor: ________________________ Partners: _____________________________

A. Measuring the specific gravity of a chunk of marble.

Weight of marble chunk	Weight of overflow can and initial water	Weight of overflow can and final overflow water	Net weight of overflow water	Volume of overflow water	Volume of marble chunk	Density of marble chunk	Specific gravity of marble chunk

B. Measuring the buoyant force on a submerged object

Type of Metal	Weight	Apparent weight in water	Apparent loss of weight (Buoyant force)	Specific gravity of metal sample	Apparent weight of metal in alcohol
a)					
b)					

Apparent loss of weight (buoyant force)	Density of alcohol	Specific gravity of alcohol
a)		
b)		

C. Specific gravity of a floating object (block of wood)

Length of block	Weight of block	Water level before immersion	Water level after immersion	Volume of displaced water	Weight of displaced water
a)					
b)					

Length of block **above** water level	Computed length of block **below** water level	Volume of wood block	Density of wood block	Specific Gravity of wood block	

LAB 3. PRELAB ASSIGNMENT

Your name:___________________________ Date completed_________________________

Complete the homework problems on this sheet and give the sheet to your instructor at the beginning of the laboratory session.

1. The equation $d = \frac{1}{2} a t^2$, that is, *the distance traveled is equal to one half the acceleration times the square of the time taken for the trip*, is incorrect if the trip began with a nonzero velocity. Circle the correct answer.

TRUE FALSE

2. Use your calculator to compute the values of the six quantities left blank in the table below. Note that according to Equation (1) the fourth entry in each row is just the acceleration for the trip.

d	t	t^2	$2d/t^2$
40.0 cm	10.3 sec		
60.0 cm	12.6 sec		
100.0cm	16.3 sec		

3. Using the above values, determine the average value of the acceleration for the three trips.

LAB 3. DATA SHEET (A) Name: ____________ Date: ____________

Instructor: ________________________ **Partners:** _____________________________

Data for smaller inclination angle:

d (cm)	t (sec)	average time $<t>$, (sec)	$<t>^2$ (sec^2)	$a=2d/<t>^2$ (cm/sec^2)	% deviation of a from $<a>$
20.0 cm	a) b) c)				
40.0 cm	a) b) c)				
60.0 cm	a) b) c)				
80.0 cm	a) b) c)				
100.0 cm	a) b) c)				

Compute the average acceleration, $<a>$ = _________

Compute the average percent deviation:___________

Data for larger inclination angle:

d (cm)	*t* (sec)	average time <*t*>, (sec)	$<t>^2$ (sec^2)	$a=2d/<t>^2$ (cm/sec^2)	%deviation of *a* from <*a*>
20.0 cm	a) b) c)				
40.0 cm	a) b) c)				
60.0 cm	a) b) c)				
80.0 cm	a) b) c)				
100.0 cm	a) b) c)				

Compute the average acceleration, <*a*> = _________

Compute the average percent deviation:___________

LAB 3. DATA SHEET (B) Name: ____________ Date: ___________

Instructor: ________________________ Partners: _____________________________

Questions

1. Plot a graph of *d* versus $<t>^2$ using the data obtained for each angle of inclination. The origin should be included in your plot (Why?). If you do the plot by hand, instead of using the laboratory plotting software, choose the scale for the two axes so that the data points occupy a considerable fraction of the grid. You will need to do some preliminary planning before committing yourself to a final graph. For each graph, label both axes and include a title.

2. On the graph prepared for each angle of inclination draw the best straight fit to the data points. Force the line to go through the origin. Determine the value of the slope of each line and the value of twice the slope. What is the physical meaning of the value of twice the slope?

	smaller inclination	larger inclination
slope		
twice the slope		

3. Using the same data, you have computed the acceleration of the disk both algebraically and graphically. Are your two results for the acceleration consistent? What criterion did you use to decide the consistency of your results?

LAB 4: PRELAB ASSIGNMENT

Your name:____________________ Date completed:__________________________________

Complete the homework problems on this sheet and give the sheet to your instructor at the beginning of the laboratory session.

1. In measuring the time it takes for fifty oscillations of a pendulum, Mo and Curly obtain results of 50.0 sec and 50.5sec, respectively. Thus, their measurements of time differ by 1%. If they each use the value $L = 25.3$ cm for the length of the pendulum, compute the value each student obtains for g.

Mo's value for g:___________

Curly's value for g:_________

2. By what percent do the above two results differ from one another? Why is this twice as large as the error in T?

3. Start with the pendulum equation $T^2 = 4\pi^2 L / g$, and convince yourself that a straight line would result if you plot $4\pi^2 L / g$ versus T^2. (Hint: think of T^2 as x, and of $4\pi^2 L / g$ as y.)

What would be the slope of this line? slope:__________

LAB 4: DATA SHEET Name: ____________ Date: ___________

Instructor: ________________________ **Partners:** _____________________________

Pendulum length L (cm)	Time for 50 oscillations (sec)	Average period (sec)	T^2 (sec^2)	$4\pi^2 L / T^2$ (cm/sec^2)
	a) b) c)			
	a) b) c)			
	a) b) c)			

Computed average value of g:__________

Accepted value of g = 9.80 m/sec^2 = 980 cm/sec^2

Percent deviation:__________

The value of g obtained from the slope of the graph from Procedure 7:_________

These two values should be within the precision of your experiment. Are they?

☐ Yes - Laboratory report is finished.

☐ No - Go back and check your calculations.

LAB 5: PRELAB ASSIGNMENT

Your name:_________________________ Date completed:____________________________

Complete the homework problems on this sheet and give the sheet to your instructor at the beginning of the laboratory session.

1. An ideal gas at atmospheric pressure (760 mm Hg) and room temperature (300 K) occupies a cylindrical column that is 10 cm in height. With the temperature held constant, the pressure is increased by 100 mm Hg. Find the new height of the column (in centimeters).

Height:___________

2. An ideal gas at atmospheric pressure and room temperature occupies a cylindrical column that has a height of 10 cm. The temperature of the gas is increased 25° C. What is the new height of the gas column?

Height:___________

LAB 5: DATA SHEET Name: ____________ Date: ___________

Instructor: ________________________ **Partners:** _____________________________

A. BOYLE'S LAW:

Air temperature in degrees Celsius: __________ and in degrees Kelvin: _________

Barometric pressure: _________ mm of Hg

Length of *mercury column* in air thermometer: _________mm of Hg

Orientation of Thermometer	Pressure, P mm Hg	Air Length, L cm	1 / L cm^{-1}	P×L
right-side-up				
horizontal				
upside-down				

Average value of $P \times L$: _________________

Average percent deviation of $P \times L$: _________________

Plot the pressure P versus the inverse length 1 / *L*. To the degree that your data points are along a straight line that passes through the origin, you have verified Boyle's law. Do you understand why?

B. CHARLES' LAW

	T (Celsius)	L (cm)
ice water bath		
room temperature		
boiling water		

Plot the length L versus the temperature T, in degrees Celsius. Make the horizontal axis range from minus 300 to plus 100 degrees Celsius. Extrapolate the best straight-line fit to your data in order to discover the Celsius temperature at which the volume of the enclosed air would go to zero. This temperature is Absolute Zero in degrees Celsius.

Your determination of the value of absolute zero in degrees Celsius: _______________
Percent deviation from accepted value: __________

LAB 6: PRELAB ASSIGNMENT

Your name:________________________ Date completed:_____________________________

Complete the homework problems on this sheet and give the sheet to your instructor at the beginning of the laboratory session.

The following information is to be used in the solution of the three problems below. A 50 gram metal can has a specific heat capacity of 0.1 cal/g°C and contains 50 grams of water. These two bodies, the metal can and the water, cool down together from 50 °C to 30 °C. The specific heat capacity of water is 1.0 cal/g °C.

1. Compute the heat lost by the metal can alone.

2. Compute the heat lost by the water alone.

3. Determine the total heat lost by the system.

LAB 6: DATA SHEET Name: ____________ Date: ___________

Instructor: _________________________ Partners: ______________________________

Procedure A.

Specific heat of the calorimeter (inner can and stirrer):

Mass of the calorimeter inner can and stirrer:

Mass of calorimeter inner can and stirrer and cold tap water:

Compute the mass of the cold tap water:

Temperature of the cold water: Temperature of the hot water:

Equilibrium temperature of the stirred hot and cold water (now tepid):

Mass of the calorimeter, stirrer and tepid water:

Compute the mass of the tepid water:

Compute the mass of the hot water you added:

Increase in the temperature of the cold water:

Decrease in the temperature of the hot water:

Heat gained by the cold water: Heat gained by the calorimeter can and stirrer:

Total heat gained by the cold system: Heat lost by the hot water:

Heat unaccounted for (difference in the two computations above):

To what percent have you verified the conservation of energy in your experiment, i.e., the heat unaccounted for is what percent of the (average) heat transferred in your experiment?

______________%

Procedure B.

Mass of the calorimeter (inner can and stirrer) from Part A:

Combined mass of calorimeter and cold water:

Compute the mass of cold water alone:

Temperature of cold water: Temperature of the hot metal pellets:

Highest temperature reached by mixture:

Mass of the calorimeter with the final contents:

Compute the mass of the aluminum pellets alone:

Compute the temperature change of the pellets:

Write an expression for the heat lost by the pellets in terms of the unknown specific heat capacity, c.

Change in temperature of the calorimeter and cold water:

Mass of the calorimeter (inner can and stirrer) from Part A:

Specific heat capacity of the calorimeter (can and stirrer):

Heat gained by the calorimeter alone:

Heat gained by the cold water alone:

Heat gained by the calorimeter and water:

Compute experimentally determined specific heat of the pellets:

Correct specific heat of the pellets (ask Lab Instructor):

Percent deviation between computed and correct values: _______________%

LAB 7: PRELAB ASSIGNMENT

Your name:________________________ Date completed:_____________________________

Complete the homework problems on this sheet and give the sheet to your instructor at the beginning of the laboratory session.

1. How much heat is required to raise the temperature of 238 grams of aluminum from 27.1°C to 35.6°C? (c = 0.220 kcal/kg°C)

2a. One complete revolution is how many degrees? ___________

2b. One complete revolution is how many radians? ___________

2c. 345 revolutions is equivalent to how many radians? ___________

3. A car with locked brakes skids to a stop in 11 meters. The total frictional force on the car is 34,000 N. How much work was done by friction?

LAB 7: DATA SHEET Name: ____________ Date: ____________

Instructor: ________________________ **Partners:** ______________________________

I. VERIFY THAT 1 KCAL = 4186 JOULES.

A. Fixed parameters

Specific heat of aluminum, c = 0.220 kcal/kg°C Mass of aluminum cylinder, m = _________

Diameter of cylinder, D_1 =_________ Diameter of cylinder plus rope, D_2 =______

Average, Do = $(D_1 + D_2)/2$ =_________ Average Radius, R = Do/2 =_________

Mass of "10 kg" mass, to 3 significant figures, m =__________kg

Weight of "10 kg" mass, to 3 significant figures, F =__________Newtons

B. "Quick and Dirty" Run

B1. Approximate *initial* temperature:

Thermistor Resistance =_________
Corresponding Temperature = __________

"Target" *final* temperature:

Target Temperature =_________
Thermistor Resistance=__________

B2. Actual *starting* temperature:

Thermistor Resistance =__________
Corresponding Temperature =____________

B3. Actual *final* temperature:

Thermistor Resistance =__________
Corresponding Temperature =___________

B4. Number of turns, N =__________ Total angle, $\theta = 2\pi N$=___________radians

B5. Computed total work you did, $W = F R \theta$ =___________Joules

Computed heat input to Aluminum cylinder, $Q = mc\Delta T$ = ___________kcal

Your computed Mechanical Equivalent of Heat (ratio of above two results):_______________
(Recall: Energy is conserved so the heat energy Q must be converted to mechanical energy W, and therefore $FR\theta$ must equal $mc\Delta T$.)

Percent deviation of your result from the accepted value of 4186 J/kcal? ____________ %

C1. Room Temperature today ____________°C

Target initial temperature ____________°C

Corresponding Thermistor Resistance __________Ω

Target final temperature _____________°C

Corresponding Thermistor Resistance ____________Ω

C2. Actual initial temperature:

Thermistor Resistance =__________

Corresponding Temperature = _____________°C

Actual final temperature:

Thermistor Resistance =__________

Corresponding Temperature = _____________°C

Number of Turns__________ Total angle, $\theta = 2\pi N$ =____________radians

C3. Compute the total work you did against friction:

$W = FR\theta$ = ___________joules

Compute the amount of heat that must have been transferred to the aluminum,

$Q = mc\Delta T$ = ____________kcal

Compute the Mechanical Equivalent of Heat and the percent deviation:

D. Did you do better in Part C than in Part B? If not, what went wrong? Give reasons.

LAB 8: PRELAB ASSIGNMENT

Your name:________________________ Date completed:_____________________________

Complete the homework problems on this sheet and give the sheet to your instructor at the beginning of the laboratory session.

1. The current through a resistor is 0.l ampere and the voltage across it is found to be 10.6 volts. What is the value of the resistor?

2. Draw a schematic circuit diagram of two resistors, each 100 ohms, in series with a 20 volt battery. Show a voltmeter connected to measure the voltage drop across the battery.

3. Draw a schematic circuit diagram of two resistors, 100 ohm and 200 ohm, connected in parallel with a 12 volt battery. Show an ammeter connected to measure the current through the 100 ohm resistor.

LAB 8: DATA SHEET Name: ____________ Date: ___________

Instructor: ________________________ **Partners:** _____________________________

Procedure A		Procedure B	
V (volts)	I (amps)	V (volts)	I (amps)

Value of R_1 obtained from your instructor:

C1. Draw a circuit diagram for the lamps in series.

C3. V for lamp #1_________ I for lamp #1__________

C5. V for lamp #2_________ I for lamp #2

C7. V for both lamps__________ I for both lamps__________

C9. When one lamp is removed, the current is I = _________

C10. Is the other lamp lit or unlit? __________

D1. Draw a circuit diagram for the lamps in parallel.

D3. V = __________ I = __________

D4. When one lamp is removed, V = __________, and I = __________

D5. What happens to the other lamp?

Questions:

1. Plot a graph of the voltage (ordinate) versus the current (abscissa) for the data obtained in Procedure A. What is the slope of this graph? Compare the result you obtain for the slope with the known value.

2. Use the data obtained in Procedure B to answer the following questions:

a) As the current increases, what is the direction of the voltage change?

b) As the current increases how does the resistance of the lamp change?

c) How might we explain this change in resistance?

3. Why is it inconvenient to have lamps (or other appliances) connected in series?

4. Explain the meter readings in Procedure D. What meter readings would you expect if three such lamps were connected in parallel?

LAB 9. PRELAB ASSIGNMENT

Your name:________________________ Date completed:_____________________________

Complete the homework problems on this sheet and give the sheet to your instructor at the beginning of the laboratory session.

1. A wave of frequency 400.0 Hz has a wavelength of 23 cm.

   a) What is the period of the wave in seconds?

   b) What is the period of the wave in ms (milliseconds)?

   c) What is the wave speed in m/s (meters per second)?

2. An oscilloscope is set-up to display the above sinusoidal wave as a function of time. If the horizontal axis is calibrated at 1 millisecond/cm, what will be the spacing in centimeters between successive maxima on the screen?

LAB 9. DATA SHEET Name: ____________ Date: ____________

Instructor: ________________________ **Partners:** _____________________________

1. For a given value of *n* what mathematical relationship holds between the length *L* and the wavelength λ?

Procedure A: String length, L = __________

n = 1 Driver frequency =__________

Actual string frequency f (twice driver frequency) = __________

Distance between nodes L =__________ wavelength =λ_1 = ____________

n = 2 Driver frequency =__________

Actual string frequency f_2 (twice driver frequency) = __________

Distance between nodes =__________ wavelength =λ_2 = ____________

n = 3 Driver frequency =__________

Actual string frequency f_3 (twice driver frequency) = __________

Distance between nodes: __________ __________

Average distance between nodes =__________ wavelength =λ_3 = ____________

n = 4 Driver frequency =__________

Actual string frequency f_4 (twice driver frequency) = __________

Distance between nodes: __________ __________ __________

Average distance between nodes =__________ wavelength =λ_4 = ____________

n = 5 Driver frequency =__________

Actual string frequency f_5 (twice driver frequency) = __________

Distance between nodes: __________ __________ __________ __________

Average distance between nodes =__________ wavelength =λ_5 = ____________

n = 6 Driver frequency =___________

Actual string frequency f_6 (twice driver frequency) = ___________

Distance between nodes: ___________ ___________ ___________ ___________ ___________

Average distance between nodes =___________ wavelength =λ_6 = _____________

n = 7 Driver frequency =___________

Actual string frequency f_7 (twice driver frequency) = ___________

Distance between nodes: ___________ ___________ ___________ ___________ ___________ ___________

Average distance between nodes =___________ wavelength =λ_7 = _____________

2a. Plot your values of the resonant frequencies versus n, the mode number. On the same graph, draw the best straight-line fit that goes through the origin. This line is the theoretical result,

$$f_n = n f_1$$

2b. The slope of this best straight-line fit to the data (which passes through the origin) is just the fundamental frequency, f_1, obtained from all your data, not just your first measurement. How good is the agreement?

Procedure B: Use your own data sheet for this part. Take all necessary data, and present data and calculations in neat tabular form.

3. To what extent do your results in Procedure B verify the relationship given in the answer to question 1?

4. For each mode you identified and recorded in the data sheets, compute the wavespeed. Compute the average value, and quote the uncertainty of your measurement as a percent.

LAB 10. PRELAB ASSIGNMENT

Your name:________________________ Date completed:_____________________________

Complete the homework problems on this sheet and give the sheet to your instructor at the beginning of the laboratory session.

1. State the law of reflection for plane mirrors.

2. Define the focal length of a concave mirror. Draw a diagram to illustrate your definition.

LAB 10. DATA SHEET Name: _____________ Date: ____________

Instructor: _________________________ Partners: ______________________________

Record the results for Procedures A to F

A. Angle of incidence =__________ Angle of reflection =__________

B. Angle of incidence =__________ Angle of reflection =__________

C. Angle of incidence =__________ Angle of reflection =__________

D. Angle of incidence =__________ Angle of reflection =__________

E. The focal length of the concave cylindrical mirror is __________

F. The focal length of the convex cylindrical mirror is __________

Questions:

1. Do the results obtained in Procedures A and B using the plane mirror verify the law of reflection? Explain.

2. Do the results obtained in Procedures C and D using the convex and concave cylindrical mirrors confirm the law of reflection? Explain.

3. For cylindrical mirrors, the focal length, f, is equal to one-half the radius of curvature. Obtain the radius of curvature of the cylindrical mirrors that were used and determine if the experimentally determined focal length equals one-half the radius of curvature.

LAB 11. PRELAB ASSIGNMENT

Your name:________________________ Date completed:_____________________________

Complete the homework problems on this sheet and give the sheet to your instructor at the beginning of the laboratory session.

1. Describe how you would determine the ratio of the velocity of light in water to the velocity of light in glass, using geometrical optics.

2. Draw a diagram to show how a converging lens can be used as a "magnifying" lens.

3. Draw a diagram to illustrate total internal reflection.

LAB 11. DATA SHEET Name: ____________ Date: ___________

Instructor: ________________________ **Partners:** _____________________________

Procedure A

1. Ray traveling from air into glass prism.

Angle of incidence = __________ Angle of refraction =__________

2. How is the ray bent when it travels from air into glass?

3. What is the index of refraction of glass? __________

4. Which is the greater value, the speed of light in air or the speed of light in glass? Explain.

5. Ray traveling from glass prism into air.

Angle of incidence = __________ Angle of refraction =__________

6. Use these data to obtain the ratio of the speed of light in glass to the speed of light in air.

Procedure G

G1. Object Distance = __________ Object Size =__________

Image Distance =__________ Image Size =__________

Image Distance/Object Distance =__________

Image Size/Object Size =__________

Reciprocal of Object Distance=_________

Reciprocal of Image Distance=__________

Reciprocal of Focal Length =__________ Focal Length =__________

G2. Object Distance =__________ Object Size =__________

Image Distance =__________ Image Size = __________

Image Distance/Object Distance =__________

Image Size/Object Size =__________

Reciprocal of Object Distance=________ Reciprocal of Image Distance =_________

Reciprocal of Focal Length =_________ Focal Length =__________

G3. Object Distance =_________ Object Size =__________

Image Distance =__________ Image Size =__________

Image Distance/Object Distance =__________

Image Size/Object Size =__________

Reciprocal of Object Distance =_________

Reciprocal of Image Distance =_________

Reciprocal of Focal Length =_________ Focal Length =_________

G4. Object Distance =_________ Object Size =__________

Image Distance =__________ Image Size = __________

Image Distance/Object Distance =_________

Image Size/Object Size =__________

Reciprocal of Object Distance =________ Reciprocal of Image Distance =_________

Reciprocal of Focal Length = __________ Focal Length =___________

G5. Focal Length = __________ Image Distance =__________

7. Compare the ratios obtained in GI to G4 above. What law do these ratios illustrate? To what percent are your ratios in agreement with the law?

8. Compute the average focal length obtained in GI to G4 above and compare the result with the focal length measured in G5.

LAB 12. PRELAB ASSIGNMENT

Your name:________________________ Date completed:_____________________________

Complete the homework problems on this sheet and give the sheet to your instructor at the beginning of the laboratory session.

Light of wavelength λ meters strikes a diffraction grating ruled with k lines per meter. The angular deviation of the first order diffraction maximum, θ is given in terms of λ and k by the expression

$$k \lambda = \sin \theta$$

1. If k = 7500 lines per cm, at what angle, to the nearest degree, would you find the first order maximum for green light of wavelength 500 millimicrons? A micron is a millionth of a meter. Therefore,

$$500 \text{ millimicrons} = 500 \text{ nanometers} = 5 \times 10^{2} \times 10^{-9} \text{ m} = 5 \times 10^{-7} \text{ m}$$

Angle =___________

2. If the diffraction grating in Problem 1 is used, what is the wavelength of light for which the diffraction angle is 30 degrees?

Wavelength =_________

LAB 12. DATA SHEET Name: ____________ Date: ___________

Instructor: _________________________ **Partners:** ______________________________

A1. Number of lines per cm = __________ per meter =__________

B2. SE = __________ SI_R =_________ tan A __________

B3. SI_R =__________ tan A =__________

Average value of tan A =__________ sin A =__________

Wavelength =__________ Accepted value =__________ Deviation =__________

B4. SE =_________ SI_R =__________ tan A =_________

SI_L =__________ tan A =_________

Average value of tan A =__________ sin A =__________

Wavelength =__________ Accepted value =__________ Deviation =__________

C2. Blue Region in Tungsten spectrum

SE =__________ SI_R =__________ tan A =__________

SI_L =__________ tan A =__________

Average value of tan A=__________ sin A =__________

Wavelength =__________ Accepted value =__________ Deviation=________

C3. Red Region in Tungsten spectrum

SE =__________ SI_R =__________ tan A =__________

SI_L =__________ tan A =__________

Average value of tan A=__________ sin A =__________

Wavelength =__________ Accepted value =__________ Deviation=________

D1. Blue Region in Tungsten spectrum

SE =__________ SI_R =__________ tan A =__________

SI_L =__________ tan A =__________

Average value of tan A=__________ sin A =__________

Wavelength =__________ Accepted value =__________ Deviation=_________

D1. Red Region in Tungsten spectrum

SE =__________ SI_R =__________ tan A =__________

SI_L =__________ tan A =__________

Average value of tan A=__________ sin A =__________

Wavelength =__________ Accepted value =__________ Deviation=_________

E1. Green Region in mercury spectrum

SE =__________ SI_R =__________ tan A =__________

SI_L =__________ tan A =__________

Average value of tan A=__________ sin A =__________

Wavelength =__________ Accepted value =__________ Deviation =__________