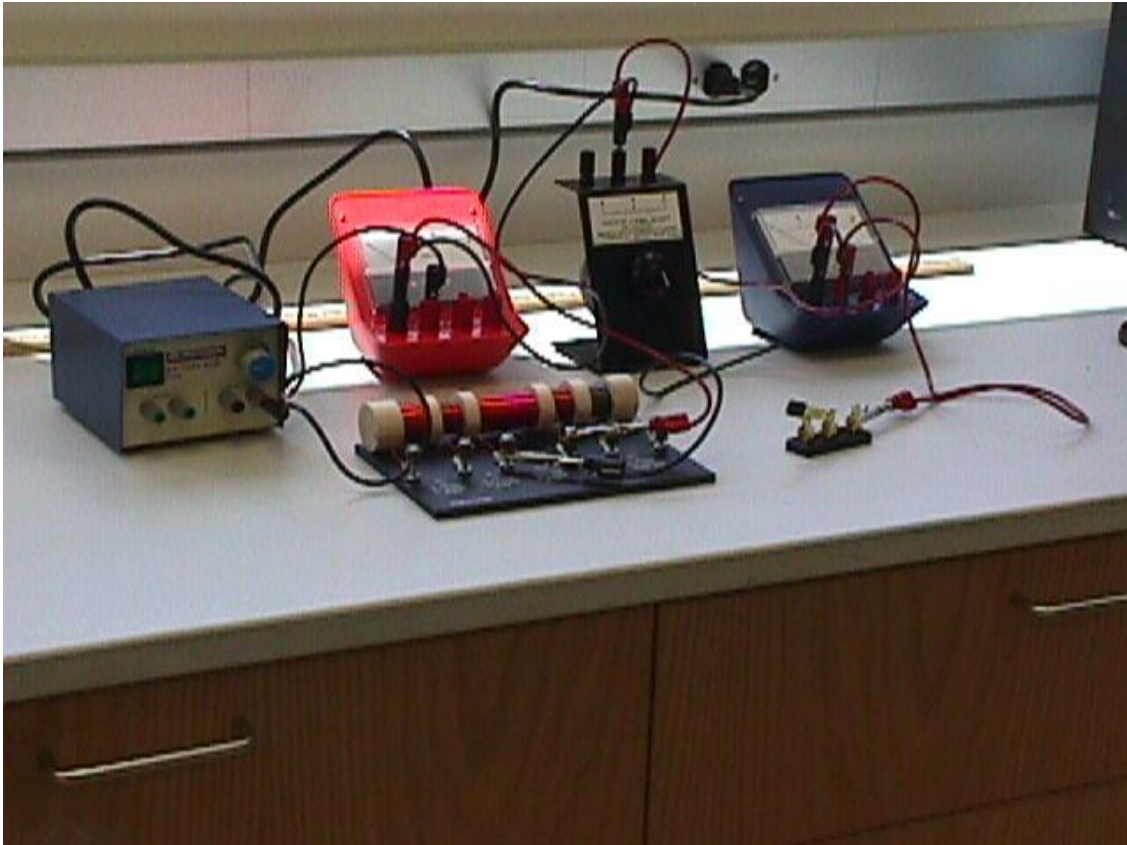


Physics 2521 Laboratory Manual



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The following is a list of experiments prepared for Physics 2521, University Physics Laboratory II. These experiments are performed during the spring and fall semesters in room 301 of the E. E. O'Banion Science Building. Near the end of the manual are suggested pre-lab experiments that are intended to accompany each lab. The purpose of the pre-lab is to get students to think ahead to the subsequent experiment, so as to arrive better prepared on the day of the experiment. A set of 10 experiments is used in the "standard list" of experiments, but the individual instructor may switch one or two of them for another on the list. Several of these labs involve use of PASCO computer interface equipment which works with the Dell computers in the lab. In general, the computerized version of a particular lab (when applicable) is presented alongside the traditional version, giving the class a choice of whether or not to use the computer interface equipment for that particular lab. Help for using the computers and the computer-interfaced equipment is located in a separate manual kept in room 305. At the end of this manual are suggested "capstone" exercises to be done in place of the traditional laboratory final exam. Please note that several of these labs may be switched with exercises not included in this manual, i.e. "instructor's choice".

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Introduction (to this Document and the Labs)

Introduction

This laboratory manual has descriptions of the laboratories which you will be doing this semester. It also explains some of the concepts required to be understood in order to successfully complete this course and provides examples from everyday life illustrating the concepts. This laboratory manual is the required reading material for this course.

The student will be learning how to apply the scientific method in the laboratory setting. Science is the study of the interrelationships of natural phenomena and of their origins. The scientific method is a paradigm that uses logic, common sense, and experience in the interpretation of observations. The underlying basis of the scientific method is understanding through repeatable experiments. No theory is held to be tenable unless the results it predicts are in accord with experimental results.

A major problem is: how does one quantify data so that experiments can adequately be compared? Physicists try to apply a rigorous method of error analysis, and then compare results with respect to the inherent experimental errors. If two experiments produce results that are the same to within experimental error, then we say that the experiments have validated each other.

Error analysis

It is up to your instructor whether some form of error analysis will be included in your lab assignments. It is recommended for the University Physics Laboratories, but not recommended for the General Physics Laboratories. In the event the instructor includes error analysis in the course work, a brief discussion on error propagation follows.

In physics we often do experiments where we wish to calculate a value that has a functional dependence on some measurable quantities, for example:

$$y = f(x, z)$$

or

$$y = f(x_1, x_2, \dots, x_n)$$

In some cases, we wish to determine how close our experimental value is compared to the published result. This is usually performed by finding the percent difference between the experimental value and the theoretical value. The percent difference is given by:

$$\% \text{ diff} = \left| \frac{(\text{experimental} - \text{theoretical})}{\text{theoretical}} \right| \times 100\%$$

NOTE: Technically the term “percent difference” refers to the difference between a measured or experimentally determined value and a theoretical or reference value. “Percent error” is the difference between two measurements of the same value made by two different methods.

Errors in measurement can readily be obtained in the following ways:

1. If only one measurement was taken, use $\frac{1}{2}$ the smallest scale division of the measuring device.
2. If multiple measurements were taken:
 - use standard deviation function on your calculator.
 - or use the standard deviation formula:

$$\sigma_x = \sqrt{\frac{1}{n-1} \left(\sum_{i=1}^n (x_i - \bar{x})^2 \right)}$$
$$\bar{x} = \frac{\sum_{i=1}^n x_i}{n}$$

Experimental Errors

There are two kinds of errors:

- systematic: associated with particular measurement techniques
 - improper calibration of measuring instrument
 - human reaction time
 - is the “same” error each time. This means that the error can be corrected if the experimenter is clever enough to discover the error.
- random error: unknown and unpredictable variations
 - fluctuations in temperature or line voltage
 - mechanical vibrations of the experimental setup
 - unbiased estimates of measurement readings
 - is a “different” error each time. This means that the experimenter cannot correct the error after the data has been collected.

These errors can be made in two ways:

- Personal: from personal bias or carelessness in reading an instrument (e.g., parallax), in recording observations, or in mathematical calculations.
- External: from the natural limitations of the physical devices. Examples are: old and misused equipment, finite accuracy of measurement devices, heat flow, extraneous electric fields, vibrations, etc.

Accuracy: how close to the true value is the result?

Precision: how much spread is in the data?

- the more precise a group of measurements, the closer together they are
- high precision **does not** necessarily imply high accuracy

Significant Digits

- exact factors have no error (e.g., 10, π)
- all measured numbers have some error or uncertainty
 - this error must be calculated or estimated and recorded with every final expression in a laboratory report

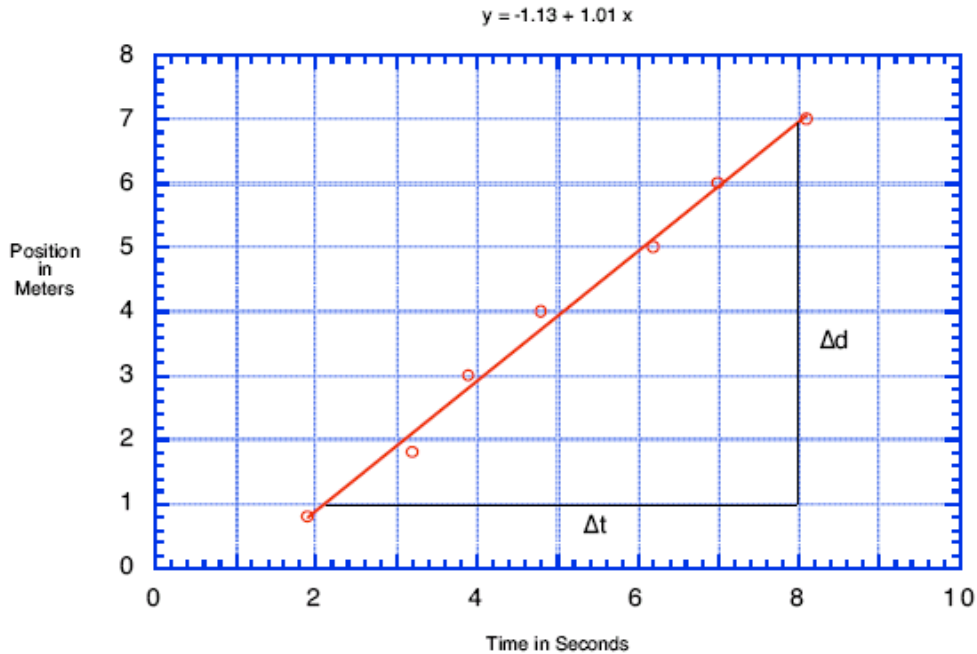
- the degree of error depends on the quality and fineness of the scale of the measuring device 3
- use all of the significant figures on a measuring device. For example, if a measuring device is accurate to 3 significant digits, use all of the digits in your answer. If the measured value is 2.30 kg, then the zero is a significant digit and so should be recorded in your laboratory report notes.
- keep only a reasonable number of significant digits
 - e.g., $136.467 + 12.3 = 148.8$ units
 - e.g., 2.3456 ± 0.4345634523 units $\rightarrow 2.3 \pm 0.4$ units
 - NOTE: hand-held calculators give answers that generally have a false amount of precision.

Round these values correctly. As a rule, the final answer should have no more significant digits than the data from which it was derived.

Graphing Techniques

1. Graphs are either to be done on a computer (using either Excel or the graphing utility of DataStudio) or on quadrille-lined paper, for example, engineering paper.
2. We draw graphs for the following reasons:
 - to see the functional dependence, that is, does it look like a straight line, a curve, or random data
 - to average out the data
 - to fit data to the linear hypothesis, that is, the data is of the form: $y = a + bx$
3. You will be asked to plot a graph of the form “y versus x”(We say y versus x rather than x versus y because we write the equation in the form: $y = a + bx$ and we usually read from left to right.) The first variable goes along the ordinate (i.e., the vertical axis) and the second is placed along the abscissa (i.e., the horizontal axis).
4. Use a meaningful graph title. Use meaningful axis titles that include the units of measurement.
5. Use appropriate scales for the axis that are easy to read and will allow the data to most nearly fill the entire graph. Do not use categories as axis labels. If practical include the origin, that is, the point $\{0, 0\}$, at the lower left of the graph. However, the origin should be suppressed if the data is bunched a long way from zero.
6. Take a set of data points by measuring a value for y for each given value of x.
7. Draw the “best fit” straight line—the line that most nearly goes through all the points. Half the points should be above the line and half should be below the line. Do not force the line to go through the origin. (Unless $\{0, 0\}$ is a measured data point.)
8. Example graph (next page):

Calculation of Velocity



$$\text{Slope} = \frac{\Delta d}{\Delta t} = v = \frac{6.9 \text{ m} - 1.0 \text{ m}}{8.0 \text{ s} - 2.2 \text{ s}} = 1.02 \text{ m/s}$$

9. Slope calculations:

- Use a large baseline on the graph to find the Δx and Δy values
- A large baseline will increase the accuracy of your calculations
- In general you should do the slope calculations on the graph
- Draw the baseline along some convenient ordinate starting from the best-fit straight line— do not start from a data point!

10. If you use a computer-graphing package, ensure that you use it correctly. Be wary of the cheap graphics packages that will graph out the x values as equally spaced categories. Do not just join the points together; you require a best-fit straight line. Ensure that there are enough grid lines so that a reasonable slope calculation can be performed. Better still, use a graphics package, which does both the best-fit straight line and the slope, and intercept calculations for you. The above graph is an example as to how you are to plot acquired data. Note that the graph has the following attributes:

1. Each axis has an informative title that contains units of measurement.
2. There is a graph title.
3. The axes are computed such that the data nearly covers the complete graph.
4. There is a “best-fit” straight line that most nearly goes through all of the data points.
5. The graph is clearly linear because the data “looks” straight, and is a good linear fit because all of the data points are near the best-fit straight line.
6. Since the data is linear it can be parameterized with the following equation:

$$x = x_0 + vt$$

7. This equation is similar to the standard equation of a straight line:
 $y = a + bx$, where a is the y-intercept and b is the slope.
8. Compare the above two equations and note that the coefficients are equal, that is: $a = x_0$, $b = v$. The value of the y-intercept is equal to the initial position and the value of the slope is equal to the velocity.
9. The slope, which is a representation of the average velocity, has been calculated as 1.02 m/s. The best-fit data for this graph using a least-squares algorithm is printed at the top of the graph. Its value for the slope is slightly less than the calculated value, but is the more accurate value. To within two significant figures, the values for the slopes are the same, and only two significant figures were used in the slope calculation. However, it is important to keep the third significant figure for future calculations to decrease cumulative round off errors.
10. Note well, the best fit straight line does not extrapolate through the point $\{0,0\}$ and so either the initial position of the device is less than zero, or there is some distortion near zero, or else there is a systematic error.

Laboratory Report Format

The finer details of the Laboratory Report Format may vary from instructor to instructor, but each will use a format similar to that described below. The student will hand in written or typed reports. If you type the report, but do not have access to a proper equation writer, then it is better to leave blank spaces and fill in the equations by hand.

For example: $\sqrt{x + 2}$ is not the same as $\sqrt{x} + 2$, nor is x^2 an acceptable substitute for x^2 . Ambiguous equations are much worse than hand-written equations. Students are expected to use the following laboratory report format:

Group Number:

Date:

Group Members:

Objective: What is to be done in this experiment?

Apparatus: Equipment used to perform the experiment.

Theory: The calculation equations used along with meaning of the symbols and units used. Equations can be neatly hand written.

Data: Raw data in tables should be placed in this section. Sample calculations should be shown. Error calculations should be shown.

Discussion: Include a discussion of some of the sources of experimental error or uncertainty. If appropriate, should also include a comparison of various experimental errors.

For example: We found that our value of the density, within one standard deviation, has a range of 2.68 to 2.78 $\times 10^3$ kg /m³. The quoted value of the density for aluminum falls

within this range, and no other material densities fall within this range, so our cylinder appears to be made of aluminum.

Conclusion: Short but comprehensive. Was the object of the experiment met?

For example: The density of the cylinder was found to be $(2.73 \pm 0.05) \times 10^3 \text{ kg/m}^3$. We selected aluminum as the material composing our cylinder because the density of aluminum, $2.70 \times 10^3 \text{ kg/m}^3$, is within the experimental error of our calculated density.

Safety Reminder

It will be necessary to follow procedures to ensure safety in each lab. Most labs do not present any significant danger, but some will require certain safety measures to be followed. The general recommendation is to follow all safety instructions, including those posted on the wall of the room you are in; if additional special safety guidelines are needed, they will be printed for each lab needing them.

Each student, student assistant, and instructor that uses the lab is required to receive a safety briefing before beginning laboratory exercises. More details on laboratory safety for Physics II laboratories are provided in the next chapter of this Laboratory Manual.

0. Safety Protocol for the Physics II Laboratory Environment

Safety in the laboratory is very important. The experiments performed in the laboratory are designed to be as safe as possible, but caution is always advised concerning the use of the equipment. When you arrive at the start of each class meeting, it is very important that you do not touch or turn on the laboratory equipment until it has been explained by the professor and permission has been granted to get started. The equipment for the labs are set up for you in advance, so resist the urge to play with the equipment when you arrive, as you may hurt yourself or others, or damage the equipment.

While the experiments done in Physics I (electricity and magnetism) are generally safe, it is always important to be cautious when using equipment, especially if you are unfamiliar with the equipment. If you have any questions about the safety of a procedure or of the equipment, ask your instructor before handling the equipment. Some specific exercises in the laboratory do pose minor safety risks (e.g. the labs that deal with electric circuits), and guidelines related to these are presented with the write up for these particular labs. In fact, each laboratory write-up contains a section on safety that should be read and followed carefully. When an electric circuit is involved it is vital that you do not power a circuit until you verify with the instructor that it is set up correctly, and then only when the instructor gives the go-ahead to do so. Not following instructions may result in personal injury, damage to the equipment, or both.

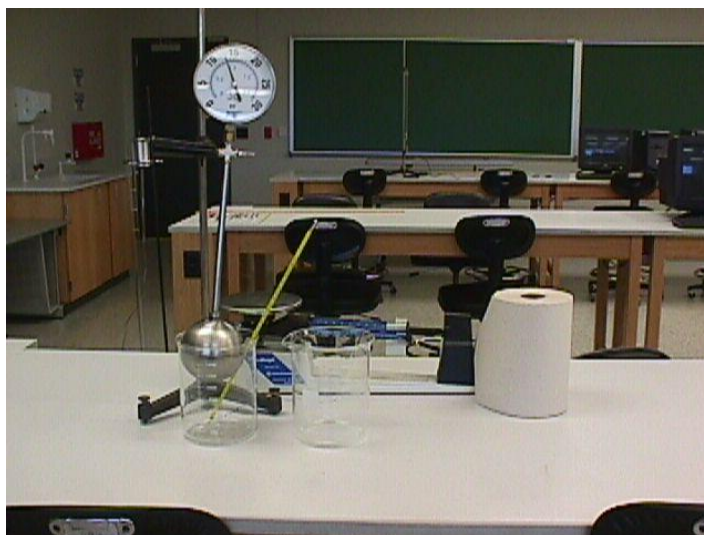
Although we do not use chemicals in the physics laboratories, we do use dry ice and liquid nitrogen, both of which present hazards due to their extreme coldness. Extra caution is strongly advised when using these substances. You will be dipping a constant-volume pressure apparatus into dry ice, then liquid nitrogen, each of which will have a student laboratory assistant or the instructor stationed so as to prevent accidents. Be careful not to splash any liquid nitrogen on yourself, or touch any of it or the dry ice as severe frostbite could result. In addition to the electricity and the cold materials, other hazards may come from broken glass or thermometers; in the event of such, these should be cleaned up by the laboratory assistant or the instructor.

Safety is important for the equipment as it tends to be expensive and oftentimes delicate. The equipment is tested and set up prior to the laboratory period, but if you have any doubts about the functionality of the equipment or the way that it is set up, it is important to ask the instructor prior to conducting the experiment. If a piece of equipment is broken during an experiment, promptly notify your instructor or laboratory assistant who will remove the broken apparatus to a designated place and replace it with functioning equipment. **Do not** try to fix the equipment yourself. All Laboratory Students, Assistants, Faculty, and Staff must abide by the following safety rules when using the Physics Laboratory. This list may be modified as deemed appropriate for specific situations.

- Follow directions carefully when using any laboratory apparatus to prevent personal injury and damage to the apparatus.
- The instructions on all warning signs must be read and obeyed.
- Wear safety goggles for the Absolute Zero laboratory, especially when working near Liquid Nitrogen. The goggles are provided by the department and each person in the lab must wear them.

- Each student MUST know the use and location of all first aid and emergency equipment in the laboratories and storage areas.
- Each student must know the emergency telephone numbers to summon the fire fighters, police, emergency medical service or other emergency response services.
- Each student must be familiar with all elements of fire safety: alarm, evacuation and assembly, fire containment and suppression, rescue and facilities evaluation.
- Use caution when working with hot plates, steam generators, open flames, and the heat lamps.
- Laboratory walkways and exits must remain clear at all times.
- Keep magnets away from computers, computer disks, and your wallet or anything containing a magnetic strip such as your ID or credit cards.
- Wear insulated gloves when handling dry ice and liquid nitrogen and take care not to splash the liquid nitrogen when pouring it from one Dewar to another.
- No open-toed shoes are allowed in the laboratory (lab assistants and professor included), as weights or other objects may accidentally drop on people's feet; ordinary footwear provides a measure of protection from such instances
- Be very careful when handling hot water; do not touch the beaker, the hot water, the hot plate, or any other container of hot water, and ensure the hot plate does not get wet; and wear gloves and/or use tongs when handling containers that have hot water.
- Glassware breakage and malfunctioning instrument or equipment should be reported to the Teaching Assistant or Laboratory Specialist. It is best to allow the Teaching Assistant or Laboratory Specialist to clean up any broken glass.
- All accidents and injuries MUST be reported to the Laboratory Specialist or Faculty teaching affected lab section. An Accident Report MUST be completed as soon as possible after the event by the Laboratory Specialist.
- No tools, supplies, or other equipment may be tossed from one person to another; carefully hand the item to the recipient.
- Although the voltages and currents used in our electricity labs are low, it is best to be cautious when working with circuits: make sure the power supply is off AND unplugged when assembling or disassembling a circuit. Ensure the circuit is assembled properly before applying power to prevent damage to the equipment.
- When using the ammeters and voltmeters in a circuit, and the following is a good habit to get into in general when using:
 1. Be very careful in the use of the meters. Start with the rheostat fully on (if your circuit is connected to one).
 2. Use the largest scale on the meter.
 3. Failure to follow this procedure could result in damage to the meters.
- When varying the resistance of a circuit, make sure that the value of R does not become small enough to burn out the meter.
- Use caution with lasers: do not point them at any person and do not look into the laser beam as blindness can result.
- Casual visitors to the laboratory are to be discouraged and MUST have permission from the Teaching Assistant, Faculty Instructor of the section in question, or Laboratory Specialist to enter. All visitors and invited guests MUST adhere to all laboratory safety rules. Adherence is the responsibility of the person visited.
- Location of PPE (Personal Protection Equipment):
 - Safety goggles are staged in the back in the drawer marked "goggles".
 - A first aid kit is available near the sink at the front of the lab.

1. Re-Introduction to Data Analysis & Find the Absolute Zero (Gay Lussac's Law)



Purpose

The purpose of this exercise is to determine the absolute zero point and find the relation between pressure, volume, and temperature in a gas.

Background and Theory

Boyle's law states that the pressure of a gas in a container is related to the volume of the gas. In other words, as the volume changes, the pressure changes. For a given amount of a gas at a fixed temperature the pressure of the gas is inversely proportional to the volume. One way to verify this is to graph the inverse of gas volume versus gas pressure.

The most common states of matter found on Earth are solid, liquid and gas. The only difference among all these states is the amount of movement of the particles that make up the substance. Temperature is a measure of the relative movement of particles in a substance because temperature is a measure of the average kinetic energy of the particles. At any specific temperature the total kinetic energy is constant. Particles with a large kinetic energy tend to collide frequently and move apart. Intermolecular forces tend to pull particles toward each other. The forces that bind some molecules together at a particular temperature are greater than the kinetic energy of the molecules.

In an "ideal gas" there are no intermolecular forces. In fact, the "ideal gas" has no mass and occupies no volume. While the "ideal gas" is fictional, real gases at room temperature and pressure behave as if their molecules were ideal. It is only at high pressures or low temperatures that intermolecular forces overcome the kinetic energy of molecules and the molecules can capture one another.

For an "ideal gas", the volume of the gas is inversely proportional to the pressure on the gas at a constant temperature. In other words, the product of the volume and pressure for the gas is a constant when the gas is at a constant temperature.

$$PV = k$$

At the same time, the volume of gas is proportional to the temperature. If a gas is heated, the volume of the gas increases. If it is cooled, the volume of the gas decreases, thus:

$$V = Tk_2 \text{ or}$$
$$\frac{V}{T} = k_2$$

At very low temperatures, the intermolecular spacing decreases for real gases, as the forces between the molecules overcome kinetic energy. The gas becomes a liquid. At still lower temperatures and higher pressures, the liquid is forced into a rigid structure we call a solid. For the “ideal gas”, this gas would continue to have a constant pressure-volume relationship. For the “ideal gas”, as the temperature decreases, the volume and the pressure of the gas also decrease, with the pressure and volume maintaining a constant relationship.

Theoretically, one can use a graph of pressure versus temperature to estimate the value of Absolute Zero by finding the temperature that the pressure reaches zero.

Safety Reminder

You may be working with liquid nitrogen and / or dry ice in this lab, either of which can produce severe frostbite on contact. Be extremely careful, and use gloves and eye protection when dipping the absolute zero apparatus bulb in the liquid nitrogen dewar. One group at a time will be permitted to do this, and it is strongly recommended that this be the last element that the bulb is exposed to (that is, have the other three or four pressure / temperature measurements: the room temperature, hot water, ice water, and dry ice [if available] measurements). The temperature of the liquid nitrogen is given below; DON'T insert the thermometer in the dewar.

Equipment

Equipment Needed	Qty.
Boyle's Law Apparatus	1
Thermometer	1
Scholar 170 hot plate or other heating device or Bunsen burner and stand	1
Absolute Zero Apparatus	1
Ice for ice water bath and dry ice (if available)	some
Liquid Nitrogen	1 L
Base and Support Rod	1
Beaker, 1.5 L	4
Buret Clamp	1

Procedure

1. Put about 800 mL of water into a 1.5 beaker and put the beaker on the hot plate. Start to heat the water (it may not reach boiling in the time allotted, but this is okay for experimental purposes).
2. OPTIONAL: Your instructor may include the optional steps that demonstrate the Ideal Gas Law. While waiting for the water to heat up, take five readings of volume, evenly spaced from the maximum to the minimum attainable with the syringe, with the Boyle's Law

apparatus. For each volume measurement, record the pressure reading from the manometer. You may need to extrapolate or estimate your pressure reading for one or two of the volume readings.

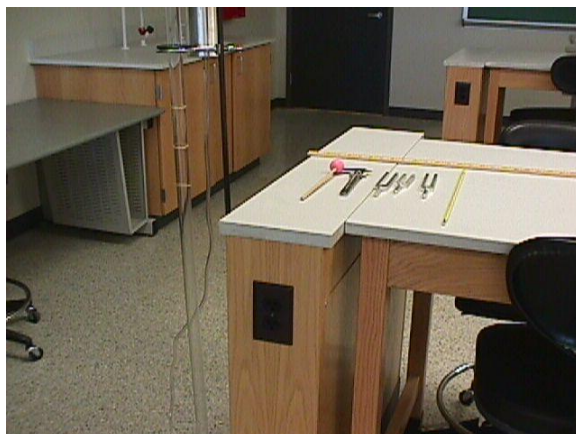
3. OPTIONAL: Include the answers to the following questions from this demonstration in your report:
 - a. From the P vs. V data, do the pressure and volume seem to be directly or inversely proportional? Does this agree with Boyle's Law?
 - b. What happened to the pressure when the volume went from 20 mL to 5 mL
4. By now the water should be heated up. Before submerging the apparatus in the water, take its reading at room temperature, and take the temperature of the room. This is your first data point.
5. Submerge the bulb of the apparatus into the water, keeping it there until the pressure reading stops changing. Record the pressure AND the temperature of the water at that point.
6. Repeat the measurements with the ice water bath, THEN with the dry ice if available, THEN liquid nitrogen LAST. DO NOT measure the temperature of the liquid nitrogen or dry ice; it is beyond the range of the thermometers. The temperature to use for liquid nitrogen is -196°C , and the temperature of dry ice is -78.5°C . After taking the last measurement, carefully place the absolute zero apparatus in the sink, without touching the metal bulb.
7. Plot the four data points on a temperature versus pressure graph. Draw (or plot with EXCEL) a best-fit line among the data points, and extend the line back until it reaches the x-axis. Allow enough room on the graph to enable you to do this. Having done this, answer the following for the conclusions section of your lab report:
 - a. What was your graphically determined value for absolute zero? Calculate the percent difference of your experimental value for absolute zero and the established value of -273°C .
 - b. In each part of the experiment, what are possible sources of error or limitations? For each one, try to decide what effect it may have on the experimental results.

Data Table

Pressure	Temp. in Celsius	Temp. in Kelvin
	100.00°	
	0.00°	
	-78.50°	
	-196.00°	
		0.00

2. The Speed of Sound in Air

(Adapted from Jerry Wilson, *Physics Laboratory Experiments*, 4th Ed, pp. 227-230, © 1994 Houghton Mifflin Company)



Purpose

The purpose of this experiment is to use resonance to measure the speed of sound in air.

Introduction

Sound is a vibration that travels through a medium as a wave. The speed of sound indicates the distance the sound travels in a given amount of time. In dry air at 20⁰ C the speed of sound is 343.14 meters per second.

The speed of sound is used in determining the distance between the objects. For example consider an echo, which is the reflection of the sound wave on a barrier. The barrier can be a wall or a canyon. If we make a loud sound within a canyon; the sound waves will hit the wall of the canyon and reflect back forming an echo. The time delay between the shout and the echo corresponds to the time for the sound waves to travel to the canyon wall and back. Measurement of this time will give an estimate of one-way distance to the canyon wall. For example if an echo is heard 2.80 seconds after making the sound, then the distance to the canyon wall can be found as follows:

$$\text{Distance} = v \cdot t = 343.14 \text{ m/s} \cdot 1.4 \text{ s} = 480.396\text{m}$$

Therefore the canyon wall is 480.396 meters away.

Bats use sound waves to hunt and navigate. Bats produce and send short bursts of ultrasonic waves which hit the objects and reflect back. They detect the time delay between sending and receiving waves and approximate the distance of the objects.

Automatic focus cameras use ultrasonic sound waves to determine the distance of the objects. The camera sends short bursts of ultrasonic waves which hit the objects and reflect back. A sensor detects the time it takes for the waves to return and then determines the distance of the object from the camera.

Air columns in pipes or tubes of fixed lengths have particular resonant frequencies. An example is an organ pipe of length L with one end closed; the air in the column, when driven at particular frequencies vibrates in resonance. The interference of the waves traveling down the tube and the reflected waves traveling up the tube produces longitudinal standing waves, which have a node at the closed end of the tube and an antinode at the open end. Sound travels through air at "**the speed of sound.**" Officially, the speed of sound is **331.3 meters per second** (1,087 feet per second) in dry air at 0° Celsius (32° Fahrenheit). At a temperature like 28° C (82° F), the speed is 346 meters per second.

The speed of sound changes depending on the **temperature** and the **humidity**; but if you want a round number, then something like 350 meters per second and 1,200 feet per second are reasonable numbers to use. So sound travels 1 kilometer in roughly 3 seconds and 1 mile in roughly 5 seconds.

Theory

The resonance frequencies of a pipe or tube depend on its length L . Only a certain number of wavelengths can "fit" into the tube length with the node-antinode requirements needed to produce resonance. Resonance occurs when the length of the tube is nearly equal to an odd number of quarter wavelengths, i.e. $L = \lambda / 4$, $L = 3\lambda / 4$, $L = 5\lambda / 4$, or generally $L = n\lambda / 4$ with $n = 1, 3, 5, \dots$ and $\lambda = 4L / n$. Incorporating the frequency f and the speed v_s through the general relationship $\lambda f = v$, or $f = v/\lambda$, we have

$$f_n = \frac{nv}{4L} \quad n = 1, 3, 5, \dots$$

Hence, an air column (tube) of length L has particular resonance frequencies and will be in resonance with the corresponding odd-harmonic driving frequencies.

As can be seen in this equation, the three experimental parameters involved in the resonance conditions of an air column are f , v , and L . To study resonance in this experiment, the length L of an air column will be varied for a given driving frequency, instead of varying f for a fixed L as in the case of the closed organ pipe described above. Raising and lowering the water level in a tube will vary the length of an air column.

As the length of the air column is increased, more wavelength segments will fit into the tube. The difference in the tube (air column) lengths when successive anti-nodes are at the open end of the tube and resonance occurs is equal to a half wavelength; for example,

$$\cancel{L_2} - L_1 = \frac{3\lambda}{4} - \frac{\lambda}{4} \quad \text{and} \quad \cancel{L_3} - L_2 = \frac{5\lambda}{4} - \frac{3\lambda}{4} \quad \text{for the next resonance.}$$

When an antinode is at the open end of the tube, a loud resonance tone is heard. Hence, lowering the water level in the tube and listening for successive resonances can determine the tube lengths for antinodes to be at the open end of the tube. If the frequency f of the driving tuning fork is known and the wavelength is determined by measuring the difference in tube length between successive antinodes, $\Delta L = \lambda / 2$ or $\lambda = 2\Delta L$, the speed of sound in air v_s can be determined from $v_s = \lambda f$.

Once v_s is determined (for a given ambient temperature), the unknown frequency of a tuning fork can be computed from the first equation using the experimentally determined resonance wavelength in an air column for the unknown tuning fork frequency. The speed of sound, which is temperature dependent, is given to a good approximation over the normal temperature range by $v_s = 331.5 + 0.6T_c$ m / s, with T_c the air temperature in degrees Celsius.

Equipment

Equipment Needed (Without Computer Assistance)	Qty.
Resonance tube apparatus	1
Tuning Forks (500 – 1000 Hz) stamped Frequency of 1 fork should be covered/unknown	3
Rubber mallet or Block	1
Meter stick	1
Thermometer	1
Vernier Calipers	1
Rubber Bands	4
Equipment Needed (With Computer Assistance)	Qty.
Sound Sensor	1
Base and Support Rod	1
Clamp, three-finger	1
Tape Measure	1
Tape, duct	some
Tube, cardboard, 15 cm diameter	1

Procedure

1. Record the room temperature in the space provided in your lab report.
2. Place several rubber bands around the tube at various heights. These will be used to mark resonance positions later in the experiment. Raise the water level to the 100 cm mark by raising the reservoir can, by depressing the can clamp and sliding it on the support rod. With the water level near the top of the tube, there should be little water in the can; if this is not the case, remove some water from the can to prevent overflow and spilling when the can becomes filled while lowering.
3. With the water level in the tube near the top, take a tuning fork of known frequency and set it into oscillation by striking it with a rubber mallet or on a rubber block. Hold the fork so that the sound is directed in the tube (experiment with the fork and your ear to find the best orientation). With the fork above the tube, quickly lower the reservoir can. The water in the tube should slowly fall at this time, and successive resonances will be heard as the level passes through the resonance length position. It may be necessary to strike the fork

several times to keep it vibrating sufficiently.

4. As the water passes through these levels of resonance, mark their approximate locations with the rubber bands. Repeat the procedure, adjusting the rubber band heights until you are satisfied that the rubber bands are at the heights for the water levels where the resonances are obtained.
5. Determine the length from the top of the tube for the first resonance condition and record this length in your lab report. Repeat this position for the other observed resonance positions. Repeat steps 3 to 5 with the other tuning fork of known frequency.
6. Finding the speed of sound and experimental error:
 - a. Compute the average wavelength for each fork from the average of the differences in the change in water level between successive anti-nodes (resonances).
 - b. Using the known frequency for each fork, compute the speed of sound for each case.
 - c. Compare the average of these two experimental values with the value of the speed of sound given by the last equation by computing the percent error (if this error is large, you may have observed the resonances of the tuning forks' overtone frequencies—consult your instructor in this case).
7. Repeat Procedures 3 through 5 for the tuning fork of unknown frequency. Compute the frequency of this tuning fork using the average experimental value of the wavelength and the speed of sound as given by the speed of sound equation.

Data Sheet

1st Primary Frequency _____

Frequency Wavelength _____

	Distance (m)	Δd (m)	Wavelength
1 st resonance			
2 nd resonance			
3 rd resonance			
4 th resonance			

Show work for calculations

Average Calculated Wavelength _____m

Calculated Speed of Sound in air _____m/s

2nd Primary Frequency _____

Frequency Wavelength _____

	Distance (m)	Δd (m)	Wavelength
1 st resonance			
2 nd resonance			
3 rd resonance			
4 th resonance			

Show work for calculations

Average Calculated Wavelength _____m

Calculated Speed of Sound in air _____m/s

Show work for calculations

Recorded room temperature _____ °C

The theoretical speed of sound in air is approximately 343 m/s at 20°C. Determine the theoretical speed of sound in this classroom based on your temperature readings.

Theoretical speed of sound in air in this classroom
_____m/s

Averaged speed of sound in air from your experiments
_____m/s

Percent Error _____ %

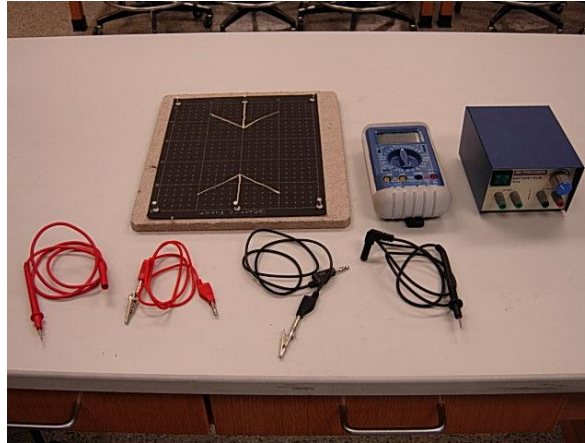
Unknown Primary Frequency _____

Frequency Wavelength _____

	Distance (m)	Δd (m)	Wavelength
1 st resonance			
2 nd resonance			
3 rd resonance			
4 th resonance			

Show work for calculations

3. Mapping Electric Field Lines Using Equipotentials



Purpose

We will investigate the nature of electric field lines by mapping equipotential lines (lines of constant potential). This lab will show you how to measure and plot equipotential lines with a voltmeter to be used for constructing the electric field which lies perpendicular to the equipotential lines.

Having completed this lab you will be able to:

1. Map equipotential lines from various shaped electrodes
2. Map the shape of electric field lines from equipotential lines

Introduction & Theory

Electric fields are defined as electric force per unit charge. This is the region where electric forces are exerted on charges. Much like a topographic map where contour lines show constant elevations, equipotential lines have identical potentials along them. That is to say, if we took any two arbitrary points along an equipotential line and calculated the differences in potential between the two points, $\Delta V = V_b - V_a$ we would get zero.

The electric field is represented by a vector which, by convention, points in the direction of the force on a positive charge. We define the electric field as the electric force per unit charge or

$$\vec{E} = \frac{\vec{F}}{q_o}$$

A free charge will move in an electric field under the influence of the electric force of magnitude $F = \frac{kqq_b}{r^2}$. We would say that work is done by the force on the charge as it moves from point "a" to point "b". If the charge were moved from point "b" to "a" then work is performed *against* the electric field (force) and an external force is required to move the charge. The work per charge q_o in moving between the two points is called the potential difference, $\Delta V = V_b - V_a = \frac{W}{q}$. If the charge moves along a path perpendicular to the electric

field lines the work $W = 0$ as there is no component of the force in this direction, hence, $\int_b^c \vec{E} \cdot d\vec{s} = 0$ and $V_b = V_c$ and the potential is constant along the path going from points “b” to “c”.

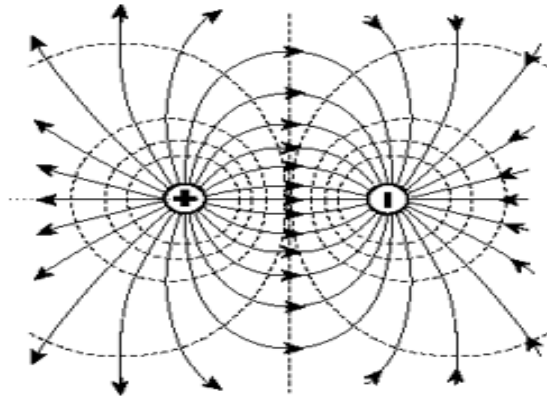
We can map electric field lines by determining either:

1. The lines of force or
2. Equipotential lines.

It is easier to work with equipotential lines. Having plotted sufficient equipotential lines we may then map out the electric field lines which are normal (perpendicular) everywhere to them.

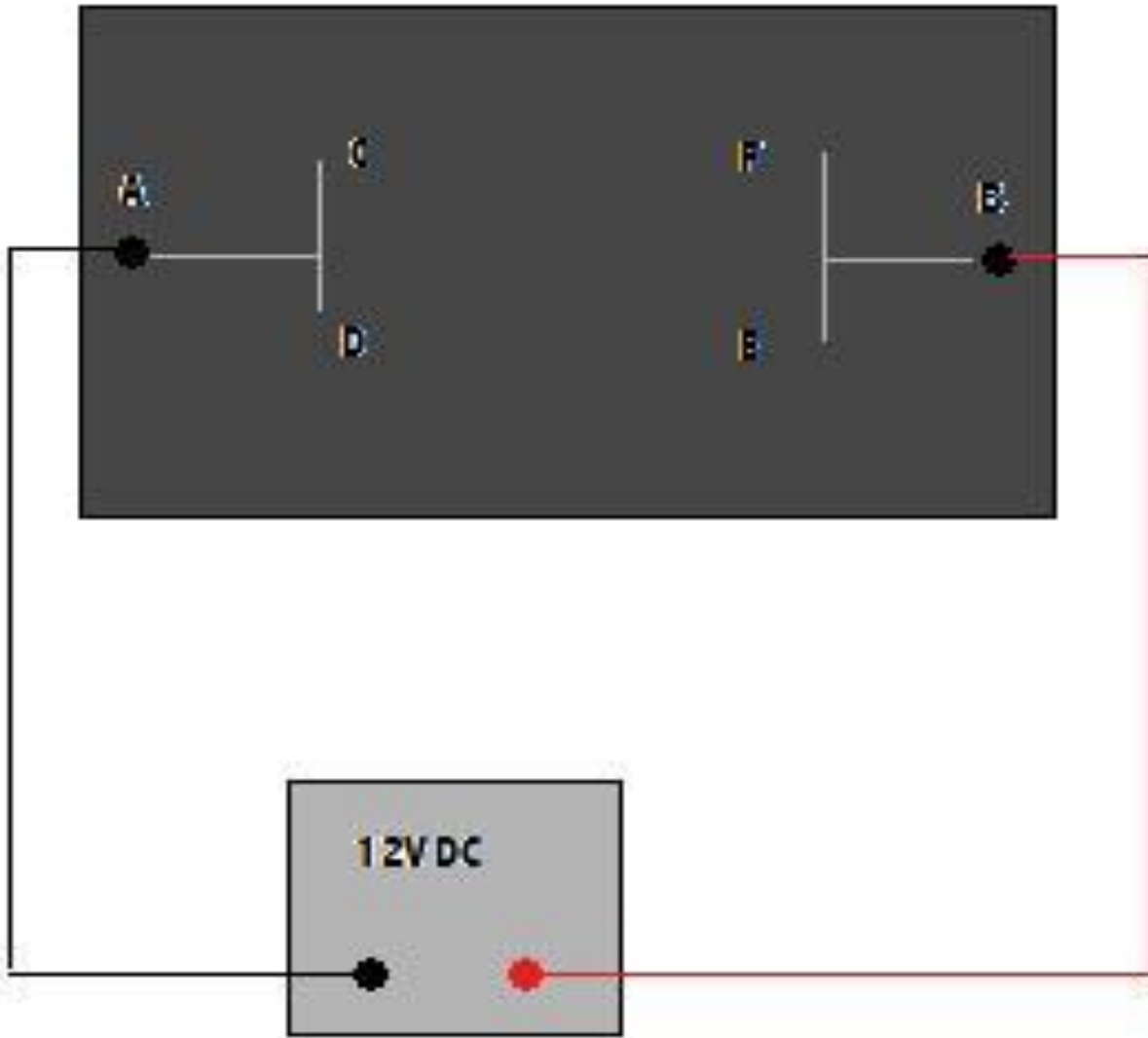
In one dimension $E_x = -\partial V_x / \partial x$ or, if we know the potential at a discrete number of points (which is what you will measure during today’s lab), then $E_x \cong -\Delta V / \Delta x$. If the direction is along a field line (which is perpendicular to the equipotential lines, then in that direction along the field line $E \cong -\Delta V / \Delta r$, where Δr is along the field line.

To the right is an example of two charges (dipole) and the associated electric field. Note the equipotential lines (dashed) which are all perpendicular to the electric fields.



Equipment

Equipment Needed	Qty.
Graph Paper	1 sheet
Conductive paper with electrode configuration	1
Push pins	several
Clip Leads	4
DC Power Supply	1
Multimeter	1



Procedure

1. Take a resistance reading of your conductive lines, making sure that the reading indicates 4-8 Ω per cm of length (read from A to C and A to D). Also read B to E and B to F). If your conductive lines do not fall within this range (or reasonably close) please alert your instructor that you need assistance.
2. Set your variable DC power supply output to the 9 to 12 volt range (as read with a meter). With the power off, connect the output leads to the circuit as shown in the illustration above. Now turn the power back on.

SAFETY NOTE: It only takes 1/10th of an ampere (0.1 amps) to kill a human being. This power supply can output 5/10th of an ampere (0.5 amps). Therefore it is important to make sure you remove power (turn off the power supply) when making any adjustments to the circuit.

3. Take a voltage reading from A to B. It should be equal to the output voltage of the power supply. If it is not, check your connections and try again.
4. Using the red lead of the multimeter, select a point between the two electrodes noting its x and y coordinates. Now place the black lead on the paper and move it slowly until you locate a point where the voltage on the multi-meter reads 0; this corresponds to $\Delta V = 0$. This shows that you are now in an equipotential plane. Now move the black lead further out along the plane until you have mapped out several coordinates within the plane. (It is recommended that you plot at least 6 points per equipotential and plot an equipotential at intervals no greater than 1 inch apart until you have mapped the entire electric field). Make a table of these points.
5. From these tables plot your equipotentials using dashed lines on the graph paper.
6. Now to find the electric field lines, you draw lines which are perpendicular at all points to the equipotentials. Use solid lines to represent the E-field.
7. On your drawing: annotate the potential source, the direction and magnitude of the E field, and the illustrative points where you calculated E-field strength.
8. To calculate the E-field strength you will take a voltage measurement (with the voltmeter) along any of your drawn E-field lines and divide it by the distance of separation (as you can deduce from the formula for E-field strength which is ...

$$E_x = -\partial V_x / \partial x$$

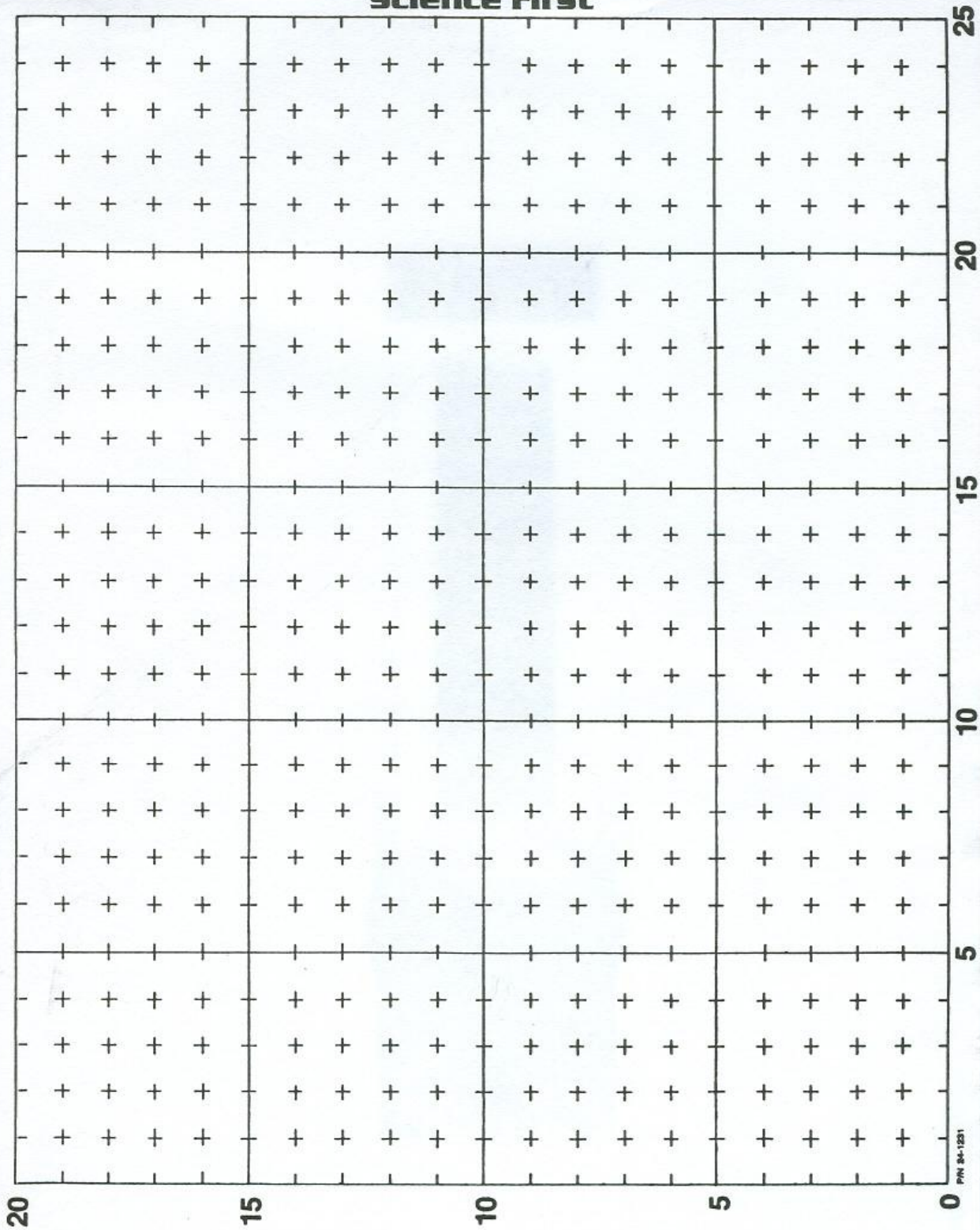
... this equates to the change in potential proportional to the distance of separation.

9. Calculate the strength of your E-field using 4 test points (2 calculations) that fall onto your drawn E-field lines. Use test points that are not straight down the middle of the drawing, as you use this value for your baseline reference when calculating percent error. Show these test points, their respective potentials and distance of separation on your drawing.
10. Calculate the strength of the E-field (one last “guaranteed” to be error free). Use this value as the reference value against the average of your other 2 calculated values and find the %error for your experiment.
11. Write a concise report in the format established at the beginning of this manual. Be sure to turn in your drawing and calculations with the report.

Food for thought:

1. What is meant by potential difference?
2. How does electric potential compare to other potential energies?
3. What is an electric field?
4. What do you notice of the shape of the equipotential lines in comparison to the shape of the electrodes?
5. Why are electric field lines drawn perpendicular to equipotential lines?
6. What is the polarity of the E-field in your experiment?

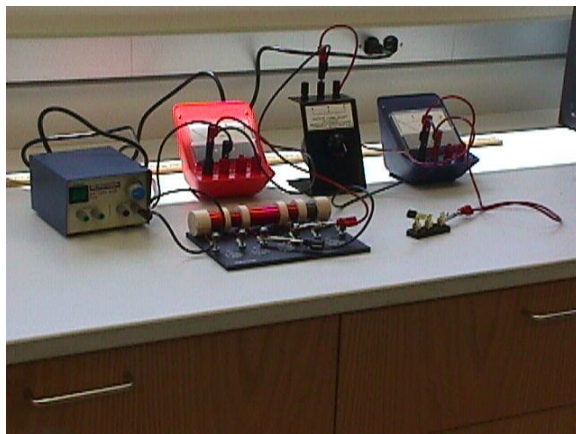
Science First



PN 84-1231

4. Resistivity

(Adapted from Jerry Wilson, *Physics Laboratory Experiments*, 4th Ed., pp. 353-357, © 1994 Houghton Mifflin Company)



Purpose

The purpose of this experiment is to investigate the resistivity of several different types of wires.

Introduction & Theory

The resistance of an electrical conductor depends on several factors, such as its physical shape, the type of material it is made of, and the temperature. The resistance of a wire is directly proportional to its length l and inversely proportional to its cross-sectional area, A :

$$R \propto \frac{l}{A}$$

An analogy for this is the flow of water through a pipe. The longer the pipe, the more resistance to flow, but the larger the cross-sectional area of pipe, the greater the flow rate or the smaller the resistance to flow. The material property of resistance is characterized by the resistivity ρ , and for a given temperature:

$$R = \frac{\rho l}{A}$$

Resistivity is independent of the shape of the conductor, and rearranging the previous expression gives the equation for resistivity:

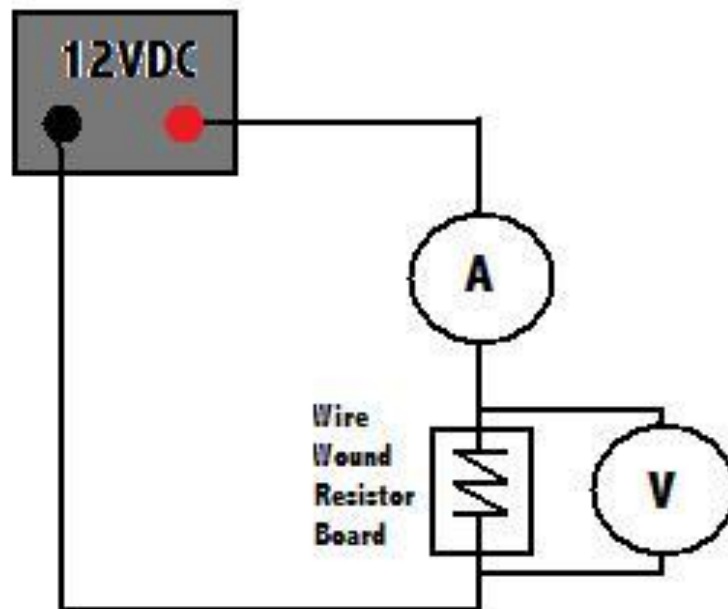
$$\rho = \frac{RA}{l}, \text{ with units of } \Omega\text{-m or } \Omega\text{-cm}$$

Equipment

Equipment Needed	Qty.
Ammeter (0-0.5 A)	1
Voltmeter (0-3V)	1
12V power supply	1
Wire Spool Resistance Board	1 (set)

Procedure

1. Set up the circuit as shown in the diagram below, with the first of the wire spools on the circuit board. Note that the ammeter is in series while the voltmeter is in parallel to the load. **DO NOT TURN ON THE POWER SUPPLY YET!!!**



2. **Ask your instructor to verify your circuit, and then proceed to step 3.**
3. Record the wire length and diameter on the table provided (you can get the length directly from the conductor board for each spool and the diameter from the black board—read off the gauge, either 22 or 28, and match that with the diameter listed).
4. Turn on the DV power supply and turn up the output knob of the power supply until the ammeter reads between 0.4 and 0.5 amps of electric current. Record the values of voltmeter and ammeter for this wire spool on the table provided.

NOTE

It is very important to take this reading promptly and then turn the power supply back to the OFF position immediately.

5. Repeat steps 1 through 3 for all 5 of the wire spools on the circuit board.
6. Calculate the resistivity for each of the wire spools and write the data into the table provided.

	Length	Diameter	Amps	Volts	ρ
Wire #1					
Wire #2					
Wire #3					
Wire #4					
Wire #5					

7. Find the percent error of the experimental values by comparing your values with the accepted values provided. You will do the actual comparison with the calculation using the percent difference formula (see the introduction section).

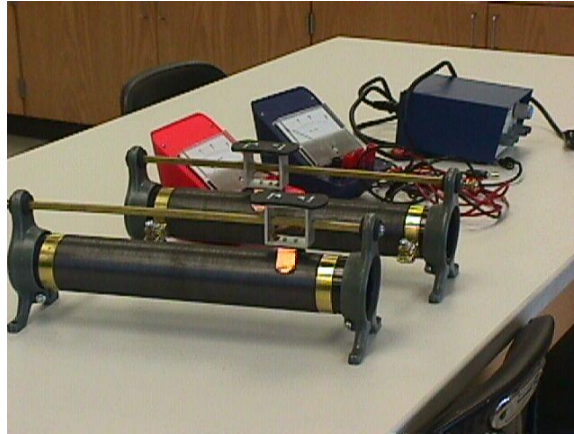
Substance	Resistivity, ρ (Ω -cm)
Constantan	49×10^{-6}
Copper	1.72×10^{-6}

Copper % Error _____

Constantan % Error _____

8. Write a report in the format provided in the introduction.

5. Ohm's Law – Resistors in Series and Parallel

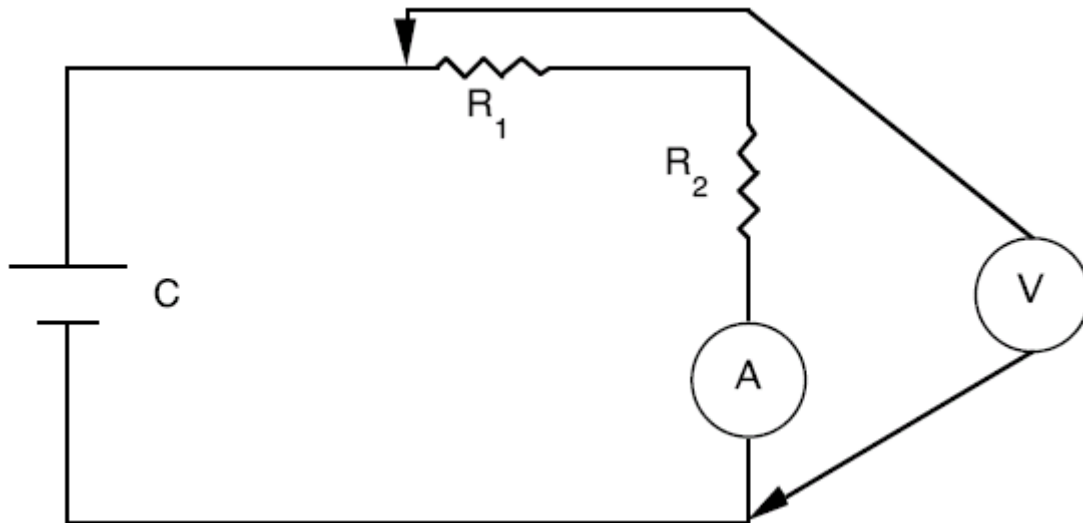


Purpose

The purpose of this lab is to learn how currents flow through simple linear series and parallel circuits.

Background and Theory

Schematic for a Series Circuit:



C = battery cell
A = ammeter
 R_1 = resistor one
 R_2 = resistor two

When some number of resistors is arranged in a circuit connected in series, as in the above diagram, then the following conditions hold:

1. The current in the circuit must be the same everywhere.
2. The sum of the voltage drops across the separate resistors must equal the applied voltage:

$$V_T = V_1 + V_2 + V_A$$

3. The total resistance in the circuit is the sum of the individual resistances. Note well, the ammeter has an internal resistance that needs to be included in this experiment.

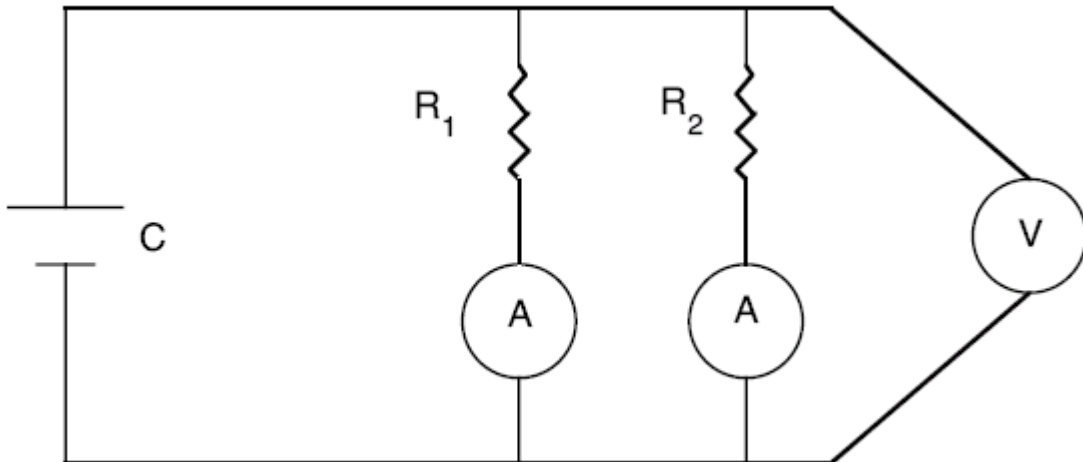
$$R_T = R_1 + R_2 + R_A$$

When a set of resistors are arranged in parallel as in the diagram below, then the following holds:

1. The voltage drop across the resistors is the same, independent of the values of the resistors, and is called the load voltage.
2. The total current into the parallel part of the circuit is equal to the sum of the currents in each branch of the parallel circuit.
3. The total resistance for resistors in parallel is:

$$R_T = \frac{1}{\sum_{i=1}^n \frac{1}{R_i}}$$

Schematic for a Parallel Circuit:



C = battery cell
 A = ammeter
 V = voltmeter
 R₁ = resistor one
 R₂ = resistor two

Equipment

Equipment Needed	Qty.
The following components can be used as is or substituted by PASCO's AC/DC Electronics Laboratory System	
Battery or Power supply	1
Ammeter (0 – 500 mA, or Current Sensor)	1
Single pole, single throw switch (if using the battery, otherwise it is optional)	1
Resistors (10 Ω , 20 Ω , 100 Ω , 10k Ω)	1 of each
Voltmeter (0 to 3V, or Voltage Sensor)	1 of each

Procedures

For the Series Circuit—

To show that the resistance formula on the previous page is valid set up the apparatus as in the series circuit diagram and then:

1. When using the multimeter try for at least three significant figures.
2. Measure the voltage drops across each of the resistors and the ammeter.
3. Measure the closed circuit voltage across the battery.
4. Is the circuit voltage drop equal to the sum of the three individual voltage drops to within experimental error? The error of the measured voltages is ± 3 in the least significant figure on the multimeter. The error of the calculated voltage is:

$$\sigma_V = \sqrt{\sigma_{V_1}^2 + \sigma_{V_2}^2 + \sigma_{V_A}^2}$$

5. Remove the wires from the battery and measure the total resistance of the circuit by placing the ohmmeter leads on these two wires. This is often called the open circuit resistance.
6. Measure the resistance of each resistor and ammeter.
7. Is the measured resistance the same as the calculated resistance to within experimental error? The measurement error using the multimeter is ± 3 in the least significant digit displayed on the multimeter. The error of the calculated resistances is:

$$\sigma_R = \sqrt{\sigma_{R_1}^2 + \sigma_{R_2}^2 + \sigma_{R_A}^2}$$

8. Does the ammeter resistance have any practical effect in your circuit? Why?

For the Parallel Circuit—

To show that the equation for resistors in parallel is valid, set up the apparatus for parallel circuits as in the above diagram:

1. Measure the voltage drop across the resistors. Is it the same for each resistor? If so, why should it be the same? If not, why not?
2. Measure the current in each branch of the parallel circuit. Calculate the total resistance of the circuit:

$$R_T = \left(\frac{I_1}{V_1} + \frac{I_2}{V_2} \right)^{-1}$$

The error in the total resistance is:

$$\sigma_{R_T} = R_T^2 \sqrt{\left(\frac{1}{V_1^2} + \frac{1}{V_2^2} \right) \sigma_I^2 + \left(\frac{I_1^2}{V_1^4} + \frac{I_2^2}{V_2^4} \right) \sigma_V^2}$$

3. Measure the open circuit resistance. Removing the wires from the battery and measuring the resistance between the two wires best achieve this. Then measure the resistance of each resistor. Calculate the total resistance and then the error in the resistance using the following formulas.

$$R_T = \frac{R_1 R_2}{R_1 + R_2} \quad \sigma_{R_T} = (R_T)^2 \sqrt{\frac{\sigma_{R_1}^2}{R_1^4} + \frac{\sigma_{R_2}^2}{R_2^4}}$$

Is this equal to the measured total resistance to within experimental error?

3. Are the values for resistance calculated in part 3 equal, to within experimental error, to the value for resistance calculated in part 2?

Remember the lab report is to consist of: Group, date, purpose, apparatus, theory, data, discussion (including some sources of error and answers to questions), and conclusion.

Bonus: When two resistors are connected in parallel, the total resistance is less than the value of either resistor. Use boundary conditions to algebraically find the ratio, R_1 / R_2 that produces the maximum decrease in the value of the total resistance, R_T . (Hint: There exist three useful boundary conditions to examine.)

Optional Electronic Workbench / MultiSim Extension

Purpose or objective


To validate Ohm's Law

Equipment

Multisim software

Procedure

Series resistors:

Open the Multisim program. Click on place source this symbol , which is in the upper left corner of the program. Select POWER_SOURCES from the left column, then DC_SOURCES from the right column, and then click ok. Go to anywhere on the page

and left click. Then select GROUND and click ok. Place the GROUND anywhere below the POWER_SOURCE. Go to the drop down menu that has sources, click it, and then select basic. In the right column, select the value resistor necessary, and then click ok. Click ok again to select another resistor until you get the required number of resistors. Then click close to go to the circuit. Connect the circuit by going to the tip of each component, left click, and then stretch the wire to the tip of the other component then left click to attach the wire to the other component. Repeat this until the circuit is complete. See figure 1 below.

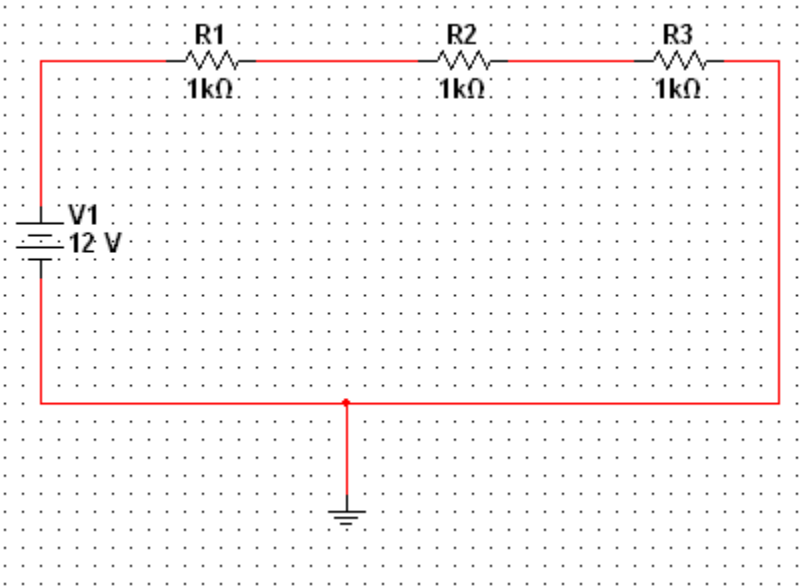



Figure 1: Resistors in series.

Now, we want to confirm Ohm's Law by measuring the voltage drop across the resistors. Let's measure the voltage drop across resistor R2 and the current between resistors R2 and R3. Click on place indicator this symbol , which is along the same row as the place sources symbol. Click on VOLTMETER in the left column and click on VOLTMETER_H in the right column, and then click ok. Then click on AMMETER in the left column and click on AMMETER_H in the right column, click ok. Then click close. Connect wires from the VOLTMETER to the wire and from the AMMETER to the wire. Click on the wire below the AMMETER and click delete. The circuit should look like figure 2 below.

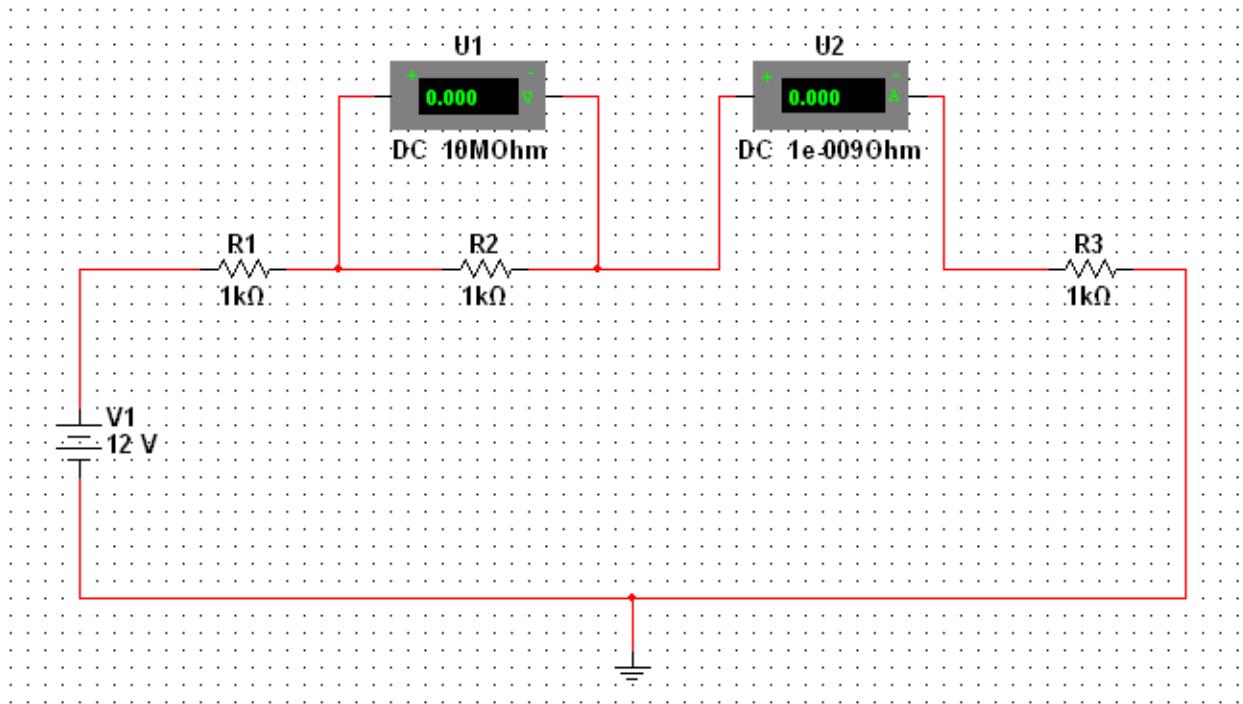





Figure 2: Circuit with VOLTMETER and AMMETER

Click the run button . Wait for a few seconds then when you see the measurements on the VOLTMETER and AMMETER, click stop . Record your measurements.

Parallel resistors

Click new . Create the schematic as shown in the figure 3 (next page). Click run and record your measurements.

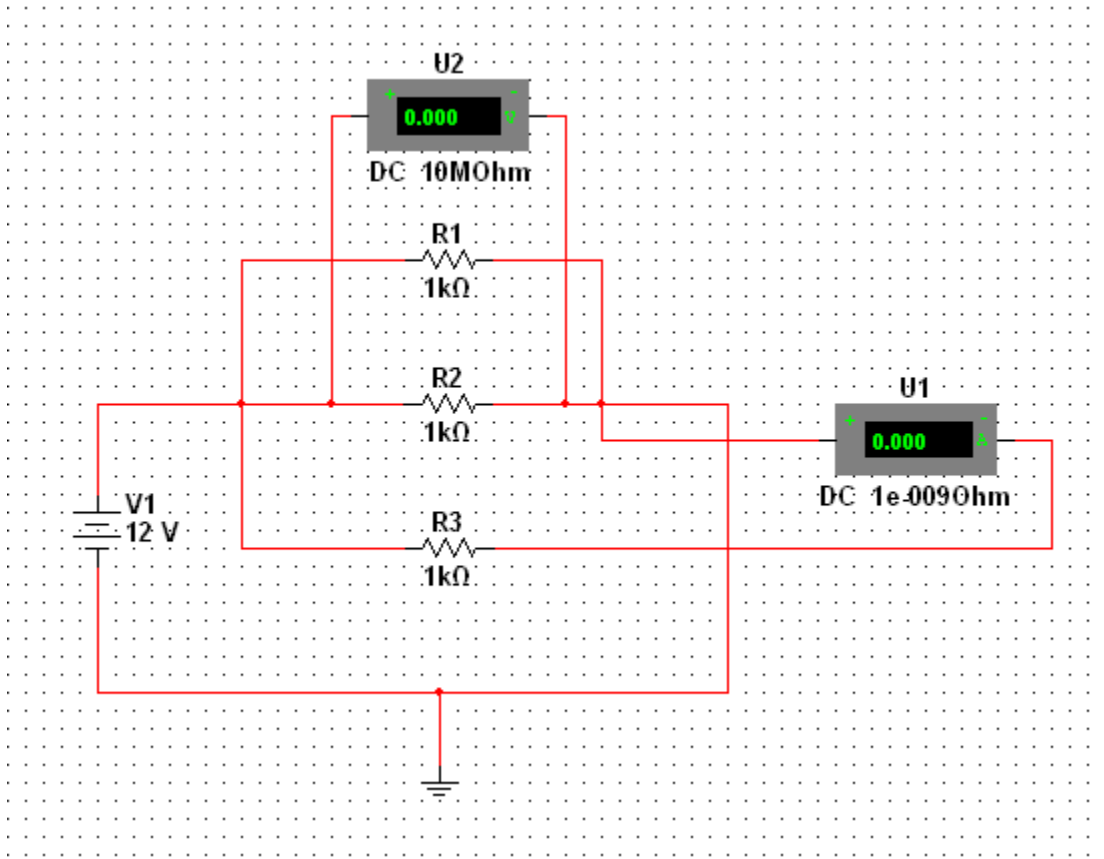


Figure 3: Resistors in parallel

Results

Series:

Voltage	Current

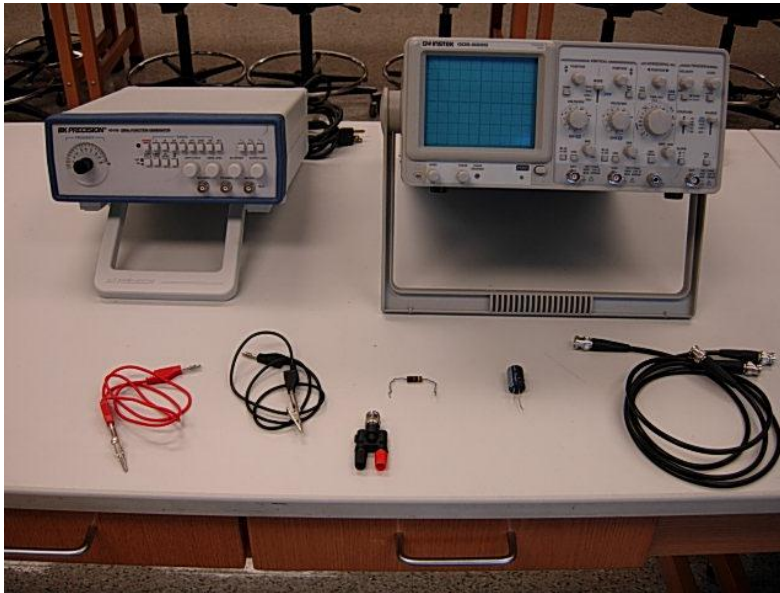
Parallel:

Voltage	Current

Conclusion and Discussion

Was Ohm's law satisfied?

6. RC Circuits



Purpose

The purpose of this activity is study currents and voltages in RC circuits. We will use a Resistor and a Capacitor to study the capacitor's transient response as it is charged then discharged.

NOTE: If you need to familiarize yourself with the oscilloscope, before you start on this experiment, work through the exercise in Appendix A designed to familiarize you with this instrument. If you are doing this experiment using the computer and PASCO's DataStudio, no such review is necessary (a write up for this version of the lab is forthcoming).

Introduction

A Resistive-Capacitance or RC circuit is an electronic circuit that is driven by a voltage or current source such as a battery or power supply. The simplest form of such a circuit is the "First Order" RC circuit consisting of one resistor and one capacitor. Along with the inductor (L, next lab) the resistor and the capacitor make up three basic linear analog components which, when put together in various combinations, exhibit behavior that is fundamental to much of analog electronics and, thus, have important applications. They are commonly used as passive filters.

Two fundamental types of passive filters are the high-pass filter and the low-pass filter. The high-pass filter presents less attenuation to high-frequency signals than low-frequency signals by passing a signal through a capacitor or a path to ground through an inductor. The low-pass filter presents less attenuation to low-frequency signals than high frequency signals by passing the signal through an inductor or by allowing a

capacitor to provide a path to ground. These are two types of electronic circuits that allow wanted frequencies to pass through while blocking unwanted ones.

Theory

The voltage across the resistor is $V_R = IR$.

The voltage across a capacitor is given as:

$$V_C = \frac{q}{C}$$

The current I is simply the flow of charge:

$$I = \frac{dq}{dt}$$

With this information, we then can write down the voltages as:

$$V_R = \frac{dq}{dt} R \quad V_C = q \frac{1}{C}$$

Closing the switch of the circuit allows current to flow through the circuit and charge the capacitor. The charge on the capacitor over time, $q(t)$, can be expressed as:

$$q(t) = CV_B (1 - e^{-t/RC})$$

The term RC has the dimensions of time and is called the capacitive time constant (τ_C).

$$\tau_C = RC$$

So the $q(t)$ expression can be rewritten as: $q(t) = CV_B (1 - e^{-t/\tau_C})$

And the current $I(t)$ is expressed as: $I(t) = \frac{dq(t)}{dt} = \frac{V_B}{R} e^{-t/\tau_C}$

After a period of time, the current will go to zero and the capacitor will be fully charged to a value $q_o = CV_B$. If the voltage source is disconnected, the capacitor will discharge through the resistor. With the battery (or power source) no longer a part of the circuit, the voltage relation becomes:

$$0 = V_R + V_C = \frac{dq}{dt} R + \frac{1}{C}$$

Solving again for $q(t)$ and $I(t)$ using $\tau_C = RC$ (next page):

$$q(t) = q_0 e^{-t/\tau_c} \quad I(t) = \frac{-q_0}{\tau_c} e^{-t/\tau_c}$$

Equipment

Equipment Needed	Qty.
Oscilloscope (or voltage sensor and PASCO DataStudio software)	1
Function Generator	1
Circuit Box or Capacitor & Inductor	1
Multimeter	1
Lead Wires	some

Procedure

The following is the recommended procedure to observe and measure the transient response of a capacitor in an RC circuit (again, the alternative procedure where DataStudio is used may be followed, the details will be provided in class, but the outcome will be the same).

1. Connect the circuit as shown (either on the board or a demonstration model)
2. Set the frequency of the function generator to 1 KHz (using the Square wave waveform), the Amplitude to maximum
3. Connect the CH1 input of the oscilloscope across the capacitor C in the circuit. Rotate the knobs on the oscilloscope to display a trace similar to what is drawn on the board
4. Measure the half-life ($t_{1/2}$) of the RC decay curve. The $t_{1/2}$ is the length of time it takes for the signal to discharge to $\frac{1}{2}$ of its maximum level, in units of seconds
5. Find the time constant, τ_c by using the half-life value $t_{1/2}$ to get the time constant. Note that $t_{1/2} = \tau \ln 2 \sim 0.693 \tau$.
6. Measure the resistance of the resistor. Use this to calculate the experimental value of the capacitor in the circuit using the formula $\tau = RC$, where R is the TOTAL resistance in the circuit (note that the internal resistance of the function generator is 50 ohms). This is the experimental C_1 value.
7. Read off the value of the capacitance written on the side of the component. This is the component value of C_1 . Calculate the percent error between the experimental and component values of capacitance.

Results and Conclusions

Answer the questions presented in the Procedure section of this write up. Sketch the shape of the RC curve, both the ramp-up and the decay portions. Your instructor may have additional questions pertaining to this exercise.

7. Magnetic Fields

Purpose

The purpose of this experiment is to understand magnetic fields and how they behave through the mapping of the field lines and through investigations of electromagnetism. An optional set of computer simulations is included near the end.

Introduction and Theory

A magnetic field is a vector force field generated by a magnetic dipole that can exert a force on a moving electric charge or another magnetic dipole. Field lines are used to graphically indicate the direction of the field, and the density of the lines indicates the strength of the field. These force fields can also be generated by electric currents of various sizes. These currents can be macroscopic, as is the case in electromagnets, or microscopic, as is true for permanent dipole or bar magnets. In the microscopic case, the magnetic field arises from electrons in atomic orbits. The magnetic field, \vec{B} , is defined in terms of a force exerted on a moving test charge, as exhibited by the Lorentz Force Law:

$$\vec{F} = q\vec{E} + q\vec{v} \times \vec{B}$$

The direction of the electric force is in the direction of the electric field if the charge on the test charge q is positive, but the direction of the magnetic force is given by the right hand rule. The magnetic field has units of Tesla and Gauss, where 1 Tesla = 10,000 Gauss.

The magnetic field due to a wire segment, ds , is given by the Biot-Savart Law:

$$d\vec{B} = \frac{\mu_0 I}{4\pi r^3} ds \times \vec{r}$$

with $\mu = 4\pi \times 10^{-7} \text{ Tm/A}$.

For complete circuits, such as a circular loop of wire with a loop radius of R and N turns:

$$\vec{B} = \frac{\mu_0 N I R^2}{2(x^2 + R^2)^{3/2}}$$

From the right hand rule, with the fingers curled in the direction of electric current flow in the loop, the thumb points in the direction that the magnetic field points-along the axis of the current loop.

Current loops act like magnetic dipoles with a dipole moment of $\mu = IA$, with A being the area of the loop. Coils of wire only produce magnetic fields when carrying electric current. The magnetic field of such a setup drops as $\frac{1}{R^3}$ at large R .

At large x , the magnetic field equation becomes $\frac{\mu_0 N I R^2}{2x^3}$. At a distance, the magnetic field from the loop is equivalent to that of a small permanent magnet.

Equipment

Equipment Needed	Qty.
Bar magnet	1
Neodymium or Rare Earth Magnet	1
Horseshoe magnet	several
Small compass	1
Solenoid with iron core	1
800 turn coil	1
DC Power supply	1
Ammeter & Voltmeter (or multimeter)	1 each
Connecting wires	4
Graph paper (can use the same as was used in the Electric Field Mapping experiment)	Several sheets
PC with Internet connection and Data Studio	1
Magnetic Field Sensor	1

Procedure

Note: this experiment is a collection of activities that explore the permanent magnet as well as the electromagnet. The instructor may choose one or more of the suggested activities, or perform one of his own choosing to demonstrate how magnetic fields work. Included below are several activities, which consist of both online and live, hands-on exercises. In addition, there are several demonstrations (e.g. jumping ring, magnet through a Helmholtz coil hooked to a galvanometer, Lenz's law, etc.) that can be performed to illustrate concepts covered in this experiment.

1. Permanent Magnet

The first activity involves mapping the magnetic field in a manner similar to what we did earlier in the semester with the electric field. In this case, it is considerably simpler. We will use small compasses ("magneto-probes") to trace out the magnetic field at various places to put together a picture of the magnetic field. We will do this for several different types of magnets.

To map out the magnetic field of a bar magnet, follow the guidelines listed below:

- ◆ Set the magnet near the center of the sheet of graph paper
- ◆ Starting about 1cm on one side of the magnet, near the middle, place the compass until the needle stabilizes (do not drop the compasses)
- ◆ Draw a point on the paper on either side of the points of the compass needle
- ◆ Move the compass up or down one compass diameter and repeat. Follow the direction of the needle, if it begins to turn, make sure you turn with it
- ◆ Continue this process, connecting the dots as you go along, until you reach a pole of the magnet.

- ◆ Repeat for the other end, toward the other pole, and also for the other side of the magnet at an equivalent distance.
- ◆ After having plotted the first pair of magnetic field lines, repeat the above steps for lines that parallel the magnet about 3cm, 5cm, 7cm and 10 cm away from the magnet.

If the instructor chooses, he may have you map the magnetic field that surrounds a different type of magnet. If so, repeat the above steps for that magnet on a separate sheet of paper.

2. Solenoids and Wire Coils

This next activity makes use of the wire coils in the following manner, starting with the solenoid. There are several questions in the procedure that you will need to write responses for in the Results section of your laboratory report.

- ◆ Connect the solenoid coil, without its core, to a DC power supply.
- ◆ Turn on the power and adjust the potential to 10V (you may wish to verify this setting with the voltmeter).
- ◆ Bring the core into the opening of the solenoid, about $\frac{3}{4}$ the way inside. Turn on and off the power supply and observe how this affects the core—does it tug on the core as you switch on and off?
- ◆ Does the coil attract the core in a certain direction or is one end of the core repelled?
- ◆ Does the core have permanent north and south poles?

We will repeat part of the above procedure with the 800 turn coil, but use the magnetic field sensor attached to the Science Workshop interface box and with DataStudio running. Place the sensor inside and outside, at various distances, and perform the following tasks:

- ◆ Connect the 800-turn coil to a DC power supply.
- ◆ Turn on the power and adjust the potential to 10V (you may wish to verify this setting with the voltmeter).
- ◆ Measure the current, I , with the ammeter and record it in the Results section data table. Measure the R , or radius, of the coil loops
- ◆ Calculate the magnetic field for a point at the center of the cavity of the coil loop using the equation $\vec{B} = \frac{\mu_o N I R^2}{2(x^2 + R^2)^{3/2}}$. Repeat at distances (from the side of the coil near the middle) of $2R$, $3R$, $5R$, and $10R$.
- ◆ At what point would you use $\frac{\mu_o N I R^2}{2x^3}$?
- ◆ Take measurements of \mathbf{B} at the same locations for which you did calculations. How do the calculated and measured values compare to each other? To better evaluate this, calculate the percent difference between the

measured and the calculated values. How does the field drop off as you move away from the coil (you may wish to plot this to get a better idea of this)?

$$\%diff = \left| \frac{B_{calculated} - B_{measured}}{B_{calculated}} \right| \cdot 100\%$$

Data and Results

Attach the map(s) of the magnetic field(s) you made from Part I to this write up. If you mapped two fields, how were they similar? How were they different? Did all of your field lines make closed loops? (Material from the computer simulation section can go on the back of this sheet, if this activity is performed). You may use the following data sheet or construct your own, or use an alternative one provided by your instructor.

Solenoid observations:

The 800-turn coil: Radius = _____ N = _____ I = _____

R	R, m	B-field Measured	B-field Calculated	% Difference
center				
2R				
3R				
5R				
10R				

Computer Simulations (Optional Extension to the Lab)

If instructed by your professor, you will do a simulation that is provided by the University of Colorado's Simulation Library. Go to "Faraday's Electromagnetic Lab" on the following website:

http://phet.colorado.edu/simulations/sims.php?sim=Faradays_Electromagnetic_Lab

Click on "run now" to launch the simulation (you may need to press the "Ctrl" button as you click "run" to enable the popup window to appear). There are five tabs for five activities: bar magnet, pick up coil, electromagnetic, transformer, and generator. We will do all five. Answer all the questions posed in the five activities below in the discussion section of your laboratory report.

I. Bar Magnet

On the screen you should have a bar magnet and a compass.

1. Compare the magnetic field around the bar magnet (represented by the little arrows) to the *electric* field around a positive and negative charge.
2. Use the magnetic field sensor to find the strength of the magnetic field at 8 points spread out around the magnet. Sketch the magnet, and at these points, draw a vector (with size and direction) that represents the field.
3. Use the magnetic field sensor to find the magnetic field *inside* the magnet. Explain your findings.
4. Measure the magnetic field strength at 10 points along a straight line extending out from the magnet's south pole. As there is no measuring tape on this simulation, use a ruler against the screen to measure distance in cm. Make a graph of magnetic field vs. distance (attach to this write up).

II. Electromagnet

Go to the "Electromagnet" tab.

1. Sketch the electromagnet. Label the parts and show what is happening in the electromagnet to create a magnetic field.
2. How does the magnetic field compare to that of a bar magnet?
3. What things can you change in the simulation that affects the magnetic field? List the options, and explain the resulting change in the field.
4. What physical factor in the electromagnet determines where the "north" and "south" pole of the magnet is located?

III. Pickup Coil

Go to the "Pickup Coil" tab and investigate the equipment. Explain 2 ways that you can get the light bulb to light. What factors determine how brightly the light shines?

IV. Transformer

Investigate the setup of this experiment. Run once with the battery-powered (DC current) electromagnet to get the light bulb to shine. Do it again with the AC current. What do you notice that is different when the AC current is run versus the DC current?

What else can you change about the pickup coil? How does that change the outcome of the experiment?

V. Generator

What is happening in this experiment and how do things change with the changing flow of water? Change out the light bulb for the meter. How does the meter behave as you change the flow of water that drives the generator?

How does this demonstration relate to the power generation methods of some locations in the U.S.?

Write your responses after each section of the simulation sequence.

8. Electromagnetic Induction

Purpose

The purpose of this experiment is to understand how changing magnetic fields can produce electric currents. In doing so, we examine Lenz's Law and the derivative form of Faraday's Law.

Introduction

Magnetic flux is defined as the product of magnetic field lines and the area through which they pass. Of importance is that the total magnetic flux through a closed surface is zero. This implies that monopoles do not exist. The magnetic flux is dependent on the strength of the magnetic field, the size of the area through which they pass and the angle between the normal of the area and the magnetic field. We will investigate the dependence of flux on these variables and how a changing flux can induce currents in other coils.

One practical use for inductance is to detect the presence of cars at a stoplight. An inductive loop is a coil of wire that winds a certain number of turns. This coil is embedded in the road's surface and works by detecting a change of inductance. This change comes about when a large steel object, namely the car, is placed within the inductor's magnetic field and that changes the inductance, which is detected by a meter, which then sends a command to the light to switch from red to green after a short interval of time.

When electric current first starts flowing in a coil, the coil's tendency is to build up a magnetic field. While the field is building, the coil inhibits the flow of current. Once the magnetic field is built up, the current flows normally through the wire. When the switch is opened, and the circuit is broken, the magnetic field around the coil maintains an electric current until the magnetic field collapses. The inductor has a characteristic called capacity which is influenced by two factors:

- The number of coils
- The material that the coils are wrapped around (the core)

Putting iron in the core of an inductor gives it much more inductance than air or any other non-magnetic core would. There are devices that can measure the inductance of a coil, and the standard unit of measure is the **Henry**.

Theory

Magnetic Flux is defined as $\phi = BA \cos \theta$, where **B** is the magnetic field in tesla, *A* the area in m², and θ the angle in degrees. We note that when θ is 90° we have a minimum flux as the $\cos(90^\circ) = 0$. This means the normal to the area and the direction of the field is 90° . The maximum flux occurs at $\theta = 0^\circ$ or 180° .

Faraday's Law states a changing magnetic field induces an electric field, this is summarized in the following equation, $\varepsilon = -\frac{d\phi}{dt}$, where ε is the electromotive force, and Φ is the flux. It states that if we have a flux associated with a loop which changes in time, it will induce an electromotive force (or emf) in a separate loop in such a direction that the flux resulting from it will counteract the changing flux from the initial loop—this is Lenz' Law:

$$\varepsilon = -\frac{d\phi}{dt} = -\frac{d(BACos\theta)}{dt} = -ACos\theta\frac{dB}{dt}$$

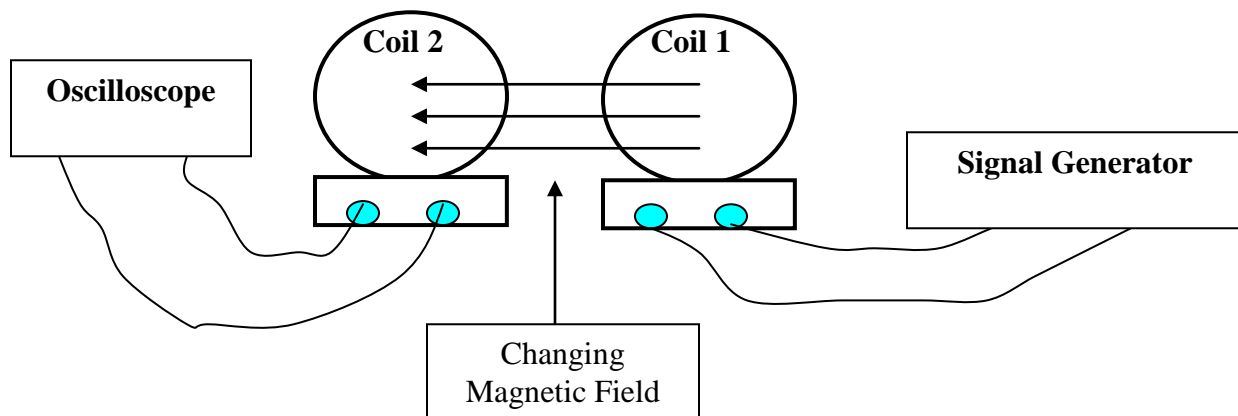
To generate our magnetic field we shall use a 200 turn field coil defined as $B = \frac{\mu_0 IN}{2r}$, where μ_0 is the constant of permeability, $\mu_0 = 4\pi \times 10^{-7} \frac{T.m}{A}$; I is the current; N is the number turns; and r is the radius of the coil.

Equipment

Equipment Needed	Qty.
Oscilloscope	1
Function Generator	1
Helmholtz Coils	1
Coaxial Cables	1

Procedure

Connect the apparatus as shown below.



Data & Results

Calculate and measure the magnetic field in coil 1:

$$B_{\text{calculated}} = \text{_____ tesla}$$

$$B_{\text{measured}} = \text{_____ tesla}$$

Complete Table 1 Below

Angle (degrees)	Distance between Coils	Frequency Coil 1 Hz	Frequency Coil 2 Hz	Voltage 1 Volts	Voltage 2 Volts
5	10 cm	200 Hz			
10	10 cm	200 Hz			
15	10 cm	200 Hz			
25	10 cm	200 Hz			
30	10 cm	200 Hz			
35	10 cm	200 Hz			
40	10 cm	200 Hz			
45	10 cm	200 Hz			
50	10 cm	200 Hz			
55	10 cm	200 Hz			
60	10 cm	200 Hz			
65	10 cm	200 Hz			
70	10 cm	200 Hz			
75	10 cm	200 Hz			
80	10 cm	200 Hz			
85	10 cm	200 Hz			
90	10 cm	200 Hz			

- a. What is the shape of the induced voltage in coil 2 versus angle?

- b. Is this what you expected and why?

- c. What do you observe about the emf values based upon the angles?

- d. What is observed of the frequency in coil 2? How does it compare to the frequency in coil 1? What does this tell you?

- e. What is observed of the voltage ratio versus angle? What does this tell you about the induced emf as a function of angle?

Complete Table 2 Below

Angle (Degrees)	Distance between Coils	Frequency Coil 1 Hz	Frequency Coil 2 Hz	Voltage 1 Volts	Voltage 2 Volts	V1/V2
0	0.02cm					
0	0.04 cm					
0	0.06 cm					
0	0.08 cm					
0	0.10 cm					
0	0.12 cm					
0	0.14 cm					
0	0.16 cm					
0	0.18 cm					
0	0.20 cm					

9. Voltages and Currents in RLC Circuits

Purpose

The purpose of this activity is study currents and voltages in RLC circuits. We will measure the response of the voltage across a resistor (V_r) as a function of a voltage applied at different frequencies.

Introduction & Theory

When an inductor L , a resistor R and a capacitor C are connected in series, the alternating current I present in the circuit depends on the frequency of the driving voltage \mathcal{E} . This type of circuit is used extensively in electronic devices, particularly radios and televisions.

These circuits are used in a number of electronics applications including the tuning of analog radios and televisions. Adjustable tuning is usually achieved by using a parallel plate variable capacitor which enables the value of C to be changed, which enables the receiver to tune to stations of different frequencies. The inductor comes with an adjustable core which enables the inductance, L , to be changed. The core is made of a high permeability material that effectively increases inductance and is threaded so that it can be screwed in or out of the inductor winding as needed.

Filters are another common use of RLC circuits. In a filtering application, the resistor R becomes the load that the filter is working into. The damping factor value is selected based on the desired bandwidth of the filter. A wider bandwidth uses a larger damping factor and vice versa. The three components of the circuit give three degrees of freedom to the designer of the circuit to enable the desired outcome to be met. Two of the components are required to set the bandwidth and the resonant frequency; the third can be adjusted in such a way so as to scale each of the three components to convenient values. In another setting, R may be predetermined by the circuitry within which this circuit is found and which will use this last degree of freedom.

Other common uses of RLC circuits include the use of the circuit as an oscillator whereby the attenuation (or damping factor) is made as small as possible. This can be adjusted by making the R be as small as possible for series circuits and as large as possible for parallel circuits. Other uses also include making the circuit a voltage multiplier or a pulse discharge circuit.

An important property in RLC circuits is **resonance**, which is the ability of the circuit to resonate at a specific frequency, called the resonant frequency. Resonance in the circuit happens because energy is stored in two different ways: as a electric field as the capacitor is charged, and as a magnetic field as the current flows through the inductor. Energy can be transferred from one to the other and back again in an oscillatory mode, much like the mass at the end of a spring oscillates back and forth between one extreme and the other. The mathematics (in the form of a second order differential

equation) describing both are identical in form. Whereas friction in the spring-mass system will eventually bring the system to a halt, the resistance in the RLC circuit will diminish the oscillation over time. Like a vibrator that can keep the mass on a spring oscillating indefinitely, the driving AC power source will keep the circuit resonating indefinitely.

The resonant frequency is defined as the frequency at which the impedance of the circuit is at a minimum. In the series LRC circuit that we will be studying, the impedance reaches a minimum when resonance is achieved (in parallel LRC circuits this happens when the impedance reaches a maximum). The resonant frequency is reached because the inductor and capacitor are equal but of opposite sign, so they cancel out.

The AC current of a RLC circuit connected in series depends on the voltage and impedance.

$$I = \frac{V}{Z}$$

Impedance is the AC circuit equivalent of resistance. This describes not only the amplitude of voltages and currents but also the relative phases. The impedance is defined mathematically as:

$$Z = \sqrt{(X_L - X_C)^2 + R^2}$$

Where the inductive reactance is, $X_L = \omega L$ the capacitance reactance is $X_C = \frac{1}{\omega C}$, and R is the resistance and the angular frequency is $\omega = 2\pi f$ where f is the linear frequency. The current will have a maximum value at resonance when $X_L = X_C$ this condition defines the resonant frequency at $\omega_{res} = \frac{1}{\sqrt{LC}}$. For this condition the impedance $Z = R$ and has a minimum value, which results in the current having a maximum value.

Equipment

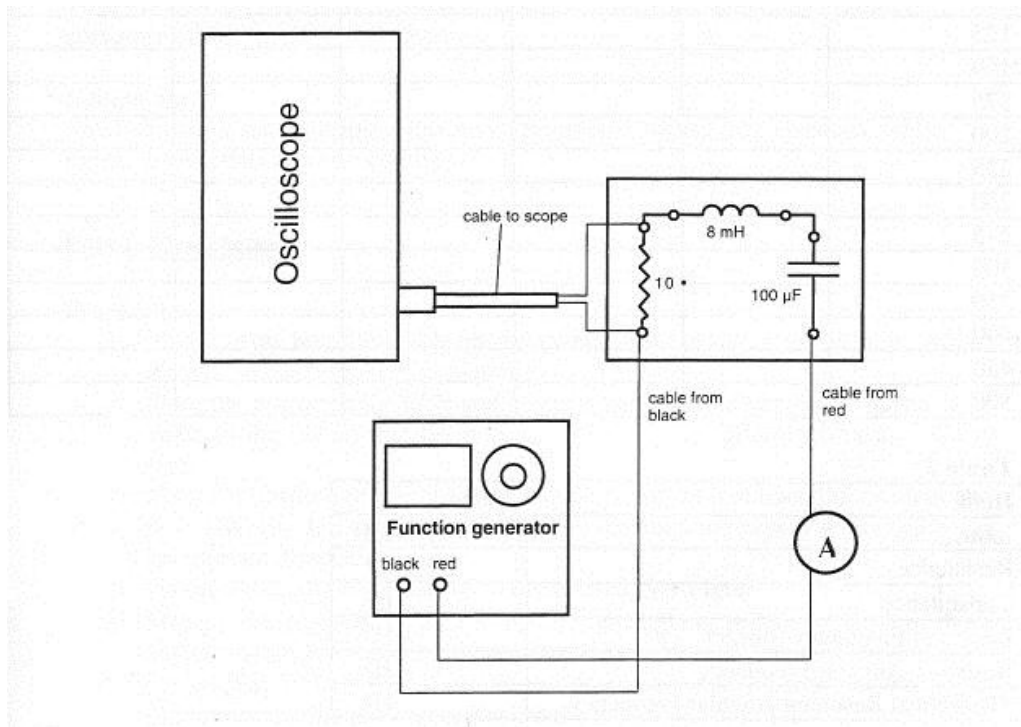
Equipment Needed	Qty.
The following components can be used as is or substituted by PASCO's AC/DC Electronics Laboratory System	
Oscilloscope	1
Function Generator	1
Inductors	2
Capacitor	1
Resistor	1

Procedure

1. Set up the circuit as shown on the next page. The function generator will apply

the voltage to the circuit at different frequencies. The oscilloscope will measure the voltage across the resistor. Record the data in the table provided or follow your professor's instructions on how to organize and present the data in your laboratory report.

2. Plot a graph of V_r vs. linear frequency (f).
3. Determine the inductive reactance, capacitive reactance, impedance and amplitude of the current through the resistor and plot, X_L vs. frequency (f), X_C vs. f , and Z vs. f .
4. Refer to the "Analyzing the data" section on the image below.



Analyzing the data

1. From the graph find the linear resonant frequency, f_{res} .
2. Using the resonant frequency f_{res} , calculate the resonant angular frequency, ω_{res} and record the value in the Table 2.
3. Calculate the theoretical resonant angular frequency using the values of the inductance and capacitance.
4. Compare the theoretical resonant frequency to your measured resonant frequency.

Complete Table 2 Below:

Parameter Name	Parameter Value
Inductance	
Resistance	
Capacitance	
Resonant Frequency (linear)	
Resonant Angular Frequency	
Theoretical Resonant Angular Frequency	

Conclusions & Questions

1. How does the measured value for the resonant angular frequency compare to the theoretical value for the resonant angular frequency?
2. Is the plot of impedance current versus frequency symmetrical about the resonant frequency? Explain.

At resonance, the reactances of the inductor and the capacitor cancel each other out so that the impedance (Z) is equal to just the resistance R . Calculate the resistance of the circuit by using the amplitude of the current at resonance in the equation $R = V/I$. Is the resistance equal to that used in the circuit? Why or why not?

Optional Electronic Workbench / MultiSim Extension

Purpose or objective


The purpose of this activity is study currents and voltages in RLC circuits. We will measure the response of the voltage across a resistor (V_r) as a function of a voltage applied at different frequencies using Multisim.


Equipment





Multisim software

Procedure

Open the Multisim program. Click on PLACE, then click on COMPONENT. Click on the drop down bar below GROUP and select BASIC. Select RESISTOR and under COMPONENT, select the value resistor then click ok. Select CAPACITOR, select the value, then click ok. Select INDUCTOR, select the value, then click ok. Click on the drop down bar below GROUP, select SOURCES, then POWER_SOURCES, then GROUND, then click on ok. Go to the same drop down bar, select INDICATORS, then select AMMETER, the select AMMETER_H then click ok. Then close the SELECT A COMPONENT tab.

Go to the right side of the program. Run the mouse over the icons and select FUNCTION GENERATOR . Drag it closer to the other components and the left click.

Go back to the right side of the program and select OSCILLOSCOPE . Drag it closer to the other components and left click. Click on the edge of the components and use the wire to connect them. The circuit should look like figure 1 below. Ensure that the positive terminal of the function generator goes to the positive terminal of the ammeter. Check the schematic in the figure 1 below to ensure that the terminal match your schematic.

Double click on the oscilloscope. Then click run  or . Then click stop  or . Pull the green vertical line that is on the left of the graph to the crest of the sine wave on the graph (It will change color to yellow). Then pull the red vertical line to the trough (it will change color to blue) and record your results given by the yellow vertical line. Your results should look like figure 2 below.

Double click on the function generator and change the frequency. Run and stop the experiment and record your results.

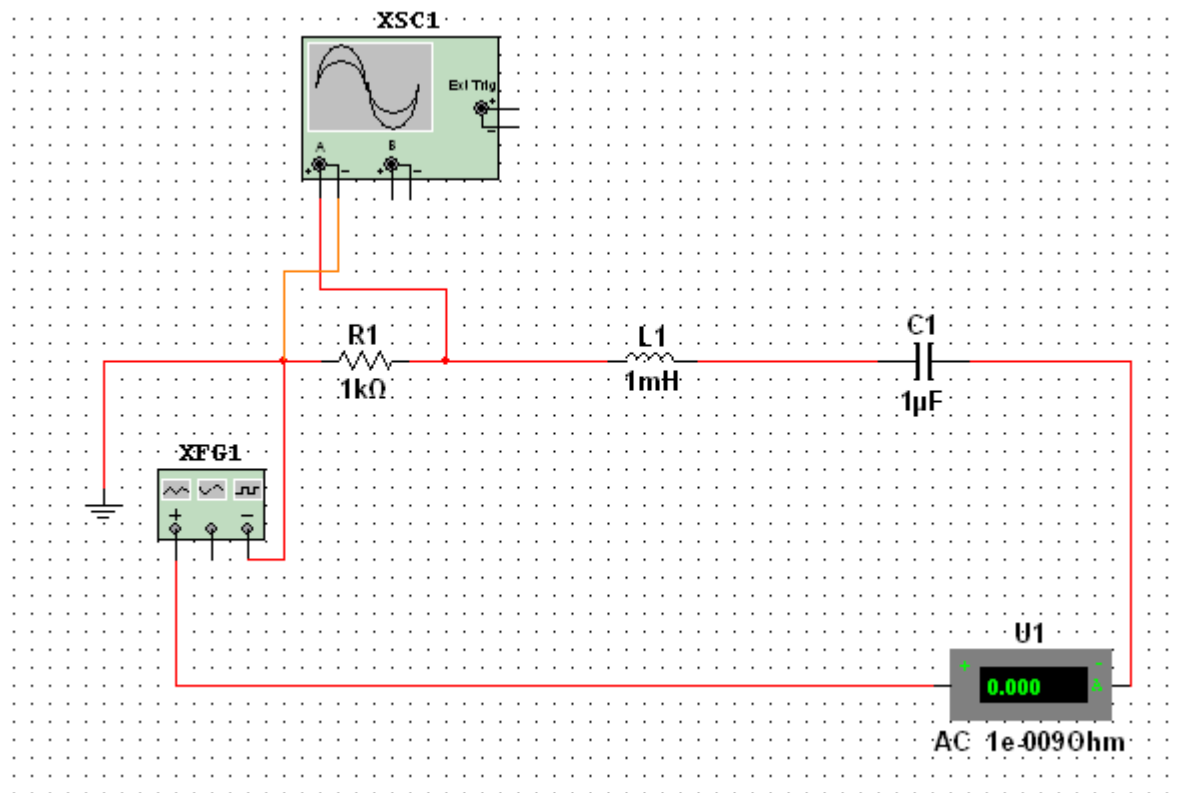


Figure 1: RLC Circuit.

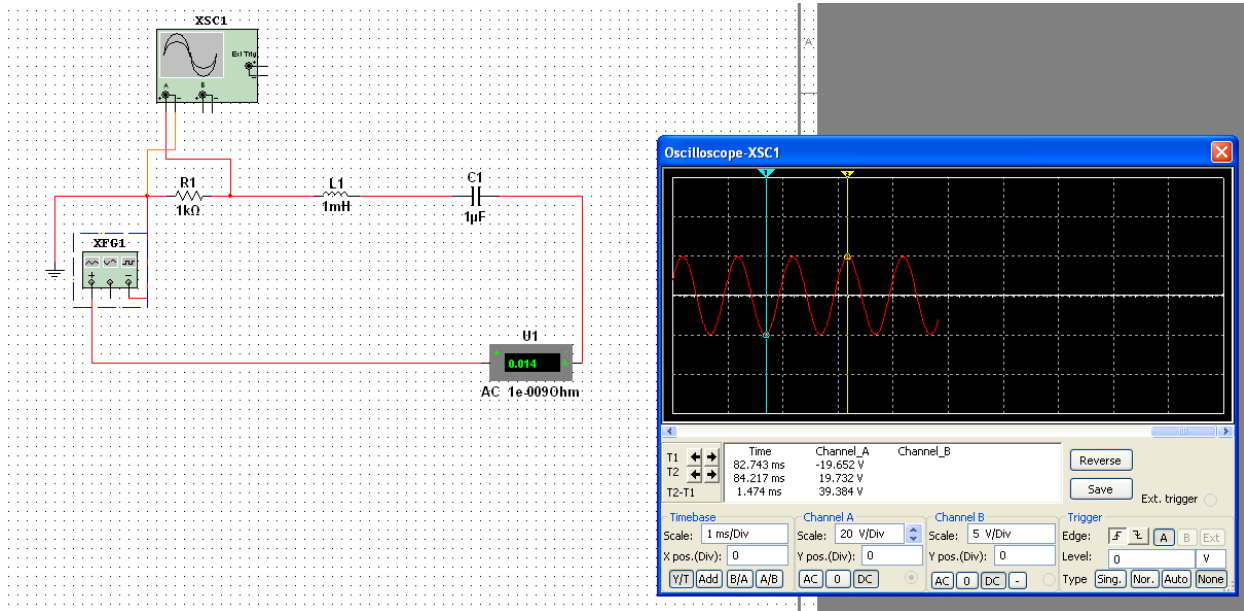


Figure 2: Results should look like this

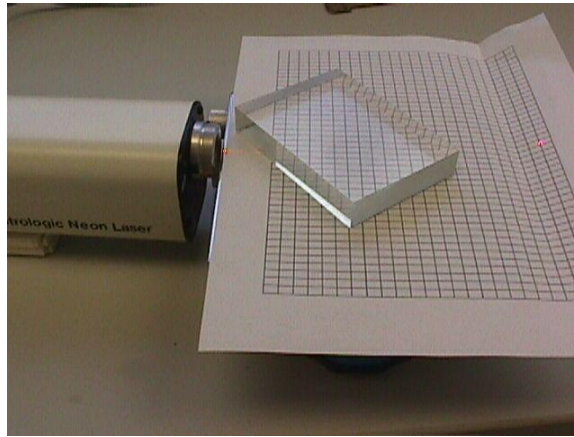
Results

Complete Table 1:

Linear Frequency	V_r (V)	$X_L = 2\pi fL$ (Ω)	$X_C = \frac{1}{2\pi fC}$ (Ω)	Z (Ω)	$I = \frac{V_R}{Z}$ (Ω)

Conclusion

10. Reflection and Refraction of Laser Light



Purpose

The purpose of this laboratory exercise is to study the nature of reflection and refraction of light with a laser.

Introduction

When a light beam falls on a surface, both reflection from the surface and refraction into the substance occurs. Refraction is the bending of light as it passes from one substance to another. As light passes from a less dense to a more dense material it bends towards the perpendicular to the plane of the surface of the material. Conversely, light entering a less dense material will bend away from the perpendicular to the plane of the surface. The amount of bending which occurs depends both on the wavelength of the light and the type of material through which the light is propagating. A property of the material related to the amount of refractive bending is called the index of refraction of the material. The index of refraction of a material is usually quoted with respect to vacuum, where the vacuum is defined to have an index of refraction of one. The index of refraction of air is almost that of a vacuum, so light traveling in air can be considered to be in a vacuum. (This is a good approximation to an accuracy of three significant figures)

In the table on the next page is a table of the index of refraction for a number of everyday items. This list is composed from lists that appear on several websites such as <http://hyperphysics.phy-astr.gsu.edu/hbase/tables/indrf.html> and the interactive website <http://interactagram.com/physics/optics/refraction/>, which provides a fairly detailed description of the phenomenon of refraction.

Index of Refraction of Selected Materials

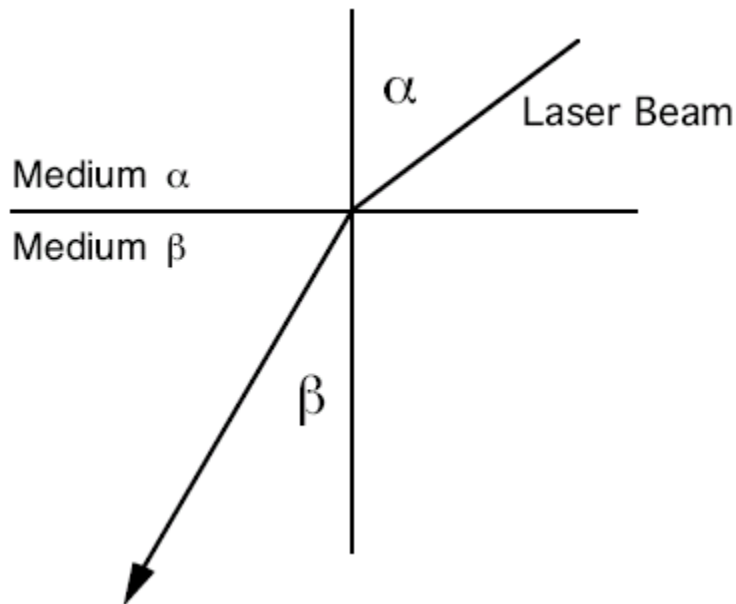
Material	Index	Material	Index
Vacuum	1.00000	Rock Salt	1.544
Water (gas)	1.000261	Sodium Chloride	1.544
Argon	1.000281	Quartz	1.544
Air at STP	1.0002926	Amethyst	1.544
Nitrogen (liq)	1.2053	Amber	1.546
Alcohol	1.329	Polystyrene	1.55-1.59
Ice	1.309	Emerald, Synth flux	1.561
Water 100'C	1.31819	Emerald, Synth hydro	1.568
Methanol	1.329	Flint glasses	1.57-1.75
Water 35'C (Room temp)	1.33157	Glass, Flint, Light	1.58038
Water 20'C	1.33335	Styrofoam	1.595
Teflon	1.35	Topaz, Blue	1.610
Acetone	1.36	Turquoise	1.610
Ethanol	1.36	Mercury (liquid)	1.62
Ethyl Alcohol	1.36	Topaz	1.620
Sugar solution (30%)	1.38	Topaz, Pink	1.620
Fluorite	1.433	Topaz, Yellow	1.620
Aluminum	1.44	Topaz, White	1.630
Opal	1.450	Glass, Flint, Medium	1.62725
Quartz, Fused	1.45843	Carbon disulfide	1.63
Plastic	1.460	Asphalt	1.635
Turpentine	1.472	Glass, Flint, Heavy	1.65548
Glycerine	1.473	Glass, Flint, Dense	1.66
Onyx	1.486	Olivine	1.670
Glass, Albite	1.4890	Methylene iodide	1.74
Sugar solution (80%)	1.49	Ruby	1.760
Ulexite	1.490	Sapphire	1.760 – 1.77
Plexiglas	1.50	Rare earth flint	1.7-1.84
Dolomite	1.503	Glass, Flint, Lanthanum	1.80
Gaylussite	1.517	Pyrite	1.810
Glass	1.51714	Lanthanum flint	1.82-1.98
Rubber, Natural	1.5191	Glass, Flint, Heaviest	1.89
Crown glasses	1.52-1.62	Sulphur	1.960
Typical crown glass	1.52	Crystal	2.00
Nylon	1.53	Arsenic trisulfide glass	2.04
Thomsonite	1.530	Zirconia, Cubic	2.170
Sodium chloride	1.54	Diamond	2.417

Theory

The defining equation for the index of refraction between any two materials is:

$$n_{\alpha} \sin \alpha = n_{\beta} \sin \beta$$

where α is the bending angle with respect to the external medium, β is the bending angle with respect to the internal medium, n_α is the index of refraction of the external medium, and n_β is the index of refraction of the internal medium.



For the case where the medium α is air, then n_α is nearly one and we can rearrange the above equation to solve for the index of refraction of the material as:

$$n = \frac{\sin \alpha}{\sin \beta} \quad (\text{where } n \equiv n_\beta)$$

We will use a red laser beam as a source for the light ray (a laser generates a coherent, monochromatic light beam) with which to find the index of refraction of a slab of transparent material. This value for the index of refraction is valid only for photons that have the same wavelength as those from the laser.

Equipment

Equipment Needed	Qty.
Laser	1
Glass block	1
Protractor or circular optics table	1
Sheet of graph paper	1

Procedure

1. Use the materials listed and the above equation to determine the index of refraction of the glass block. A good procedure is to lay the block flat on a piece of paper and shine the laser light through the edge at a sufficiently large angle. Make a mark on

the paper where the light enters and leaves the block. Construct perpendicular lines to the face of the edge to be used for measuring the appropriate angles.

2. What are the units of the index of refraction?
3. What are some sources of error?
4. Do you have enough information to determine the type of material the block is made of (assuming the table above was not provided)? Why or why not?
5. Round off your final answer correctly with respect to the amount of error.
6. Write up your report in the usual manner, remembering to answer all questions.

Bonus 1: Calculate the value of the speed of light inside the object used for refraction.

Bonus 2: Given that the wavelength of the helium-neon laser light is 632.8 nm, what material is the object used for refraction made of?

Extensions: Because of the brief nature of this lab, it is likely that your instructor may include some additional steps to provide more opportunity to explore the reflection and refraction of light. These steps may include (but are not limited to):

- Using the table provided in the Introduction, and the physical appearance of the object used to determine the index of refraction, identify the material out of which your block was made of.
- Repeat the experiment, but also trace the reflected beam as well as the refracted beam. Measure the reflected beam's angle to the normal along with the incoming beam's angle relative to the normal. What do you notice?
- Repeat the experiment with two or three other substances, to include a plastic container filled with water, a slab of glass, or anything else we may find in the storage room.
- Repeat the experiment with a green laser instead of a red one. Try to keep the orientation identical to that of the red laser (or better yet, shine them side by side). Are they reflected differently? Do they refract differently? What is the index of refraction as determined by the green laser and how does it compare with that determined by the red laser?

11. Concave and Convex Lenses

(Adapted from: Jerry Wilson, *Physics Laboratory Experiments*, 4th Ed., pp. 471-475, © 1994 Houghton Mifflin Company)

Purpose

The purpose of this experiment is to investigate the optical properties of convex and concave lenses.

Introduction

Mirrors and lenses are familiar objects that we use on a daily basis. The most commonly used mirror is what is called a plane mirror, which is used for cosmetic applications. Spherical mirrors have many common applications, such as security monitoring of store aisles and merchandise, and concave spherical mirrors are used as flashlight reflectors. Mirrors reflect light, while lenses transmit light. Spherical lenses are used to converge and focus light (convex spherical lenses) and to diverge light (concave spherical lenses).

This experiment will focus on spherical lenses of two types—convex and concave. Convex lenses are sometimes called converging lenses because rays parallel to the principle axis converge at the focal point. A concave lens is called a diverging lens because rays parallel to the perpendicular axis appear to diverge from the focal point.

Theory

If the image is formed on the side of the lens opposite the object, it is real and can be observed on a screen. However, if the image is on the same side of the lens as the object, it is a virtual image and cannot be seen on the screen. Analytically, the thin-lens equation and magnification factor are used with the sign convention similar to that in the following table. These equations apply only to thin lenses. The focal length of a lens is given by the lensmaker's equation:

$$\frac{1}{f} = (n - 1) \left(\frac{1}{R_1} + \frac{1}{R_2} \right)$$

where n is the index of refraction for the lens material and the R 's are taken as positive for convex surfaces. Lenses used in the laboratory are made from glass, which has an n between 1.5 and 1.7. As an example, for glass with $n = 1.5$ and symmetrical converging lenses, ($R_1 = R$ and $R_2 = R$), the equation yields $f = R$ (for f to be equal to $R/2$ for a symmetrical lens requires $n = 2$, which is greater than the index of refraction of glass). The focal length of a lens depends on the R -values in general, which can be different, as well as n .

Quantity	Conditions	Sign
Focal Length, f	Convex Lens	+
	Concave Lens	-
Object distance, d_o	Usually (always in this experiment), although there are some cases of lens combinations where d_o may be negative when an image is used as an object.	+
Image distance, d_i	Image real	+
	Image virtual	-
Magnification, M	Image upright	+
	Image inverted	-

Equipment

Equipment Needed	Qty.
Concave and Convex Lenses (one of each)	1
Convex Lens (focal length longer than 1 st convex lens)	1
Meter stick optical bench (white cardboard can serve as the screen) or precision (PASCO) bench with lens holder and white screen	1
Light Source: candle and candleholder, or electric light source with object arrow.	1

Procedure

Convex Lenses

1. Sketch a ray diagram for a convex lens with the object at its focal point. The image is formed at infinity.
2. Using the lens equation, determine the image characteristics for an object at infinity.
3. Experimentally determine the focal length of the lens. (The lens may be placed in a lens holder and mounted on a meter stick.)
4. Solve cases 1 to 4.

Case 1: $d_o > R$

- a. Sketch a ray diagram for an object at a distance slightly beyond R (i.e., $d_o > R$) and note the image characteristics.
- b. Set this situation up on the optical bench, with the object placed several centimeters beyond the radius of curvature (known from f determination with $R=2f$). Measure the object distance d_o , and record it. It is usually convenient the lens manually and adjust the object distance by moving the lens rather than the object light source. Move the screen along the side of the optical bench until an image is observed on the screen. This is best observed in a darkened room. The lens may have to be turned slightly to direct the rays toward the screen.
- c. Estimate the magnification factor M and measure and record the image distance d_i .
- d. Using the lens equation, compute the image distance and the magnification factor.

- e. Compare the computed value of d_i with the experimental value by computing the percent difference

Case 2: $d_o = R$. Repeat the procedure for this case.

Case 3: $f < d_o < R$. Repeat the procedure for this case.

Case 4: $d_o < f$. Repeat the procedure for this case.

It is initially instructive to move the lens continuously toward the object light source (decreasing d_o) from a $d_o > 2f$ and to observe the image on the screen, which also must be moved continuously to obtain a sharp image. In particular, notice the change in the size of the image as d_o approaches f .

Concave Lens

5. Sketch ray diagrams for objects at (1) $d_o > R$, (2) $f < d_o < R$, and (3) $d_o < f$, and draw conclusions about the characteristics of the image of a convex lens. Experimentally verify that the image of a convex lens is virtual (i.e., try to locate the image on the screen).
6. It is possible to determine the focal length of a concave lens experimentally by placing it in contact; the lens combination has a focal length f_c given by

$$\frac{1}{f_c} = \frac{1}{f_1} + \frac{1}{f_2}$$

Place the concave lens in contact with the convex lens (convex surface to concave surface) in a lens holder and determine the focal length of the lens combination f_c by finding the image of a distant object. Record the results in the Laboratory Report.

Using the equation $\frac{1}{f_c} = \frac{1}{f_1} + \frac{1}{f_2}$ with the focal length of the convex lens determined in procedure **1**, compute the focal length of the concave lens.

12. Laser with Diffraction Grating

(Adapted from Halliday / Resnick / Walker *Probeware Lab Manual*, 6th Ed., pp. 182-183, © 2003 John Wiley & Sons, Inc.)

Purpose

The purpose of this experiment is to investigate the optical properties diffraction gratings using a laser.

Safety Note

Do not stare into the aperture (opening where the light comes out) of a laser at any time! Exposure to the laser light could result in permanent eye damage.

Introduction & Theory

When monochromatic light from a distant source such as a laser passes through a narrow slit then falls on a viewing screen, the light produces on the screen a diffraction pattern. This pattern consists of a broad and intense (very bright) central maximum and a number of narrower and less intense maxima (secondary maxima). Minima lie between the maxima. A Light Sensor measures the intensity of this pattern; the Rotary Motion Sensor mounted on the Linear Translator measures the relative positions of the maxima in the pattern.

The diffraction pattern for a single slit is similar to the pattern created by a double slit, but the central maxima is measurably brighter than the maxima on either side. Analysis of wave diagrams for light of wavelength λ passing through a single slit with width “ a ” gives the following general equation: $a \sin\theta = m\lambda$ where θ is the angle of the first dark fringe on either side of the central maxima. The dark fringes can be located with the general equation for $m = 1, 2, 3\dots$ relating wavelength (λ), the number of fringes (m), and the slit width (a).

Analysis of wave diagrams for light of wavelength λ passing through a double slit with slit spacing “ d ” gives the following formula: $d\sin\theta = m\lambda$. The bright fringes can be located with this equation.

Equipment

Equipment Needed (Without Computer Assistance)	Qty.
Optical Bench	1
Diode Laser	1
Single Slit and Multiple Slit accessories	1 each
Lens mount and screen	1 each
Transmission gratings, 200, 300, 600, 13,400 lines/mm	1 each

Procedure

1. The apparatus should already be set up for you. Make sure the lens bracket and laser are close to one end of the bench with the white screen near the other.
2. Rotate the SLIT SET disk, the Single Slit one, on the Slit Accessory until a slit pattern is in line with the laser beam. Use the 0.04 mm slit. Use the adjustment screws on the back of the Diode Laser to adjust the beam if necessary.
3. Examine the diffraction pattern on the white screen. If the pattern is not horizontal, loosen the thumbscrew on the Slit Accessory. Slowly rotate the Slit Accessory until the laser beam is centered on the slit pattern you want and the diffraction pattern is horizontal on the white screen on the Aperture Bracket, parallel to the ruled paper attached to the screen. Tighten the thumbscrew on the Slit Accessory to hold it in place.
4. Read off the position of the dark fringes, in mm, on either side of the central maximum. For better accuracy, a set of Vernier calipers can be used to measure the distances between the minima. If you use the ruler, to get the distance between the two, subtract the smaller number from the larger, and write this in the Data Table, first space. Repeat for the second and third sets of slits
5. Take each of the values you wrote in #4 and divide by two to get the distance of the minima from the central maxima and record these in the next column
6. Using the parameters for a and λ on the Slit Accessory and laser respectively, plug these values into the equation, along with $m=1$ to solve for $\sin\theta$; record in data table. Repeat for $m=2$ and $m=3$
7. Refer to the Board to find out how to calculate the theoretical value for d .
8. Repeat 2 to 5 for the multiple slit case (you will only need to measure the distances, and compare these to the corresponding distances for the single slit case) and fill in that data table.
9. For the first table, compare the measured values for d with your calculated ones using the % difference formula:

$$\% \text{ diff} = \left| \frac{(\lambda_{\text{calc}} - \lambda_{\text{given}})}{\lambda_{\text{given}}} \right| \times 100\%$$

Finally, in the back corner of the room are several lasers with transmission gratings. Place each available grating, one at a time, between the laser and wall and note the pattern of dots on the wall. How does the pattern change with each different grating? You do not have to take measurements, just a qualitative observation should be sufficient. Record your response in the Discussion section of your lab report.

13. Computer Experiment Simulation (Thermodynamics, Electricity & Magnetism, Optics, or Modern)

Introduction:

One of the many conveniences of computers is their powerful ability to simulate natural phenomena. Computer simulations save scientists billions of dollars per year by avoiding expensive experiments in wind tunnels and blast chambers as two examples. Computer simulations can be performed to simulate a phenomenon that we cannot readily access, such as the gas flows inside a star in the process of going supernova, the fluctuations of an atom, and the evolution of a solar system over billions of years' time. Back on Earth, much simpler simulations can be used in the classroom to repeat live experiments using an array of initial conditions, enabling students to see clearly how changing parameters can change the outcome of an experiment.

In this Lab, we are going to run such a simulation. The assignment (which will vary by instructor and class section) is to select an experiment of your choosing in the areas of Thermodynamics, Electricity & Magnetism, Optics, or Modern and run through that experiment several times, virtually, changing the initial conditions and recording the outcomes of each run.

Equipment:

Equipment Needed

Computer with Internet access (the instructor will decide whether to use the website given below, another website, or a CD-ROM simulation program),

-OR -

Physics Computer Simulation Program found on the laboratory computers (Instructor will give specifics)

Procedure:

There is a large number of simulation packages available, from CD's and DVD's in the Physics Learning Center (NSCI 324), to websites that offer applets and downloads that demonstrate various principles of physics. For this experiment, we will choose one such simulation within the areas mentioned above from a website (to be determined)

Go to the website provided in class, and click on one of the choices in the list. The list includes simulations in the following areas:

- Archimedes' Principle
- The Ideal Gas Law
- The Kinetic Theory of Gases
- The Carnot Cycle and the Efficiency of Engines

PP Physics in Practice: Gasoline Engines
Hooke's Law
Damped Harmonic Motion
Pulses on a Rope
Sound Waves
The Doppler Effect
Standing Waves on a String
Beats
Superposition of Electric Fields
Electric Resistance and Ohm's Law
Applications of Kirchhoff's Rules
Magnetic Forces on Moving Charged Particles
Generators and Motors
Electromagnetic Waves
The RC Circuit
R-L-C Series Circuit
Models of Light: Rays and Waves
Reflection and Refraction
Thin Lenses
Locating Images by Ray Tracing.
The Thin-Lens Equation
Reflection and Refraction of Light Waves
Interference of Light
Dispersion
Crystals and X-Ray Diffraction
Spectroscopy
The Photoelectric Effect
Successes of the Bohr Theory
Tunneling or Barrier Penetration
Colors by Addition and Subtraction
The pn-junction

Select one or more simulations from this list and do them, varying the parameters and seeing how this varying affects the outcome of the experiment. You could either choose an experiment that will not be done this semester, or an experiment that has been done already. In the latter case, the initial conditions of the experiment can be modified to see how the results differ from that experienced in the classroom.

Your instructor may decide to use the simulation programs included in the Physics Learning Center instead of going online to the above site. Internet problems may result in this as well. Follow the directions given by the instructor and the simulation program(s) being used.

Appendix A. Introduction to the Oscilloscope

By Dr. Kevin Storr

Purpose-Introducing the Oscilloscope

The purpose of this exercise is to learn how to operate an oscilloscope, which includes observing and measuring fast and periodic electrical voltages.

Introduction & Theory

The cathode-ray oscilloscope is an instrument which can be used to display the magnitudes of rapidly changing electric currents, potentials, or pulses as a function of time. The information is displayed on a "cathode ray tube" (CRT). The CRT appears as a circular or rectangular window usually with a centimeter graph superimposed on it. (Of course, a similar cathode-ray tube is also an integral part of your television set.)

The cathode-ray tube consists essentially of an "electron gun" for producing a beam of rapidly moving electrons called cathode rays, a fluorescent screen upon which a luminous spot is produced by the impact of the cathode rays, and a means for displacing the spot from its quiescent position as the result of current or voltage applied to the deflecting mechanism. Although the electron beam may be focused by means of magnetic fields, electrostatic focusing is usually used.

Fig. 1 shows the electrode structure of a typical cathode-ray tube having an electron gun with electrostatic focusing.

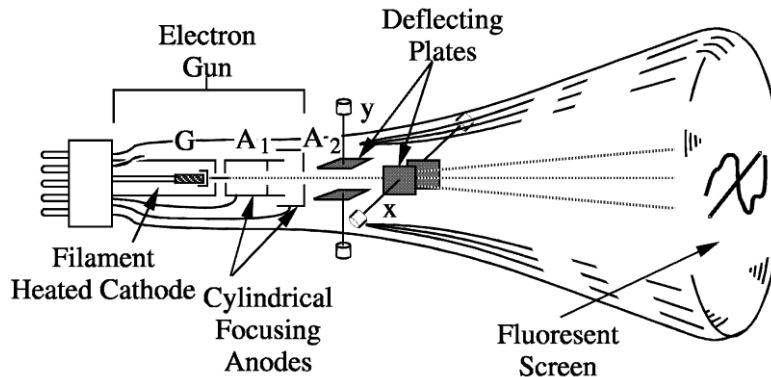


Figure 1

The electron gun consists of an electron source (i.e. an electrically heated cathode which "boils off" electrons), a grid G for controlling the intensity of the electron beam, hence the brightness of the luminous spot, and two anodes A_1 and A_2 . The final velocity with which the electrons leave the gun is determined by the potential of A_2 which is normally maintained constant. The electrostatic fields between G and A_1 and between A_1 and A_2 focus the stream of electrons in a manner somewhat analogous to the

focusing of light rays by lenses. Usually, the focus control on the oscilloscope adjusts the potential of A_1 .

After leaving the electron gun, the electron beam passes between a pair of horizontal plates. A potential difference applied between these plates deflects the beam in a vertical plane in direct proportion to the instantaneous voltage applied between the deflecting plates. This pair of plates provides the y -axis or vertical movement of the spot on the screen. A pair of vertical plates provides the x -axis or horizontal movement of the spot on the screen.

The screen of a cathode-ray tube consists of a thin layer of a phosphor, which is a material that luminesces as the result of bombardment by rapidly moving electrons. The bombardment gives rise to both fluorescence and, emission of light after bombardment. The phosphor is applied to the inside of the end of the tube by spraying, dusting, or precipitation from a liquid. Slow decay of phosphorescence makes possible the visual observation of non-repeating transients and prevents flicker in the visual observation of periodic voltages of low frequency. However, if it is too slow it causes blurring whenever an image on the screen changes form.

The main circuits of an oscilloscope and their functions are described below in (a) through (f). Fig. 1 of **Appendix A** (to this experiment) shows the control areas for these circuits for the Tenma 72-6805 oscilloscope, similarly identified as (a) through (f).

(a) The time-base generator. In order that the image plotted on the scope screen shall show the unknown y -axis voltage as a function of time, it is necessary that the spot shall periodically sweep across the screen horizontally (along x -axis) with uniform velocity up to a certain point and then return rapidly to its zero position. If the time taken for one timing sweep is equal to the period of the voltage applied to the y plates, the pattern will consist of one cycle of the y voltage. If the sweep frequency is equal to f_y/n , the image will show n waves of the y voltage. The required horizontal movement of the fluorescent spot can be produced by means of an x voltage that periodically increases uniformly with time and falls to zero instantaneously upon reaching a given value. The wave form of such a linear sweep voltage is shown in Fig. 2. Because of its shape, this signal is called a "sawtooth" voltage.

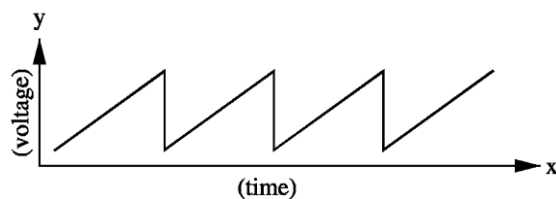


Figure 2

(b) The horizontal and vertical signal amplifiers. The oscilloscope amplifiers serve two purposes. 1) Providing sufficient voltage to give any desired deflection of the electron beam. 2) Making possible the variation of the deflection voltages without

drawing appreciable current from the source under observation or from the sweep generator.

(c) The z-axis modulation controls the intensity and focus of the electron beam.

(d) and (e) The synchronization circuit ties the sweep of the horizontal time-base in with the vertical signal so that any harmonic signal can be displayed as a stationary pattern. The horizontal sweep is begun by a signal or condition called the "trigger." A variety of triggers are available as well as a variety of display selections following the trigger.

(f) The power supply provides the various potential differences and currents for complete operation of the instrument.

The individual controls for the above circuits are identified in Fig. 1 of **Appendix A**. The corresponding list of controls and descriptions of their function are given in **Appendix A** as well. Study this list and try to understand the function of as many of the controls as you can before going to the lab. In lab you will experimentally study the functions of most of them.

Apparatus

Equipment:	Qty.
Oscilloscope	1
Function Generator	1
DC Power Supply	1
60 Hz AC Power Source	1
Coaxial Cables	3

Procedure

A. Familiarizing Yourself with the Oscilloscope

- ◆ To prepare the oscilloscope for operation, follow the instructions for "How to Produce the Bright Line" in **Appendix A**. These procedures will avoid damage to the various oscilloscope circuits at turn-on. At the conclusion of these procedures, you will have observed the horizontal line (called a trace). Be sure the trace is not too bright or the electron beam might burn the phosphor on the screen.
- ◆ Now you should analyze and become familiar with the operation and functions of as many of the various controls as you can. Design and perform simple tests for the controls. Since most of these are fairly obvious, you need not record them in your report unless something unusual happens. If it does, of course, you should seek out the reason. Performing **Part B** will help you become acquainted with various controls.

B. Measurement of DC and AC voltages

Note: *Bold italic* numbers below are knobs indicated schematically and described in **Appendix A**. **Also note:** Connections will typically be made with co-axial cables that are terminated by BNC connectors. A coaxial cable consists of a central wire surrounded by a dielectric (typically plastic) which is itself surrounded by a braided copper shield. The signal typically travels on the center wire and the copper shield is grounded. The center post of the BNC connector is attached to the central wire and the metal twist lock on the BNC connector is attached to the grounded shield. These connections are schematically shown in figures in the next two labs.

Using Channel 1 (CH 1 or X) controls only:

- (1) Set the "DC-GND-AC" Switch **11** on GND.
- (2) Adjust the vertical "position", knob **19** so the horizontal trace is vertically centered on the screen. Now you can measure voltages relative to this ground position.
- (3) Set the "DC-GND-AC" switch to DC.
- (4) Turn the variable, "VAR" dark gray knob **15**, voltage control fully clockwise. The surrounding light gray knob "VOLTS/DIV" **13**, can be adjusted to change the vertical scale calibration in volts per centimeter above and below the zero (central) or ground position. The calibration is correct **only** when the dark gray knob is fully clockwise. Test this vertical deflection with a 1.5 volt battery connected to the "CH1 INPUT" **9**. Reverse its polarity. Again test the vertical deflection. Now observe the effect of the variable calibration control **15**.
- (5) Set the "DC-GND-AC" switch to AC and repeat the test with the battery and explain what happens. (Hint: refer to **Appendix A**.)
- (6) Repeat (4) but use an AC voltage source, e.g., the AC line source box. With the "TRIGGER MODE" switch **35** at AUTO, set the "TRIGGER SOURCE select switch **31** to CH 1. Adjust the "TRIGGER LEVEL" control knob **34** if the wave display is not stationary. Measure on the horizontal scale the time period of voltage oscillation. Compare your result with $T = 1/f$ for $f = 60$ Hz. The horizontal time scale is chosen by knob **26**, "TIME/DIV". Test what happens when **31** is not set as indicated. **EXPLAIN!** (See **Appendix A**.)
- (7) Reset all controls and replace the AC line source box with the sine wave output of the function generator. Adjust knob **13** so that the sine wave voltage amplitude about fills the CRT, and vary the frequency of the function generator. Start at about 10 Hz and increase by about factors of three to about 100,000 Hz. Calculate the frequency at each interval by measuring the time for a full cycle, as you did in part (6). Compare this measured value with the value you read off the function generator. Which set of values are more precise? Plot these data as frequency

against frequency, including appropriate error bars. Does a straight line of slope 1 pass through the data (including 0-0)?

- (8) Disconnect the function generator. Set the horizontal sweep (i.e. TIME/DIV) for 5 ms/cm, turn the vertical gain (i.e. CH 1 VOLTS/DIV) up high so that you can see very small signals, and touch your finger to the center wire of the BNC cable, without touching the grounded outer cable. Adjust the vertical gain until you see a wave pattern with a few centimeters amplitude. Measure the period of the wave and deduce its frequency. Identify the source of the signal for which your body is serving as an "antenna". (Hint: What else has that frequency?) What is the AC output voltage of your body antenna?

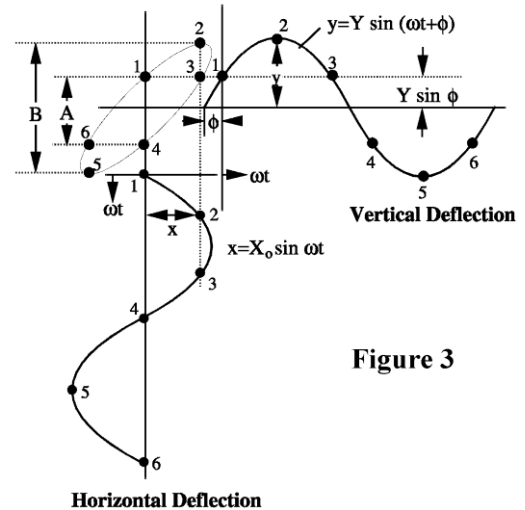


Figure 3

C. Lissajous Figures

Now set the horizontal sweep (i.e., the "TIME/DIV" knob) at the position "X-Y". Then connect the Channel 2 input **10** to the transformer (small yellow box) which is plugged into the AC line power of the laboratory. This box serves as a 60 Hz reference standard. The electron beam of the oscilloscope is now displaced vertically by a sinusoidal potential at a frequency of 60 Hz. Connect the "Sine-Wave" output of the Function Generator to the horizontal input of Channel 1, **9**. Observe the various stationary "Lissajous patterns" which occur as the frequency of the signal generator is varied.

Note: If "TIME/DIV" is set on "X-Y", then the CH 1 input voltage results in a horizontal (x) deflection and a CH2 input voltage gives a vertical (y) deflection. However when "TIME/DIV" is at any of the time settings then the x-axis of display is time while CH 1 or CH 2 inputs give a vertical deflection.

The Lissajous figures can be used to calibrate the Function Generator.

Whenever a stationary pattern is achieved as the frequency is varied, the frequency ratio of the vertical input to the horizontal input is equal to the ratio of the number of horizontal to vertical points of tangency to a rectangle that encloses the pattern (or the ratio of the number of horizontal to vertical axis crossings). Explain why this is true. (Note: Fig. 3 gives a rough sketch of the Lissajous pattern resulting from the X and Y input voltages shown. In this case the frequency ratio $f_x/f_y = 1$ and the phase angle between the two sine waves is about 30° .)

Assuming that the vertical signal is exactly 60 Hz, check a few points on your Function Generator frequency reading (e.g. 30, 60, 90, 120, 240 Hz) and evaluate correction factors if any, for them (i.e. the number which must be added to the generator reading to obtain the actual frequency defined by your standard and the oscilloscope, as a function of generator frequency.)

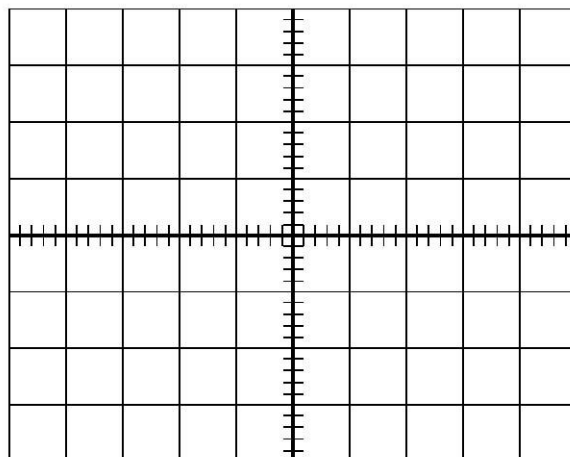
The sine of the phase angle φ is given by $\sin(\varphi) = A/B$, as defined in Fig. 3. (Can you show this mathematically?) Does this relation uniquely define the phase angle φ (in the range $0 - 2\pi$)?

Results-Analog Oscilloscope

Using the settings that were assigned in lab, answer the following questions:

1. What is the setting on the Volts/Div control knob?
2. How many vertical divisions are there from peak-to-peak?
3. What is the peak-to-peak voltage (V_{pp})? Remember $V_{pp} = \text{___ volts/div} \times \text{___ div} = \text{___ volts}$
4. What is the setting on the sec/div control knob?
5. How many horizontal divisions are there?
6. What is the period (T) of the signal? $T = \text{___ sec / div} \times \text{___ div} = \text{___ sec.}$
7. What is the frequency (f) of the signal (in Hertz)?
8. Draw the displayed signal on the graph below. Be neat, to scale, and concise.

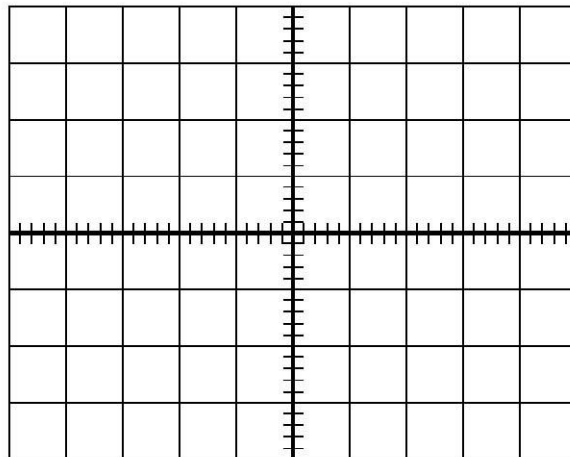
Write down the scale (V/div and Sec/div settings) on the graph.



The next part is to adjust the function generator to output another signal and repeat the measurements in Step 1:

1. Generate a sine wave between 5 and 10 kHz with an amplitude setting of at least 6 vertical divisions
2. Adjust the V/div and sec/div settings to maximize the display of the signal on the CRT. Make sure you show the signal from peak-to-peak and at least one full cycle (period) of the signal.
3. What is the setting on the Volts/div control knob?
4. How many vertical divisions from peak-to-peak?
5. What is the peak-to-peak voltage (V_{pp})? $V_{pp} = \text{___ volts/div} \times \text{___ div} = \text{___ volts}$
6. What are the settings on the sec/div control knob?
7. How many horizontal divisions are there?
8. What is the frequency (f) of the signal (Hz)?
9. Draw the displayed signal on the graph (below)

Write down the scale (V/div and Sec/div settings) on the graph.



Appendix 5Aa – THE OSCILLOSCOPE: TENMA Model 72-6805

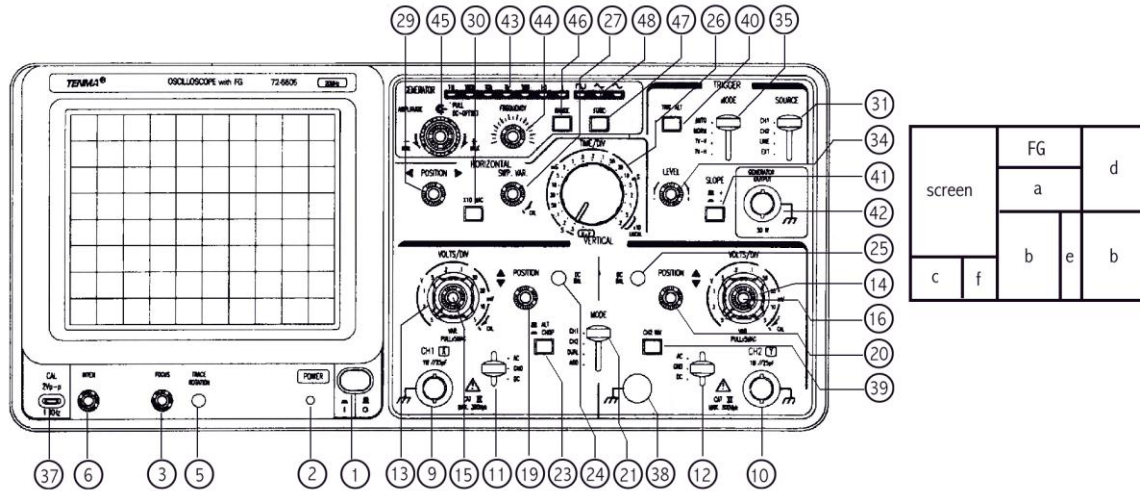


Figure 1

First Time Operation – How to Produce the Bright Line

Before turning on the power, insert the plug of the power cord on the rear panel into the power supply wall socket and set the controls as follows.

POWER (1)	OFF
INTEN (6)	Midrange
FOCUS (3)	Midrange
VERTICAL MODE (21)	CH1
ALT/CHOP (12)	Released (ALT)
AC-GND-DC (11), (12)	GND
VERT. POSITION (19), (20)	Midrange
VOLTS/DIV (13), (14)	0.5V/DIV
VARIABLE (15), (16)	CAL (Rotate fully clockwise.) In this case, the VOLTS/DIV is calibrated to its indicated value.
CH2 INV (39)	Released
TRIGGER MODE (35)	AUTO
TRIGGER SOURCE (31)	CH1
TRIG. ALT (40)	Released
SLOPE (41)	+
TIME/DIVISION (26)	0.5 msec/DIV
HORIZ. POSITION (29)	Midrange

SWP. VAR (27)	CAL (Rotate fully clockwise.)
X10 MAG (30)	Released

After setting the switches and control knobs as mentioned, turn ON the POWER. A trace will appear on the screen in about 20 seconds. Adjust the trace to the appropriate brightness and image sharpness with the INTEN and FOCUS control knobs, respectively.

DESCRIPTION OF THE OSCILLOSCOPE CONTROLS AND CONNECTIONS

<p>1 POWER SWITCH Main power switch of the instrument. The unit is set ON when the switch is at the pushed-in position.</p>	<p>2 POWER LAMP This LED lights up when the main power switch is ON.</p>
<p>3 FOCUS CONTROL Focus the trace to the sharpest image by turning this knob clockwise or counterclockwise.</p>	
<p>5 TRACE ROTATION Used to align the trace of the CRT with the horizontal graticule.</p>	<p>6 INTENSITY control Controls the brightness of the spot or trace. Brightness is increased by turning the INTEN knob clockwise.</p>
<p>7 POWER SOURCE SELECT SWITCH Line voltage selector used to select power sources.</p>	<p>8 AC Inlet Connect the AC power cord (supplied) to this connector.</p>
<p>9 CH1 INPUT Connector Terminal for the input signal to CH1. The input signal to CH1 is the X-axis signal when the oscilloscope is used in X-Y operation.</p>	<p>10 CH2 INPUT Connector Terminal for the input signal to CH2. The input signal to this terminal becomes the Y-axis signal when the oscilloscope is used in X-Y operation.</p>
<p>11, 12 AC-GND-DC Selects the connection mode between the input signal and the vertical amplifier. AC At this setting, the DC component of the signal is cut off and only the AC component is displayed. GND The vertical amplifier input is grounded and input terminals are disconnected. DC At this setting, the input signal is directly connected to the vertical amplifier and is displayed unchanged including the DC component.</p>	<p>13, 14 VOLTS/DIV Selects the vertical axis sensitivity from 5mV/DIV to 5V/DIV with 10 ranges totally. Set this switch to an easily observable range corresponding to the amplitude of the input signal.</p>

<p>15, 16 VARIABLE (VAR.) PULLx5MAG</p> <p>Fine adjustment of sensitivity with a factor of greater than or equal to 1/ 2.5 of the indicated value. For normal operation, this knob must be turned all the way clockwise to the CAL position where the sensitivity is calibrated to the indicated value. When this knob is pulled out (x5MAG) the amplifier sensitivity is multiplied by 5.</p>	<p>19, 20 VERTICAL POSITION Controls</p> <p>This knob is used to adjust the vertical position of the trace or spot.</p>
<p>21 VERTICAL MODE Select Switch</p> <p>Selects the operation modes of the CH1 and CH2 amplifiers.</p> <p>CH1 Operate the oscilloscope as a single channel instrument, displaying the signal applied to CH1 alone.</p> <p>CH2 Operate the oscilloscope as a single channel instrument, displaying the signal applied to CH2 alone.</p> <p>DUAL Operate the oscilloscope as a dual-channel instrument, displaying both signals applied respectively to CH1 and CH2.</p> <p>ADD The oscilloscope displays the algebraic sum (CH1 + CH2) or subtraction (CH1 – CH2) of the two signals. (The subtraction is in effect when the CH2 INV button (39) is pushed in.)</p>	<p>22 CH1 SIGNAL OUTPUT</p> <p>Delivers a voltage of approximately 20mV/DIV from the CH1 signal to 50 ohm terminal for frequency counting. Provides a sample of the signal applied to the CH1 connector.</p>
<p>23 ALT/CHOP</p> <p>Used in conjunction with (21) VERTICAL MODE DUAL trace operation. When the ALT/CHOP switch is released in the DUAL trace mode, the input signals at CH1 and CH2 are alternately displayed (normally used at faster sweep speeds). When this switch is depressed in the DUAL trace mode, the CH1 and CH2 inputs are chopped and displayed simultaneously (normally used at slower sweep speeds).</p>	<p>24 25 DC BAL Adjustment Controls</p> <p>The knobs are used for adjusting the attenuator balance. See oscilloscope manual, p. 20 DC BAL adjustments for details.</p>
<p>26 TIME/DIV Select Switch</p> <p>Provides sweep time ranges from 0.2 uS/div to 0.5 S/div with 20 steps totally.</p> <p>X-Y In this setting the instrument is used as an X-Y oscilloscope where the X (horizontal) signal is the input to CH1 and the Y (vertical) signal is the input to CH2.</p>	<p>27 SWP. VAR</p> <p>The sweep time of the TIME/DIV can be varied continuously when this knob is not at the CAL position. Counterclockwise rotation to the full, delays the sweep by 2.5 times or more. For normal operation, rotate the knob to the CAL position and the sweep time will be calibrated to the preset value of the TIME/DIV switch.</p>
<p>29 HORIZONTAL POSITION CONTROL</p> <p>This knob is used to adjust the horizontal position of the trace or spot. The trace is moved toward the right with clockwise rotation and toward the left with counterclockwise rotation.</p>	<p>30 x10 MAG</p> <p>Magnify by 10 by pressing this button.</p>

<p>31 TRIGGER SOURCE Select Switch Selects the internal triggering source signal, and the EXT TRIG IN input signal. CH1 Select CH1 to get internal triggering source signal. CH2 Select CH2 to get internal triggering source signal. LINE Use the power line frequency signal as triggering signal. EXT Obtain external trigger source signal by applying external signal to the EXT TRIG IN input terminal (33).</p>	<p>33 EXT TRIG IN Input Terminal This input terminal is used for external triggering signal by setting the SOURCE switch (31) to the EXT position.</p>
<p>34 LEVEL This knob is used to decide at which portion of the waveform should the sweep be started by setting the trigger level. This helps to display a synchronized and stationary waveform.</p>	<p>35 TRIGGER MODE Select Switch Trigger mode selection. AUTO The oscilloscope is brought into automatic triggering sweep in which sweep is always conducted. In the presence of a triggered signal, normal triggered sweep is obtained and the waveform stands still. In the case of no signal or out of triggering, the sweep line will appear automatically. This is the usual and convenient setting. NORM Triggered sweep is obtained and sweep is conducted only when triggering is in effect. No sweep line will appear in case of no signal or out of synchronization. Use this mode when effecting synchronization to very low frequencies. TV-V Used for observing the entire vertical picture of television signal. TV-H Used for observing the entire horizontal picture of television signal. (Both TV-V and TV-H synchronize only when the synchronizing signal is negative)</p>
<p>36 Z-AXIS Input Input terminal for external intensity modulation signal.</p>	<p>37 CAL 2V p-p This terminal delivers the calibration voltage of 2 V p-p, 1 KHz, positive square wave.</p>
<p>38 GND Terminal Ground terminal of oscilloscope mainframe.</p>	<p>39 CH2 INV When this button is pressed, the CH2 input signal is inverted and in the ADD mode, the CH2 signal is also inverted.</p>
<p>40 TRIG/ALT If you set VERT MODE (21) to DUAL or ADD, press CH1 or CH2 on the TRIGGER SOURCE switch (31), then press the TRIG/ALT button, the internal triggering source signal will display alternately from CH1 and CH2.</p>	<p>41 SLOPE Triggering slope button. “+” Triggering occurs when the trigger signal crosses the trigger level by positive going course. “-” Triggering occurs when the trigger signal crosses the trigger signal by negative going course.</p>

The TENMA Model 72-6805 Oscilloscope also provides the basic features of a Function Generator to satisfy general demand with simple and intuitional operation by adjusting the control knobs directly from the front panel for output

waveform, amplitude, frequency and range. All the function generator control knobs are located in the front panel with the same color.

<p>42 GENERATOR OUTPUT This is the main output terminal of the function generator with 50 ohms impedance.</p>	<p>43 FREQUENCY RANGE DISPLAY The selected frequency range is lighted up on this display panel.</p>
<p>44 FREQUENCY KNOB This knob is used to adjust the frequency. Rotate the knob clockwise to get higher frequency and rotate counterclockwise to get lower frequency.</p>	<p>45 AMPLITUDE/DC OFFSET Adjustment Knob The outer knob is used to adjust the amplitude of the wave. Rotate clockwise to increase the amplitude and rotate counterclockwise to decrease the amplitude. The inner knob is for DC Level adjustment and works only when the knob is pulled up. Pull up the knob and rotate clockwise to get positive DC Level and reverse the rotation of the knob to get negative DC Level.</p>
<p>46 FREQ RANGE Switch The frequency range can be selected by pressing this button, following 1M, 100k, 10k, 1k, 100, 10 and 1 sequence.</p>	<p>47 WAVEFORM SELECTOR Pushing this button will change the waveform following a Sine wave, Triangle wave and Square wave sequence.</p>
<p>48 OUTPUT WAVEFORM DISPLAY The current output waveform is lighted up on this display panel.</p>	

Appendix 5Ab - The Function Generator

Controls and Indicators

<p>1. PWR Switch. Turns power on and off.</p>	<p>2. Range Selectors. Selects frequency range. Decade frequency type, seven ranges from 1 Hz to 1 MHz. Frequency can be adjusted from 0.2 to 2 times the range selected. For example, if the 100 K range is selected, frequency can be adjusted (see Frequency Control) from 20 kHz to 200 kHz. Numbers under pushbuttons indicate gate time (see GATE LED)</p>
<p>3. Function Selectors. Selects square, triangle, or sine waveform at OUTPUT jack.</p>	<p>4. AMPL Control. Controls amplitude of signal at OUTPUT jack. When control is pulled out, signal is attenuated 20 dB (PULL -20 dB).</p>
<p>5. OUTPUT Jack. Waveform selected by FUNCTION switches as well as the superimposed DC OFFSET voltage is available at this jack</p>	<p>6. TTL/CMOS. When control is pushed in, a TTL signal is present at the TTL/CMOS jack. Level is fixed at 3 V p-p and turning control has no effect. When the control is pulled out (PULL CMOS), a CMOS signal is present at the TTL/CMOS jack. Turning the control clockwise increases the amplitude and turning the control counterclockwise decreases amplitude (amplitude is adjustable from approximately 4 V p-p to 14.5 V p-p).</p>
<p>7. TTL/CMOS Jack. Square wave selected by TTL/CMOS control (either TTL or CMOS) is available at this jack. The output is independent of the AMPL and OFFSET controls.</p>	<p>8. OFFSET Control. When control is pushed in, DC offset is set at zero. When control is pulled out (PULL ADJ), clockwise rotation changes DC offset in a positive direction and counterclockwise rotation changes DC offset in a negative direction. Full clockwise rotation gives approximately +5 V into 50 load (+10 V open circuited). Full counterclockwise rotation gives approximately -5 V into 50 load (-10 V open circuit).</p>
<p>9. VCF IN Jack. Voltage Controlled Frequency input. Permits external sweep or frequency control. Positive voltage decreases the output frequency.</p>	<p>10. DUTY Control. Rotation adjusts the duty cycle of both the main OUTPUT signal and the TTL/CMOS signal. Fully counterclockwise rotation is the CAL position (normal duty cycle). Duty cycle changes when control is rotated away from CAL position. When control is pulled out (PULL INV), the square wave at the main OUTPUT and the TTL or CMOS signal are inverted.</p>
<p>11. FINE Frequency Control. Vernier adjustment of output frequency for ease of setting to a precise frequency.</p>	<p>12. COARSE Frequency Control. Coarse adjustment of output frequency (main output and TTL/CMOS output) from .2 to 2 times the selected range.</p>
<p>13. Frequency Counter Display. Displays frequency of internally generated frequency.</p>	<p>14. Hz and kHz LED. Indicates whether display is showing Hz or kHz.</p>

15. **GATE LED.** Indicates when frequency counter display is updated, When the 10 K through 1 M frequency switches are selected, the LED will flash 10 times per second (every 0.1 second). When the 10 through 1 K switches are selected, the LED will flash once each second and when the 1 switch is selected, the LED will light every 10 seconds. As the LED turns off, the display is updated.

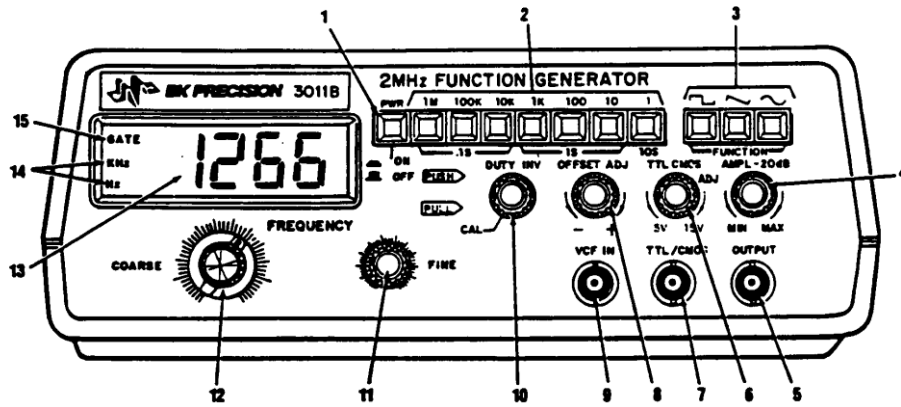


Figure 2

Appendix B. Suggested Pre-Lab Activities

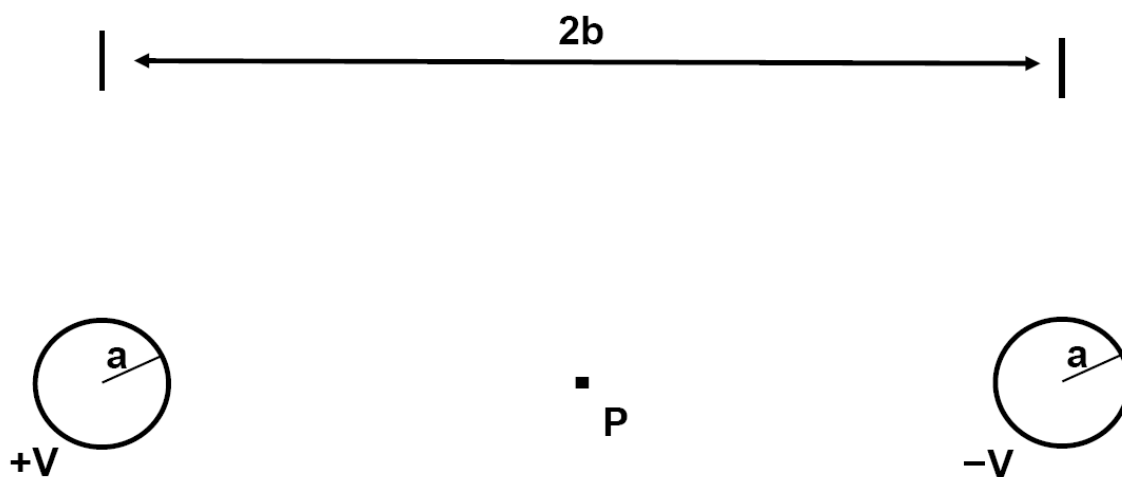
Pre-Lab #2: Electric Field Mapping

Name: _____

Course: _____

Date: _____

1. The sketch shows cross sections of equipotential surfaces between two charged conductors that are shown in solid black.



(a) What is the potential difference between points **B** and **E**?

(b) At which of the labeled points will the electric field have the greatest magnitude?

(c) What is the electric field at point **A** (magnitude and direction)?

2. The sketch on the back of this page shows cross sections of two conducting spherical shells.

(a) Using dashed curves draw representative equipotentials around and between the spheres.

(b) Using solid curves and arrows draw the electric field lines.

(c) If $a = 50.0$ cm, $b = 0.50$ m, and $V = 100$ V, what is the potential at point **P** midway between the two spheres? _____

(d) If $a = 50.0$ cm, $b = 0.50$ m, and $V = 100$ V, what is the magnitude and direction of the electric field at point **P** midway between the two spheres?

Pre-Lab #4: Resistivity

Name: _____

Course: _____

Date: _____

1. Of the five wires, which one has the smallest resistance? _____
2. Which one of the wires carries the smallest current when they are connected to identical batteries? _____
3. What is the resistance of wire **B**? (Show work.) _____