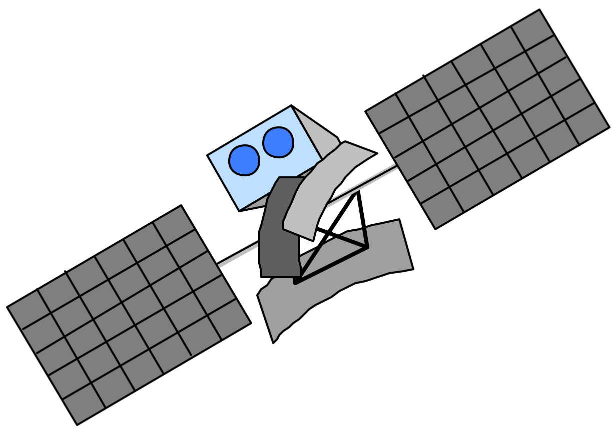
PHY 241: PHYSICS II
ELECTRICITY AND MAGNETISM



LAB MANUAL
STUDENT'S EDITION

Spelman College
Physics Department
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PHY 241: Physics II
Electricity & Magnetism

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Introduction

The Scope of this Manual

The laboratory exercises in this manual are designed to enhance the student's practice and understanding of the scientific process via activities dealing with electricity and magnetism. Although some modern instrumentation and techniques will be introduced, this is of secondary importance. The main purpose is to emphasize the scientific process. The scientific process is the same no matter what level of the experiments or instruments. The student will acquire skills to observe and measure physical quantities associated with natural phenomena and verify relationships between these quantities.

Use this manual as a guide to the experiments, not as a constraint. Your approach to the experiments should not be to simply follow a set of instructions. You should know clearly what each experiment is designed to measure or verify and should use the procedure as a guide rather than as a recipe. Feel free to design or adjust the procedure or technique within the boundary of the available equipment. In short, you should question or challenge the manual. If a measurement is called for, you should ask why; if a measurement is not called for, you should ask why not. Engage yourself, as a scientist would, in critical and analytical thinking, aware of the intentions of all your actions.

What Is Expected of the Student

The following is a partial list of how students should approach the laboratory, their responsibilities, and what is expected of them. The laboratory instructor will provide a more complete description, if necessary.

The Scientific Process

The student is expected to know the process by which scientists acquire knowledge. It is the responsibility of the student to know or find out from the instructor about the scientific process and to understand where the specific activity, of the lab, enters this process. Thus, the student should think carefully about everything, no matter how minor.

Crucial to this process is that all relationships and theories must be verified by an experiment. Experiment is never justified by theory. Note, however, that a previously known result or measurement can be used to test new experimental techniques or instruments for systematic effects, as well as to calibrate instruments. Experimental techniques are constantly being revised to obtain more precise measurements, which in turn yield a stricter test of the theory.

Measurements

Before using an instrument, the student must know or find out what the instrument is designed to measure, how to use the instrument, how to read the instrument, the limitations of the instrument, and all safety precautions. Handle all instruments with care; do not handle them roughly or put them in a place where they could be damaged, such as near heat

Record data with all possible significant figures. The last significant digit is estimated. The meter stick, for example, can be read in centimeters to two decimal figures. Include an uncertainty for each measurement. The uncertainty is based on sources that you identify, such as limitations of the instrument and human limitations.

Results

The student is expected to achieve reasonable results appropriate for the activity. If these results are not met, then the student must offer a scientific explanation. There is a limit to which faulty equipment can be blamed. It is the responsibility of the student to recognize absurd results from faulty equipment during the experiment and to replace that equipment. Human error such as reading or recording the wrong number, using the wrong units, and other correctable mistakes will not be accepted as explanation for poor results.

The student should not confuse reasonable results with precision or accuracy. A 60% difference from the expected outcome can be a reasonable result if it is consistent with the equipment and measurement technique, but it is not precise. See a later section that is devoted to precision and accuracy.

The student should use The Method of Least Squares, whenever appropriate, to fit data to a particular functional form.

Uncertainty Analysis

All results must include an uncertainty analysis. The student is expected to know the following from the previous physics course:

a) how to compute arithmetic averages (mean);
b) when and how to compute the standard deviation;
c) how to propagate uncertainties in calculated results using the maximum / minimum method;
d) how to estimate the uncertainty on the slope of the 'best' straight line through data points by using the diagonals of a box drawn around a plot of the data points.
e) how to estimate the uncertainty of the slope and intercept using linear regression in Excel.

Additional analysis is introduced in this manual. The student must learn the material in the section entitled Method of Least Square. The laboratory instructor will inform and teach the student about any other uncertainty analysis that is required, if that procedure is not covered in this manual.

Uncertainty must be recorded for all data. Estimate uncertainty from the limitations of the apparatus, from the range through which settings can be changed while maintaining a particular result, and from all known systematic and random effects. The goal is not to record the smallest number to please the instructor but to record an uncertainty that balances confidence and precision. The student must be confident that the actual number lies within the range determined by the estimated uncertainty.

Uncertainties are important for comparisons among your results, the results of other experiments, and the predictions of theory. In making comparisons, you should look at the overlap between the ranges of the results. For example, a measurement of the universal gravitation constant $6.2 \pm 0.6x10^{-11}\,\frac{Nm^2}{kg^2}$ is consistent with the accepted value of $6.67x10^{-11}\,\frac{Nm^2}{kg^2}$, while a measurement of $6.61 \pm 0.01x10^{-11}\,\frac{Nm^2}{kg_2}$ is not consistent, even though the second measurement is actually closer to the accepted value and has a smaller uncertainty. Note that the key criterion is consistency within your uncertainty, not simply comparison of the numbers without their uncertainty.

Other Responsibilities

The student is expected:

- To bring a ruler, protractor, diskette, or CD, and calculator to the laboratory (graph paper will be provided).

- To read the section on Safety in the Laboratory.

- To hand in a paper for all activities. A scientific paper is described in the section, **Grading and Policies.**

- To study the activity before coming to the laboratory. This means that the student must be knowledgeable about all that is to occur in the lab. The student must be acquainted with the purpose, the procedure, the measurements, the expected outcomes, and the data analysis before entering the lab.

- To read the section on Uncertainty Analysis.

- To be honest in reporting data and analyses.

- To use one's own data unless otherwise approved by the laboratory instructor. The use of data from someone else without approval is considered academic dishonesty. This behavior is governed by rules on academic dishonesty as set by Spelman College. It is published in the Student's Handbook which can be obtained in the Dean's office.

Safety in the Laboratory

- Accidents are usually caused by carelessness, ignorance, or both. While in the lab, be serious-minded. You must do your part to ensure the safety of yourself and the safety of others. Report all negligence to the person(s) involved and to the laboratory instructor.

- Be care when heavy equipment is involved. Do not move it unless you are absolutely sure you are able to do so without muscular strain and without dropping it.

- Short circuits in electric wiring are accompanied by intense heat, occasional sparks, and/or smoke. Before closing the circuit, check wires, plugs, and contacts to make sure it is safe. **The Instructor Must Check Any Circuit Before It Is Turned On.** After you have finished using a circuit, disconnect it from the power source before dismantling it. **NEVER** touch any uninsulated wire or connection when the power is on.

- Glass tubes, rods, thermometers, etc., may break when subjected to strains. Do not handle broken glass directly.

- Do not obstruct aisles and doorways or place heavy equipment near the edges of tables.

- Under no circumstances shall a student endanger herself to save equipment, but she should be ready to act intelligently and quickly when an injury occurs. Injuries, however slight, must be reported at once to the instructor.

- There is a first-aid kit located on the wall next to the door, at the front of the lab room.

- Check with the instructor before operating any laser. **Do not** look into the output port of a laser, point it arbitrarily, or move equipment or apparatus while it is in operation.

- Do not put anything in your mouth or use your mouth to handle equipment or supplies. For example, do not put string, wire, or radioactive samples in your mouth.

- Check with your instructor before handling any radioactive sample. Minimize contact with radioactive sources. Do not store or dispose of radioactive samples arbitrarily. Check with your instructor on the proper way to store or dispose of radioactive samples. Report any spills or other problems to your instructor immediately.

Grading and Policies

The laboratory grade is based on the papers turned in every week (100 points each), a quiz at the beginning of each session (20 points each), a participation grade (20 points for each session), and a lab exam given at the end of the semester (200 points). The grade is computed as the total points earned divided by the total possible points.

Quiz

The quiz at the beginning of the class is based on material in the manual about the current activity and any other preparatory material assigned the week before. Students who are late will not be given extra time. Quizzes cannot be made up, but any quiz missed because of an excused absence will not be counted in the total possible points.

Participation

The participation grade is based on the active participation of each student to carry out the experiment in a timely fashion, to record everything completely and neatly, and to engage in meaningful discussions with her group members and with her instructor. The participation grade is 0, 5, 10, 15, or 20. A student who is late cannot receive 20, unless here tardiness was approved by the instructor before the class.

Paper

The paper consists of two parts. The first part is due the week following the activity. It consists of the data, calculations, graphs, uncertainty analysis, and a schematic of the experiment. The second part consists of a revised first part that is based upon the instructor's comments, and narrative. It is due the week following the return of the first part. The narrative consists of the results, conclusions, improvements, comparisons, and relation to appropriate laws. The narrative is written in essay style, and it must demonstrate your understanding of the activity, its purpose, and its relevance to the overall course material. A guide to both parts is given at the end of each activity.

The paper is worth 100 points – 50 points for the revised first part and 50 points for the narrative. Your instructor will allow at least one re-write of the narrative so that you will learn what is expected of you. After the third activity, points will be subtracted if the first part is poor, even though you will be allowed to revise it.

Exam

The exam is given at the end of the semester, and it is comprehensive. It consists of a written part and a practical, 100 points each. It is designed to test your experimental skills, data analysis, uncertainty analysis, and relevant physics of all the lab activities.

Other policies are:

- no eating or drinking is allowed

- use of cell phones, use of computer for non-laboratory work, and use of the telephone for non-laboratory reasons are not allowed, unless approved by the instructor

- no early departure is allowed, unless approved by the instructor. If a student finishes early, she may begin the data analysis or the write-up.

- a student may make up a missed experiment if it is approved by the instructor before the experiment. She must take the initiative to meet with the instructor to set a make-up time and date.

UNCERTAINTY ANALYSIS

When physical quantities are measured in the laboratory, limitations on the measuring instruments and other effects introduce uncertainty. It is important to know how reliable experimental results are so that proper conclusions and relationships can be found. The following summarizes the major points for our purposes on uncertainty analysis. An uncertainty analysis must be included in all lab reports.

1. Significant Figures

The precision of a physical measurement is indicated by the number of digits used to record it. The experimental value is written within the range of uncertainty. For example, 4.63 ± 0.22 says that the true value lies between 4.41 and 4.85 with 4.63 as the best estimate. However, if the measurement is only significant to two figures, it could be written as 4.6 with an uncertainty on the last figure. This form of stating the measurements is known as scientific notation. The notation has been devised to convey significant figures in measurements.

2. Errors

The errors that may arise from experimental measurements are classified into two categories: systematic error and random error.

Systematic error: Affects all measurements the same way. For example, if a scale (in units of lbs.) starts at +3 instead at zero, it will add an error of +3lbs. to all weight measurements.

It is not always possible to avoid systematic errors. In devising different apparata and methods, one tries to reduce systematic errors and, thus, gets a more accurate measurement. For example, it is not easy to eliminate the earth's field. So one may have to account for its unwanted presence in any given experiment. We will typically ignore systematic errors in most of our measurements. However, if you are aware of any such uncertainties, you should record and discuss them in the report.

Random error: Affects all measurements differently. In some measurements, it adds, in others it subtracts in different amounts, leading to small fluctuations in the measuring quantity.

Random errors, while not ever reducible to zero, can be accounted for by statistical analysis. This analysis is absolutely necessary in all reported measurements.

3. **<u>The best Estimate of A Measurement</u>**

If a measurement is made once, then that value alone is the best estimate. If a measurement is repeated (which normally should be the case), then the **average (mean)** value is the best estimate and is given by

$$\bar{x} = \frac{\Sigma x_i}{n},$$

where x_i's are the individual measurements and n is the number of measurements. The argument for this statement that the average value is the best estimate of the true value is as follows:

Let t be the true value of the measurement. Each measurement deviates from the true value by an amount e_i given by $e_i = x_i - t$. The average of these deviations, $\bar{e}$, is given by

$$\bar{e} = \frac{\Sigma e_i}{n} = \frac{\Sigma(x_i - t)}{n} = \frac{\Sigma x_i}{n} - \frac{nt}{n} = \bar{x} - t.$$

Since some e_i's are negative and some are positive, Σe_i will tend to zero as n gets larger. Thus, for larger and larger n, $\bar{e}(\propto \Sigma e_i)$ will approach zero and $\bar{x}$ approaches t, the true value.

4. **<u>The Uncertainty of A Measurement</u>**

If a measurement is made once, then the uncertainty is estimated while making the measurement. If the measurement is made repeatedly, then the uncertainty is estimated statistically. Note that the term repeatedly is taken to mean, keeping all conditions and chances of errors virtually the same. From statistics, one defines the variance, s^2, as

$$s^2 = \frac{\Sigma(x_i - \bar{x})^2}{n} = \overline{x^2} + \bar{x}^2.$$

The uncertainty estimate is taken to be s, known as the standard deviation. Since $x_i - \bar{x}$ is the deviation of the i^{th} measurement, F is the root mean square of the deviations. The best outcome of the measurement is then stated as $\bar{x} \pm s$. Other methods of determining uncertainties or confidence levels, where appropriate, will be discussed in specific experiments.

Example of Expressing A Measured Quantity

Suppose a measurement of the length of a wire is repeated five times with the results: 30.8 cm, 31.9 cm, 32.1 cm, 31.5 cm, 31.6 cm. The best estimate of the wire's length,

$$\overline{L} = \frac{30.8cm + 31.9cm + 32.1cm + 31.5cm + 31.6cm}{5} = 31.58cm.$$

The standard deviation is computed by finding the square root of the average of the square of the deviations as follows:

$$s = \sqrt{\frac{(30.8-31.58)^2 + (31.9-31.58)^2 + (32.1-31.58)^2 + (31.5-31.58)^2 + (31.6-31.58)^2}{5}}$$

$$= 0.4cm$$

The wire's length is then quoted as: $L = 31.6 \pm 0.4cm$.

5. <u>Propagation of Uncertainty</u>

How does one obtain an uncertainty on a calculated value, that's based on some formula, from the uncertainty on measurements? For example, how does one propagate the uncertainty on the measurement of the radius and length of a cylinder to the uncertainty on the calculated volume of the cylinder? There are various methods, but this course will use the following that's called **the method of max/min:**

Suppose for a cylinder, one has measured values

$$r = 0.342 \pm 0.008cm,$$

$$L = 31.6 \pm 0.4cm,$$

where r is the radius and L is the length: then the volume is given by

$$\overline{V} = pr^2 L = p(0.342cm)^2(31.6cm) = 11.6115cm^3.$$

Note that the number of significant figures for $\overline{V}$ will be found from the uncertainty. Since the measurements of r and L have three significant figures, so $\overline{V}$ should have three (equaling to the number of digits of the quantities involved with the least number of significant figures), or $\overline{V} = 11.6cm^3$.

An **uncertainty** of V can be determined by calculating the max and min values of V from the uncertainty on r and L. thus,

$$V_{max} = p(0.342cm + 0.008cm)^2(31.6cm + 0.4cm) = 12.3cm^3,$$

$$V_{min} = p(0.342cm - 0.008cm)^2(31.6cm - 0.4cm) = 10.9cm^3.$$

Then V is given by:

$$V = \overline{V} + \frac{V_{max} - V_{min}}{2} = 11.6cm^3 + \frac{12.3cm^3 - 10.9cm^3}{2} = 11.6cm^3 + 0.7cm^3.`$$

Finally, one should note for a formula such as $r = m/V$, the max value of r is determined from the maximum value of m and the minimum value of V.

6. <u>**Accuracy and Precision**</u>

The central point to experimental physical science is the measurement of physical quantities. It is assumed that there exists a true value for any physical quantity, and the measurement process is an attempt to discover that true value. On the other hand, it is not assumed that the process will be perfect and lead to the exact true value. Instead, it is expected that there will be some difference between the true value and the measured value. The terms, accuracy (denoted by deviation from the true value or deviation from the accepted value or deviation from the mean) and similarly, precision (denoted by the number of significant figures in the mean, and the standard deviation from the mean) are used to describe different aspects of the difference between the measured value and the true value of some quantity. Note that although most dictionaries make no distinction between them, from a scientific point of view, the terms accuracy and precision have very different meanings. Also, it is worth noting that even for current research-level experimental work, the determination of the accuracy of a result is extremely difficult in most cases.

As an illustration of these ideas about accuracy and precision, consider the following sets of hypothetical measurements of the acceleration due to gravity made by four students named Alf, Ayana, Carl, and Keyanna. Each student made three independent measurements and then took the mean of those three measurements as his or her value for g. Also shown in the table is the magnitude of the deviation of each individual measurement from that particular student's mean, and the standard deviation. The results, all in units of m/s^2, are in Table 1.

Table 1
Comparison of Measured Data of Four Persons

	Alf	(Dev)	Ayana	(Dev)	Carl	(Dev)	Keyanna	(Dev)
Measurement 1.	7.83	1.60	9.53	0.27	8.70	0.04	9.72	0.04
Measurement 2	11.61	2.18	9.38	0.12	8.75	0.01	9.86	0.10
Measurement 3	8.85	0.58	8.87	0.39	8.77	0.03	9.70	0.06
Mean	9.43		9.26		8.74		9.76	
Standard Deviation	1.60		0.28		0.03		0.04	

The accuracy of each student's data is determined by comparing the mean with the accepted value of 9.81. Doing so indicates that Keyanna's value of 9.76 is the most accurate, Alfa's value of 9.43 is second, Ayana's value of 9.26 is third, and Carl's value of 8.74 is the least accurate. Using the standard deviation as a criterion for precision, one finds that Carl's value is the most precise, Keyanna's is second, Ayana's is third, and Alf's value is the least precise. Study the data very carefully to be sure that the basis for these conclusions is clear from the ideas that have been given thus far.

In fact the situation is not quite so simple as has been presented. There is an **interplay between the concepts of accuracy and precision** which must be considered. If a measurement appears to be very accurate, but the precision is poor, a question arises whether or not the results are really meaningful, as in the case of Alf's data. His mean of 9.43 which only differs from the accepted value of 9.81 by 0.38 appears to be quite acceptable, because of its apparent accuracy. However, his standard deviation is 1.60, much greater than 0.37 Thus, it seems very much likely that Alf's mean of 9.43 is due to luck rather than to a careful measurement. It seems much more likely, however, that Keyanna's mean of 9.76 is meaningful because of her small standard deviation. In other words, unless a measurement has high precision (particularly with only a few data points involved), it cannot really be considered to be accurate. Alf's data cannot really be taken to be as accurate as his mean implies because his precision is not good enough to warrant faith in that mean.

Carl's results, on the other hand, are an example of a situation that is common in the interplay between accuracy and precision. His precision is extremely high yet his accuracy is not very good. Such outcomes point to systematic error in his measurements. However, in comparison, Carl's results are much better that Alf's. Finally, Ayana results are marginally accurate and marginally precise; ok or partially acceptable at best. In summary, in order of best data, Keyanna is first, Carl is second, Ayana, is third and Alf is fourth. Use great care during your measurements to have acceptable data as depicted by the data of Keyanna, Carl, and Ayana.

7. **<u>Method of Least Squares</u>**

In the analysis of data, there are many problems in which the method of simple averaging cannot be applied. This is the case for a known straight line array of data points, such as, $x_i y_i, x_2 y_2, x_3 y_3, \cdots$.For these data points, a straight line representation is given by,

$$y = mx + b \quad (1)$$

If there are only two points, the two constants m and b, which define the straight line, can be unequivocally determined. But, in general, there will be more points available than constants to be determined. However, the Method of Least Squares allows the determination of the constants a and b under this condition The method, for a straight line, states that the best straight line for the given data points is determined by minimizing the sum of the square differences of the most probable values and the experimental points (sum of the square errors). For example, Eq (1) states that the value of y corresponding to $x = x_1$ is $(b + mx_1)$. But the first experimental point has a value of $y = y_1$ Therefore the error in the first point, e_1, is given by

$$e_i = (b + mx_i) - y_i \quad (2)$$

One can calculate the errors in the other points in similar fashion, and then write down the expression for the sum of the squares of these errors as:

$$\Sigma(e^2) = b + mx_i - y_i)^2 + (b + mx_2 - y_2)^2 + \ldots \quad (3)$$

In minimizing this summation with respects to m and b respectively, one obtains two simultaneous algebraic equations, as given by:

$$\sum_i^N y_i = bN + m\sum_i^N x_i, \tag{4}$$

$$\sum_i^N x_i y_i = b\sum_i^N x_i + m\sum_i^N x_i^2 \tag{5}$$

where N is the number of data points.

These two equations can be solved to obtain *a* and *b*, as given by:

$$m = \frac{N(\sum_i^N x_i y_i) - (\sum_i^N x_i)(\sum_i^N y_i)}{N(\sum x_i^2 (-(\sum_i^N x_i)^2} \tag{6}$$

$$b = \frac{(\sum_i^N y_i)(\sum_i^B x_i^2) - (\sum_i^N x_i)}{N\sum_i^N x_i^2) - \sum_i^N x_i)^2} \tag{7}$$

In situations of determining *m* and *b*, the two parameters of the straight line through the given data point, one also needs to obtain the uncertainties in these parameters. The uncertainties corresponding respectively to the slope, s_m^2, and to the y-intercept, s_b^2 are (the derivation of these is beyond the scope of this manual, but the interested reader may consult "Statistical Treatment of Experimental Data" by Hugh D. Young):

$$s_m^2 = \frac{Ns^2}{\Delta} \tag{8}$$

$$s_b^2 = \frac{s^2 \sum x_i^2}{\Delta} \tag{9}$$

where,

$$\Delta = N \sum x_i^2 - (\sum x_i)^2$$

$$s^2 = \frac{1}{N-2} \sum (m x_i + b - y_i)^2$$

As an example of determining the slope, m, y-intercept, b, the uncertainty in m, s_m^2 and the uncertainty in b, s_b^2, consider four data points: (1.0, 3.0), (2.0,5.0) (3.0,8.0), and (4.0,9.0). The values are:

m	b	s_m	s_b
2.1	1.0	0.26	0.72

Note that a spreadsheet program, such as Excel, can readily determine the above quantities. Your instructor may request that you manually make an initial determination of equations 6-9.

Using Excel for Data Analysis and Graphing

You can use Excel to help make your graphs and fit lines to data points.

Making Graph

First, you must select the numbers that you want to plot. If you want to plot column B versus column A, just select these columns of numbers. If you want to plot column C versus column A, without plotting column B, first select column A, then hold down the Ctrl key while selecting column C. Columns A and C should be highlighted, but not column B.

Click on the Chart Wizard icon (picture of a graph with a magic wand). Drag the cursor over some blank space on the spreadsheet; an outline of a box will appear while you do this. This box is the size of the graph, so make it big enough for viewing a graph.

Work your way through the friendly Chart Wizard. Set up a scatter plot (XY plot), with horizontal and vertical gridlines, appropriate labels, and a title.
Select the chart (it will appear outlined in blue), then select the data points. On the menu bar (at the top of the screen), choose Insert, then Trendline. Set up for a linear fit. Select the Option tab, then select Show Equation. Your graph should now have a straight line and the equation for the line. Drag the equation to a place on the graph where you can clearly see it.

To print a full-page graph by itself, select the chart, then in the menu bar choose File, then Print. If you want to print the full spreadsheet, look at page Preview to make sure that everything looks, as desired (to help save paper), then Print.

Finding the Uncertainty in Fitting Line

When you fit a line to data and determine the slope and intercept, you also want the uncertainties in slope and intercept. Do this by first selecting a 2x2 block of <u>empty</u> cells. Then, type= and click on the friendly function wizard that appears to the left of the formula bar (**fx**). Choose the function **linest** and select the appropriate ranges for y and x. Enter **true** for the other choices, then click on **finish**. Finally, <u>simultaneously</u> hold down the Ctrl key, the Shift key, and the Enter key. The upper left cell now contains the slope, while the lower left cell now contains the uncertainty in slope. Similarly, the upper right cell now contains the y-intercept, while the lower right cell now contains the uncertainty in the intercept.

Least Squares Calculations for Any Curve

If your data points do not lie on a straight line, and you suspect that a certain curve might describe them, then you can use Excel to help you find the parameters of the considered curve. For instance, you might believe that the curve

$$y = ax^2 + bx + c \tag{10}$$

describes your data. Then, you can use Excel to help you find the best values of a, b, and c. Here, the "best values" are those that minimize the distance between the data points and the fitted curve.

Suppose that your x values are in column A and your y values are in column B, starting in the first row. You can put your first guesses for a, b, and c into cells D1, E1, and F1. To put the curve into column C, select cell C1 and type=**D$1*A1^2+E$1*A1+F$1** which is the Excel code for equation (10), then press the **Enter** key. Now, select cell C1 and copy it downwards. If you check cell C2, you should see the formula copied, except **A1** has changed to **A2.** Note that using the **$** symbol force the cell in the formula to remain the same. In this case, **D$1** means that, when the formula is copied, it is forced to refer to row number 1.

To find the curve that best describes your data, you can adjust cells D1, E1, and F1 until you have the best curve. You can tell when the curve improves by calculating a statistical quantity known as chi squared, c^2 , which is defined as

$$c^2 = \sum_i \left[\frac{y_i - y(x_i)}{s_i} \right]^2$$

In this equation, (x_i, y_i) is a data point, $y(x_i)$ is the value of the curve at x_i, and s_i is the uncertainty in the measured y_i. So, you can set up the spreadsheet to calculate c^2 and adjust the values of a, b, and c until you have found the smallest value of c^2. After obtaining the values of a, b, and c that minimizes c^2, you should graph the theoretical curve and see how it coincides with the data points.

Uncertainty in the Parameters

To determine the uncertainty in the fitted parameters, change each a little while keeping the others fixed until c^2 increases by 1 above the minimum. The change in the parameter to accomplish this is the uncertainty of that parameter.

Supplement: The Universal Lab Interface

You will sometimes use measuring instruments that connect directly to the computer through a Universal Lab Interface (ULI). The data is, then, sent directly to the computer where it is recorded. This section contains general instructions for using the ULI. There are various sensors associated with the ULI. The motion detector, photogate, and voltage sensors are described here.

Connecting the Interface Box to the Computer

- The interface box is the light green box and the connection cord has pins at both ends. The 9-pin cord goes into the computer and the circular end goes into the interface box. There is only one place on the interface box that will fit the cable, but there are two places on the computer – one on the bottom and one on the top left. Use the top left.

- Connect the power adaptor to the socket on the interface box and plug the other end into an outlet.

- You may now turn on the computer. Various sensors are attached; some are described below. Go to the description for the particular sensor you will use.

The Motion Detector

- The motion detector has "motion detector" written on it. Connect the cord to DIG/SONIC 1 or 2 of the interface box.

- From Windows, click on the icon Logger Pro on the desktop

- If asked, com is 1, and scan.

- On the menu bar, select Setup --> Sensors --> D/S1 --> Motion Detector in Sensor box; make sure all others are None.

- The sampling rate is the number of measurements per second. To set sampling rate, select Setup --> Data Collection --> Sampling. Set sampling rate to 50 samples/second. If results are flaky, try a lower sampling rate. Set length of time to appropriate value.

- Position the motion detector facing the moving object and click start with the left mouse in the lower left corner or click on the Collect button. While the data is being collected, there will be a clicking sound from the motion detector; wait until the data is collected (no more clicking sound) before doing anything else. A graph of distance from the motion detector vs time should appear on the screen. Be careful of motion in the foreground and background.

- Click on the graph to change scale; click on axis limit to change it. You may change the total time of collection by clicking setup --> Data Collection --> Sampling and typing in the time in the correct box. You may also make such changes by clicking on the graph.

Analyzing Data from the Motion Detector

- Points on the graph may be read by clicking Analyze --> Examine. The numbers in the little window correspond to the data where the vertical line intersects the graph. Do not forget to record uncertainties on any measurement. Portions of the data may be selected for curve-fitting. Select Analyze-->Examine-->linear fit after dragging mouse to select portion.

- If you want graphs of velocity and acceleration, click on Data --> New Column --> Formula --> Definition. Use a derivative to calculate chosen from the function box and a variable chose from variable box. Click on the vertical axis to plot the new column. To display graphs, select View --> Graph Option --> Axis Option.

- To display multiple graphs, select View-->Graph Layout-->2 or 3 Panes.

Timing with Photogates

- Plug a photogate lead into DIG/SONIC 1 or 2 of the interface box and start the Logger Pro 2.0 program on the desktop.

- Start the program by using the left mouse to click the start button in the bottom. Try blocking and unblocking the photogate and observe the program's output to understand how to measure time intervals. Because the program can be unstable, do not stop the timing program; just keep running it.

- More than one photogate may be connected to the interface box.

- To operate the photogate, select Setup-->Sensors-->and select the appropriate port (DIG1 or DIG2) and scroll the selection to select photogate.

- For collision or decay experiments, set Data Collection-->Mode to Photogate Timing, and Data Collection-->Sampling to Collision Timing.

- You may get rid of any gridlines if they appear.

- Quit the program by selecting quit at the bottom or by choosing File --> Exit at the top with the left mouse.

<u>Voltage Measurement</u>

- Use the voltage leads supplied with the universal lab interface to connect to wherever you want to measure the voltage. Plug the other end into Ch 1 or others on the interface box.

- From Windows, click on the icon Logger Pro 2.0.

- On menu bar, click Setup --> Sensors. Click on the appropriate place corresponding to where you plugged in the leads. Select voltage measurement.

- Connect the leads to the place where the voltage is to be measured, and start collecting.

- You may save your data on a floppy diskette. Select File --> Export Data A. Export the data as a text file with a filename of your choice.

An Introduction To Circuits

Goals

You will continue to learn how to explore physical phenomena. In particular, you will explore the basic properties of electrical circuits and the use of electrical instrumentation.

Background

During this lab session, your instructor will guide you through a series of activities and discussions. Through this session, you will learn to use a variety of instruments that measure electrical quantities.

Exercises

Each lettered section below is intended to be completed in one lab session.

A. Introduction

1. Basic Elements
   Activity: Use wires to connect a battery, SPST switch, and bulb to make a controllable light.
   Group discussion: What is physically happening in this circuit?
   Class discussion: Group conclusions.

2. Voltmeters
   Mini-lecture: Introduce concepts of emf, electrical potential, and potential difference, using analogy of gravitational potential energy and height. Discuss analog voltmeter and its function. Introduce circuit diagrams, including series and parallel parts of circuit.
   Activity: Measure voltages across different parts of the circuit, including wires; do with switch opened and with switch closed. Decide which scale to use. Also measure voltage of the battery when disconnected from circuit. Estimate last digit in measurements.
   Class discussion: Results of measurements.

3. Ammeters
   Mini-lecture: Function of analog ammeter; circuit diagram for using ammeter.

Class discussion: Predictions of measurements of currents in the circuit, both with switch opened and switch closed. Let students come up with question of where to measure the current, and suggest they check all possibilities.

Activity: Make measurements. Draw circuit diagrams for each measurement (this should be done for all ensuing circuits).

Group discussion: What is physically happening in this circuit?

Class discussion: Group conclusions, focusing on the behavior of the current as it goes through the circuit. Guide the students to a qualitative understanding of the nature of electrical current.

Data and Analysis

- Circuit diagram for #2 with voltage measurements and uncertainties for each situation. List sources of uncertainty.

- Circuit diagram for #3 with current measurements and uncertainties. List sources of uncertainty.

Narrative

- Conclusions about what is physically happening in the circuit.

- Discussion of voltage and its meaning.

- Discussion of current and its meaning.

- Discussion of the choice of scale in a multi-scale meter.

- General observations concerning the measurements of voltage and current in the specific circuits.

- Discussion about uncertainties.

Note: The narrative is not a set of disconnected paragraphs. It is a paper that should flow logically and incorporates the above points.

B. <u>Resistance</u>

1. General Concept

Mini-lecture: Follow up on the previous activities by formally defining electrical potential energy and electrical current. Introduce idea that voltage and current are related. Introduce the use of a power supply.

Activity: Use power supply in place of battery in previous circuit. Measure voltage across the bulb and current through the bulb simultaneously; observe the physical behavior of the bulb while changing the voltage. Make simultaneous quantitative measurements of current and voltage. Plot current versus voltage.

Group discussion: Discuss conservation of energy in connection with observations of light and heat.

Mini-lecture: Definitions of resistance. Electrical energy and conservation of energy.

2. Ohmic Resistors

Activity: Repeat measurements of current versus voltage with a color-coded resistor. Plot data and find slope of line with uncertainty. Use a least square software.

Mini-lecture: Ohm's law. Resistor color code.

Activity: Use color code and compare with experimental value of resistance.

Data and Analysis

- Data tables for both bulb and resistor including uncertainties.
- Graphs for both bulb and resistor including error bars.
- Graphical analysis of the resistor data, including uncertainty.
- Calculate the slope and intercept, along with uncertainties, also using the formulae in section on Uncertainty analysis.

Narrative

- Compare and discuss the shapes of the graphs for both bulb and resistor.
- Explain the meaning of resistance and how it is measured.
- Comparison of color-code and experimental measurement of resistance for resistor.
- A discussion of Ohm’s Law and its applicability.

C. <u>Simple Circuits</u>

1. Series Circuits

Class discussion: Predict qualitative behavior of current and voltage in a circuit consisting of two different resistors in series.

Activity: Measure currents and voltages across the resistors and power supply for two different resistors in series. Draw circuit diagrams. Use digital multimeter (DMM) to measure the resistances of each resistor.

Group discussion: Create rules for current and voltage in series circuits.

Class discussion: Group rules, leading to Kirchhoff's law for voltages.

Mini-lecture: Equivalent resistance for series circuits, derived from Kirchhoff's law.

2. Parallel Circuits
   Activity: Measure currents and voltages for two different resistors in parallel. Use DMM to measure the resistance of each resistor.
   Group discussion: Create rules for current and voltage in parallel circuits.
   Class discussion: Group conclusions, leading to Kirchhoff's law for current.
   Group discussion: Create rule for equivalent resistance for parallel circuits.
   Class discussion: Group rules. Guide discussion to correct result.

   Data and Analysis
   - Circuit diagrams for series and parallel circuits.
   - Measurement and uncertainty (use tables) for the current and voltage measurement for each.
   - Use the current and voltage data to determine the equivalent resistance for each case.
   - Calculate the predicted equivalent resistance using the data for each resistor from the DMM.

   Narrative
   - Discuss the basis behind each of Kirchhoff's Laws..
   - Compare the value of the equivalent resistance to the value of the resistance for each resistor for both types of circuits.
   - Explain whether Kirchhoff's Laws were verified or not by your data.

D. <u>Complex Circuits</u>

1. Kirchhoff's Laws
   Mini-lecture: Review Kirchhoff's laws and show their use in analyzing complex circuits. Show the use of a digital multimeter to measure currents and voltages.
   Group discussion: Predict currents in parts of circuit shown below. Show work to instructor before proceeding with measurements.
   Activity: Make measurements, using DMM.

2. Equivalent Resistance in Circuit Analysis

Mini-lecture: Use of equivalent resistance of subcircuits to analyze some complex circuits.
Activity: Check individual resistors with DMM. Calculate equivalent resistance of circuit; check with DMM.

Data and Analysis

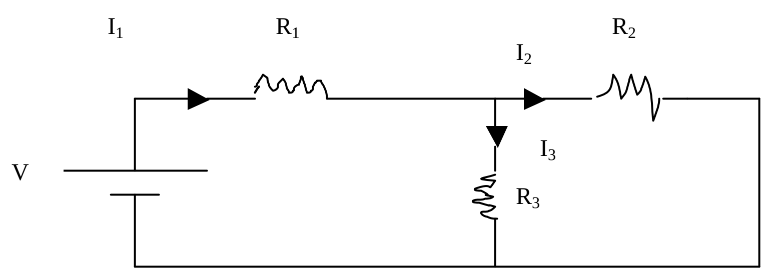
- Calculate the predicted currents and compare with measured values.

- Calculate equivalent resistance from the data, and compare to value from DMM.

Narrative

- Summarize results and write conclusions.

- This is the end of the workshop. Write a paper on how to teach high school seniors about resistance, and about Kirchhoff's Laws. (They probably won't learn without hands-on activities.)



CONDUCTIVITY OF PLAY-DOH

Goals

In this experiment, you will test the validity of Ohm's law, measure the resistivity of play-doh, study the dependence of the resistance on length and cross sectional area of a conducting element, and plan the experiment to consider these effects.

Background

According to Ohm's law, the ratio of the voltage drop, V, across a conducting element to the current, I, existing within the element is given by the resistance, R, a constant, where:

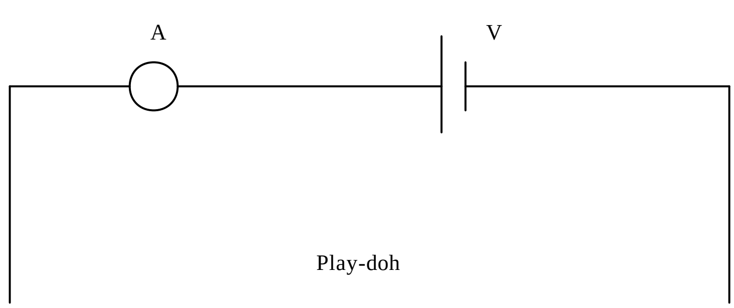
$$R = \frac{V}{I}. \qquad (1)$$

The resistance of a particular wire, or conducting element depends on its length L, cross-sectional area A, and conductivity D. According to the Drude model, it is

$$R = \frac{I}{s}\frac{L}{A} \quad . \qquad (2)$$

The conductivity, s , is a basic electrical property of the material of the wire, or conducting element.

To determine the resistance of a conducting element, equation (1) indicates that one can measure the voltage drop when a known current exists within the conducting element. The circuit must be set up carefully to avoid measuring voltage drops across connecting wires and contact points. The circuit shown in Fig. 1 avoids these problems. Since no current exists through the voltmeter probe, the only voltage drop measured is that across the particular section of the conducting element, L.



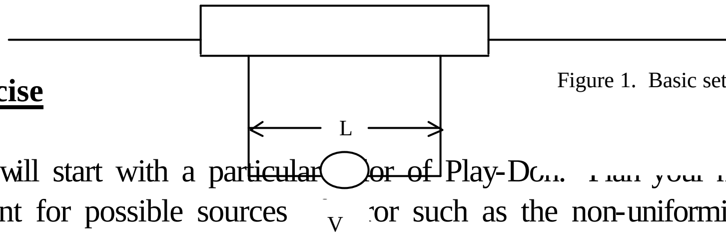


Figure 1. Basic set-up for the “Play-doh” exercise.

Exercise

You will start with a particular color of Play-Doh. Plan your measurements to minimize or account for possible sources of error such as the non-uniformity of the diameter. This may require repeated or separate measurements of some quantities. Also, carefully plan how you will make measurements for different lengths and cross-sections. Discuss your strategy with your instructor before making measurements.

1. Make wires of various diameters. Does Ohm’s law describe the electrical properties of Play-Doh? Support your conclusion with graphical evidence (Hint: Rearrange Equation 1). Is the dependence on length and cross-sectional area ,of the resistance of your Play-Doh elements, consistent with equation (2)? Support your answer with numerical results and a graph. Be careful making your graph. For instance, if you plot resistance vs. length, use data with the same diameter.

2. Use your results to determine the conductivity of your color Play-Doh; include propagation of uncertainty. Are the results from different wires consistent with one another (within your calculated uncertainty)?

3. Determine the conductivity of another color of Play-Doh from another group. Comment on your results. Does conductivity depend on the color? Suggest a physical explanation for your answer.

4. Examine the current-carrying wires that actually stick into the Play-Doh. Record your observations and suggest a physical explanation for what you see.

Data and Analysis

- Graph of the data to support if the Play-Doh is ohsmic or not.
- Graphical analysis of the data on resistance and length, and resistance and cross-sectional area.
- Determine the conductivity from the graphical analysis for the color you chose. Include the uncertainty on the conductivity via propagation of the uncertainty in the measured area, length, and slope.
- Draw a schematic of the experimental set-up.

Narrative

- Summarize results and conclusions.
- Discuss whether the Drude model can describe Play-Doh, as determined from your experiment.
- Discuss the dependence of color on conductivity, suggest a physical explanation.

- Improvements.
- Comparision of conductivity of Play-Doh to the literature (see Physics Today, 1992).

ELECTRIC FIELD MAPPING

Goals

In this experiment, you will consider the relationship between electric field lines and equipotential surfaces. You will produce graphs to depict the observed relationships.

Background

The electric field strength, $\vec{E}$, is defined by

$$\vec{E} = \frac{\vec{F}}{q} \tag{1}$$

when, $\vec{F}$, is the electric force on a test charge q. The direction of the electric field at any point is the same as the direction of the force on a positive test charge placed at that point in space.

Potential Difference: The work done per unit charge in moving a charge from one point to another in an electric field is known as the potential difference. It is given by

$$\Delta V = \frac{W}{q}, \tag{2}$$

where $)V$ is the potential difference, W is the work and q is the charge. The work is also independent of the path between the two points. The absolute potential can be obtained from the potential difference if a point of zero potential is chosen.

Equipotential Lines (Surfaces): There may be many points in an electric field that are at the same potential. If a line (surface) is drawn so that it connects all such points, the line (surface) is called an equipotential line (surface). The electric field vector must be everywhere perpendicular to this line since no work is done in traversing this line. The direction of the electric field vector is from the higher potential line to the lower one, or away from positive charges and towards negative charges.

Exercise

In this exercise, the resistors on the mapping board, each at a particular potential, will be used to generate the equipotential lines as shown in Fig.1. The points on an equipotential line are located where the galvanometer reads zero for each resistor. Familiarize yourself with the apparatus and the use of a galvanometer. The galvanometer is treated as an ammeter that can indicate current in either direction. A zero reading means that no current is flowing.

Operation of The Apparatus

1. Carefully screw in place the selected pattern on the underside of the electric field mapping board, making sure that its conducting surface faces downward.

2. Connect the power source to the terminals marked X and Y on the field mapping board as shown in Fig. 3, and the galvanometer to the probe and the resistor labeled A.

3. Place and secure the graph (or blank) paper on the upper side of the mapping board and trace the selected pattern on it using the corresponding template design.

4. Turn the power on and using the probe locate a point that produces a "zero deflection" on the galvanometer. This point is located directly below the circular hole in the front end of the probe. Mark this point on your paper.

5. Move the probe to another "zero deflection" position. Obtain several points across the paper that yields a "zero deflection". Connect these points to obtain the equipotential line of the same potential as A.

6. Move the terminal to the B position and obtain its corresponding equipotential line. Repeat for all terminals of the series of resistors.

The electric field vector at a point can be obtained from the equipotential lines by drawing a perpendicular to the tangent to the equipotential line. This observation should be done for two different plates. Draw the electric field vector for at least five points for each equipotential line.

Data and Analysis

- Equipotential lines and electric field vectors for two different plates.
- Schematic of the experimental set-up.

Narrative

- Discuss how the direction of electric field vector is defined, and how to determine it at a point.
- For one of your charged plates, choose one point and qualitatively determine the direction of the electric field vector from Coulomb's Law, and compare to the experimental results.

CAPACITORS AND THE RC CIRCUIT

Goals

In this experiment, you will consider the charging, and discharging of electric circuits, containing a resistor and a capacitor, and will become familiar with the time constant, and maximum charging voltage . Finally, you will measure the time constant for a circuit having specific values of R and C.

Background

The basic RC circuit is shown in Fig. 1. When the switch is thrown, the capacitor is charging since the source of emf is included in the circuit. When the battery is taken out, the source of emf is excluded from the circuit, and the previously charged capacitor discharges.

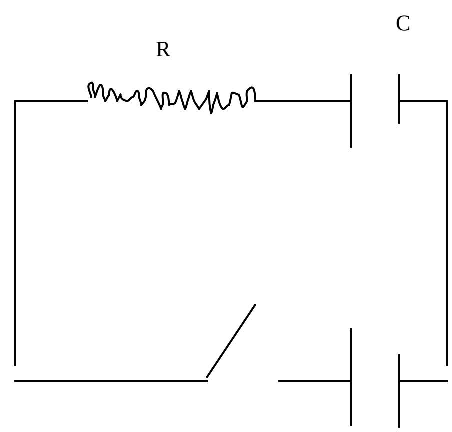


Figure 1. Schematic diagram of a RC circuit

Kirchhoff's Laws can be applied to obtain the charge on the capacitor or current through the circuit as a function of time when the capacitor is being charged or discharged. Assume there is no charge on the capacitor at time zero. During charging, the charge on the capacitor, q(t), and the current, I(t), are given by

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

$$I(t) = \frac{V}{R} e^{-t/RC}$$

After some later time, the switch is now opened and the source of emf eliminated. Assume that the charge on the capacitor is q_0 at this time. For the discharging process, let time zero when the charge is q_0 . From Kirchhoff's Laws, the charge and current as functions of time are

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

$$I(t) = -\frac{q_o}{RC} e^{-t/RC}$$

You should do the following before performing this experiment:

- Verify that the expression RC has units of time. In each of the above expressions for the current, what fraction of the initial current is flowing after RC amount of time. RC is called the time constant of the circuit. Discuss the importance of the time constant.

- Explain the significance of the negative sign in the expression for the current in the discharging process.

- Qualitatively you should understand how the current varies with time for each case. Sketch graphs of these functions. Show that ln(*I*) is a linear function of time. What is the slope of this graph?

Exercise

<u>Qualitative Observations</u>

Connect a series circuit with a power supply, a switch, a resistance substitution box, an ammeter, and a 1 F capacitor. Leave the switch open until your instructor has checked your circuit. Connect a voltmeter across the output of the power supply and set the power supply voltage to some convenient value, such as 4.5V. You will use this circuit to charge up the capacitor. To discharge the capacitor, you will disconnect the power supply and connect the leads together.

Before proceeding, set the resistance box so that the initial current during the charging of the capacitor will be between 0.2 and 0.5 A. Hint: What does Kirchhoff's law for voltages say about the voltages just as the switch is thrown closed? Discuss your choice with your instructor.

Use appropriate devices to observe the behavior of the current in the circuit and the voltage across the capacitor as the capacitor charges up. Record your observations, including a circuit diagram that indicates the direction of current flow and which side of the capacitor has higher electrical potential. Do the same while discharging the capacitor. Discuss how your observations relate to the properties of capacitors and resistors, including the direction of current flow and the change in current and voltage with time.

<u>Quantitative Measurements</u>

Your instructor will give you a smaller capacitor for this part of the experiment. The capacitance is printed on the capacitor; for instance, 1000 MFD means 1000 µF. Set the resistance substitution box so that the expected time constant will be about 45 to 60 seconds. Before connecting the resistance box into the circuit, check its resistance with a digital multimeter.

Connect the same circuit as before. Use a power supply voltage of 4.5 V (even if you have a battery and voltage divider). To measure the voltage across the capacitor as a function of time for both charging and discharging, you will use the Universal Lab Interface (ULI). Connect the ULI voltage leads across the capacitor. See the instructions for the Universal Lab Interface.

You should start taking data (run the computer program) before you close the switch in the circuit, since the program takes a few seconds to actually start. Also, when you are going to charge up the capacitor, you should briefly short out the capacitor leads just before you start, to make sure that you are starting with a fully discharged capacitor. Save your data on a floppy diskette.

Data and Analysis

- You can use Microsoft Excel to analyze your data. Import your data to Excel.
- For both the charging and discharging data, fit the Voltage across the capacitor as a function of time to the following curves:

  charging: $A(1-e^{-bt})$

  discharging: e^{-bt} ,

  Where A and b are the parameters. Fit the data using the Method of Least squares to minimize c^2, and obtain the best value for A and b. Determine the uncertainty in A and b also.

  You need to set up Excel where initial guesses for A and b are in certain cells. Write a formula to calculate c^2 so that you may vary A and b, c^2 varies automatically.

Narrative

- Describe the behavior of the current and voltage across the capacitor from the qualitative part.

- Discuss the physical significance of the parameter *A* and *b* and compare to what are expected. Explain discrepancies.

- Compare the voltage across the capacitor as a function of time for both the qualitative and qualitative parts.

- Describe in detail how the parameters of a curve is determined, along with their uncertainties, from experimental data.

MAGNETIC FORCE ON A CURRENT ELEMENT

Goals

In this experiment, you will measure the magnetic field, (magnetic induction, B) by considering a free-body diagram involving the magnetic force on a current carrying wire.

BACKGROUND

The expression for the magnetic force, $\vec{F}$, on a current carrying element is given by

$$\vec{F} = L\vec{I} \times \vec{B} \quad (1)$$

where $\vec{I}$ is the current, $\vec{B}$ the magnetic field, L the length of the wire in the magnetic field in the direction of the current, and $\vec{F}$ the magnetic force.

EXERCISE

Place the magnet on the hanging pan of the balance, measure its mass, and determine its weight. Select one of the printed-circuit wires and plug it into the holder, measure the length of the horizontal section of wire. Connect the holder onto a ring stand so that the wire runs down the middle of the magnet. Connect the holder to the DC output of the power supply. Note and record the direction that current will flow through the wire. Before you turn on the power supply, have the instructor check your circuit.

For several values of the current, measure the apparent mass of the magnet and determine the direction of the force on the magnet. Determine the direction of the force on the wire; use the appropriate rule to determine the direction of the magnetic field. Reverse the direction of the current and make more measurements. Verify the direction of the magnetic field.

Draw free-body diagrams for the magnet and the wire, and use your knowledge of mechanics to verify that the change in apparent weight of the magnet is equal in magnitude and opposite in direction to the magnetic force acting on the wire. Calculate the force on the wire for each value of the current.

For one value of the current, measure the force for wires of different lengths

Data and Analysis

- Data Table with mass of magnet, current , including direction, apparent mass of magnet, length of printed-circuit wire, and uncertainties.

- Calculation of magnetic force for each trial, magnitude and direction.

- Graphs of magnetic force vs. current for constant length magnetic force vs. length for constant current.

- Graphical analysis to determine equation of graphs for best fits curve.

- Schematic of experimental set-up.

- Calculation of the magnetic field (units, magnitude, and direction). Include uncertainties.

Narrative

- Explanation of how the magnetic force on the wire is determined using mechanics. Include a free-body diagram.

- Discussion of whether the data supports the force law given in equation (1).

- Explanation of how the magnetic field is determined, and the result of the experiment.

- Improvements and a discussion of the sources of uncertainty.

- Discussion of whether the earth's magnetic field introduces any measurable effects in the experiment.

THE OSCILLOSCOPE (Cathode Ray Tube)

Goals

In this experiment, you will learn the operations of the oscilloscope and make qualitative and quantitative observations, by using the oscilloscope in electrical circuits

Background

The Cathode Ray Tube (CRT) is the central component of the oscilloscope. It consists of a long vacuum tube with a phosphorescent screen at one end and an electron gun at the other end. The electron gun contains a cathode from which electrons are thermally emitted. These electrons are then accelerated and focused into a narrow beam and sent to the screen. The beam of electrons can be deflected either horizontally or vertically, respectively, thus displaying a connected waveform (voltage pattern).

The electrical signal to be studied is usually applied through an amplifier to deflect the beam vertically at the same time that a reference potential difference sweeps the beam horizontally. The horizontal sweep form that is the most useful is the one in which the voltage increases linearly with time so that the signal under study moves across the screen as a linear function of time.

Exercise

1. Familiarize yourself with the following controls on the oscilloscope. Do this with Channel 1 connected to a function generator. Record your observations.

   ON-OFF: Power Switch

   INTENSITY: Controls the brightness of the spot on the screen.

   FOCUS: Controls the sharpness of the spot or trace.

   VERTICAL POSITION: Moves the spot or trace vertically.

   X-POSITION: Controls the horizontal deflection of the trace or spot.

   VOLTS/DIV: Controls the amplification of the signal applied to the vertical plates.

TIME/DIV: Controls the frequency of the linear sweep signal applied to the horizontal deflection plates. This knob may also be set on X-Y. This turns off the internal sweep.

QUESTION: What happens when the X-POSITION knob is pulled out?

AC/GND/DC: Connect the oscilloscope to a 9 Volt battery and adjust this knob. Observe what happens to the signal.

2. Place the probe in the metal hole on the oscilloscope to calibrate the axes of channel 1. The known calibration frequency is 1000 Hz and calibration voltage is 0.2 V. Adjust the calibration knobs and observe what happens. Adjust the AC/GND/DC knob and observe what happens.

3. An antenna is any device that can detect an electromagnetic signal. Hook up an antenna to channel 1. Measure the frequency and maximum voltage of the signal observed. Move the antenna around and record your observations. Wrap the antenna around a live power cord and observe. Connect the function generator to channel 2. Press the X-Y knob: This puts channel 1 on the horizontal axis and channel 2 on the vertical axis. Record your observations. Look up the meaning of Lissajous figures. See if you can create a Lissajous figure.

4. Place the signal from a microphone or function generator in channel 2. Measure the frequency of various voice sounds. Explain how pitch and loudness affect the signal.

5. Connect the circuit in Fig.1 which consists of a diode (the triangle), a small resistor (use a rheostat) and the function generator. Observe the outputs across the resistor and function generator simultaneously on the oscilloscope. From Ohm's Law, the voltage across the resistor is proportional to the current. Other than an overall factor, observing the output across the resistor is like observing the current. From your observations, describe what effect the diode has on the circuit. You may repeat the observations with a circuit without the diode.

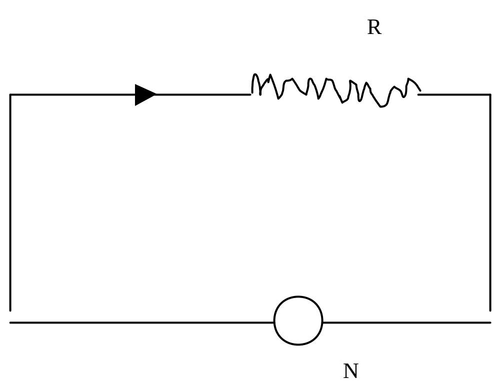


Figure 1. Schematic diagram of a resistor in series with a diode.

6. For your lab report, write a summary on the CRT and brief explanations of how an antenna and diode operate. You may need to look up references for your explanation.

RLC CIRCUIT

Goals

This experiment will introduce you to the behavior of resistors, capacitors, and inductors in an electrical circuit when the input voltage is oscillating. Such circuits are often known as AC (alternating current) circuits. Although capacitors and inductors are not ohmic devices, one can still study the ratio of voltage to current, known generally as impedance, and examine the factors that affect that ratio. (Resistance is a special case of impedance.) This experiment will thus provide motivation for defining impedance for capacitors and inductors. Finally, in this experiment you will study resonance in an oscillating circuit.

Background

In an AC circuit, one has various resistors, capacitors, and/or inductors in series or in parallel with a source of voltage. In this case, however, the voltage is a sine function of time, with a particular frequency. (Remember that frequency is the number of times that the function peaks every second.) To analyze the behavior of resistors in an AC circuit, you can use still Ohm's law. In this experiment, you will explore whether a similar law applies to capacitors and inductors. We *define* the impedance as the ratio of the amplitude of the voltage divided by the amplitude of the current. (Remember that the amplitude of the voltage is the highest voltage value.) Note that the highest voltage value and the highest current value may not always occur at the same time, although they do for resistors.

If you disturb a stable system, the system will oscillate at a particular frequency. For instance, if you pull back on a pendulum and let go, the pendulum will oscillate at a frequency that depends on the length of the pendulum. Moreover, if you nudge the pendulum at the same frequency (for instance, by giving it a small push every time it comes back to your hand), you very quickly build up the amplitude of the oscillation and the energy of the system. This phenomenon is known as resonance. If you nudge the pendulum with some other frequency, its response will be smaller, sometimes very small if your nudging frequency is very different from the resonance frequency.

Before doing this experiment, you should review the basic behaviors of a series resistor circuit. In particular, review the rule for how voltages add up in such a circuit.

Figure 1 shows the basic circuit diagram for this experiment. The function generator supplies an oscillating voltage. Our function generators, however, work best if the circuit has a large resistance (or impedance). If the resistance is too low, the function generator acts like a short-circuited battery, and its voltage drops to a value that depends on the resistance of the circuit. One prefers to have a voltage source that does not change when you change the circuit. Therefore, you will put a transformer between the function generator and the circuit. The transformer supplies more current at a smaller voltage, and voltage is more steady than without the transformer.

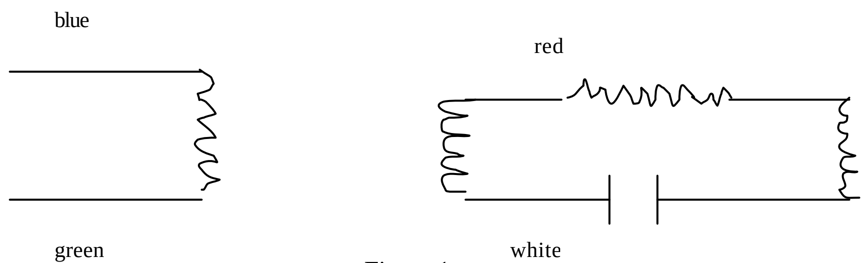


Figure 1

Caution: When you set up or modify a circuit, make sure that the power is off. Also, follow the circuit diagram carefully when hooking up the transformer; the diagram shows the colors of the wires on the transformer. If you hook up the transformer backwards, you could create high voltages that could give you an unpleasant shock.

The signal displayed by the oscilloscope is the voltage of the hook of the probe relative to ground. The alligator clip on the probe is a ground connection. The use of the transformer means that the resistor-capacitor circuit does not have a particular ground point. When you connect the oscilloscope probe, therefore, you set a particular point of the circuit as ground. You should review the section on grounds in your text (section 29.9).

When connecting the oscilloscope to the circuit, you may need to look at two voltages simultaneously (for instance, across the resistor and across the capacitor in Figure 1). This connection only causes problems if you end up grounding two different points of the circuit. Therefore, in Figure 1, you should put both ground clips at the same place, between the resistor and the capacitor.

These connections, however, make the two probes have their positive directions opposite each other. You can compensate by inverting one of the signals on the oscilloscope. In general, during this experiment you must pay close attention to the directions and signs of voltages, since you will examine how different voltage patterns are shifted relative to one another.

Exercise

RC Circuit

Connect the circuit shown in Figure 1. Set the resistance box to 10 Ω and start with a 100 mF capacitor. (After doing this section, you should check the resistance with the digital multimeter.) connect the oscilloscope to monitor the voltage across the resistor and the voltage across the capacitor simultaneously; review the background information if necessary. Make sure that the oscilloscope knobs are all set to Calibrated. Begin with the function generator set to produce 1000 Hz sine waves. Make the measurements and perform the analysis necessary to answer the following questions:

1. Is the ratio of the voltage amplitude across the capacitor to the current amplitude through the circuit a constant when you change the output voltage of the function generator? (How do you determine the current with this set-up? Hint: You do not need a separate meter.) Define this ration as the impedance of the capacitor.

2. How does the impedance of the capacitor depend on frequency? Give a mathematical equation, with supporting data, graph(s), and discussion.

3. How does the impedance of the capacitor depend on its capacitance? Give a mathematical equation, with supporting data, graph(s), and discussion.

4. Is the capacitor voltage signal shifted in time relative to the current? If so, does the shift depend on anything? (Remember to set up the probes correctly and to invert one of the inputs.)

RL Circuit

Replace the capacitor in Figure 1 with an inductor. Do what is necessary to answer the following questions:

1. Is the ratio of the voltage across the inductor to the current through the circuit a constant when you change the output voltage of the function generator? Define this ratio as the impedance of the inductor.

2. How does the impedance of the inductor depend on frequency? Give a mathematical equation, with supporting data, graph(s), and discussion.

3. Is the inductor voltage signal shifted in time relative to the current? If so, does the shift depend on anything? Is the shift different from the shift you saw for the capacitor?

RLC circuit and Resonance

Modify the series circuit of figure 1 to consist of a 5Ω resistor, a 3.3 mF capacitor, and the inductor. Use the oscilloscope to simultaneously monitor the function generator output directly and the voltage across the resistor. Describe how the current through the circuit changes as you change the frequency (a graph might help). Where is the resonance?

At the resonance frequency, check the voltage across each of the components. Be consistent about always having the probe clockwise relative to the ground clip. Describe the relative shifts and amplitudes of each voltage. Repeat with frequency below resonance. Repeat with frequency above resonance.

Questions

1. Explain how your results for the RLC circuit are consist with your results for the RC circuit and for the RL circuit, including discussion of impedance changes with frequency.

2. What interesting things happened at resonance? List all of the ways of knowing that you reached resonance in the RLC circuit.

DESIGN OF AN EXPERIMENT

Goals

In this experiment, the student will design and implement an experiment.

Activity

This activity is to develop your understanding of the scientific process and the procedures involved in the design of an experiment. It may take two weeks.

Some possible topics to investigate are:

- The Earth's magnetic field
- The accuracy of the meters: galvanometer, voltmeter, ammeter
- Lenz's Law
- Electrostatic forces
- Measuring the type and charge of an object
- Build a voltmeter or ammeter from a galvanometer and resistors
- Other types of AC circuit other than the series RLC

However, you should choose a topic you are curious about. Try to be as exact and quantitative as possible in what you are investigating and the expected outcome before deciding on the procedure.

Discuss your topic, logic, design, and understanding with your instructor. Your instructor may also conduct a general discussion with the class about the factors involved in the design of an experiment.

Perform your experiment. The experiment may be open-ended and you may not be able to finish everything you intended. Some progress, however, must be accomplished and presented in a paper.