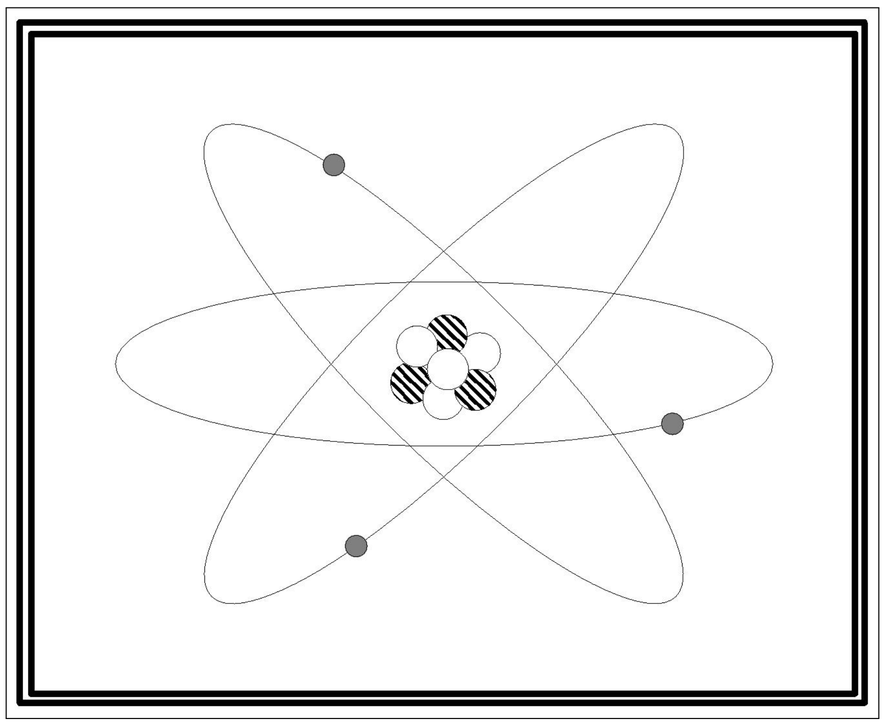
University of Northern British Columbia



Physics 101/111

Laboratory Manual

Winter 2018

Contents

1. Introduction to Lab Reports

1.1. Lab Report Outline

Physics 1??	*Your Name*
section L?	*student #*
date	*lab partner's Name*

Lab #, Lab Title

The best laboratory report is the shortest intelligible report containing ALL the necessary information while maintaining university level spelling and grammar. Use full sentences and divide the lab into the sections described below.

Object - One or two sentences describing the aim of the experiment. Be specific in regards to what you hope to prove. (In ink)

Theory - The theory on which the experiment is based. This usually includes an equation which is to be verified. Be sure to clearly define the variables used and explain the significance of the equation. (In ink)

Apparatus - A brief description of the important parts and how they are related. In all but a few cases, a diagram is essential, artistic talent is not necessary but it should be neat (use a ruler) and clearly labeled. (All writing in ink, the diagram itself may be in pencil.)

Procedure - Describes the steps of the experiment so that it can be replicated. This section is not required.

Data - Show all your measured values and calculated results in tables. Show a detailed sample calculation for each different calculation required in the lab. Graphs, which must be plotted by hand on metric graph paper and should be on the page following the related data table. (If experimental errors or uncertainties are to be taken into account, the calculations should also be shown in this section.) Include a comparison of experimental and theoretical results. (Except graphs, this section must be in ink.)

Discussion and Conclusion - What have you proven in this lab? Support all statements with the relevant data. Was your objective achieved? Did your experiment agree with the theory? With the equation? To what accuracy? Explain why or why not. Identify and discuss possible sources of error. (In ink)

1.2. Lab Rules

Please read the following rules carefully as each student is expected to be aware of and to abide by them. They have been implemented to ensure fair treatment of all the students.

Missed Labs: A student may miss a lab without penalty if due to illness(a doctor's note is required) or emergency. As well, if an absence is expected due to a UNBC related time conflict (academic or varsity), arrangements to make up the lab can be made with the Senior Laboratory Instructor in advance. Students will not be allowed to attend sections, other than the one they are registered in, without the express permission of the Senior Laboratory Instructor. Failure to attend a lab for any other reason will result in a zero (0) being given for that lab.

Late Labs: Labs will be due 24 hours from the beginning of the lab period, after which labs will be considered late. Late labs will be accepted up until 1 week from the beginning of the lab. Students will be allowed 1 late lab without penalty after which all subsequent late labs will be given a mark of zero (0). Any labs not received within one week will no longer be accepted for grading and given a mark of zero (0).

Completing Labs: To complete the lab report in the lab time students are strongly advised to read and understand the lab (the text can be used as a reference) and write-up as much of it as possible before coming to the lab. We urge you to stay the entire lab time - it is provided for your benefit; if you run into problems writing up the lab, the instructor is there to help you.

Conduct: Students are expected to treat each other and the instructor with proper respect at all times and horseplay will not be tolerated. This is for your comfort and safety, as well as your fellow students. Part of your lab mark will be dependent on your lab conduct.

Plagiarism: Plagiarism is strictly forbidden! Copying sections from the lab manual or another person's report will result in severe penalties. Some students find it helpful to read a section, close the lab manual and then think about what they have read before beginning to write out what they understand in their own words.

Lab Presentation: Labs must be presented in a paper duotang. Marks will be given for presentation, therefore neatness and spelling and grammar are important. It makes your lab easier to understand and your report will be evaluated accordingly. It is very likely that, if the person marking your report has to search for information or results, or is unable to read what you have written, your mark will be less than it could be!

Contact Information: If your lab instructor is unavailable and you require extra help, or if you need to speak about the labs for any reason, contact the Senior Laboratory Instructor, Dr. George Jones, by email at gjones@unbc.ca, by phone at (250) 960-5169, or in his office, 10-2014.

Supplies needed:

Clear plastic 30 cm ruler
Metric graph paper (1mm divisions)
Paper duotang
Lined paper
Calculator
Pen, pencil and eraser

Experiment 1: Standing Waves in a Tube

UNBC Department of Physics

January 13, 2015

1. Introduction

In this experiment, you will set up standing sound waves inside a resonance tube using a speaker and function generator. You will then use a miniature microphone and oscilloscope to determine the characteristics of the standing waves.

A sound wave propagating down a tube is reflected back and forth from each end of the tube, and all the waves, the original and the reflections, interfere with each other. If the length of the tube and wavelength of the sound wave are such that all of the waves that are moving in the same direction are in phase with each other, a standing wave pattern is formed. This is known as a resonance mode for the tube, and frequencies at which resonance occurs are called resonant frequencies.

Knowing the wavelength, λ, and frequency, f, of a wave, one is able to calculate its speed by multiplying them together,

$$v = f\lambda \tag{1}$$

The expected speed of sound is given by

$$v_{\text{expected}} = 331.5\,\mathrm{m}\,/\,\mathrm{s} + (0.607\,\mathrm{m}\,/\,(\mathrm{s}\cdot{}^{\circ}\mathrm{C}))\,T, \tag{2}$$

where T is the temperature in Celsius.

2. Apparatus

- computer running PASCO Capstone
- PASCO 850 Universal Interface
- PASCO Resonance Tube

- PASCO Voltage Sensor
- Miniature Microphone

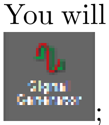
3. Procedure

1. Set up the PASCO resonance tube in such a way that the piston is in the tube and the end caps are against the tube ends. Connect the microphone to the PASCO voltage sensor (remember to swatch on the microphone), and connect the voltage sensor to an Analog Input on the PASCO 850 Universal Interface. Connect Output 2 on the PASCO 850 Universal Interface to the speaker input on the side of the cap containing the speaker.

2. Connect the PASCO 850 Universal Interface to the computer using the USB cable and switch it on. Launch Capstone.

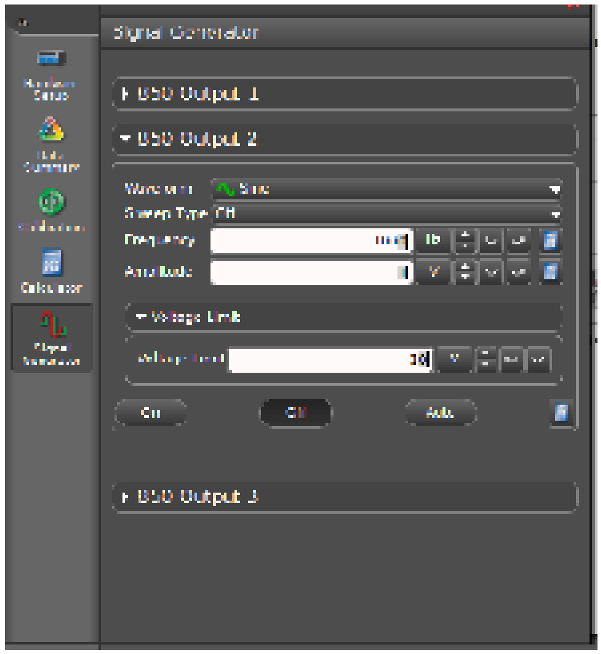
3. Click on Hardware Setup (if it has not already come up) to open the Setup window. Click on the Analog Input to which the voltage sensor is physically connected. In the drop-menu, scroll to and click on Voltage Sensor. You can click on Properties for that sensor, and adjust the gain. However, in this case, leave it set to 1x. Click Hardware Setup to close the Setup window.

4. Click on Table & Graph and delete the Graph. Double-click on Scope to the far left of the Capstone window . Now delete the Table and expand the Scope to occupy the whole page.

5. You will see the signal generator button to the bottom left of the Capstone window 

; click it.

6. You will now see the signal generator controls window,



7. Familiarize yourself with the controls. Use the fine tuning controls  to control the frequency. Make sure Waveform is set to Sine, Amplitude is 4 V and Voltage Limit is 10 V. Use On and Off to switch the signal generator on/off. Leave Sweep Type Off.

8. Finally set the sample rate on the Voltage Sensor at the bottom of the window to 100 kHz.

9. Insert the piston into the tube, as in figure below, until it reaches the maximum point that the microphone can reach coming in from the speaker end. Record this piston position, P_1, in Table 1.

10. Find a resonant frequency around 800 Hz for this new tube configuration by clicking Record and looking for a peak on the Scope whilst moving the piston into

the tube. Remember, when writing data or doing something other than using the Scope, click Stop so as not to overload the buffer with large data. You will have to frequently Delete Last Run (bottom of the Capstone window).

11. Use the microphone to locate the maxima and minima for this closed tube configuration by moving it into the tube from the speaker and looking at the waveform on the Scope. When the waveform reaches maximum amplitude and is stable, then you have a standing wave. When it is fairly flat, you are at a minima. Record the position for maxima (use the graduated tape (in cm) on the inside of the tube) in Table 1 and do the same for the minima. Keep doing this until the microphone is at the piston or until you run out of wire.

12. Keeping the **frequency** the same, move the piston towards the speaker very carefully and record the position, P_2, at which another resonance mode occurs. Repeat step 11.

13. Repeat steps 11 and 12 for a different resonant frequency.

14. Using the data that you have recorded for the first resonant frequency, sketch the wave activity along the length of your tube. Label it with the frequency used, and indicate the horizontal scale and piston position. Repeat this for each of the seven other trials.

15. The microphone used is sensitive to pressure. The maxima are therefore points of maximum *pressure* and the minima are points of minimum *pressure*. On each of your drawings, indicate where the points of maximum and minimum *displacement* are located.

16. Determine the wavelength for the waves in each of your trials.

17. Given the frequency of the sound wave you used, calculate the speed of sound in your tube for each configuration using Equation (1).

18. Find the average speed of sound, $\bar{v}$.

19. Calculate the expected speed of sound using Equation (2). Find the percent difference between $\bar{v}$ and v_{expected}.

4. Discussion and Conclusion

Comment on whether your results support Equation (1) and Equation (2). Explain. Comment on whether the piston position affects the wavelength. Explain. Outline and discuss at least two possible sources of error which may have occurred during the collection of the data and how they could have been avoided.

Table 1: Standing Waves in a Tube

f_r (Hz)				f_r (Hz)			
P_1 (m)		P_2 (m)		P_1 (m)		P_2 (m)	
Maxima (m)	Minima (m)	Maxima (m)	Minima (m)	Maxima (m)	Minima (m)	Maxima (m)	Minima (m)

Date:
Instructor's Name:

Instructor's Signature:

Experiment 2: Two-Slit Interference

UNBC Department of Physics

January 13, 2015

1. Introduction

What is light? There may be no complete answer to this question. However, in certain circumstances, light behaves exactly as if it were a wave. In fact, in this experiment you will measure the wavelength of light, and see how that wavelength varies with colour.

2. Theory

In two-slit interference, light falls on an opaque screen with two closely spaced, narrow slits. As Huygen's principle tells us, each slit acts as a new source of light. Since the slits are illuminated by the same wave front, these sources are in phase. Where the wave fronts from the two sources overlap, an interference pattern is formed.

The essential geometry of the experiment is shown in Figures 8.1 and 8.2. At the zeroth maxima, light rays from slits A and B have travelled the same distance from the slits to your eye, so they are in phase and interfere constructively on your retina. At the first order maxima (to the left of the viewer) light from slit B has travelled one wavelength further than light from slit A, so the rays are again in phase, and constructive interference occurs at this position as well.

At the n^{th}-order maxima, the light from slit B has travelled n wavelengths further than the light from slit A, so again, constructive interference occurs. In the diagram, the line AC is constructed perpendicular to the line PB. Since the slits are very, very close together (in the experiment, not the diagram) lines AP and BP are nearly parallel. Therefore, to a very close approximation,

$$AP = CP \tag{1}$$

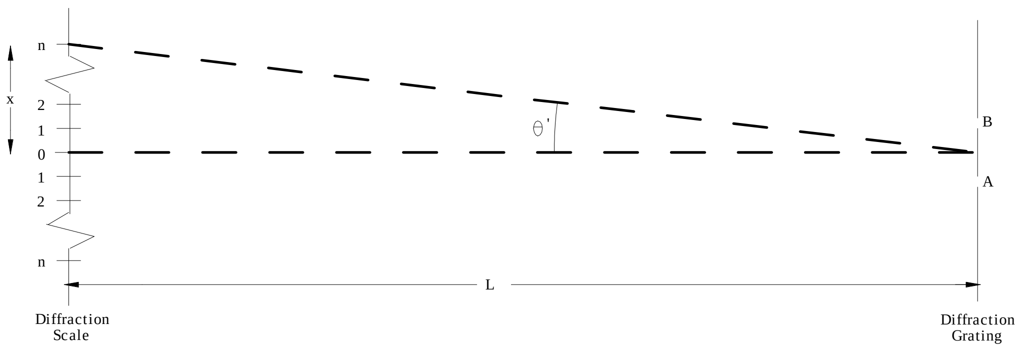


Figure 8.1: Geometry to the Left of the Diffraction Grating

This means that, for constructive interference to occur at P, it must be true that

$$BC = nG\lambda. \tag{2}$$

From the right angle triangle ACB, it can be seen that

$$BC = AB \sin\theta, \tag{3}$$

where AB is the distance between the two slits on the Diffraction Plate. Therefore,

$$n\lambda = AB \sin\theta. \tag{4}$$

Consequently, you need only to measure the value of θ for a particular value of n to determine the wavelength of the light.

To measure θ, notice that the dotted lines in the illustration show a projection of the interference pattern on the Diffraction Scale (as it appears when looking through the slits). Notice that

$$\theta' = \tan^{-1}(X/L). \tag{5}$$

It can also be shown from the diagram that, if BP is parallel to AP as we have already assumed, then

$$\theta' = \theta. \tag{6}$$

Therefore,

$$\theta = \tan^{-1}(X/L) \tag{7}$$

and

$$n\lambda = AB \sin\left(\tan^{-1}(X/L)\right). \tag{8}$$

Hence, wavelength is given by

$$\lambda = \frac{AB}{n} \sin\left(\tan^{-1}(X/L)\right). \tag{9}$$

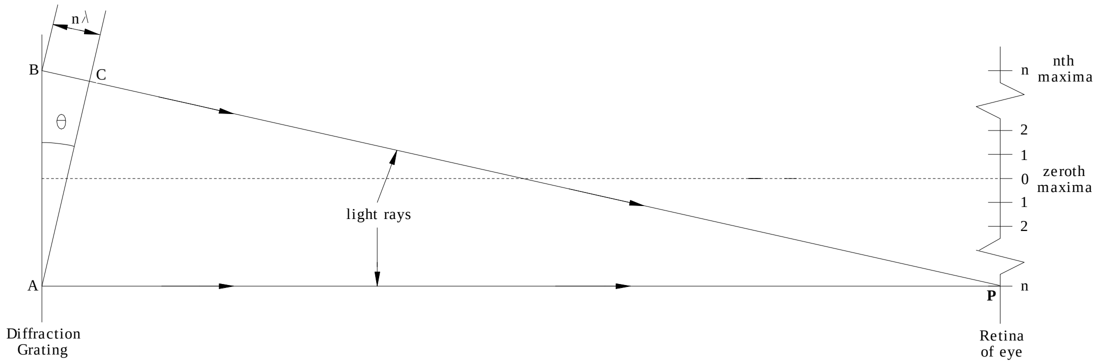
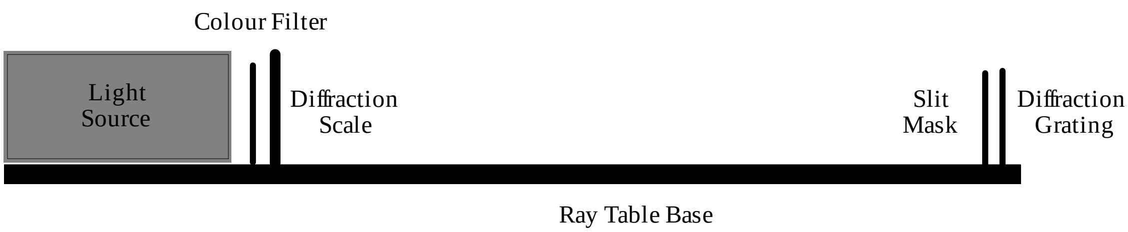


Figure 8.2: Geometry to the Right of the Diffraction Grating

3. Apparatus

- 3 Coloured Filters (red, green, blue)
- Diffraction Plate and Diffraction Scale
- Slit Mask and Light Source
- 2 Component Holders and Optics Bench



4. Procedure

1. Set up the equipment as shown in the apparatus diagram. To increase the accuracy of your measurements, arrange your equipment such that L is as large as possible. The Slit Mask should be centered on the Component Holder on the side closest to the Light Source.

2. While looking through the Slit Mask, adjust the position of the Diffraction Scale so you can see the filament of the Light Source through the slot in the Diffraction Scale.

3. Attach the Diffraction Plate to the other side of the Component Holder. Center pattern D ($AB = 0.125\,\mathrm{mm}$), on the Diffraction Plate, with the slits vertical (in the aperture of the Slit Mask).

4. Now, look through the slits. By centering your eye so that you look through both the slits and the window of the Diffraction Scale; you should be able to see clearly, both the interference pattern and the illuminated scale on the Diffraction Scale.

   Note: In this experiment, you look through the narrow slits at the light source, and the diffraction pattern is formed directly on the retina of your eye. You then see this diffraction pattern superimposed on your view of the illuminated diffraction scale. The geometry is therefore slightly more complicated than it would be if the pattern were projected onto a screen, as in most textbook examples. (A very strong light source, such as a laser, is required in order to project a sharp image of a diffraction pattern onto a screen.)

5. Place the red filter over the Light Source aperture. Then, select a value of n as large as possible. You will notice that the maxima are not as sharp as n gets larger. So, you may find that $n = 4$ is just about the right choice to optimize the accuracy of n.

6. Look carefully at where your chosen light band lines up with the Diffraction Scale. Record this value as X in the Data Table. Now calculate λ for red light.

7. Repeat steps 5. and 6. for the green and blue filters.

8. Repeat steps 5., 6. and 7. for pattern E ($AB = 0.250\,\mathrm{mm}$).

9. Compare the values of wavelength for the same colour of light by finding the percent differences.

10. Do each of your six measured wavelengths fall into the appropriate range for that colour? (Red: 640 nm - 750 nm, Green: 500 nm - 550 nm, Blue: 450 nm - 500 nm)

11. Give reasons why the percent difference between wavelength values for exactly the same light might not be zero.

5. Conclusion

Did your results support the theory? Explain. Was equation (8.9) proven correct? Explain. Give some possible sources of errors which may have occurred during the collection of the data.

Data Table: Two-Slit Interference

Colour	n	$AB_{\text{slit spacing}}$	X (m)	L (m)	λ (m)
Red					
Green					
Blue					
Red					
Green					
Blue					

Date:

Instructor's Name:

Instructor's Signature:

Experiment 3: Bernoulli's Principle

UNBC Department of Physics

January 15, 2015

1. Introduction

In the Venturi Apparatus, air or water flows through a channel of varying width. As the cross-sectional area changes, the volumetric flow rate remains constant but the velocity and pressure of the fluid vary. With a Quad Pressure Sensor connected to the built-in Pitot tubes, the Venturi Apparatus allows the quantitative study and verification of the Continuity Equation, Bernoulli's Priciple and the Venturi effect.

2. Theory

An incompressible fluid of density ρ flows through a pipe of varying diameter. As the cross-sectional area decreases from A_0 (large) to A (small), the speed of the fluid increases from v_0 to v.

The flow rate, R, (volume/time) of the fluid through the tube is related to the speed of the fluid (distance/time) and the cross-sectional area of the pipe. This relationship is kown as the Continuity Equation and can be expressed as

$$R = A_0 v_0 = Av. \tag{1}$$

As the fluid travels from the wide part of the pipe to the constriction, the speed increases from v_0 to v and the pressure decreases from P_0 to P. If the pressure change is due only to the velocity change, then Bernoulli's Equation can be simplified to

$$P = P_0 - \frac{1}{2}\rho\left(v^2 - v_0^2\right). \tag{2}$$

3. Equipment

- Fluid tubing (at least 1.5 m)

- 2 restriction clamps
- 3 3-litre water pails
- 1-liter Water reservoir
- 1-meter tall rod and stand with clamp
- 1 PASCO Venturi Apparatus ME-8598
- 1 PASCO Quad Pressure Sensor PS-2194
- 1 PASCO Motion Sensor
- 1 PASCO 850 Universal Interface
- Cables to connect sensors to the interface

4. Procedure

4.1. Pre-Setup Preparations

Remove the top plate from the Venturi Apparatus. Measure the depth of the channel and the widths of the wide and narrow sections. Calculate the largest cross-sectional area (A_L) and the smallest cross-sectional area (A_S). Re-assemble the Venturi Apparatus. Do not over-tighten the T-screws.

Ensure that the Quad Pressure Sensor couplings are not connected to the 4 tubes at the bottom of the Venturi. Connect the sensors to the 850 Universal Interface and launch Capstone. Click on Table & Graph. Click on Calibrate on the left of the window.

1. Click Next.
2. Click the checkbox next to Pressure Measurements to select all the ports on the sensor. Click Next.
3. Select One Standard (1 point offset). Click Next.
4. Enter 101 kPa for the Standard Value. Click Set Current Value to Standard Value. Click Next.
5. Review and click Finish.

For the Motion Sensor, ensure that the switch is set to the short-range setting which has a cart engraved next to that position. Set the water reservoir so that it is at least 1.5 m above the water catch pail, and that it is above the Venturi. The Motion Sensor will need to be set up so that it is almost touching the top of the water reservoir, when it is moved into position after water has been added to the reservoir.

Connect the tubes at the bottom of the Venturi to the Quad Pressure Sensor in the correct order (1-1, 2-2 and so on). Attach the two restriction clamps to one piece of tubing, and connect that piece of tubing to the outlet of the Venturi. Ensure that the tube is well over the port. One of your clamps will be for regulating the flow of water. The other will be used to cut off the flow of water completely.

Connect the other piece of tubing to the reservoir and the inlet port of the Venturi. Ensure a tight seal. Fill one of your pails with lots of water. Now pour water into the reservoir until it is just below the top port. You are going to have to do the following fast. Release the cut-off clamp fully, so that water is now flowing through the system. Tilt the Venturi all the way to the inlet side so that the air in the system is pushed out the outlet into the catch pail. Now put the Venturi back onto the table horizontally. Close the clamp fully to cut off the flow of water. You have to do this fast enough so that the reservoir does not run out of water, otherwise air will be re-introduced into the system.

Top up the reservoir with water. You are now ready to perform the experiment.

4.2. Running the Experiment

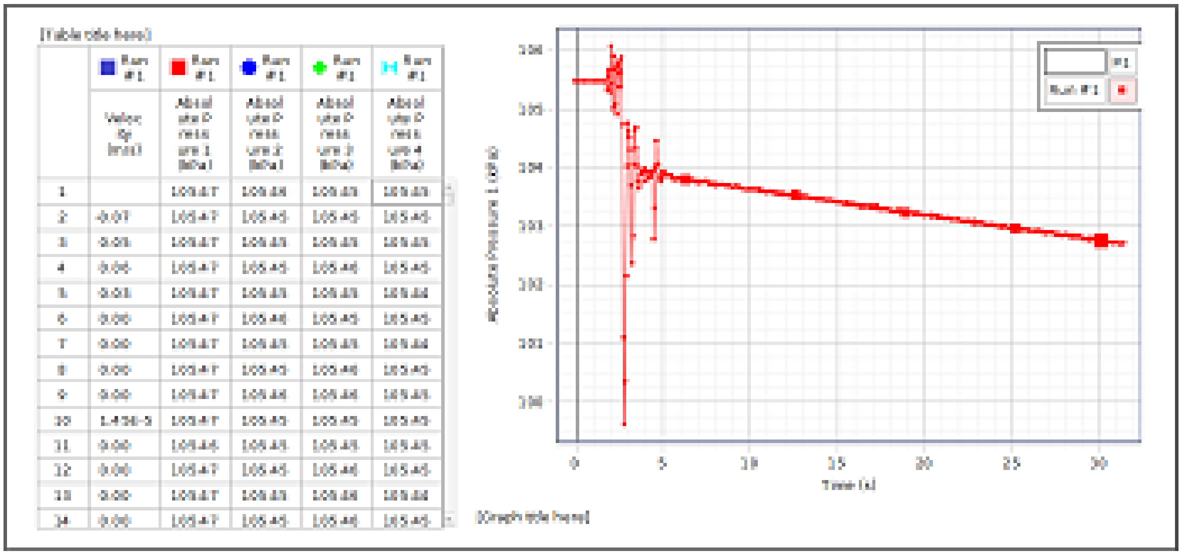
1. In Capstone, ensure that the sample rate for the motion sensor is set to 50 Hz. Do this using the section of the bottom toolbar to the right of Record. You have to use the drop-down menu and click on Motion Sensor.

2. Make sure the Motion Sensor is in position just above the top of the reservoir, and that the sensor is centered on the tube. You need to move quickly now.

3. Click Record. Quickly release the clamp on the outflow tube to allow the water to flow through the system. Return to Capstone and observe the reservoir.

4. Allow the recording to run for 30 seconds, or for just long enough that the reservoir does not lose all of its water. Click Stop and secure the clamp on the outlet fully closed.

5. In Capstone, on the data table, click Select Measurement and select Absolute Pressure 1 (kPa). That column will load with that data. In the other column,



do the same thing except click on Velocity (m/s) under Motion Sensor. You can plot these data in the graph by clicking on Select Measurement on the y-axis and selecting, say, the pressure measurement. This will show as a plot against time. Likewise for the velocity.

6. In the data table, you can add new columns by clicking  . This will add a new empty column to the right. Do this 3 times so that you can load them with the pressure data for the other 3 pressure points. You can click and drag a column to reposition it in the table layout.

7. Your experiment page should now look similar to

8. You can enter a title for the data table by clicking Table Title Here. Likewise for the graphs. Remember, you can use Journal to capture various pages with different graphs for inclusion in your report.

5. Analysis

1. Ensure you measured the depth of the Venturi tube and the widths of the wide and narrow sections. Convert your measurements to metres. Use this to calculate the cross-sectional area of the wide and narrow sections.

2. Measure the diameter of the reservoir and convert to metres. Use this to calculate the cross-sectional area of the reservoir.

3. View your data on a graph of pressure versus time for P_1 which is labelled Absolute Pressure 1 in your data table. The pressures are correctly matched to each pressure point in the Venturi.

4. Select a time interval of 2 seconds in which all the pressures are relatively clean (though not necessarily constant or noise-free).

5. Within this time interval, determine the average of each pressure measurement; P_1, P_2 and P_3.

6. Over the same time interval, determine the average flow rate, $R_{1_{mean}}$, $R_{2_{mean}}$ and $R_{3_{mean}}$. You have to use the data from the Motion Sensor to obtain the mean velocity of the water.

7. If there were no friction or turbulence in the channel, the pressures in both wide sections, P_1 and P_3, would be equal; however, you will find that this is not the case. Because the channel is symmetrical about Point 2, you can estimate the pressure lost at Point 2 due to friction and turbulence by assuming that it is half of the pressure lost between Point 1 and Point 3. In other words, if the tube were straight, the pressure at Point 2 would be the average of P_1 and P_3. Calculate this theoretical pressure:

$$P_0 = \frac{P_1 + P_3}{2} \tag{3}$$

8. Use the mean flow rate, R_{mean}, and Equation 1 to calculate the fluid speed in the wide parts of the tube (v_0), and the speed in the Venturi constriction (v).

9. Use these values of v_0 and v and Equation 2 to calculate the theoretical pressure (P) in the Venturi constriction. Compare this to the actual pressure measured by the sensor (P_2).

10. Repeat these analyses for Points 2, 3 and 4.

6. Discussion and Conclusion

Compare the theoretical and actual values for pressure. Discuss possible sources of error.

Experiment 5: Electric Field Mapping

UNBC Department of Physics

January 14, 2015

1. Introduction

The electric field lines between two conductors can be mapped by first mapping the lines of equipotential. Knowledge of the electric field lines provides insight into the strength of the electric field at different points in space and also the nature of the charge distribution over the surfaces of the conductors. In this experiment we will map electric field lines between conductorsof various shapes by first mapping the equipotential lines.

An interesting example is the case of two conducting spheres, held a fixed distance apart (Figure 1), one of which has a net charge +Q uniformly distributed over its surface, the other being electrically neutral. The light lines in Figure 1 indicate lines of constant electric potential (equipotential lines) and the heavy lines are electric field lines. The density of electric field linesindicates the strength of the field: the greater the density of lines, the stronger the electric field.

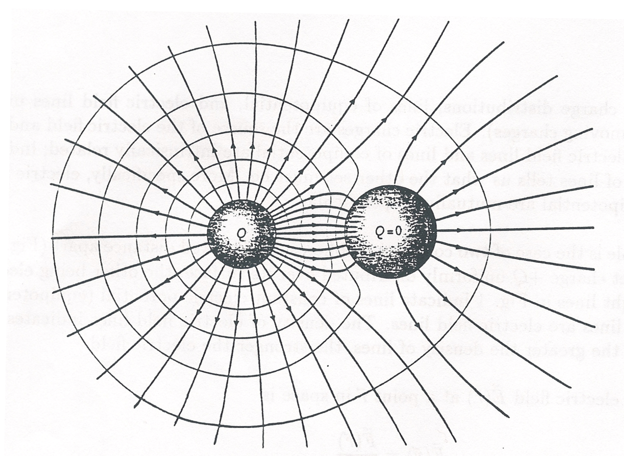


Figure 1

The definition of the electric field $\vec{E}(\vec{r})$ at a point $\vec{r}$ in space is

$$\vec{E}(\vec{r}) = \frac{\vec{F}(\vec{r})}{q_t}, \tag{1}$$

where $\vec{F}(\vec{r})$ is the net electric force on a positive test charge q_t placed at $\vec{r}$. The source of $\vec{E}(\vec{r})$ is the set of all other charges surrounding q_t. Electric field lines originate on positive charges and terminate on negative charges; in a figure such as Figure 1, the electric field lines do not actually terminate as shown — in other words, the lines do not simply "vanish into thin air".

If a positive test charge q_t is moved a tiny distance Δr in the direction of the electric field $\vec{E}$, the work done by the electric force is $q_t E \Delta r$. Since the electrostatic force is a conservative force, energy is conserved in the process, and the corresponding change ΔU in the electrostatic potential energy U is $\Delta U = -q_t E \Delta r$. The electrostatic potential V is defined in a manner similar to that of the electric field:

$$V = \frac{U}{q_t}. \tag{2}$$

The difference ΔV in the electrostatic potential between two neighbouring points is given by

$$\Delta V = V_2 - V_1 = -E\Delta r \tag{3}$$

where V_1 is the potential at point "1", V_2 is the potential at point "2", r is the distance between the two points, and the two points lie along a segment which is parallel to the electric field. If, instead, the two points lie along a segment which is perpendicular to the electric field, then the difference in electrostatic potential between the two points is zero. This tells us that equipotential lines are everywhere perpendicular to electric field lines, as indicated in Figure 1.

2. Apparatus

- Power Supply and connecting wires
- Digital Multimeter and probes
- 2 pieces of conductive paper with predrawn patterns

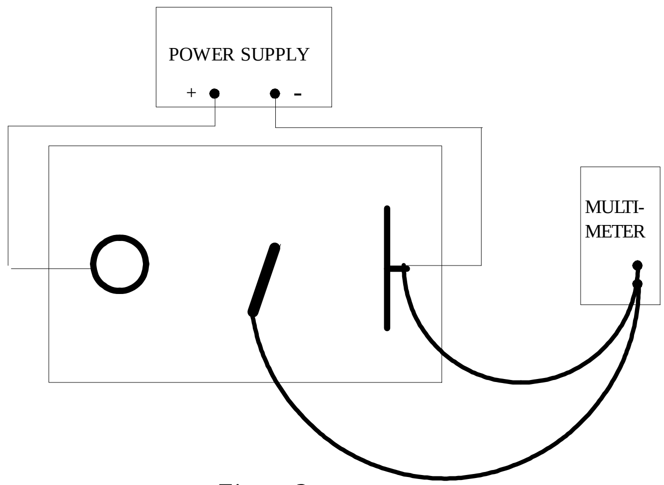


Figure 2

3. Procedure

1. Spend a few moments familiarizing yourself with the experimental setup and apparatus as shown in Figure 2. A power supply and a digital multimeter are connected to two conductors which are indicated in Figure 2 by the heavy dark lines. Also shown are the sheet of conductive paper on which the two conductors sit, and the red probe with its conducting tip. Upon examining the conductive sheet you will notice a grid of blue crosses and x– and y– axes along the edges of the sheet. Your lab instructor will supply you with two pieces of white paper which are replicas of the grid on the conductive sheet. It is on these sheets of paper that you are to draw the conducting electrodes, the equipotential lines, and the electric field lines, not on the conductive paper!

   Note: You will need to pace yourself through this experiment. You need to take enough data (coordinates of points of equal potential) to be able to draw smooth equipotential and electric field lines, but you do not want to take so many that you run out of time!

2. In this experiment you will obtain the equipotential and electric field lines for two different conducting electrode shapes, one of which is shown in Figure 2. You will obtain these lines as described below, but before proceeding further, it is essential that you recognize the following. You are to collect your data by carefully touching the probe to various points on the conductive paper, **but you must NOT damage the conductive paper in any way**. Your lab instructor will explain further as required.

3. Equipotential lines are obtained and plotted in the following manner. With the power supply turned on and set to the 15–30 volt range, and the digital multimeter turned on, gently bring the probe into contact with the conductive paper. Begin by placing the probe roughly midway between the two conducting electrodes. Gently move the probe slightly toward one electrode or the other until a “nice round number” appears on the multimeter — for example, if the potential difference between electrodes is 30.00 volts, you could begin by finding the point where the multimeter reads 15.00 volts. Note the x– and y–coordinates of this first point, and plot the point on the white grid sheet supplied. NOTE: Avoid touching the probe to the printed grid mark on the conductive sheet, as the ink of the grid mark may prevent proper electrical connection.

4. Next, move the probe until you find another point on the conductive sheet which gives the same, or almost the same, voltage reading on the digital multimeter. Again note the coordinates of this point and plot another point on your white grid sheet.

5. Repeat step 4. until you have enough points (minimum 10) to draw a smooth equipotentialline from one side of the white sheet to the other and be sure to label it with its potentialvalue.

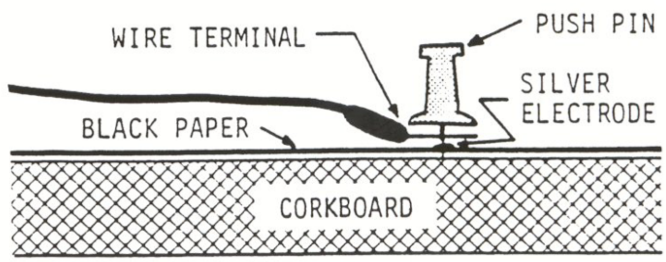
6. Choose another potential (e.g. 10.00 volts) and repeat steps 3., 4. and 5. to obtain another equipotential line on your white grid sheet.

7. For electrode patterns where there is a conductor with an interior region, such as that of Figure 2, be sure to measure the values of the potential at points on the inside of the conductor. Also label the positive and negative conductors.

8. Repeat steps 3. through 6. until you have enough (minimum 10) equipotential lines spread out over your white grid sheet to allow you to draw the electric field lines for the conducting electrodes on the conductive sheet. Draw in the electric field lines by exploiting your knowledge that they are everywhere perpendicular to the equipotential lines. Be sure to include arrows to show the direction of the electric field.

9. Repeat steps 3. through 8. for the other conducting electrode pattern. These conductive grid sheets will be supplied by the lab instructor. You are to replace one conductive sheet with another as follows. First remove the 4 pins which hold the sheet to the corkboard at the corners. Next, very carefully remove the 2 conducting pins and the connecting wires at each of the two electrodes on the sheet. Remove the sheet and place the new sheet on the corkboard. Pin the four corners down so the sheet lies smoothly on the board. Then, very carefully, attach

the connecting wires to the two electrodes using the 2 conducting pins, as shown below. Be sure to obtain a good electrical contact by pushing the pins firmly into the corkboard.



4. Discussion

1. Where is the electric field strongest in each map of equipotential and electric field lines, and how can you tell?
2. Where is the electric field weakest in each map of equipotential and electric field lines,n and how can you tell?
3. What is the direction and orientation (angle) of the electric field at the surface of a conductorand why does it have that direction?
4. What is the electric field inside a conductor, and how can YOU tell?

5. Conclusion

Did your results support that equipotential lines and electric field lines are perpendicular to each other? Explain. Did your results support that electric field lines begin on positive charges and end on negative ones? Explain. Give some possible sources of errors which may have occurred during the collection of the data.

Experiment 5: Capacitance and Capacitors

UNBC Department of Physics

January 15, 2015

1. Introduction

In this laboratory session you will learn about an important device used extensively in electric circuits: the capacitor. A capacitor is a very simple electrical device which consists of two conductors of any shape placed near each other but not touching. While a primary function of a capacitor is to store electric charge that can be used later, its usefulness goes far beyond this to include a wide variety of applications in electricity and electronics. A typical capacitor, called the parallel-plate capacitor, consists of two conducting plates parallel to each other and separated by a nonconducting medium that we call dielectric (see Fig. 1a). However, capacitors can come in different shapes, configurations and sizes. For example, commercial capacitors are often made using metal foil interlaced with thin sheets of a certain insulating material and rolled to form a small cylindrical package (see Fig. 1b). Some of the properties of capacitors will be explored in this experiment, including the concept of capacitance and the mounting of capacitors in series and in parallel in electric circuits.

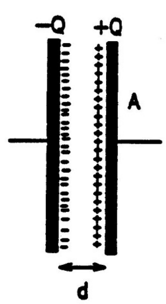


Figure 1a:

Parallel Plate Capacitor

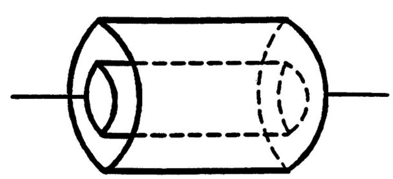


Figure 1b:

Cylindrical Capacitor

2. Theory

If a potential difference V is established between the two conductors of a given capacitor, they acquire equal and opposite charges $-Q$ and $+Q$. It turns out that the electric charge Q is directly proportional to the applied voltage V. The constant of proportionality is a measure of the capacity of this capacitor to hold charge when subjected to a given voltage. We call this constant the capacitance C of the capacitor and we have

$$Q = VC. \tag{1}$$

The value of C depends on the geometry of the capacitor and on the nature of the dielectric material separating the two conductors. It is expressed in units of Coulomb/Volt or what we call the Farad (F). For the parallel-plate capacitor (Fig. 1a) one can show that the capacitance is given by

$$C = \frac{\epsilon A}{d}, \tag{2}$$

where A is the area of the plate, d the distance separating the two plates, and ϵ the permittivity of the dielectric material. In case of empty space, the value of ϵ is $\epsilon_0 = 8.85 \times 10^{-12} - 12u\,\mathrm{C}\,/\,\mathrm{N}\cdot m^2$.

We can also show that if two capacitors of capacitance C_1 and C_2 are connected in series (Fig.2a) or in parallel (Fig. 2b), then they are equivalent to one capacitor whose capacitance C is given by

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} \qquad \text{(series)} \tag{3}$$

$$C = C_1 + C_2 \qquad \text{(parallel)} \tag{4}$$

Note that in a series combination each capacitor stores the same amount of charge Q, while in a parallel combination the voltage V across each capacitor is the same.

Figure 2a

Capacitors in Series

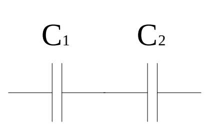
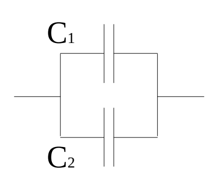


Figure 2b

Capacitors in Parallel



3. Apparatus

- Large Parallel Plate Capacitor and Insulating Materials
- Digital LCR Meter
- Common Capacitors

4. Procedure

Measuring the Capacitance of a Parallel-Plate Capacitor:

You are provided with a parallel-plate capacitor which you can use to test equation (2). A systematic approach to this would be to measure how the capacitance changes as you vary one of the parameters upon which the capacitance depends while keeping the others constant. There are two parameters that you can change here, the separation between the two plates and the insulating medium separating them.

The capacitance can be measured directly using a digital capacitance meter (LCR meter). Note, however, that your reading of a capacitance will have to be corrected for the intrinsic capacitance of the connecting cables. To see how important this correction may be, connect he cables to the LCR meter and measure the capacitance of the cables using the 200 pF scale on the meter. Move the cables around and observe how the readings change, confirming that capacitance depends on the distance separating the cables. Also investigate the effect of placing your hands around the cables. Set the plate separation to $d = 2\,\mathrm{mm}$. Measure and record the diameter of the plates.

1. Take a capacitance measurement of the cables at a separation equal to their separation when connected to the capacitor. Record your reading. Connect the cables to the metal posts of the capacitor and measure the total capacitance. Record your reading and then correct for the capacitance of the cables. To apply this correction, assume that the cables behave as a capacitor connected in parallel with the parallel-plate capacitor and refer to equation (4). Record the actual capacitance.

2. Repeat step 1. for separations up to $d = 2\,\mathrm{cm}$ in $2\,\mathrm{mm}$ steps and record your results in the Data Table.

3. Plot C versus $1/d$. Calculate the slope of the best straight-line fit to your data points. Estimate the experimental error on the calculated slope.

4. From these slope values and using equation (2) calculate an experimental value for ϵ and find its corresponding error.

5. Now you can investigate how capacitance changes with ϵ. You are provided with three different slabs of insulating materials. Set the separation between the plates of the capacitor to 3 mm and repeat step 1. Calculate ϵ with each of the two slabs of known permittivity (#1 and #2) inserted between the plates and compare with $\epsilon_1 = 11.2 \times\ 10^{-12}\,\mathrm{C\,/\,N \cdot m^2}$ and $\epsilon_1 = 14.0 \times\ 10^{-12}\,\mathrm{C\,/\,N \cdot m^2}$.

6. Insert the slab with unknown permittivity (#3) and repeat step 5. Deduce the value of ϵ for this material.

Capacitors in Series and Parallel

7. Choose two equal capacitors C_1 and C_2 from the set you are provided with. Connect the capacitors in series and measure the resulting capacitance. Calculate the expected capacitance using equation (3).

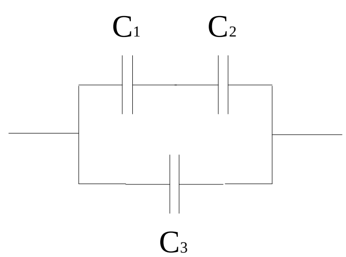
8. Now connect the same capacitors in parallel. Again measure the resulting capacitance and calculate the expected capacitance using equation (4).

9. Repeat steps 7. and 8. for another pair of capacitors.

10. Connect 3 capacitors as shown in Fig. 3. Calculate the equivalent capacitance C in terms of C_1, C_2, and C_3. Carry out the necessary measurements to test your calculation.

Figure 3

Mixed Parallel/Series Combination



5. Conclusion

Did your results support the theory? Explain. Were equations (2), (3) and (4) proven correct? Explain. Give some possible sources of errors which may have occurred during the collection of the data.

Data Table: Capacitance

d (m)	$\frac{1}{d}$ $\left(\mathrm{m}^{-1}\right)$	Total Capacitance (F)	Cable Capacitance (F)	Actual Capacitance (F)

Date:

Instructor's Name:

Instructor's Signature:

Experiment 6: Resistors in Circuits

UNBC Department of Physics

January 15, 2015

1. Introduction

The purpose of this lab is twofold:

1. to investigate the validity of Ohm's Law;
2. to study the effect of connecting resistors in series and parallel configurations.

2. Theory

Ohm's law states that the electric resistance R of any device is defined as

$$R = V/I, \tag{1}$$

where V is the voltage drop across the device and I is the current passing through it.

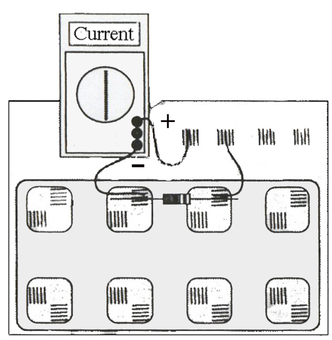


Figure 1

If both the voltage across and the current through a device change, while the ratio V/I remains the same, this device is said to obey Ohm's law.

Resistors in Series

If we have two resistors connected in series (Figure 2), we can replace them by a single equivalent resistance R whose value is given by

$$R = R_1 + R_2, \tag{2}$$

where R_1 and R_2 are the values of the individual resistances.

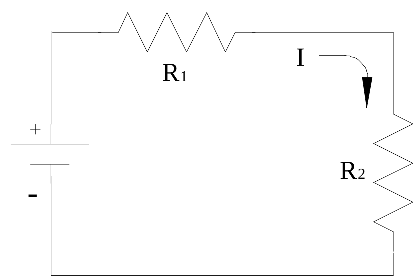


Figure 2: Resistors in Series

Resistors in Parallel

Similarly, if we have two resistors connected in parallel (Figure 3), we can replace them by a single equivalent resistance R whose value is given by

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}, \tag{3}$$

where R_1 and R_2 are the values of the individual resistances.

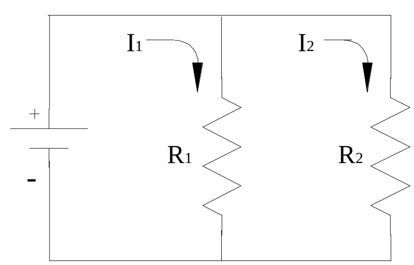
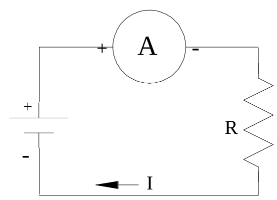


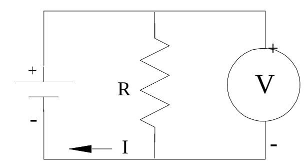
Figure 3: Resistors in Parallel

3. Apparatus

- Ammeter (micro-Amp. range)
  An ammeter is a device used to measure electric current flowing in a closed loop of a circuit. It has to be connected in series with the rest of the loop. It should have a negligible resistance as compared to the rest of the electric components that form the circuit. This is so in order to keep the current value unchanged when the ammeter is inserted to make a measurement. For this reason, you should never connect an ammeter directly across the terminals of a battery.



Measuring current
with an ammeter



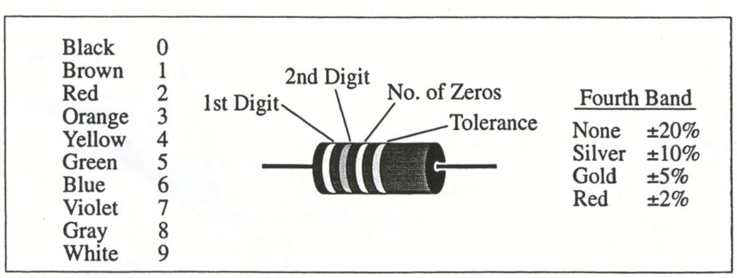
Measuring voltage
with a voltmeter

- Digital Multimeter
  A voltmeter is an instrument used to measure a potential difference across any given device. In order to do so, we have to connect it in parallel with the device as shown. It has a much higher internal resistance than any of the circuit elements. This is so in order not to alter the current value in the circuit as the voltmeter is connected.

  There are two types of meters, DC and AC meters. DC meters are distinguished by a short bar (–) under V (for voltmeter) or A (for ammeter). Similarly, the AC meters are marked by ($\sim$). It is very important to use DC meters in DC circuits and AC meters in AC circuits.

- Circuits Experiment Board, Wire Leads and D-cell Battery

- Assorted Resistors



4. Procedure

1. After measuring and recording the voltage of the battery, choose one of the resistors that you have been given. By looking at the coloured bands on the resistor and using the chart given, decode the resistance value and record that value as R_{th} in the first column of Table 1.

2. Construct the circuit shown in Figure 1 by pressing the leads of the resistor into two of the springs on the Circuit Board.

3. Connect the micro-ammeter in series with the resistor. Read the current that is flowing through the resistor. Record this value in the third column of Data Table 1.

4. Using the multimeter measure the voltage across the resistor. Record this value in the second column of Data Table 1.

5. Remove the resistor and choose another. Record its coded resistance value in Data Table 1, then measure and record the current and the voltage values as in steps 3. and 4.

6. Repeat step 5. until you have completed the same measurements for all of the resistors you have been given. As you have more than one resistor with the same value, keep all resistors in order, because you will use them again in the next part of this experiment.

7. Complete the fourth column of Data Table 1 by calculating the ratio of Voltage/Current. Compare each of these values with the corresponding colour coded value of each resistance by finding the percent difference and entering it in the last column.

8. Calculate $1/R_{\text{calculated}}$. Construct a graph of current (Y-axis) versus [1/Resistance] (Xaxis), and calculate the slope and its error from the resulting line.

   Resistors in Series

9. Find two resistors whose resistances are approximately equal to $5\,\text{k}\Omega$ and $10\,\text{k}\Omega$. Using the multimeter, measure their actual resistances and enter them in the first two columns in Table 2.

10. Using the values you found with the multimeter, calculate the theoretical resistance and enter it in the appropriate column ($R_{th} = R1 + R2$).

11. Connect the two resistors in series as shown in Figure 2 and measure the total voltage drop across them as if they were one resistor. Also measure the current flowing in the circuit.

12. To find the resistance of this combination, divide the voltage drop by the current flowing in the circuit. Enter this value in Data Table 2. Compare this value to the expected value by finding the percent difference.

13. Repeat steps 9. through 12. but for resistance values of$R_1 = R_2 = 10\,\mathrm{k}\Omega$.

Resistors in Parallel

14. Choose two resistors having the same value of about $10\,\mathrm{k}\Omega$ from the set of resistors.

15. Enter the necessary pieces of information as indicated in Data Table 3, including the theoretical resistance $\left(R_{th} = \frac{R_1 R_2}{R_1+R_2}\right)$.

16. Connect these two resistors in parallel as shown in Figure 3. Measure the resistance of the combination as one resistor following the same steps as you did in the previous parts of this experiment.

17. Compare your measured value of resistance with the expected value by finding the percent difference.

18. Repeat steps 15. through 17. for $R_1 = 20\,\mathrm{k}\Omega$ and $R_2 = 10\,\mathrm{k}\Omega$.

Resistors in Combination

19. Find one resistor whose resistance is approximately $R_1 = 20\,\mathrm{k}\Omega$ and two resistors about $R_2 = R_3 = 10\,\mathrm{k}\Omega$. Record the values measured using the multimeter values in Data Table 4

20. Showing your work, calculate the theoretical resistance of the combination given in Figure 4.

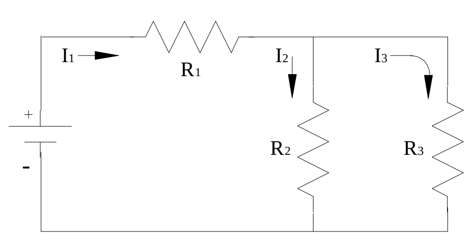


Figure 4: Resistors in Combination

21. Now set up the combination circuit as shown in Figure 4. Measure and record the current and voltage of the system. Calculate and record V/I and compare it to the theoretical value by finding the percent difference.

5. Discussion

1. Compare the slope of your graph with the voltage readings. Explain how the graph shows that Ohm's Law holds true.
2. Do equations (2) and (3) hold true according to your measurements? Explain.

6. Conclusion

Did your results support the theory? Explain. Was equation (1) proven? Explain. Give some possible sources of errors which may have occurred during the collection of the data.

Data Table 1: Resistance

Coded R_{th} (Ω)	Measured Voltage (V)	Measured Current (A)	Calculated Resistance (Ω)	$\frac{1}{R_{\text{calculated}}}$ (Ω^{-1})	Percent Difference %

Date:

Instructor's Name:

Instructor's Signature:

Data Table 2: Resistors in Series

Measured R_1 (Ω)	Measured R_2 (Ω)	Theoretical R (Ω)	Measured Current (A)	Measured Voltage (V)	Calculated R (Ω)	Percent Difference %

Date:

Instructor's Name:

Instructor's Signature:

Data Table 3: Resistors in Parallel

Measured R_1 (Ω)	Measured R_2 (Ω)	Theoretical R (Ω)	Measured Current (A)	Measured Voltage (V)	Calculated R (Ω)	Percent Difference %

Date:

Instructor's Name:

Instructor's Signature:

Data Table 4: Resistors in Combination

Measured R_1 (Ω)	Measured R_2 (Ω)	Measured R_3 (Ω)	Theoretical R (Ω)	Measured Current (A)	Measured Voltage (V)	Calculated R (Ω)	Percent Difference %

Date:

Instructor's Name:

Instructor's Signature:

Experiment 7: Capacitors in Circuits

UNBC Department of Physics

January 15, 2015

1. Introduction

The purpose of this lab is to determine how capacitors behave in RC circuits, and to study the manner in which two capacitors combine.

2. Theory

When a capacitor is connected to a DC power supply or battery, charge builds up on the capacitor plates and the potential difference or voltage across the plates increases until it equals the voltage of the source, V_0. At any time, the charge on the capacitor is related to the voltage across the capacitor plates by

$$Q = CV, \tag{1}$$

where C is the capacitance of the capacitor in farads (F). The rate of voltage rise depends onthe capacitance of the capacitor and the resistance in the circuit. Similarly, when a charged capacitor is discharged, the rate of voltage decay depends on the same parameters.

Both the charging and discharging times of a capacitor are characterized by a quantity called the time constant, τ , which is the product of the capacitance and the resistance of a given circuit. In this experiment, the time constant will be determined by studying the discharging of a capacitor, C, through a resistor, R.

When a fully charged capacitor is discharged through a resistor (Points A and C in Figure 1 are connected) the voltage, V, across (and the charge on) the capacitor "decays" or decreaseswith time, t, according to the equation

$$V = V_0 e^{-\frac{t}{\tau}}. \tag{2}$$

After a time equal to one time constant (at $t = \tau$) the voltage across the capacitor decreases to a value of V_0/e; that is, $V = 0.37V_0$. This is one way to determine the RC constant experimentally. Another, more accurate, way to get τ is to measure V as a function of time and analyze the data according to equation (2). In order to do that, one has to put equation (2) in the form of a straight line equation. Taking the natural logarithm of both sides of equation (2) gives

$$\ln V = -\frac{t}{\tau} + \ln V_0. \tag{3}$$

Therefore, the time constant, τ, can be found from the slope of a graph of $\ln V$ versus t.

3. Apparatus

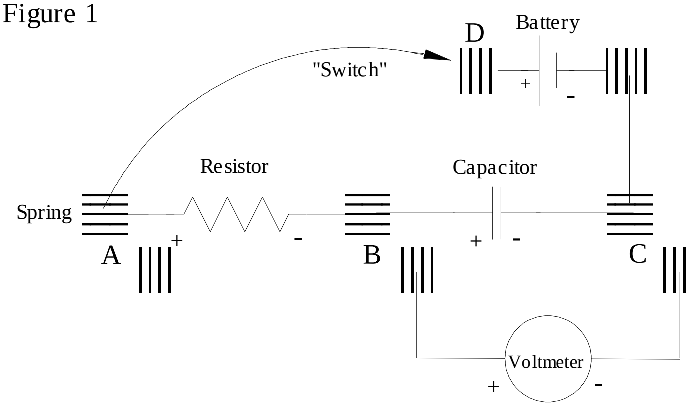
- Digital Multimeter
- LCR Meter
- Stopwatch
- Circuits Experiment Board
- D-cell Battery
- Wire Leads
- Resistors and Capacitors

4. Prodedure

The RC Time Constant

1. Measure the actual values of the capacitors and resistor using the LCR meter and record them. Connect the circuit shown in Figure 1, using the capacitor with the larger value. Use one of the spring clips as a "switch" as shown. Select the DC volt function for your multimeter, and connect the black "ground" lead is on the side of the capacitor that connects to the negative terminal of the battery.

Figure 1



2. Start with no voltage across the capacitor and the wire from the "switch" to the circuit disconnected. If there is a remaining voltage across the capacitor, use a piece of wire to" short" the two leads together, (touch the ends of the wire to points B and C) draining any remaining charge.

3. Now close the "switch" by touching the wire to the spring clip labelled as point D, the voltage over the capacitor should increase with time.

4. If you now open the "switch" by removing the wire from the spring clip, the capacitor should remain at its present voltage with a very slow drop over time. This indicates that the charge you placed on the capacitor has no way to move back to neutralize the excess charges on the two plates.

5. Close the switch and allow the capacitor to fully charge. Record this value in Data Table 1 as the voltage at $t = 0$. Open the switch, remove the wire between C and the negative battery terminal and immediately proceed to the next step.

6. Now you need to be very careful in doing two things simultaneously:

   - connect the end of the "switch" which was originally connected to point D to point C to allow the charge to drain back through the resistor;
   - start your stopwatch.

7. Record, in Data Table 1, a minimum of 10 voltage readings from the multimeter at regular time intervals. (Choose intervals which will put your last measurement after the theoretical value of τ.)

8. Plot a graph of $\ln(V)$ versus t, and calculate the slope of the best straight-line fit to your data points. Estimate the experimental error in the calculated slope.

Calculate an experimental value for τ utilizing the information from the graph and equation (3). Alsom find the corresponding error, δt.

Capacitors in Parallel

9. Using the same circuit, connect the smaller capacitor in parallel with the larger capacitor.

10. Calculate the total capacitance, $C_T = C_1 + C_2$.

11. Repeat steps 2. through 8. recording the data in Data Table 2.

12. Calculate the experimental capacitance and its error from the values for τ and $\delta\tau$ determined from the graph.

Capacitors in Series

13. Using the same circuit, connect the capacitors in series. Make the necessary adjustments to measure the voltage drop across both of them as if they were one capacitor.

14. Calculate the total capacitance, $1/C_T = 1/C_1 + 1/C_2$.

15. Repeat steps 2. through 8. recording the data in Data Table 3.

16. Calculate the experimental capacitance and its error from the values for τ and $\delta\tau$ determined from the graph.

5. Discussion

1. Does your value for the time constant in step 8. equal the theoretical τ within error?

2. Compare the equivalent capacitance, calculated in step 12., with the value of C_T . Does it agree within error?

6. Conclusion

Did your results support the theory? Explain. Were equations (2) and (3) proven correct? Explain. Give some possible sources of errors which may have occurred during the collection of the data.

Data Table 1: Single Capacitor

R (Ω) =		
C (F) =		
τ_{th} (s) =		
Time (s)	Voltage (V)	$\ln V$

Date:

Instructor's Name:

Data Table 2: Capacitors in Parallel

R (Ω) =		
C_1 (F) =		
C_2 (F) =		
τ_{th} (s) =		
Theoretical C_T (F) =		
Time (s)	Voltage (V)	$\ln V$

Date:

Instructor's Name:

Data Table 3: Capacitors in Series

R (Ω) =		
C_1 (F) =		
C_2 (F) =		
τ_{th} (s) =		
Theoretical C_T (F) =		
Time (s)	Voltage (V)	$\ln V$

Date:

Instructor's Name:

Experiment 8: Kirchhoff's Laws

UNBC Department of Physics

January 15, 2015

1. Introduction

In this experiment we will test the validity of Kirchhoff's laws for different DC circuits. We will take measurements of the currents through and the voltage drops across the resistors in the multiloop circuits shown in Figures 1 and 2. We will use these measured values to test Kirchhoff's laws.

2. Theory

Kirchhoff's laws may be stated as follows:

1. The Junction Rule. The algebraic sum of the currents flowing into or out of a node is zero. Alternatively, the sum of currents flowing into a branch point is equal to the sum of the currents flowing out of a branch point.

   A branch point or node is a point at which three or more wires meet; a point into or out of three or more currents flow. In Figure 1 points b and e are nodes. In Figure 2 points b, c, f and g are nodes.

2. The Loop Rule. The sum of the potential drops around any closed loop is equal to zero. Alternatively, the algebraic sum of the changes in potential around any closed loop is zero.

   A loop is any closed conducting path. In Figure 1 there are three loops: abeda, acfda and bcfeb. In Figure 2 there are six loops: abfea, acgea, adea, bcgfb, bdfb and cdgc.

By assigning a direction to the current through each of the resistors and voltage sources in Figures 1 and 2, application of Kirchhoff's laws provide N equations and N unknowns. For example, given the values of the resistances and voltages in a multiloop circuit, one may then solve for the values of the currents in each of the branches or "legs" of the circuit.

3. Apparatus

- Digital Multimeter
- Ammeter
- Circuits Experiment Board
- D-cell Battery
- Wire Leads
- Resistors

4. Procedure

1. Find resistors of the following values: R1 = 4.7 k, R2 = 8.2 k and R3 = 2.2 k. Draw the circuit shown in Figure 1, then set it up without connecting the resistors to each other or the batteries.

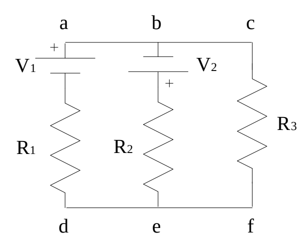


Figure 1

2. Using the multimeter, measure the value of the resistance of each resistor. (Note that the values given above are only approximate.)

3. Now connect the resistors and batteries to each other as illustrated using the wire leads provided. Using the microammeter, measure the current in each of the resistors and indicate, with an arrow, the direction in which it flows on your drawing.

4. Using the multimeter, measure the potential drop across each resistor and indicate which end is at the higher potential on your drawing with a + sign. Also measure and record the voltage of each battery.

5. Enter your values of resistance, current and voltage drop in the Data Table. Include the calculated value $V_{\text{calculated}} = IR$ of the potential drop across each resistor.

6. Find resistors of the following values: R1 = 4.7 k, R2 = 8.2 k, R3 = 2.2 k, R4 = 8.2 k , R5 = 8.2 k and R6 = 4.7 k. Draw the circuit shown in Figure 2, then set it up, again leaving the resistors and batteries disconnected.

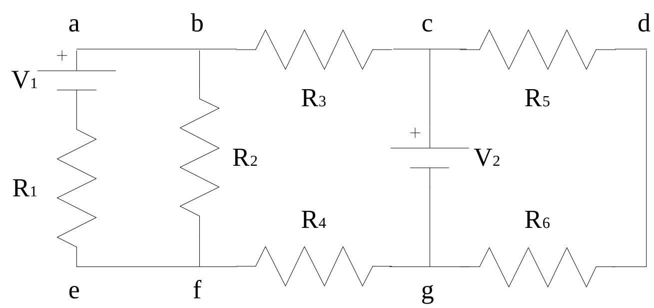


Figure 2

7. Repeat steps 2. through 5. for this circuit.

5. Discussion

1. Compare your calculated values for $V_{\text{calculated}}$ with the measured values and comment on the difference.

2. Explain why The Loop Rule holds. (What would be happening if it didn't hold?)

3. Explain how The Junction Rule is simply a statement of conservation of charge.

5.1. Conclusion

Do your measurements support Kirchhoff's laws? Explain. Were the loop and junction rules proven correct? Explain. Give some possible sources of errors which may have occurred during the collection of the data.

Data Table 1: Kirchoff's Law for Circuit 1

V_1 (V) =			V_2 (V) =			
R_n	$R_{labelled}$	$R_{measured}$	I	$V_{measured}$	$V_{calculated}$	% difference in V

Date:

Instructor's Name:

Instructor's Signature:

Data Table 2: Kirchoff's Law for Circuit 2

V_1 (V) =			V_2 (V) =			
R_n	$R_{labelled}$	$R_{measured}$	I	$V_{measured}$	$V_{calculated}$	% difference in V

Date:

Instructor's Name:

Instructor's Signature:

Appendix A: Dimensional Analysis

UNBC Department of Physics

August 25, 2014

The method of dimensional analysis simply consists of making sure that the dimensions (units) on one side of an equation are the same as on the other side. For example, the force F required to keep an object moving in a circle is known to depend on the mass, m, of the object, its speed, v, and its radius, r, so we expect a relation of the form

$$F = cm^{\alpha}v^{\beta}r^{\gamma}, \tag{1}$$

where c is a numerical constant having no dimensions, and the exponents α, β, and γ will be found using dimensional analysis.

Writing the units for the quantities in equation (1), we have

$$\mathrm{kg} \cdot \mathrm{m} \cdot \mathrm{s}^{-2} = \mathrm{kg}^{\alpha} \cdot \left(\frac{\mathrm{m}}{\mathrm{s}}\right)^{\beta} \cdot \mathrm{m}^{\gamma}.$$

Note: Force is measured in Newtons and a Newton is equal to $\mathrm{kg} \cdot \mathrm{m} / \mathrm{s}^2$.

Making sure that (mass) is consistent on both sides of the equation tells us that $\alpha = 1$. In order that (time) has the power -2 on both sides we must have $\beta = +2$, since the unit for time on the right is already in the denominator. Finally, to get (length) to come out to the power of 1, we require that

$$1 = \beta + \gamma. \tag{2}$$

Using $\beta = 2$ in equation (2) gives

$$\begin{aligned} 1 &= 2 + \gamma \\ \gamma &= -1. \end{aligned}$$

Using these values of α, β, and γ, equation (1) becomes

$$F = cmv^2r^{-1} = c\frac{mv^2}{r}.$$

Dimensional analysis does not tell us the value of c, but the description of circular motion shows that $c = 1$.

Appendix B: Error Analysis

UNBC Department of Physics

August 25, 2014

1. Measurements and Experimental Errors

The word "error" normally means "mistake". In physical measurements, however, error means "uncertainty". We measure quantities like temperature, electric current, distance, time, speed, etc. ... using measuring devices like thermometers, ammeters, tape measures, watches etc. When a measurement of a certain quantity is performed, it is important to know how accurate or precise this measurement is. That is, a quantitative evaluation of how close we think this measurement is to the "true" value of the quantity must be established. An experimenter must learn how to assess the uncertainties or errors associated with a physical measurement so that he/she can convey a true picture of just how accurately a certain quantity has been measured. In general there are three possible sources or types of experimental errors: systematic, instrumental, and statistical. The following are guidelines which are commonly followed in defining and estimating these different forms of experimental errors.

1.1. Systematic Errors:

These errors occur repeatedly (systematically) every time a measurement is made and in general would be present to the same extent in each measurement. They arise because of miscalibration of a measuring device, ignoring some physical assumptions that should be taken into account when using an instrument, or simply misreading a measuring device. An example of a systematic error due to miscalibration is the recording of time at which an event occurs with a watch that is running late; every event will then be recorded late. Another example is reading an electric current with a meter that is not zeroed properly. If the needle of the meter points below zero when there is no current, then the reading of any current will be systematically less than the true current.

As an example of a systematic error due to ignoring some physical assumptions in a measurement, consider an experiment to measure the speed of sound in air by measuring the time it takes sound (from a gun shot, for example) to travel a known distance.

If there is a wind blowing in the same direction as the direction of travel of the sound then the measured speed of sound would be larger than the speed of sound in still air, no matter how many times we repeated the measurement. Clearly this systematic error is not due to any miscalibration or misreading of the measuring devices, but due to ignoring some physical factors that could influence the measurement.

An example of a systematic error due to misreading an instrument is parallax error. Parallax error is an optical error that occurs when a laboratory meter or similar instrument is read from one side rather than straight on. The needle of the meter would then appear to point to a reading on the side opposite to the side from which the meter is observed.

There is no general rule for the estimation of systematic errors. Each experimental situation has to be investigated individually for the possible sources and magnitudes of systematic errors. Care should be taken to reduce as much as possible the occurrence of systematic errors in a measurement. This could be done by making sure that all instruments are calibrated and read properly. The experimenter should be aware of all physical factors that could influence his/her measurement and attempt to compensate for or at least estimate the magnitude of such influences. A widely used technique for the elimination of systematic errors is to repeat the measurement in such a way that the systematic error adds to the measured quantity in one case and subtracts from it in another. In the example about measuring the speed of sound given above, if the measurement was repeated with the position of the source and detector of the sound interchanged, the wind speed would diminish the sound speed in this case, instead of adding to it. The effect of the wind speed will thus cancel when the average of the two measurements is taken.

1.2. Instrumental Uncertainties:

There is a limit to the precision with which a physical quantity can be measured with a given instrument. The precision of the instrument (which we call here the instrumental uncertainty) will depend on the physical principles on which the instrument works and how well the instrument is designed and built. Unless there is reason to believe otherwise, the precision of an instrument is taken to be the smallest readable scale division of the instrument. In this course we will report the instrumental uncertainty as one half of the smallest readable scale division. Thus if the smallest division on a meter stick is 1 mm, we report the length of an object whose edge falls between the 250 mm and 251 mm marks as (250.5 ± 0.5) mm. If the edge of the object falls much closer to the 250 mm mark than to the 251 mm mark, we may report its length as (250.0 ± 0.5) mm. Even though we might be able to estimate the reading of a meter to, let's say, 1/10 of the smallest division we will still use one half of the smallest division as our instrumental uncertainty. Our assumption will be that had the manufacturer of the instrument thought that his/her device had a precision of 1/10 of the smallest division, then he/she would have told us so explicitly or else would have subdivided the reading into more divisions. For meters that give out a digital reading, we will take the instrumental uncertainty again to be one half of the least significant digit that the instrument reads. Thus if a digital meter reads 2.54 mA, we will take the instrumental error to be 0.005 mA, unless the specification sheet of the instrument says otherwise.

1.3. Statistical Errors:

Several measurements of the same physical quantity may give rise to a number of different results. This random or statistical difference between results arises from the many small and unpredictable disturbances that can influence a measurement. For example, suppose we perform an experiment to measure the time it takes a coin to fall from a height of two meters to the floor. If the instrumental uncertainty in the stop watch we use to measure the time is very small, say 1/100 second, repetitive measurement of the fall time will reveal different results. There are many unpredictable factors that influence the time measurement. For example, the reaction time of the person starting and stopping the watch might be slightly different on different trials; depending on how the coin is released, it might undergo a different number of flips as it falls each different time; the movement of air in the room could be different for the different tries, leading to a different air resistance. There could be many more such small influences on the measured fall time. These influences are random and hard to predict; sometimes they increase the measured fall time and sometimes they decrease it. Clearly the best estimate of the "true" fall time is obtained by taking a large number of measurements of the time, say t_1, t_2, t_3, ..., t_N ; and then calculating the average or arithmetic mean of these values.

The arithmetic mean, $\bar{t}$, is defined as

$$\bar{t} = \frac{t_1 + t_2 + t_3 + \ldots + t_N}{N} = \frac{1}{N}\sum_{i=0}^{N} t_i, \tag{1}$$

where N is the total number of measurements.

To indicate the uncertainty or the spread in these measured values about the mean, a quantity called the standard deviation is generally computed. The standard deviation of a set of measurements is defined as

$$\begin{aligned}\sigma_{\text{sd}} &= \sqrt{\frac{1}{N-1}\left(t_1-\bar{t}\right)^2+\left(t_2-\bar{t}\right)^2+\left(t_3-\bar{t}\right)^2+\ldots+\left(t_N-\bar{t}\right)^2} \\ &= \sqrt{\frac{1}{N-1}\sum_{i=0}^{N}\left(\Delta t_i\right)^2},\end{aligned} \tag{2}$$

where $\Delta t_i = t_i - \bar{t}$ is the deviation and N is the number of measurements. The standard deviation is a measure of the spread in the measurements t_i. It is a good estimate of the error or uncertainty in each measurement t_i. The mean, however, is expected to have a smaller uncertainty than each individual measurement. We will show in the next section that the uncertainty in the mean is given by

$$\delta\bar{t} = \frac{\sigma_{\text{sd}}}{\sqrt{N}}. \tag{3}$$

According to the above equation, if four measurements are made, the uncertainty in the mean will be two times smaller than that of each individual measurement; if sixteen measurements are made the uncertainty in the mean will be four times smaller than that of an individual measurement, and so on; the larger the number of measurements, the smaller the uncertainty in the mean.

Note that a repeatedly measured quantity, the standard deviation of the measurement, and error in the mean, all have the same physical units.

Most scientific calculators have functions that calculate averages and standard deviations. Please take the time to learn how to use these statistical functions on your calculator. Some calculators have two functions for standard deviation, a sample standard deiation that uses $N-1$ in the denominator of equation (2), and a population standard deiation that uses N in the denominator of equation (2). Make sure that you use the correct one; for TI (Texas Instruments) calculators, the correct function is `stdDev`.

Significance of the standard deviation: If a large number of measurements of an observable are made, and the average and standard deviation calculated, then 68% of the measurements will fall between the average minus the standard deviation and the average plus the standard deviation. For example, suppose the time it takes a coin to fall from a height of two meters was measured one hundred times, and the average was found to be 0.6389 s and the standard deviation 0.10 s. Then approximately 68% of those measurements will be between 0.5389 s (0.6389-0.10) and0.7389 s (0.6389+0.10), and of the remaining 32 measurements approximately 16 will be larger than0.7389 s, and 16 will be less than 0.5389 s. In this example, the statistical uncertainty in the mean will be 0.010 s $\left(\frac{0.10}{\sqrt{100}}\right)$.

A comment about significant figures: The least significant figure used in reporting a result should be at the same decimal place as the uncertainty. Also, it is sufficient in most cases to report the uncertainty itself to one significant figure. Hence, in the example given above, the mean should be reported as (0.64 ± 0.01) s.

1.4. Combining Statistical and Instrumental Errors

In the following discussion, we will assume that care has been taken to eliminate all gross systematic errors, and that the remaining systematic errors are much smaller than the instrumental or statistical ones. Let IE stand for the instrumental error in a measurement and SE for the statistical error; then the total error, TE, is given by

$$TE = \sqrt{(IE)^2 + (SE)^2}. \tag{4}$$

In a good number of cases, either the IE or the SE will be dominant, and hence the total error TE will be approximately equal to the dominant error. If either error is less than one half of the other then it can be ignored. For example, if, in a length measurement, $SE = 1$ mm and $IE = 0.5$ mm, then we can ignore the IE and say $TE = SE = 1$ mm. If we had done the exact calculation (i.e., calculated TE from the above expression) we would have obtained $TE = 1.1$ mm. Since it is sufficient to report the error to one significant figure, we see that the approximation we made in ignoring the IE is good enough.

Equation (3) suggests that the uncertainty in the mean gets smaller as the number of measurements is made larger. Can we make the uncertainty in the mean as small as we want by simply repeating the measurement the requisite number of times? The answer is no; repeating a measurement reduces the statistical error, not the total error. Once the statistical error is less than the instrumental error, repeating the measurement does not buy us anything, since, at that stage, the total error becomes dominated by the IE. In fact, you will encounter many situations in the lab where it will not be necessary to repeat the measurement at all because the IE error is the dominant one. These cases will usually be obvious. If you are not sure, then repeat the measurement three or four times. If you get the same result every time then the IE is the dominant error and there is no need to repeat the measurement further.

1.5. Propagation of Errors

Very often in experimental physics, a quantity gets "measured" indirectly by computing its value from other directly measured quantities. For example, the density of a given material might be determined by measuring the mass m and volume V of a specimen of the material, and then calculating the density as $\rho = \frac{m}{V}$. If the uncertainty in m is δm and the uncertainty in V is δV, what is the uncertainty in the density? We will not give a proof here, but the answer is given by

$$\delta\rho = \rho\sqrt{\left(\frac{\delta m}{m}\right)^2 + \left(\frac{\delta V}{V}\right)^2}.$$

More generally, if N independent quantities x_1, x_2, x_3, ... are measured, and their errors x_1, x_2, x_3, ... are determined, and if we wish to compute a function of these quantities,

$$y = y\left(x_1, x_2, x_3, \ldots, x_N\right),$$

then the error in y is

$$\delta y = \sqrt{\left(\frac{\partial y}{\partial x_1}\delta x_1\right)^2 + \left(\frac{\partial y}{\partial x_2}\delta x_2\right)^2 + \left(\frac{\partial y}{\partial x_3}\delta x_3\right)^2 + \ldots} = \sqrt{\sum_{i=1}^{N}\left(\frac{\partial y}{\partial x_i}\delta x_i\right)^2}. \tag{5}$$

Here, $\frac{\partial y}{\partial x_i}$ is the partial derivative of y with respect to x_i. Note that the x_is are not repeated measurements of the same observable, they are measurements of independent variable. For example, x_1 could be a length, x_2 a time, x_3 a mass and so forth. It often makes the notation easier to call them x_is rather than L,t, m and so forth.

Applying the above formula to the most common functions encountered in the lab give the following equations that can be used in error analysis.

1.5.1. Linear Functions

$$y = Ax, \tag{6}$$

where A is a constant (i.e., has no error associated with it). Then,

$$\delta y = A\delta x. \tag{7}$$

1.5.2. Addition and Subtraction

$$z = x \pm y \tag{8}$$

Then,

$$\delta z = \sqrt{(\delta x)^2 + (\delta y)^2}. \tag{9}$$

Clearly, if

$$z = Ax \pm By \tag{10}$$

where A and B are constants, then

$$\delta z = \sqrt{(A\delta x)^2 + (B\delta y)^2}. \tag{11}$$

1.5.3. Multiplication and Division

$$z = xy \qquad \text{or} \qquad z = \frac{x}{y} \tag{12}$$

Then,

$$\frac{\delta z}{z} = \sqrt{\left(\frac{\delta x}{x}\right)^2 + \left(\frac{\delta y}{y}\right)^2}. \tag{13}$$

1.5.4. Exponents

$$z = x^n, \tag{14}$$

where n is a constant. Then,

$$\frac{\delta z}{z} = n\frac{\delta x}{x}. \tag{15}$$

For the more general case,

$$z = Ax^n y^m, \tag{16}$$

where A, n, and m are constants, equations (13) and (15) can be combined to give

$$\frac{\delta z}{z} = \sqrt{\left(\frac{n\delta x}{x}\right)^2 + \left(\frac{m\delta y}{y}\right)^2}. \tag{17}$$

Examples of the application equation (17):

$$\begin{array}{ll} z = Axy & \frac{\delta z}{z} = \sqrt{\left(\frac{\delta x}{x}\right)^2 + \left(\frac{\delta y}{y}\right)^2} \\ z = Ax^2 & \frac{\delta z}{z} = 2\frac{\delta x}{x} \\ z = A\sqrt{x} = Ax^{\frac{1}{2}} & \frac{\delta z}{z} = \frac{1}{2}\frac{\delta x}{x} \\ z = \frac{A}{x} = Ax^{-1} & \frac{\delta z}{z} = \frac{\delta x}{x}. \end{array} \tag{18}$$

1.5.5. Other Frequently Used Functions

$$\begin{array}{ll} y = A\sin(Bx) & \delta y = AB\cos(Bx)\,\delta x \\ y = e^x & \delta y = e^x\,\delta x \\ y = \ln x & \delta y = \frac{1}{x}\delta x \end{array} \tag{19}$$

1.5.6. Percent Difference

Calculating percent difference between an experimentally measured value and a theoretical value, or between an experimentally measured value and an accepted value, is often useful and appropriate.

$$\%\ \text{difference} = \left|\frac{\text{theoretical value} - \text{experimental value}}{\text{theoretical value}}\right| \cdot 100\% \tag{20}$$