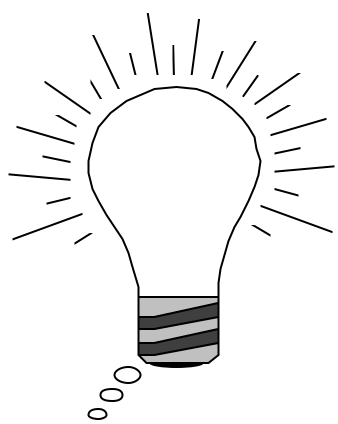
Physics 112: General Physics II

Laboratory Manual

Spelman College

Spring 2003



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Experiment #1
Lenses and Images

Goals

Part of learning physics is learning to explore the general features of physical phenomena by making qualitative observations. This exploration includes deciding what to observe and how to observe it, as well as communicating the observations clearly. In this experiment, you will discover the properties of images made by lenses, and how those properties depend on the type of lens and on the viewing conditions. This experiment will form the foundation for later quantitative measurements. For now, focus on how changing a parameter affects the image and on what ranges of parameters allow an image to be formed.

Background

In this experiment, you will make observations about the images produced by different lenses. To your eye, an image is formed when a lens changes the direction of light coming from an object, so that your eye interprets the light as coming from another place, the image.

Your report should include your observations and appropriate sketches of images, estimates of distances to images, and answers to the questions asked in this experiment.

You can use the parallax method to estimate the locations of the images. To understand how this method works, hold your left index finger at arm's length and hold your right index finger closer to your eye (close the other eye). Do it right now. Line the fingers up, then move your head side-to-side. One of the fingers appears to follow the direction your head moves, while the other goes the opposite direction. Which is which?

The parallax method allows you to tell which is closer to you, the lens or the image formed by the lens. If the image appears to move opposite the direction of the motion of your head, then the image is closer than the lens; that is, the image is between you and the lens. If the image appears to follow your head, then the image is beyond the lens. So, if you move your head to the right and the image also moves right, the image is beyond the lens.

You can also use parallax to estimate the actual location of an image. If your lab partner moves her finger along your line of sight and you look at the finger directly (not through the lens) while viewing the image (through the lens), then the finger is at the location of the image when finger and image move together as you move your head.

Exercise

You have two lenses that are thicker in the middle than at the edge; these are converging or convex lenses. The other lens is thinner in the middle; this is a diverging or concave lens.

Converging Lens: General Observations

Use the converging lens labeled with the smaller number. Look at a distant object (a few meters away) through this lens while holding the lens at arm's length. Record your observations of the image (examples of observations include the orientation and relative size of the image).

Looking through the same lens at the same object, what can you do that changes the image (for instance, does changing the distance to the object make the image change)? Record your procedure and your observations.

Converging Lens: Image Location

Hold the lens so that you see a clear image of a distant object. Use parallax to estimate the location of the image. Repeat for an object that is closer (about one meter away). Record your observations and discuss how the image size and location change when the object location changes.

Connect a small lightbulb to a battery and use the lens to focus an image of the filament onto a piece of paper. Change the distance from the lens to the bulb, then move the paper to again achieve a focused image. Record your qualitative observations of how the size and location of a focused image change as you change the lens-bulb distance (for instance, does the image get bigger or smaller as the lens moves farther from the bulb?). Are there lens-bulb distances that do not give a focused image on the paper, no matter where the paper is relative to the lens?

Look at your finger through the lens, holding the lens close to your finger. Record your observations about the image. Use parallax to estimate the position of the image. How do the image and its position change as you move the lens farther from your finger? At some point, the image should change drastically.

Considering your observations of images, what distance from the lens distinguishes a "nearby" object from a "distant" object? What are the differences between the image for a "nearby" object and the image for a "distant" object?

Diverging Lens: General Observations and Image Location

Repeat the previous two sections, using the diverging lens. Comment on the differences between the two types of lenses.

Additional Questions

1. Considering your observations, which lens and what lens-object distance(s) would be best for a magnifying glass? Support your answer with evidence from your observations.

2. Considering your observations, which lens and what lens-object distance(s) would be best for a camera lens that must project an image onto a piece of film? Support your answer with evidence from your observations.

3. A real image exists if you can put a screen at the image location and see the image on the screen. Of the images that you saw, which do you think are real? Why?

Experiment #2
Lenses and Optical Instruments

Goals

Ultimately, you will design, build, and test a simple telescope or microscope. To help you choose the design, you will measure the properties of images formed by lenses and check the thin-lens equation. In addition, you will practice estimating the uncertainty of a measurement by determining how much you can change something before it makes a difference.

Background

This is a two-week experiment. You will turn in a single report for the experiment. At the beginning of the second week, however, you will turn in answers to the questions titled <u>Midway Questions</u>.

Before the first week, you should review the sign conventions for image and object distances, as well as the equation for magnification and the thin-lens equation.

Usually, you have recorded the uncertainty of a measurement by deciding how sure you were of the reading. For instance, in measuring length you are limited by how accurately you can read the meterstick. In the force table experiment last semester, however, you had another situation. There, when you applied weights to balance the ring in the middle of the table, you could add or subtract weight without changing the balance. Although you knew the weights precisely, your knowledge of the weight to maintain balance was less precise, making your uncertainty greater than your uncertainty in the individual weights. In this experiment, you will have a similar situation. When you focus an image, check how far you can move the lens and still have a reasonably focussed image. For instance, if your uncertainty in reading the position of the lens is 0.5 mm but you can move the lens 2 mm and still have a focussed image, then your uncertainty is 2 mm, not 0.5 mm.

Exercise

<u>Converging Lenses</u>

Take your optical bench with a converging lens and a screen to the window or outside. Focus a clear image of a distant object onto the screen. Record the *positions* of the lens and the screen. Describe the image's orientation and measure its height. Also determine the uncertainty of the experimental focal length by moving the lens over the full range of lens positions that give a "reasonably" focused image. <u>Do not</u> simply use the uncertainty of the scale on the optics bench.

Calculate the distance from the lens to the screen, including uncertainty. Compare your experimental focal length with the "nominal" focal length printed on the lens; are the numbers consistent, within uncertainty?

Repeat this procedure for the other converging lens.

Return to your table. Place the crossed-arrow object on the light source. Use the 150 mm converging lens to form a focused image of the object onto the screen. Describe the orientation of the image and measure its height. Also measure the height of the object, and calculate the magnification. Measure the object distance and the image distance, estimating uncertainties as you did in the previous section.

Use the other converging lens with the same object distance to form a focused image on the screen. Measure the image height and calculate the magnification.

Move the lens and the screen simultaneously, keeping the image in focus, until you can determine which object distance gives the greatest magnification.

Use your measurements to check the thin-lens equation and the equation relating magnification to image and object distances; include uncertainty propagation. Comment on your results.

Diverging Lens

Set up a converging lens to produce a focused image on the screen. Measure the *positions* of everything. Place the diverging lens between the converging lens and the screen and measure its position. Then, move the screen for a new focused image. Measure the new position of the screen. Discuss the effect of the diverging lens on the light rays, based on your observations. For instance, are the rays more strongly focussed or less strongly focussed?

Use your measurements to check the thin-lens equation for the diverging lens. In this case, the object of the diverging lens is the *original* image (produced by the converging lens alone), even though that image is no longer formed. The object distance for the diverging lens is the distance from the diverging lens to the original image. Because the object of the diverging lens is on the "wrong" side of the lens, the object distance is *negative* for the diverging lens (in other words, this is a *virtual* object). You should draw a diagram showing the location of the lenses and the images, as well as object distances and image distances.

Midway Questions

1. A telescope consists of two lenses. The light from a distant object first hits the objective lens, which forms a real image. You then use the second lens, the eyepiece, as a magnifier to examine that "first" image. The first image is located between the objective and the eyepiece. Considering your

data, which of the two lenses you used would make the best objective lens, by forming the largest real image of a distant object? Considering your observations from the previous experiment, which lens would make the best eyepiece by acting as a magnifier? Include experimental evidence for your answers.

2. A microscope also consists of two lenses. Now, the objective lens is close to the object being examined. Again, the objective lens forms a real image. Considering your data, which converging objective lens and what object distance would you use for a microscope, to make the largest image? Include experimental evidence for your answers.

Telescopes and Microscopes

Telescopes and microscopes work on the same basic principle. You use a converging lens (the objective) to form a real (first) image as you did in the "Converging Lenses" section. Then, you use a second converging lens (the eyepiece) as a magnifying glass to magnify that first image.

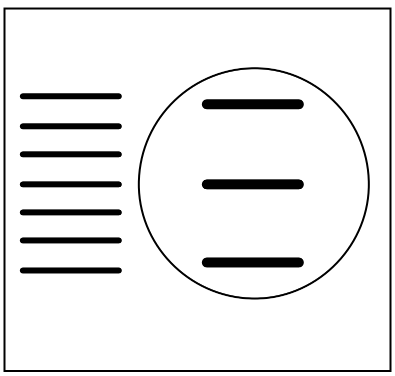


Figure 1. Angular magnification 2.7.

The power of a telescope or a microscope is usually given by its angular magnification. For a telescope, angular magnification expresses how something "looks" bigger through a telescope, compared to viewing it with the unaided eye at the same object distance. For a microscope, angular magnification expresses how something "looks" bigger through a microscope, compared to viewing it with the unaided eye as close as possible without blurring.

To measure angular magnification, you can use two metersticks. For a telescope, the metersticks should be side-by-side; look at one through the telescope and the other directly. For a microscope, one meterstick should be as close as possible to your eye; look at that meterstick directly and at the other meterstick through the microscope. The number of intervals in the directly viewed meterstick covered by one interval of the meterstick viewed through the instrument gives the angular magnification. Figure 1 gives an example. One interval for the meterstick viewed through the telescope (on the right) covers about 2.7 intervals for the meterstick on the left (viewed directly). This procedure requires some practice and visual dexterity.

Design and build a telescope or a microscope; do both if time permits. Document and justify your design. Determine the angular magnification of your instrument, including uncertainty. If your angular magnification is less than one, then you should re-think your design. Compare your experimental angular magnification with that calculated from the equations in the textbook.

Experiment #3
Diffraction Grating and Atomic Spectra

Goals

Often, one must figure out how to use an instrument (with minimal guidance) before one can make observations or perform an experiment. You will practice figuring out the operation of a simple grating spectrometer. You will also learn to calibrate the spectrometer. Finally, you will use the spectrometer to make precision measurements of light emitted from gasses.

Background

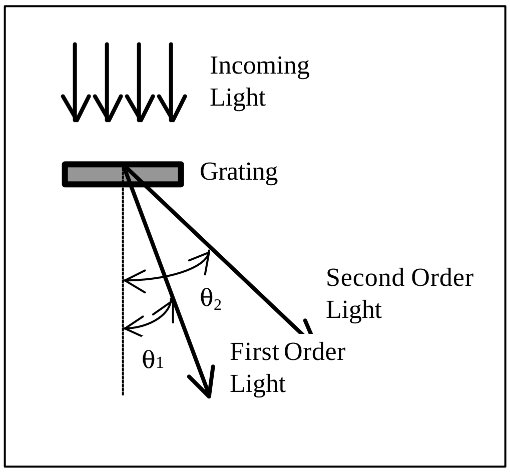


Figure 1. **Diffraction grating.**

A diffraction grating consists of a glass plate inscribed with closely spaced parallel slits. See Figure 1 for an example of how a grating is used in a spectrometer. Light passing through each slit interferes with light passing through all of the other slits. Because of the large number of slits, the interference usually is destructive. For any angle θ (relative to the direction perpendicular to the grating), however, the interference will be constructive for wavelengths λ such that

$$l = \frac{d \ \sin q_m}{m} \quad , \qquad (1)$$

where *m* (an integer) is the <u>order</u> of the line. If you shine light of a particular wavelength through the grating, then you will see constructive interference at several angles given by Equation 1 for *m*=1, *m*=2, and so on. As *m* increases, the light deviates more from the perpendicular direction. As you swing the spectrometer telescope away from the perpendicular direction, you will see the spectrum repeat for each value of *m*. Note that Equation 1 assumes that the original light hits the grating at a 90° angle.

Exercise

Examine the spectrometer and figure out how to use it. In particular, identify the four knobs on the base of the unit that do the following:

- Lock grating table in place;
- turn grating table slightly while it is locked in place;
- lock telescope in place;
- move telescope slightly while it is locked in place.

<u>Do not</u> adjust the knobs on the collimator tube and on the telescope itself, except to adjust the telescope focus if necessary. Also, examine the vernier scale and identify the smallest increment. Make sure that you know how to read this vernier scale.

Place the grating on the grating table so that the grating is perpendicular to the collimator tube. To check this, first measure the angular position for the straight-through light (same color as the discharge tube). Then pick a prominent spectral line and measure its angular position with the telescope swung to the right, and then with the telescope swung to the left. For left and right, calculate the angle θ relative to the straight-through light. These two angles should be the same, within a few minutes. If not, then adjust the grating orientation and check again. This process may require a few iterations.

When you measure the angle for each spectral line, you should measure it to the left and to the right, and average the results. Remember that the angle θ in Equation 1 is the angle relative to the line perpendicular to the grating (which is the line of the straight-through light if the grating orientation is correct). You must, therefore, record the angular reading for the straight-through light. Then, the angle θ is calculated by subtracting the reading for the straight-through light from the reading for the spectral line.

At some point during the lab session, you must calibrate your grating. Do this by shining light from the sodium lamp into the spectrometer and measuring the angles for the yellow line(s). The wavelengths of the two sodium lines are 589.0 nm and 589.6 nm. If the collimator slit is too wide, you may only see one (combined) line. Use this wavelength information to calculate the value of d for your grating. This number should be close to the inverse of the number printed on the frame of the grating.

Select a discharge tube. For the main lines, determine θ for each of the orders that you see. Calculate the wavelengths of the lines, including uncertainty. Compare your results to accepted values.

Experiment #4
Introduction to Electrical Apparatus

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.

Your report will include a summary of the activities and the results of those activities; this should include appropriate circuit diagrams. You will also draw a graph of current versus voltage for the lightbulb. Finally, discuss in your report how energy is converted from one form to another as electrical current goes around the circuit that includes a battery and lightbulb.

Experiment #5
Resistivity of Play-Doh™

Goals

The general goal is to gain further experience in planning an experiment intended to answer specified questions. The specific goal is to explore the factors that determine the resistance of a wire.

Background

If Ohm's law describes a wire, then the ratio of the voltage drop ΔV across the wire to the current I flowing through the wire is a constant, defined as the resistance R:

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

Theory predicts that the resistance of a particular wire depends on its length L, its cross-sectional area A, and the resistivity D:

$$R = r \frac{L}{A} \quad . \qquad \textbf{(2)}$$

The resistivity is a basic electrical property of the material that the wire is made of. In this experiment, you will study the resistivity of a malleable substance made from a proprietary formula. You will also determine whether Ohm's law describes the electrical properties of this substance and whether Equation 2 describes how the resistance depends on length and cross-sectional area.

To determine the resistance of a wire, Equation 1 says that you can measure the voltage drop when a known current flows through the wire. The circuit must be set up carefully, however, to avoid measuring voltage drops produced by the resistance of connecting wires and contact points between different materials. The circuit shown in Figure 1 (a "four-lead" circuit for measuring resistance) avoids these problems. Since no current flows through the voltmeter probes, the only voltage drop measured is that across the particular section (length L) of wire whose resistance is being measured. Note that the voltage leads should not be at the ends of the wire. Also, L is the distance between the voltage leads, not the length of the total wire. (A lead, pronounced "leed", is just a wire used to make an electrical connection.)

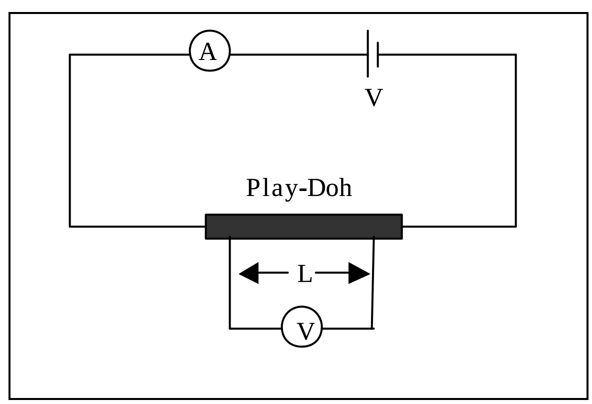


Figure 2. Four-lead circuit.

Exercise

You will plan, perform, and analyze an experiment to answer the following questions. Support your conclusions with calculations and with graphs. You may wish to review the section on analyzing graphs in your General Physics I lab manual.

1. Does Ohm's law describe the electrical properties of Play-Doh?

2. Does Equation 2 describe the dependence of the resistance on length and on cross-sectional area?

3. What is the resistivity of Play-Doh, and does it depend on the color?

First, discuss in your group how you will perform the experiment. Make sure that you know what quantities you will need to measure and what instruments you will use to measure them. Plan your measurements to minimize or account for possible sources of error (such as nonuniformity of the thickness of the wire); this may require repeated or separate measurements of some quantities. Remember to plan a properly controlled experiment. For instance, if you want to know how resistance depends on length, you must keep all other variables constant while changing the length. Discuss your strategy with your instructor before beginning your measurements.

Perform your experiment, recording your procedure and your data. Remember to include uncertainty in your measurements. Analyze your data and make any appropriate graphs. Be sure that you support your conclusions with your analysis and graphs.

Discuss possible improvements to your procedure. Focus on sources of error in your experiment and suggest modifications to the experiment to minimize, eliminate, or account for those errors.

Question

In Figure 1, why is the length L measured between the voltmeter probes only, not over the full length of the Play-Doh wire?

Experiment #6
The Oscilloscope

Goals

The general goal is to continue to learn how to figure out the operation of apparatus. The specific goal is to learn the use of an oscilloscope.

Background

The oscilloscope is commonly used to examine electrical signals. The central component of the oscilloscope is the cathode ray tube, which consists of a long vacuum tube with a phosphorescent screen at one end and an electron gun at the other. The electron gun contains a cathode that emits electrons when heated. These electrons are accelerated towards the screen and focused into a narrow beam. The phosphorescent screen glows at the point where the electron beam hits it.

A voltage supplied to the oscilloscope can deflect the electron beam horizontally or vertically. Usually, you would use the internal horizontal sweep, in which a steadily increasing deflection sweeps the beam horizontally across the screen at a steady rate. By also applying an interesting voltage to the vertical deflection, you obtain a constantly changing display that shows the interesting voltage (vertical axis) as a function of time (horizontal axis).

In this experiment, you will learn to use a variety of features of the oscilloscope. The best way to learn to use the oscilloscope is to systematically try different knobs and switches and observe the effects on the display, for various types of input voltage.

Exercise

Connect a probe to channel 1. Attach the other (positive) end of the probe to the metal calibration tab on the oscilloscope (metal tab located on the lower front of the scope). As you try the following controls, record your observations; in your report, discuss the purpose of these controls:

On-off
Intensity
Focus
Vertical position
Horizontal position
Volts/div (outer knob; inner knob set to CAL)
Time/div (outer knob; inner knob set to CAL)

Set the vertical scale to 2 V per division (a division is one of the big squares on the screen). With the AC/GND/DC switch set to DC, observe the screen as you connect and disconnect the probe across a battery. Repeat for the other settings of the switch. Which setting allows you to measure a DC voltage such as a battery?

Measure the voltage of your battery. Check your result with your instructor before proceeding.

Try changing the AC/GND/DC switch with the probe attached to the calibration tab. Which position of the switch produces a reference horizontal line at 0 V on the display? Which position simply displays the signal "as is"? Which position would let you look at a small changing signal that is combined with a large constant voltage, by centering the changing signal on the zero voltage line?

What happens when you pull out the horizontal position knob while looking at the calibration signal? How might this feature be useful? Hint: What does it say next to the knob?

Measure the peak voltage and the frequency of the calibration signal. Verify your results with your instructor before proceeding.

Attach the oscilloscope to a microphone, using the cable with alligator clips and the microphone jack. Sing different vowels into the microphone and set the oscilloscope to display a few waveforms. Sketch the waveforms, and measure their frequency and peak voltage. How does changing the pitch affect the waveforms? How does changing the volume affect the waveforms? Is pitch or volume more closely related to frequency? Is pitch or volume more closely related to the voltage? Can you create unusual waveforms?

Attach the red alligator clip to a long wire, and wrap the wire around the power cord (leave the other clip unattached). Sketch the waveform and determine its frequency and peak voltage. Now unwrap the wire from the power cord and move it around. Record your observations. This wire is a basic antenna. Can you pick up a signal from a radio station? (Hint: What time scale would you need to see such large frequencies?)

Connect a function generator in series with a rheostat and a diode. Attach the oscilloscope input to the function generator, using a "T". Attach another probe, connected to channel 2, across the rheostat. Set the buttons on the oscilloscope to display both channels simultaneously; record the settings necessary to do this. Describe the effect of the diode on the circuit. You may want to try observing the circuit without the diode for comparison (replace the diode with a wire).

Question

What common medical or biological instruments might incorporate an oscilloscope? Describe how the oscilloscope would be used for one such instrument.

Experiment #7
Circuits

This will be a two-week experiment. Each student will turn in one combined lab report for both weeks.

Goals

The general goals are to interpret data and form hypotheses that describe them, and to learn to work with electric circuits. The specific goal is to explore the properties of series circuits, parallel circuits, and combined circuits.

Week #1: Series and Parallel Circuits

Resistor Color Code

The colored stripes on a resistor indicate its nominal value. The first two stripes (closest to the end) give a two-digit number, while the third stripe gives the power of ten that the two-digit number is multiplied by. The code is (including a mnemonic devised by a Spelman student):

black ...... 0 ...... bright
brown..... 1 ...... busy
red .... 2 ...... respectful
orange .... 3 ...... organized
yellow..... 4 ...... young
green...... 5 ...... girls
blue .... 6 ...... become
violet ...... 7 ...... very
grey........ 8 ...... great
white ...... 9 ...... women

So, suppose that the resistor has the color sequence brown, black, red. Then, the value would be 10×10^2 Ω: brown (1), black (0) gives 10, and red (2) means times 10^2. The resistance is therefore 1000 Ω.

What color bands would indicate a nominal value of 22 Ω? (Answer: red, red, black.)

Exercise

When you first set up a new circuit or modify an existing circuit, leave the negative terminal of the battery disconnected. Your instructor must check your circuit before you make the negative battery connection.

You should do all of the calculations and discussion while you are in lab.

Resistors in Series

Connect a series circuit using two resistors and the battery. Make a schematic diagram of the circuit, showing the nominal values of the resistors and indicating where the positive voltage is. Measure the voltage across each resistor and the battery. Be consistent with + and – signs; that is, decide to either go clockwise or counterclockwise around the circuit and look at voltage gains or drops as you go in that direction.

What is the sum of the voltage changes as you go exactly once around the circuit?

Your circuit should have three connecting wires. In your group, predict which wire (if any) will carry the greatest current and which will carry the smallest current. Tell your instructor your predictions before proceeding. Then, measure the current through each wire by physically replacing the wire with an ammeter and its two leads. That is, all of the current will now go through the meter. Discuss your results--what do they tell you about the nature of electrical current?

Use Ohm's law and your measured voltages and currents to calculate an *experimental* value of resistance for each *individual* resistor. Compare these numbers to the value given by the colored stripes on the resistors. Also use Ohm's law, the measured battery voltage (which is the total voltage drop across the circuit), and the measured current to calculate the resistance of the two resistors combined *together* in series; this is called the equivalent resistance of the circuit. That is, the total current supplied by the battery would be the same if the two resistors in series were replaced by a single equivalent resistor. Considering your results, suggest a simple equation for the equivalent resistance in terms of the individual resistances.

Resistors in Parallel

Connect the same two resistors in parallel across the battery. Draw a schematic diagram of the circuit, including the values of the resistors. Measure the voltage across each resistor and across the battery; be consistent with + and – signs. Discuss your results--how do they relate to the idea that the electrical force is conservative?

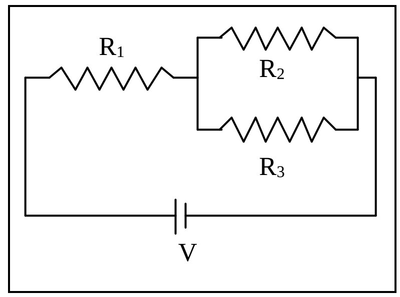
Your circuit has four branches: one wire connected to each terminal of the battery, and each of the two resistors. Measure the current through each of these branches. On your circuit diagram, show the directions of the currents. Your circuit has two junctions where three branches meet. Let a current coming into a junction be + and the current leaving a junction be –. What is the sum of the currents for each junction?

Formulate a rule for the behavior of currents in circuits that is valid both for series circuits and for parallel circuits. Discuss your rule.

Use your measurements of total current and voltage to calculate the *experimental* equivalent resistance for the parallel circuit; include uncertainty. Compare to the theoretical value (see your book).

Week #2: Combination Circuit

Exercise



Choose three resistors and measure each resistance with a multimeter. Also measure the voltage of the battery. You will arrange the resistors and the battery in the circuit shown. Before connecting the circuit, predict the current that will flow through each of the resistors. (Hint: You will first need to find the equivalent resistance for the circuit. Note that R_2 and R_3 form a parallel combination; this combination is in series with R_1. Look at the parallel combination first, then put that equivalent resistance in series with R_1.) Show all of the algebra necessary to justify your predictions. Discuss your predictions with your instructor before proceeding.

Connect the circuit and measure the currents, including uncertainty. Draw a circuit diagram that includes the voltage and the resistances. Compare your measurements with your predictions.

Experiment #8
Magnetic Force

Goals

You will explore the properties of the magnetic force acting on a current.

Background

A wire carrying a current *I* through a magnetic field experiences a force. The direction of the force is perpendicular to the current and to the field. In this experiment, you will investigate the properties of this magnetic force.

Exercise

Place the magnet in the hanging pan of the balance and determine its weight. Select one of the printed-circuit wires and measure the length of the horizontal section of the printed wire. Plug the printed circuit into the holder. Place the holder onto a lab stand so that the printed wire runs down the middle of the magnet; make sure that the wire does not touch the magnet. Connect the holder to the DC output of the power supply, with an ammeter in the circuit. **Before you turn on the power supply, have your instructor check your circuit.**

Current

You will first determine how the magnetic force depends on the current. **Do not exceed the maximum current printed on the holder.**

Start with the scale balanced for the magnet, with no current. For several values of current and for both directions of the current (switch the wires from the power supply), adjust the mass reading of the balance so that it is again level; use this is the *apparent* weight of the magnet.

Before you leave, draw two free-body (force) diagrams, one for the magnet and one for the wire. Use your knowledge of Newton's laws to figure out how to calculate the magnitude and direction of the magnetic force acting on the wire from the weight of the magnet and the apparent weight of the magnet. Have your instructor check your diagrams and your equations before you leave. These diagrams and equations should be in your report, along with textual explanations of them.

Graph your results of force (including sign for direction) versus current. If the graph is a straight line, calculate its slope and uncertainty; use the results and the theory in your text to calculate the magnitude and direction of the magnetic field.

Length

You will also determine how the magnetic force depends on the length of the printed wire. For a particular *fixed* current, determine the magnetic force for several different wires. Graph your results and fit them with a straight line, if appropriate. Use the slope and theory to calculate the magnitude of the magnetic field.

Compare your two values for the magnitude of the magnetic field. Comment on whether your graphs support the theory found in your text.

Question

Considering your observations, suggest a design for a device that measures mass using magnetic forces. Digital balances actually use magnetic forces.

Experiment #9
Design Your Own Experiment

Choose a topic relating to this course. The topic should be specific enough for a short experiment. Form a hypothesis or pick some quantity to measure. Design, perform, and analyze an experiment to test that hypothesis or measure that quantity. Your experiment should be controlled and reproducible.

Your report must include justification for performing the experiment as well as detailed procedure. Also, discuss sources of error in your experiment and comment on how your experiment could be improved.

<u>Possible General Topics (need narrowing down)</u>

In some cases, specialized apparatus exists. Ask your instructor.

- Coulomb's law
- Faraday's law
- Parallel plate capacitors
- Circuits with capacitors and/or inductors
- Detection of electric or magnetic fields
- Dispersion of light using a prism
- Resolution and apertures
- Snell's law
- Law of Malus (polarizers)
- Mirrors
- Microwaves
- Radioactive decay
- Radiation shielding

Experiment #10
WellQM--Trapped Particle Waves

Goals

Since much of science involves computer simulations, you should learn to use simulations and to understand and interpret their results. Specifically, you will explore the properties of a simple system that exhibits the wave properties of particles.

Background

WellQM is a computer program that simulates a particle trapped in a one-dimensional potential well. The potential energy is zero inside the well, infinite on the left side, and some nonzero constant value on the right side. The particle has total energy that is less than the potential energy on the right side, so it cannot escape the well. In fact, according to classical physics the particle cannot even exist in the region where the total energy is less than the potential energy (the forbidden region). As an analogy, imagine that you have an extremely high cliff on one side and a short cliff on the other side. You are stuck between the cliffs.

Quantum theory describes particles as waves. The wavefunction describes how such a wave depends on position. If you measure the position of the particle, the result is random; the probability of measuring a certain position, however, depends on the square of the wavefunction (the probability amplitude). If the wavefunction is zero at a certain position, you will never measure the particle as being at that position. Also, quantum theory predicts that the energy of the particle depends on the shape of its wavefunction.

In quantum physics, the eV (or electronvolt) is a useful unit of energy. One electronvolt is equal to 1.6×10^{-19} J. Also, mass is often expressed in units of eV/c^2, where c is the speed of light. In more familiar units, 1 eV/c^2 is the same as 1.1×10^{-17} kg. In this experiment, however, the relative numbers will be more important than how they relate to SI units.

To run the program, follow the sequence **Start** ® **Programs** ® **Simulations** ® **WELLQM**. Answer the questions.

Display

The program begins with a potential well having an infinite wall on the left side and a 50 eV step located 2 Å to the right. The trapped particle initially is an electron, with mass 5.11×10^{5} eV/c^2. The upper half of the screen shows the potential energy in red. The allowed energies (the energy levels) of the particle appear in green and purple; the "chosen" level is the one in purple. The display scale is 100 eV vertically and 5 Å horizontally.

The lower half of the screen shows the wavefunction of the "chosen" level, in this case the lowest energy level (n=1). The red lines show the zero line of the wavefunction (horizontal) and the location of the 50 eV step (vertical). At the bottom of the screen, information about the potential, the particle, and the chosen level is displayed, as well as "Plot psi", indicating that the wavefunction itself is plotted. If the probability amplitude were plotted, you would see "Plot psi^2" instead.

Commands

You can give commands to alter the parameters of the well and the mass of the particle by pressing the highlighted letters that appear at the bottom of the screen. These commands are:

- Width........change width of well; you will be asked to enter the new width in Å (must be less than 5 Å).
- Depth........change depth of well; you will be asked to enter the new depth in eV (must be less than 100 eV).
- Mass.........change the mass of the trapped particle; you will be asked to enter the new mass in eV/c^2.
- Plot psi......controls whether the lower display shows the wavefunction or the probability amplitude; in the latter case, this reads Plot psi^2.
- Level.........choose the quantum number of the level to be displayed; you will be asked for the number.

Press **h** for a summary of all commands. There are other commands available to change the parameters of the well, to add sound, and to quit the program; the following is a summary of those commands.

Infinite Well
You may switch between a semi-infinite well and a fully infinite well by pressing **i**. When the well is infinite, instead of displaying the depth, the program will show "Infinite well" at the bottom of the screen. Press **i** again to return to the semi-infinite well.

Depth of Well
You may also increase or decrease the depth of the well by using the up-arrow and down-arrow keys; these will change the depth in increments of 5 eV.

Mouse Use and Level Number
You may use the mouse to choose a level to examine. Point the cursor at the desired level, then click the mouse button.

Quitting the Program
You may quit the program by pressing **q**.

Sound
If you press **s**, you will add sound to the program. The sound that you will hear has frequency linearly related to the energy of the chosen level; lower pitch means lower energy. In combination with the arrow keys, this feature gives you a quick way of tracking the effects of the well parameters on the energy of a particular level.

Width of Well
You may increase or decrease the width of the well, in increments of 0.25 Å, by using the right-arrow and left-arrow keys.

Exercise

Throughout this experiment, record your observations, including sketches where appropriate. Support your answers to questions with specific observations and data.

Set the width of the well to 4.0 Å and turn on the sound; also set the lower display to show the probability amplitude. Describe how the shape of the probability amplitude changes as you look at levels with increasing energy (higher *n*). Be specific about the shape both within the well and in the region beyond 4.0 Å. How does the wavelength of a particle appear to relate to its energy?

How does the ability of the particle to penetrate into the forbidden region appear to relate to its energy? Does that ability change if you change the height of the potential step?

Examine the behavior of the lowest energy level as you gradually decrease the width of the well. How does the probability amplitude change? How does the energy change? Is this consistent with what you saw before?

Try changing the mass of the particle. How do the number of levels, energies, wavelengths, and penetration into the forbidden region appear to depend on mass? Try some small masses (smaller than an electron) and some large masses (such as protons, atoms, molecules). Classically, a particle can have <u>any</u> energy. For a particle to behave classically, should it have a small mass or a large mass? Is this consistent with everyday observations?