Physics 7B

Labs

NAME: ____________________ SECTION DAY/TIME: ____________________________
GSI: ___________________________ LAB PARTNER: ____________________________

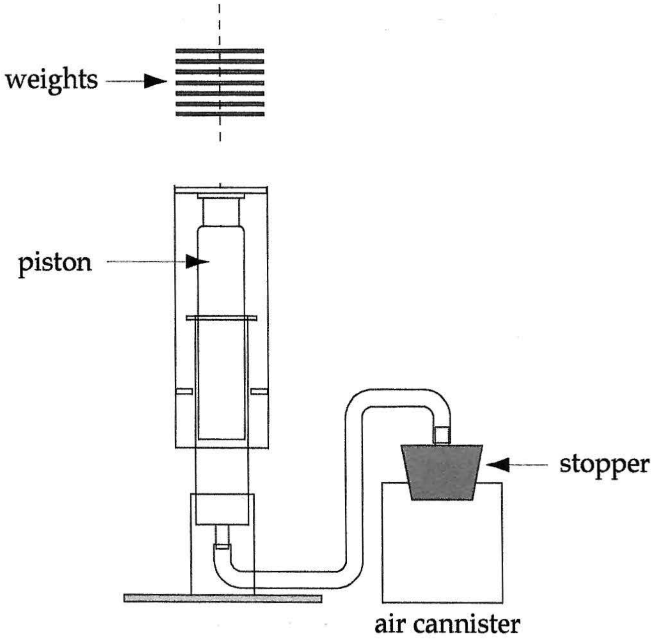
Lab 1: Thermodynamic cycles and engines

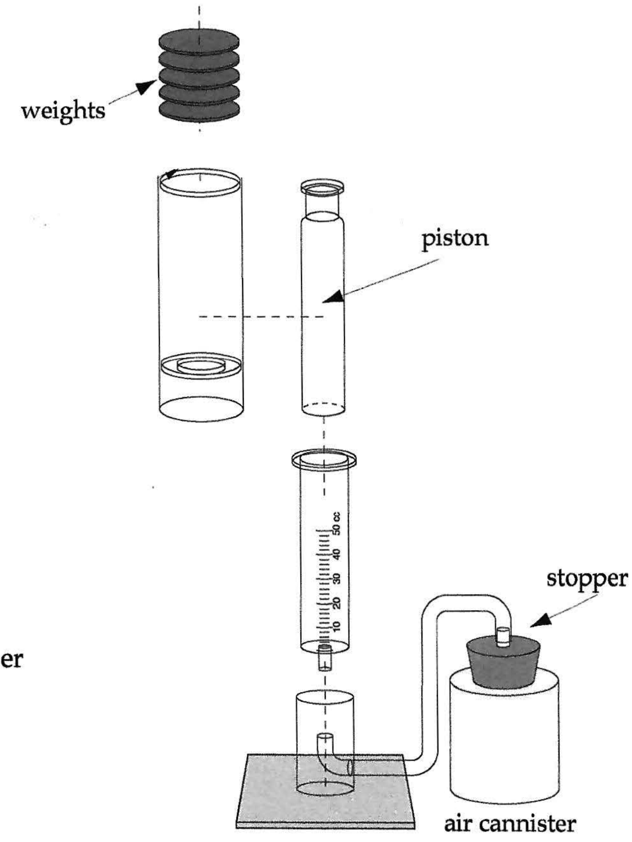
Introduction

As presented in textbooks, heat engines and refrigerators can seem very theoretical. The point of this lab is thus to help you draw connections between abstract p–V diagrams and real life. We want p–V diagrams and cycles to make sense, both mathematically and physically.

Equipment and useful information

◊ Cylindrical piston (Radius = 0.014 meters. Mass of piston & outer sleeve = 0.100 kg.)
◊ Containers of hot and cold water.
◊ Ten 10-gram masses. Never put more than 100 grams onto the piston, or else air may leak out.
◊ Air pressure = 1.00×10^5 N/m^2.





Pre–lab Questions

[Do 1a and 1b before coming to lab. Your GSI will initial these pre–lab questions when you arrive in lab.]

1. This question gives you a sense of the pressure differences we'll see in this experiment.

(a) When no masses are placed on the piston, what is the pressure of the air inside the piston? Show your work here.

(b) When 100 grams are placed on the piston, what is the pressure of the air inside the piston?

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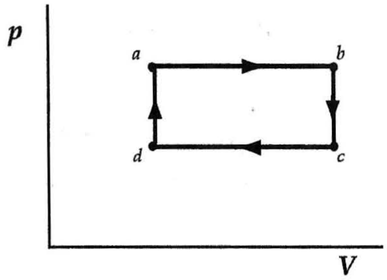
The lab starts on the next page

2.

- With everything at room temperature, place 100 grams on the piston.
- If necessary, remove the stopper from the air canister, let the piston slide down almost as far as it will go, and then replace the stopper (making it airtight!). We want the piston to start near the bottom.
- If the temperature of your hot water is below 50° C, scoop some hot water from one of the hot plates. If the water is boiling, dilute it with some cooler water in your beaker.



NOTE: As suggested by question 1, the pressure and volume differences in this experiment are actually very small.

The gas in the piston now corresponds to point *a* on this *p–V* diagram. Here, you'll figure out how to make the gas inside the piston undergo the *cycle* shown. Then, you'll actually do it, and answer questions about each step.

In these experiments, you may add or remove masses from the piston, and you may place the air canister in the water beakers; but you may not push or pull on the piston, because that tends to make it leak.

(a) How will you make the gas go along path *ab*? Along path *bc*? *cd*? *da*? Write down your plan for each of the four steps.

- Now do it. If something doesn't work as predicted, see if you can correct the problem. Next to your original plan, jot down any modifications you used.
- When you are finished, call your GSI over and explain the necessary steps. Your GSI will initial here when your explanation is correct.

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(b) In all these questions "gas" refers to the gas trapped inside the piston. Along path *ab*, is the work done *by* the gas *on* the piston positive, negative, or zero? Answer this question, and others like it, both in terms of the abstract *p*–*V* diagram and in terms of your actual experiment. (Ask your GSI for help with this, if it's not clear what is meant.) Most important, make sure you understand how the theoretical ideas connect to what you're doing.

(c) Along path *bc*, is the work done by the gas on the piston positive, negative, or zero? How do you know?

(d) Along *ab*, is the heat added to the gas positive, negative, or zero? How could you have figured this out based on theory, even if you hadn't done the experiment? Hint: think about the First law of thermodynamics.

(e) Along *bc*, is the heat added to the gas positive, negative, or zero? Explain.

(f) Along path *abcda* (the whole cycle), is the net change in the internal energy of the gas ($\Delta E_{internal}$) positive, negative, or zero? How do you know?

(g) Along path *ab*, the gas does positive work on the piston. Said another way, the piston does negative work on the gas. Along path *cd*, the piston does positive work on the gas. Which of these two *W*'s is bigger in magnitude: the work done by the gas in step *ab*, or the work done on the gas in step *cd*? Explain your answer in terms of the p–V diagram, and *also* in terms of your actual experiment. (Hint: Think about the mass on the piston during *ab* versus the mass on the piston during *cd*.)

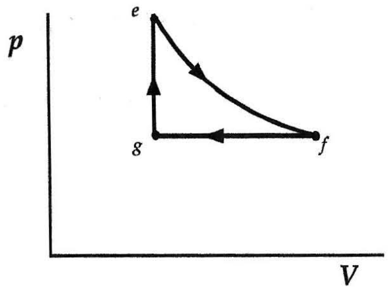
(h) Along paths *ab* and *da*, the gas absorbs heat. Along paths *bc* and *cd*, the gas loses heat (i.e., it "absorbs" negative heat). Is the net heat absorbed by the gas zero? Explain how you know. Hint: Your part (f) and (g) answers might be helpful.

(i) In a *heat engine,* net heat is added to a system, and the system uses some of that energy to do work. In the experiment you just performed, did the piston function as a heat engine? Explain.

Question 2 parts (a) through (i) are typical exam problems. Everyone needs to understand this material well. After most students have finished these questions, your GSI will go over them. If you finish early and feel reasonably confident, go on to the next experiment.

3.

- Place 80 grams on the piston, and place the air chamber in hot water. If the piston is in danger of reaching the top, use cooler water.
- Let the piston settle.



NOTE: pV is constant along path *ef*

The gas in the piston now corresponds to point *e* on this new p–V diagram. Once again, you'll figure out how to make the gas inside the piston undergo the *cycle*. But since you already did paths *fg* and *ge* in question 2, let's focus on *ef*. As before, you cannot push or pull the piston. All you may do is add and remove masses, and use the beakers of water.

(a) How will you make the gas go along path *ef*? Since pV is constant along that path, and since $pV = NkT$, the temperature of the gas stays constant along that path.

- Now do it. Make any necessary corrections to your process above.

(b) Discussing this experiment, Jason makes the following comment: "Since the temperature stays constant along *ef*, the gas neither absorbs nor loses heat along that path. Hence, the internal energy of the gas stays constant." Evaluate Jason's argument. What is he right about? What is he wrong about (if anything)? Are there flaws in his reasoning?

(c) Along path *fg*, the gas loses internal energy. Along path *ge*, it gains internal energy. Which of those two $\Delta E_{internal}$'s (if either) is bigger in magnitude: The internal energy lost during step *fg*, or the internal energy gained during step *ge*? Explain.

(d) When the piston goes through this whole cycle (*efge*), does it function as a heat engine? Explain.

Answer the following questions only if you have time. In a related worksheet, you'll cover this material more fully.

4. A heat engine converts heat into work. Needless to say, we want a heat engine to be as efficient as possible. Suppose that, during a cycle, the engine absorbs 10 joules of heat. If the engine does 10 joules of work, then it's 100% efficient (efficiency = 1.0). If it does 9 joules of work, it's 90% efficient (efficiency = 0.9). And so on.

"Work" here refers to the net work. For instance, if the gas inside the piston does 8 joules of work during one leg of cycle, but we do 6 joules of work *on* that gas during another leg of the cycle, then we get only 2 joules of work out of the cycle overall.

(a) Based on the above passage, write a formula for the efficiency of a heat engine.

(b) Your part (a) answer probably contains a Q somewhere. But is that Q the (positive) heat absorbed, or the *net* heat absorbed? To consider the difference, think about the heat engine from question 2: Suppose the engine absorbs 15 joules of heat during *dab*, and loses 5 joules of heat during *bcd*. When calculating the efficiency, should you use $Q = 15$ joules or $Q = 10$ joules? Explain your reasoning.

(c) Consider your heat engine from question 2. Is the efficiency 100%? Nearly 100%? Significantly less than 100%? How did you figure it out? (Answer this *without* performing detailed calculations.)

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Equipotential lines and electric fields

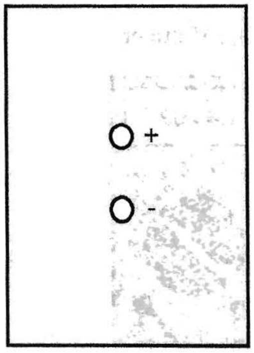
Introduction

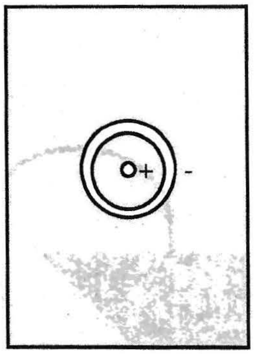
This lab gets at one of the most difficult concepts in the course: electric potential, and its relationship to electric fields and potential energy. The lab activities and associated questions can help you get a real-world feel for these concepts and their conceptual underpinnings. The hardest thing about potential, however, is to see how all this fits together.

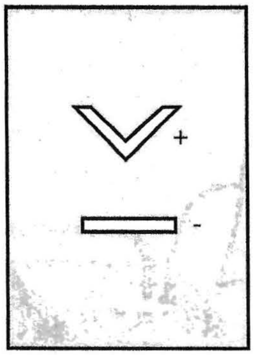
The activities below are designed to take only a portion of this period. We will take the rest of the time to continue with discussion section activities.

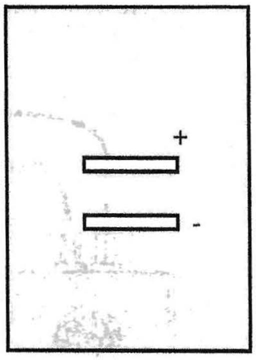
Questions

1. In these pictures, the two conducting regions (marked in white) carry equal and opposite charges. What will the *equipotential lines* look like in each case? Remember, two points have the same potential if a charge would have the same potential energy at either point. Sketch your predictions here using dotted lines.









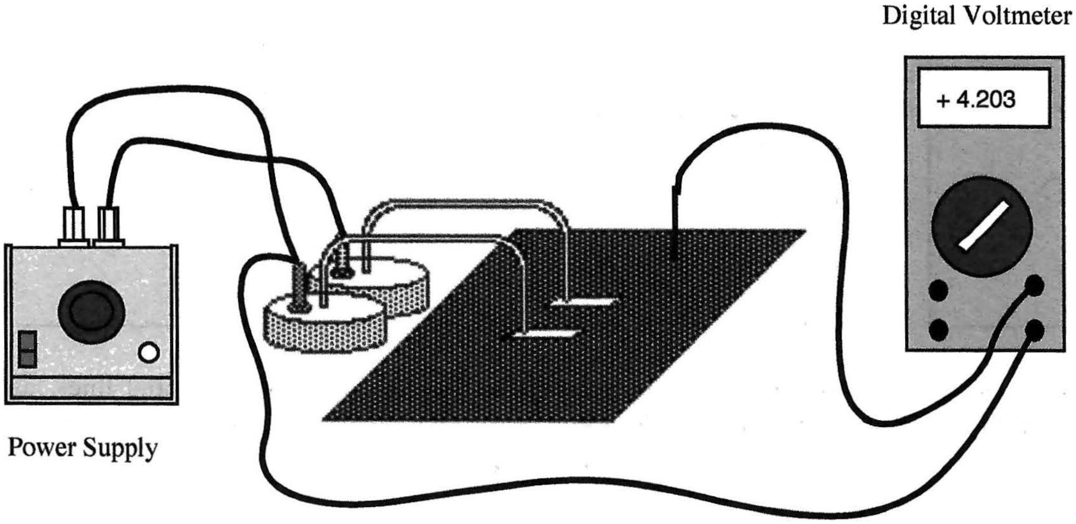
Now pick *two* of the four configurations, and experimentally sketch the equipotential lines, using the procedure on the next page. You should do one; your partner the other. To check your other two predictions, you can look at the work done by other lab tables.

Before starting the experiment, make sure the equipment is working properly, and answer a brief question.

- Layer a piece of paper on the bottom, then a piece of carbon paper (dark side down), then a piece of the teledeltos paper with conducting paint regions on top. Tape two corners down so you can keep them aligned but still lift up to write on the bottom paper.
- The equipment should already be set up as drawn on the next page, with the power supply set to 5 volts. So, the power supply enforces a 5 volt potential difference between the two metallic regions on your paper. Touch the voltage probe to one metallic region, and then to the other. It should register 0 V and then plus or minus 5 V (or vice versa).

2. Prediction: *Within* a metallic region, is the potential the same everywhere, or does it vary point by point? *Explain* why; don't just quote a result. (Note, within the metallic region means within the actual metal, not inside a cavity or region surrounded by metal.)

- Now, test *two* of the predictions you made earlier with the voltage probe (the "free" wire sticking out of the digital voltmeter). Use the following procedure. Remember: you should test one configuration, your partner the other.



Procedure for "sketching" the equipotential lines.

- Using the voltage probe, find a place on the paper where the potential is 1.0 volt. If it's 1.03 V or 0.98 V, that's fine; just get close. Mark that point by lightly rubbing the probe on the top layer. Check the bottom layer to make sure the mark was transferred by the carbon paper. Then, find another 1-volt point, about a centimeter from the first one. Mark it. And so on. By using symmetry and your above prediction, you may be able to save yourself some work.

- On the **bottom sheet of paper**, connect the dots. This curve is an equipotential line; every point along the curve has potential 1 volt.

- Now make the equipotential lines for 2 V, 3 V, and 4 V, again using light pressure to mark the locations and connecting the dots on the **bottom sheet of paper**. Work pretty fast; it's more important to think about what these lines mean than it is to draw them perfectly.

- If you've made any major errors in your predictions, please correct them now.

3. Using solid lines, add sketches of the electric field for each configuration on p. 1. Explain here how you know how to draw the fields.

4.

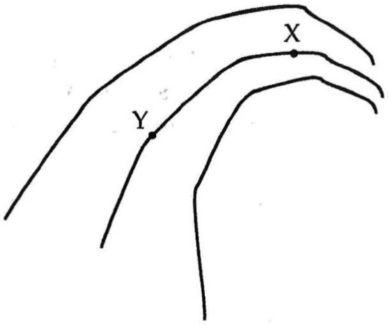
- Estimate the electric field at a point you select between the two conductors on your plot. Record your data here, and explain your measurement. Hint: $E_x = -dV/dx$.

Please lightly erase any stray marks on your conducting paper, so that the next lab group gets a fresh start.

5. *(Just a question, not an experiment.)* In figure 5, at which of these two points, X or Y, is the electric field stronger? How do you know?

FIGURE 5

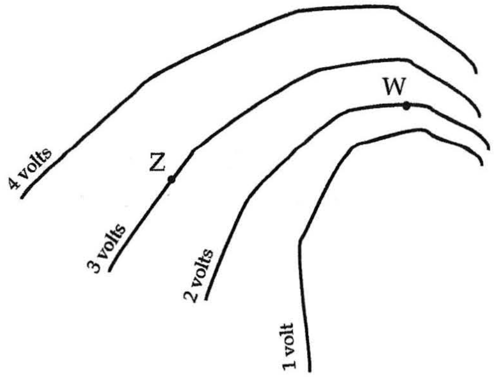
Segments of equipotential lines



6. **(a)** In question 5, you compared the electric field at two points on the same equipotential line. Now consider two points on different equipotential lines. In figure 6, where is the field stronger—point W or point Z? How do you know?

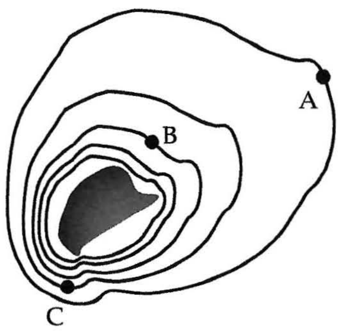
FIGURE 6

Segments of equipotential lines



(b) Sketch on figure 6 the direction in which a positive charge placed at point *Z* would move. Sketch the direction in which a negative charge placed at point *W* would move.

7.



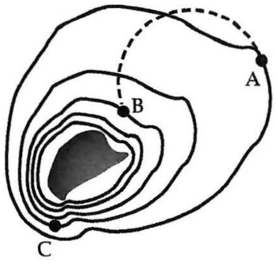
The gray charge distribution shown generates an electric field corresponding to the following equipotential surfaces. The potentials at points A and B are $V_A = 3.0$ V and $V_B = 1.0$ V.

(a) On this diagram, sketch some of the electric field lines resulting from the charge distribution. Is the charge distribution positive or negative? (Yes, you have enough information to tell.)

(b) Where is the electric field strongest? Explain.

(c) How much work would it take to move a $Q = 0.50$ C point charge along a straight line from B to A?

(d) Now consider a semicircular path from B to A. To move the $Q = 0.50$ C charge along this path, would it take more work, less work, or the same work, as compared to part (c)? Explain.



(e) Which takes more work: Moving charge Q from point C to point A, or moving it from point B to point A? Justify your answer.

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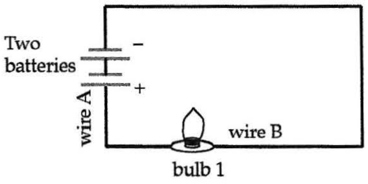
Lab 3: Introduction to DC circuits

Introduction

This lab introduces direct-current (DC) circuits, focusing on *conceptual understanding.* On a later worksheet, you'll integrate this qualitative understanding with mathematical problem-solving. Although everybody should do questions 1 through 4, people who already know a lot about circuits will be able to get to the challenge problems at the end.

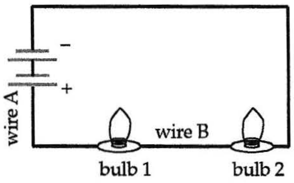
CIRCUIT 1



Technical hints

- When your two batteries are hooked up in series; you can think of them as a single, double-strength battery.
- Your GSI will show you how to "transform" one circuit into another. Ask for help if you're having trouble achieving a clean transformation.

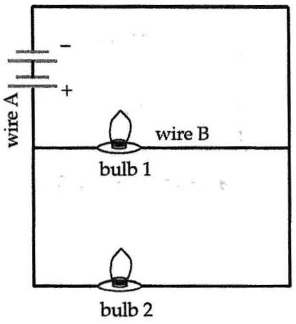
CIRCUIT 2



Questions

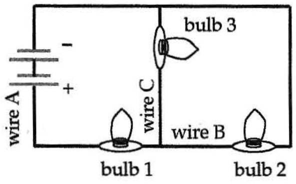
IMPORTANT NOTE: For each question, first write your answer (prediction), then do the experiment. Finally, amend your original answer, if necessary. But don't erase your original prediction—it's helpful to have a record of what mistakes you're liable to make in the future.

CIRCUIT 3



1. In circuit 1, which (if either) is bigger: The current through wire A or the current through wire B? What gets "used up" when current flows through a light bulb?

CIRCUIT 4



2. When circuit 1 is transformed into circuit 2 (by hooking up the 2nd light bulb), what happens to

(a) The brightness of light bulb 1?

(b) The current through wire A? Why?

3. When circuit 1 is transformed into circuit 3, what happens to

(a) The brightness of bulb 1?

(b) The current through wire A?

(c) The current through wire B? Explain all your answers. If the experiment comes out different from your prediction, you can amend your answer by trying to explain the discrepancy.

> Because the rest of the lab builds on questions 1 - 3, your GSI will go over those three questions with the whole class. If you try question 4 before this discussion, please look over your answers *after* the discussion, to take your GSI's ideas into account.

4. (*This one is hard, but very important.*) When circuit 2 is transformed into circuit 4 (by hooking up the third bulb), what happens to

(a) The current through wire A?

(b) The brightness of bulb 1?

(c) The brightness of bulb 2? Explain your answers intuitive (*not* just with formulas). Check your answers with your GSI.

5. Let I_1 denote the current through wire A in circuit 1. In terms of I_1, what is the current through wire A in. . .

(a) circuit 2? Is it $2I_1$, *or* $I_1/2$, or what? Explain conceptually, even if you know a formula.

(b) circuit 3? Explain.

(c) *(harder)* circuit 4? Explain.

6. With your battery, your three light bulbs, and all the wires you want, build a circuit that produces as much light as possible. Diagram the circuit here, and explain why it's the brightest.

7. With that same equipment, build a circuit that produces as *little* light as possible. Should the circuit use all three bulbs? Be sure to test this issue experimentally. Diagram your circuit, and explain why it's the dimmest.

8. In this lab, you've built a total of six circuits: the four on page 1, the "brightest" circuit from question 6, and the "dimmest" circuit from question 7.

(a) Of those six circuits, which one has the *most* current flowing through the battery? Explain.

(b) Which has the *least* current flowing through the battery? Explain.

9. Give at least *two* separate reasons why it's advantageous to wire holiday lights in parallel. (Ask your GSI if you don't know what we mean by "holiday lights.")

10. Are the electrical outlets in your house/room wired in series or in parallel? Explain.

11. In electrostatic systems, a potential difference (i.e., a voltage) always corresponds to an electric field. Is this also true about circuits? Specifically, does the potential difference between the two terminals of the battery correspond to an electric field anywhere? Or do circuits allow us to have "voltages without fields?"

NAME: ________________________________ DL SECTION NUMBER: __________________

GSI: ____________________________________ LAB PARTNERS: ______________________

MAGNETISM LAB:

The Charge-to-Mass Ratio of the Electron

Introduction

In this lab you will explore the motion of a charged particle in a uniform magnetic field, and determine the charge-to-mass ratio (e/m) of the electron. We hope that you will also begin to develop an intuitive feel for magnetism.

There are more prelab exercises for this experiment than has been normal in Physics 7B. Be sure to complete these before arriving at lab—they will count for half of your final lab score, and your GSI will initial page 2 at the start of lab to indicate that you have completed them. We suggest reading through the entire lab before attempting to complete the Prelab questions, so that they will make more sense.

Prelab Questions

1. Using your Physics 7B knowledge about the force on a charged particle moving in a magnetic field, and your Physics 7A knowledge of circular (centripetal) motion, derive an equation for the radius r of the circular path that the electrons follow in terms of the magnetic field B, the electrons' velocity v, charge e, and mass m. You may assume that the electrons move at right angles to the magnetic field.

2. Recall from electrostatics, earlier in the course, that an electron obtains kinetic energy when accelerated across a potential difference V. Since we can directly measure the accelerating voltage V in this experiment, but not the electrons' velocity v, replace velocity in your previous equation with an expression containing voltage. The electron starts at rest. (Don't get capital V, voltage, confused with lowercase v, velocity.) Now solve this equation for e/m. You should obtain

$$\frac{e}{m} = \frac{2V}{B^2r^2} \qquad \textbf{Eq. 1}$$

3.

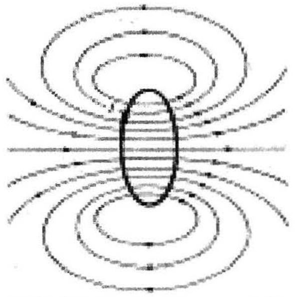


FIGURE 30–15 Magnetic field due to a circular loop of wire.

(Fig. from D. Giancoli's *Physics*)

The magnetic field on the axis of a circular current loop a distance z away is given by

$$B = \frac{\mu_0 I R^2}{2\left(R^2 + z^2\right)^{\frac{3}{2}}}, \qquad \textbf{Eq. 2}$$

where R is the radius of the loop and I is the current. (See example in text for a derivation and discussion of this result.) Using this result, calculate the magnetic field at the midpoint along the axis between the centers of the two current loops that make up the Helmholtz coils, in terms of their number of turns N, current I, and radius R—see Fig. 2 on page 5. [Hint: magnetic fields add as any vector fields do.] Helmholtz coils are separated by a distance equal to their radius R.
You should obtain

$$|B| = \left(\frac{4}{5}\right)^{3/2} \mu_0 \frac{NI}{R} = 9.0 \times 10^{-7} \frac{NI}{R} \qquad \textbf{Eq. 2}$$

where B is the magnetic field in tesla, I is the current in amps, N is the number of turns in each coil, and R is the radius of the coils in meters.

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Important Background Information About Atoms

All normal matter is made up of atoms. Atoms have a "size" of roughly 1 Å ("Ångstrom", 10^{-10} meters), and range in mass from about 10^{-27} kg to 10^{-25} kg. Atoms are in turn made up of smaller particles: positively-charged **protons**, uncharged **neutrons**, and negatively-charged **electrons**. Protons and neutrons have almost the same mass (about 10^{-27} kg) while electrons are about 10^{-30} kg. Protons and electrons have equal and opposite charge, $|e| = 1.6 \times 10^{-19}$ C.

An atom's protons and neutrons are contained in the atom's **nucleus**, which is about 1 fm ("femtometer", or "fermi", 10^{-15} meters) across—a miniscule fraction of the atom's total size. The number of protons in an atom's nucleus determines what kind of atom it is, where it sits on the periodic table, and its chemical properties. For instance, any atom with six protons is carbon, whereas any atom with seven protons is nitrogen. The number of neutrons in an atom determines which **isotope** of that atom it is. Helium-4 (2 protons + 2 neutrons = 4) has 1 more neutron than helium-3 (2 protons + 1 neutron) and is therefore a different isotope, but both isotopes are still helium atoms because they both have two protons. The study of nuclei is known as **nuclear physics**.

The nucleus is surrounded by the lighter electrons, which take up most of the volume of the atom. A normal atom has the same number of electrons as protons, and so has zero net charge. If the atom has a different number of electrons than protons it is called an **ion**; ions with more electrons than protons have a net negative charge and are said to be **negatively ionized**, while ions with fewer electrons than protons have a net positive charge and are said to be **positively ionized**. The study of atoms in general, and their electrons in particular, is known as **atomic physics**.

Experiment description

Understanding the electron is essential for understanding atoms and matter in general. Two important properties of the electron are its charge e and its mass m. In this experiment we will measure the ratio of the two (e/m) with the method first used by J.J. Thomson in 1897. The experiment is based on the fact that a charged particle moving in a magnetic field feels a force at right angles to its velocity: $\mathbf{F_B} = q\mathbf{v}\times\mathbf{B}$. If we send a beam of electrons into a magnetic field uniform in strength and direction, then the trajectory of the electrons is a circle whose radius depends on e/m. We measure the radius of the circle for different values of B, and deduce e/m.

The Electron Beam

To produce a beam of electrons, we heat a metal plate called a **cathode** and boil electrons off of its surface. (We won't worry about the details of this boiling off here.) The cathode is held at a low voltage, and the boiled-off electrons accelerate towards a high-voltage plate a few centimeters away called an **anode**. Some electrons pass through a small hole in the anode and are collimated into a narrow beam (see figure 1). The electrons are not accelerated further once they pass through the anode. Since human eyes can't see electrons, the whole experiment is encased in an evacuated glass bulb with a small amount of helium gas inside.

When the gas molecules are struck by electrons they radiate a blue color, making the path of the electron beam—though not the electrons themselves—visible.

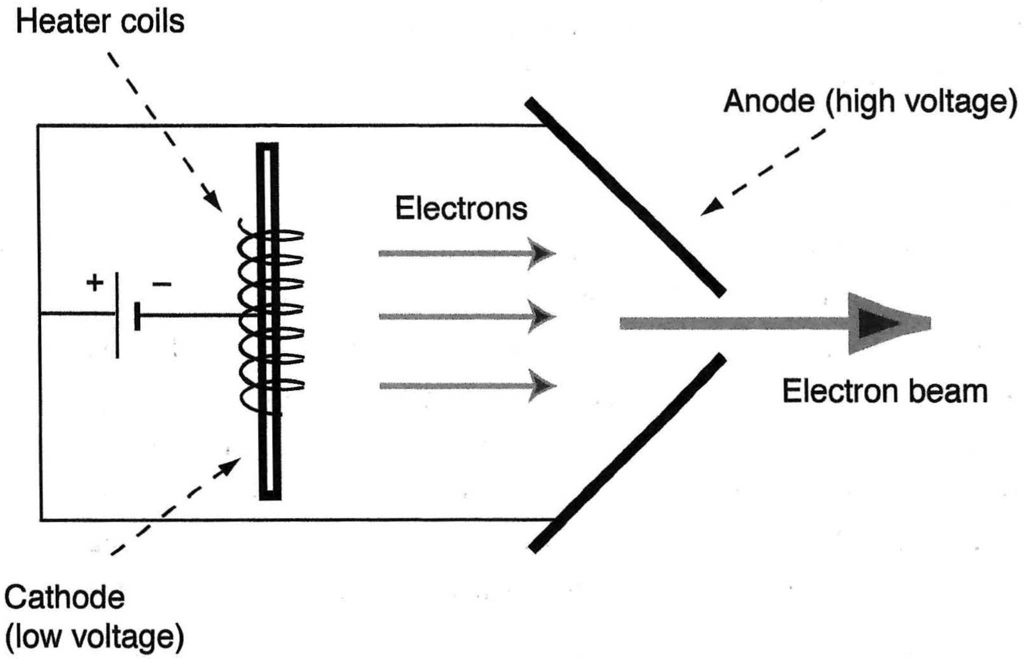


Figure 1: A schematic drawing of the cathode-anode assembly, showing how the electron beam is generated from electrons boiled off of the cathode and accelerated towards the anode.

The Magnetic Field

To produce a uniform magnetic field, we place two large circular coils of wire known as **Helmholtz coils** around the tube, one on either side (see figure 2). The two coils have the same radius and the same number of turns (R = 0.15 meters and N = 130), and are placed exactly one radius R apart. When a current is passed through both coils in the same direction, the fields add to produce a very uniform magnetic field B_{tot} in the center region between them. The field B_{tot} is pointed along the line joining the centers of the two coils, and its magnitude at the center is related to the current in each coil by Eq. 2 above.

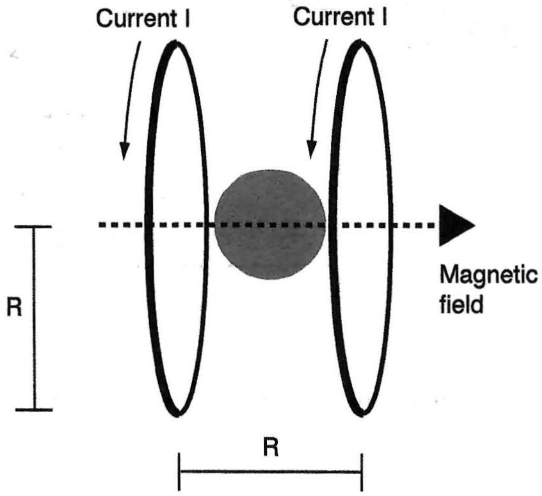


Figure 2: Helmholtz coils. The same current running in the same direction through both coils produces a uniform magnetic field in the shaded center region between the two coils.

We won't ask you to show it here, but you should know that (1) the first derivative, dB_{tot}/dz evaluated at the midpoint between the coils is zero by symmetry; (2) the second derivative, d^2B_{tot}/dz^2, is also zero *if* the coils are separated by a distance equal to their radius R. Because we want as uniform a field as possible, Helmholtz coils are separated by just this distance R.

Parallax Errors

Close one eye and hold up a ruler between you and a far wall. Now move the ruler towards or away from your eye without moving your head, so that the ruler just covers the wall from end to end. If you didn't know better, you'd think that you had just measured the length of the wall to be the same as that of the ruler. This is a **parallax** error, which can occur when a measuring stick is not placed directly against the object it is measuring. (If you had put the ruler right up against the far wall, you'd immediately see your mistake.) Since the circling electron beam is encased in a glass bulb, we can't put a measuring stick directly up against it and so we are susceptible to parallax errors. But there is some additional equipment on the apparatus that will help you avoid these errors—we'll ask you to figure out how rather than describe the procedure here.

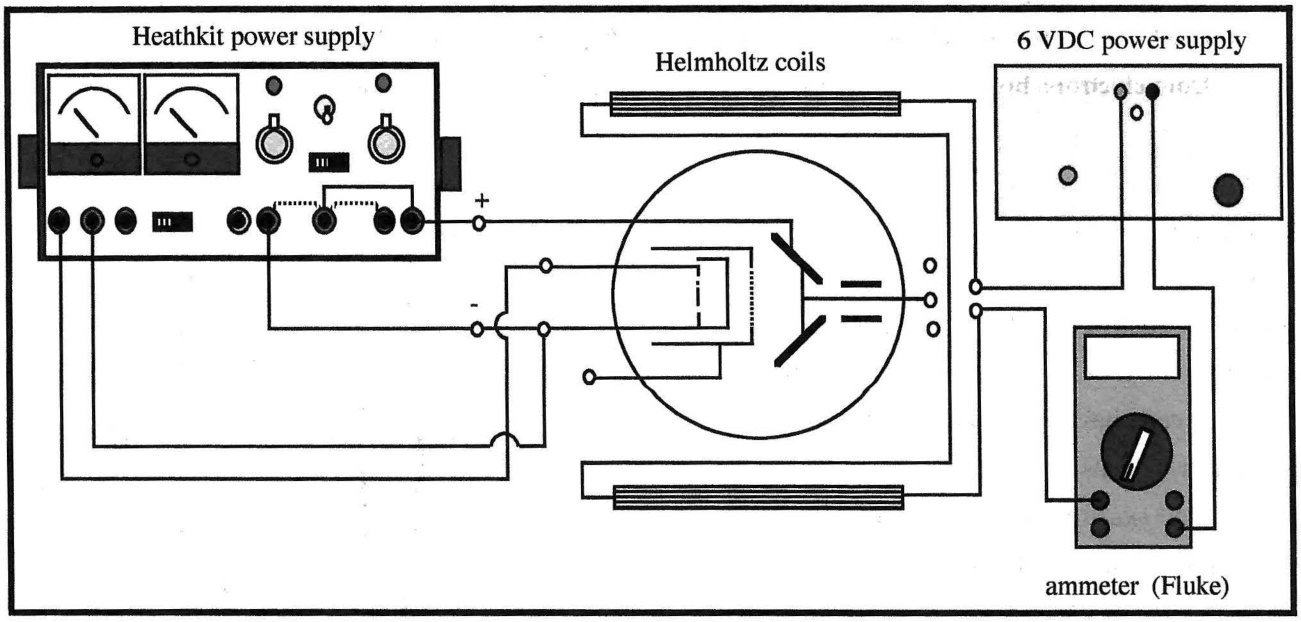


Figure 3: Connections in the e/m experiment.

Procedure

- Connect the power supplies to the baseboard as shown in Figure 3. Switch the Heathkit power supply to "B+" voltage: this is the voltage difference V between the anode and the cathode, and you will read its value from the top (red) scale. Set this voltage to zero and turn on the power supply. Turning on the power supply applies an alternating current to the cathode heater in the glass bulb, which will glow orange after a few seconds. *(Note: "B+" is a bizarre historical term for the voltage between an anode and a cathode. Don't get it confused with the magnetic field, B.)*

1. *Prediction:* You are now going to turn up the voltage and the electron beam will appear. Will it be curved or straight? Why?

- Turn up the voltage until you can see a glowing blue electron beam (the room may have to be dark for this to be visible.)

2. Is the beam curved or straight? Explain.

- Connect the 6 VDC (Volts Direct Current) power supply and the Fluke meter to the Helmholtz coils as shown in figure 3. <u>Be sure to use the 10 amp connection on the Fluke meter to avoid damaging it!</u> This applies 0 – 1.2 amps DC to the coils, creating the uniform magnetic field as per Eq. 2. You can adjust the current using the black knob on the power supply and read its value on the Fluke meter.

3. *Predict:* (i) Will the beam radius increase or decrease if you increase the magnetic field? (ii) What if you increase the anode-cathode (B+) voltage? Explain your reasoning for each conceptually, without simply referring to Eq. 1.

- Increase the magnetic field. Were your predictions correct? If not, explain the correct reasoning here.

- Set the voltage and magnetic field so that you see a well-defined circular electron beam path. You will in a moment measure the radius of the path. But first, develop a radius-measuring technique to avoid the parallax error. (Hint: notice the illuminated scale, or the mirror strip and washers attached to the apparatus.)

4. Explain your method of avoiding parallax errors and why it works.

5. Now measure the radius of the electrons' path. Record your data below, and repeat for four other B-field and voltage combinations. (You may want to make a table so you can calculate your values for e/m right here too.)

6. The electron beam path isn't exactly circular; it spirals slightly inward. Why is this? (Hint: What variables affect the beam's radius?)

7. Calculate the average value of e/m from your four measurements, and compare to the accepted value of 1.76×10^{11} C/kg.

8. What sources of error were present in this experiment? What amount of uncertainty do you estimate each source of error contributed to your final e/m determination? Justify your estimates with words and/or numbers.

NAME: ____________________ SECTION DAY/TIME: ____________________________
GSI: ___________________________ LAB PARTNERS: __________________________

Lab 6: Introduction to oscilloscope and time dependent circuits

Introduction

In this lab, you'll learn the basics of how to use an oscilloscope. Then you'll investigate time dependent circuits. When dealing with capacitors and inductors in DC circuits, it's easy to get lost in mathematics, without understanding what's going on conceptually. These questions and lab activities are designed to help you develop an understanding of these circuits, allowing you to address conceptual questions without plugging through unnecessary math. You'll also see what these circuit components look like in real life.

Part I of this experiment, on the basics of the oscilloscope, should take approximately 30 minutes. The rest of your time in lab should be spent working on Part II, on the time dependent RC and LR circuits. (Don't worry if you aren't fully comfortable with the scope by the end of Part I. You'll get more practice in Part II.)

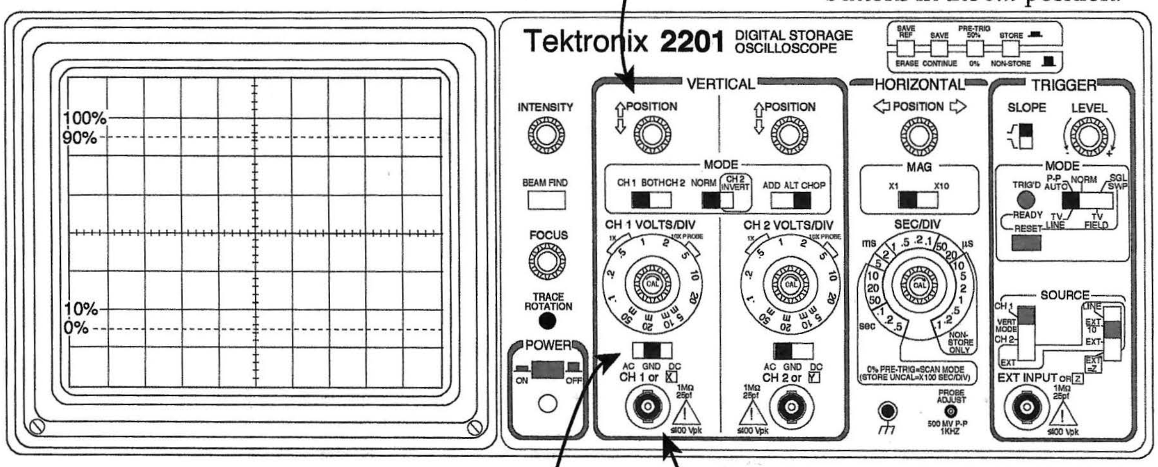
Part I: Oscilloscope Basics

Activity 1: Reset the oscilloscope

- Turn on the oscilloscope, and disconnect any probes plugged into the "channel 1" (CH 1) input connector.
- Set all the levers and buttons as indicated here, if they're not already.

Channel 1 vertical position knob

Storage section. Keep all buttons in the *out* position.



Coupling mode switch

Channel 1 input connector

- Set the CH 1 coupling mode switch to "ground" (GND).
- Turn down the INTENSITY knob, if necessary, to avoid burning out the screen. The sweeping dot should be clear but not too bright.

Since channel 1 is now "grounded" to zero volts, the oscilloscope should read zero on the vertical axis (using the coordinate axes centered on the screen). If it doesn't. . .

- Adjust the channel 1 vertical POSITION knob so that the oscilloscope reads 0 volts.

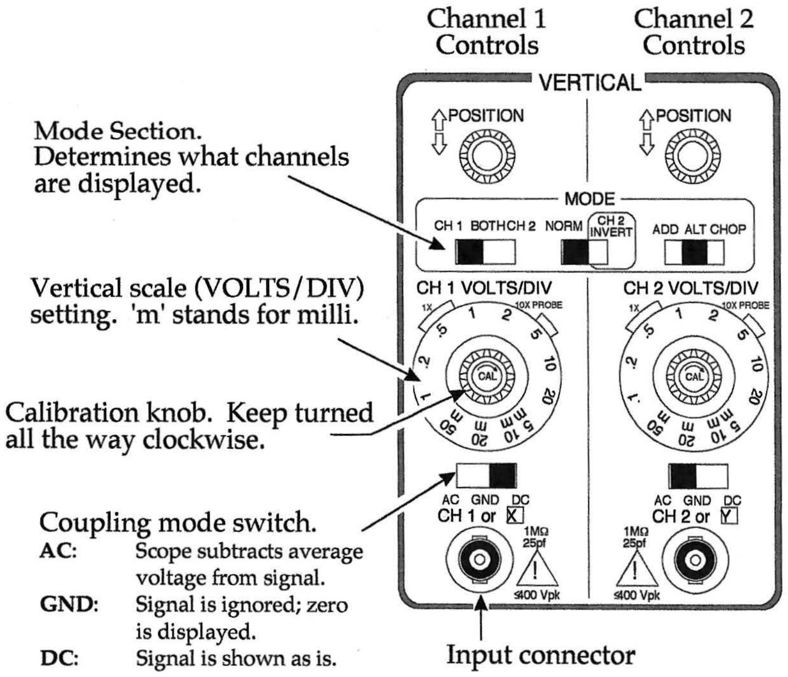
What the oscilloscope does

The oscilloscope graphs voltage vs. time, by sweeping an electron beam across the phosphor screen. Wherever the beam hits the screen, it glows green. For most measurements, the beam sweeps rightward at a constant rate. As you can see, when the beam gets to the right-hand side of the screen, it jumps back to the left-hand side. In this way, the horizontal axis shows time.

When a probe is plugged into the CH 1 input connector, the vertical axis shows the potential difference—i.e., the voltage—between the two wires coming out of that probe. If you're interested, ask your GSI what's going on inside the oscilloscope to deflect the electron beam up or down. Better yet, see if you can figure it out! Hint: Parallel-plate capacitor.

Activity 2: Measuring DC voltages, and using the VOLTS/DIV setting

The point of this brief activity is to practice measuring a voltage with the oscilloscope, and to get a feel for what the VOLTS/DIV control does.



Mode Section. Determines what channels are displayed.

Vertical scale (VOLTS/DIV) setting. 'm' stands for milli.

Calibration knob. Keep turned all the way clockwise.

Coupling mode switch.

AC:	Scope subtracts average voltage from signal.
GND:	Signal is ignored; zero is displayed.
DC:	Signal is shown as is.

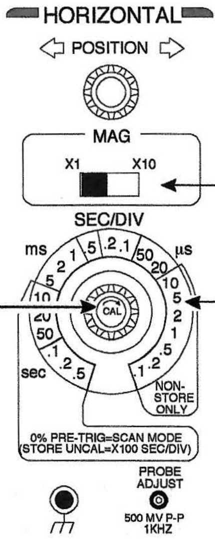
- Set the CH 1 VOLTS/DIV to 2, by aligning the "2" next to the "1X" bracket.
- Set the CH 1 coupling mode switch to DC.
- Now use the oscilloscope to measure the voltage across a 1.5-volt battery.

Make sure you understand what the VOLTS/DIV setting is doing. Students often err in thinking in terms of DIV/VOLT instead of VOLT/DIV.

1. To get a more precise reading of the battery's voltage, should you turn the VOLTS/DIV knob clockwise or counterclockwise? Why? Try it, to get a feel for how much precision can be gained.

Activity 3: Measuring AC voltages, and the SEC/DIV setting

Now you'll practice using an AC power supply, and you'll figure out what the SEC/DIV knob does. The "AC" means "Alternating Current"—that is, the voltage put out by the power supply oscillates with a frequency that you set.



Magnification. Keep on X1

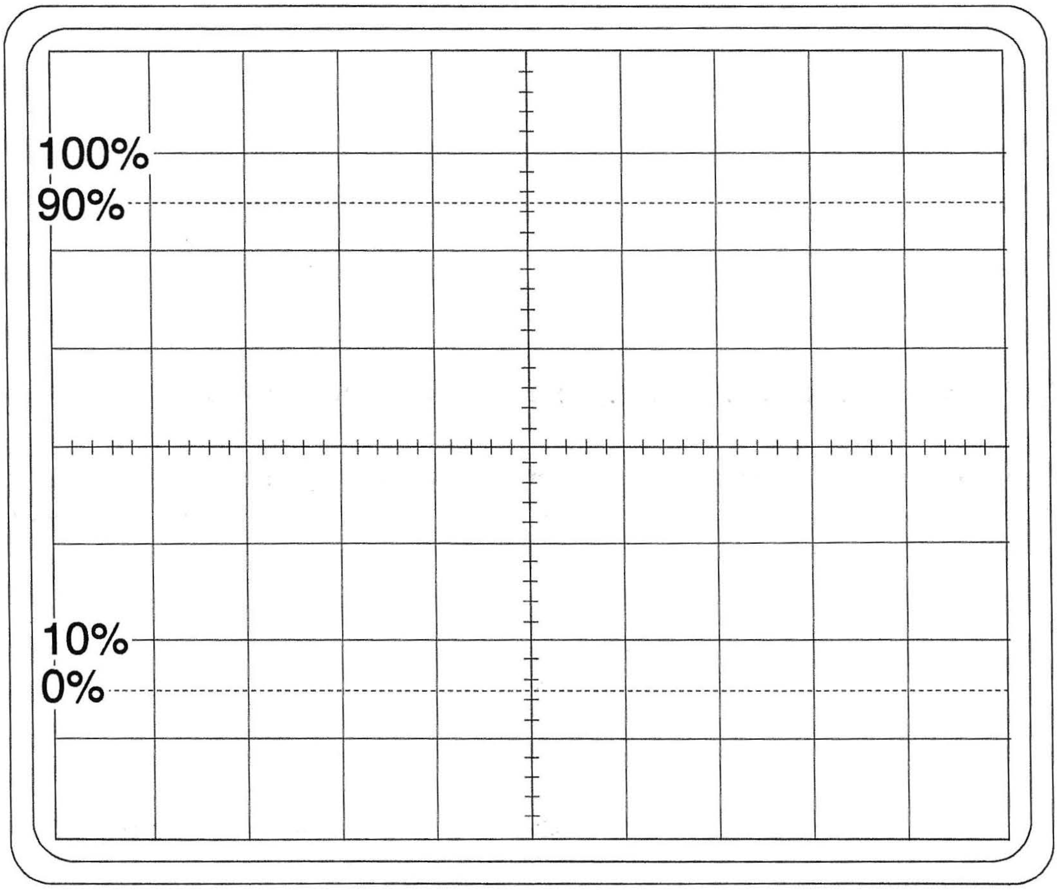
Calibration knob. Keep turned all the way clockwise.

Horizontal scale setting (SEC/DIV). 'm' is short for milli (x10^{-3}), and 'µ' is short for micro (x10^{-6}).

- Set SEC/DIV to 0.5 milliseconds.
- Set the CH 1 VOLTS/DIV to 5.

- Turn on the AC signal generator. Set it to sinusoidal wave, 1000 Hz (i.e., 1.0 kHz). (Note: make sure the sweep width knob is all the way to the left, so it clicks.) But don't connect the AC signal generator to the oscilloscope, until answering this question. . .

2. When you use the oscilloscope to measure the voltage produced by this AC signal generator, what will the screen look like? Sketch your detailed prediction on the next page, paying attention to the amplitude and "wavelength."



- Now hook up the AC power supply to the oscilloscope.

If your prediction was wrong, see if you can figure out what's going on, or get help from your GSI. Sketch the actual screen display in a different color.

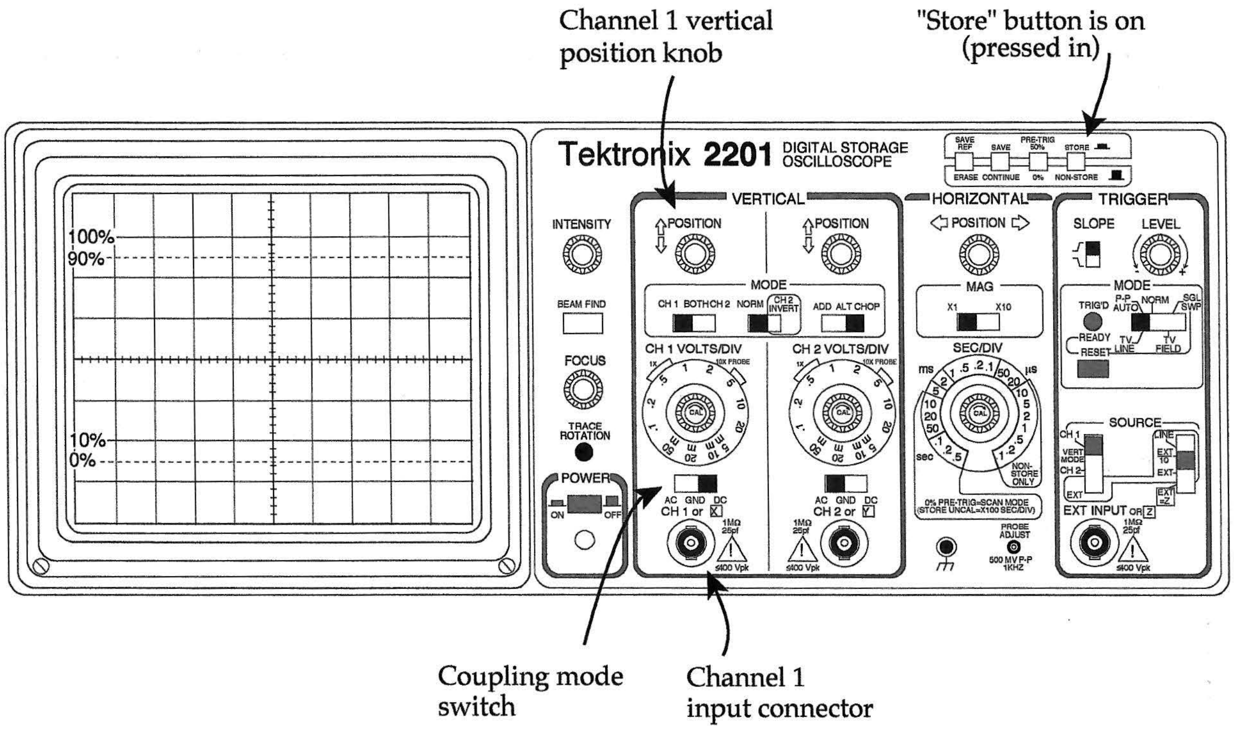
3. To get a more precise measurement of the period of the oscillating voltage, should you turn the SEC/DIV knob clockwise or counterclockwise? Try it.

Part II: Time dependent RC and LR circuits

NOTE: The remainder of the lab is probably too long for the time you have left; your GSI will direct you to which parts of the lab you must complete. Make sure you understand at least questions 1 through 4 before you leave.

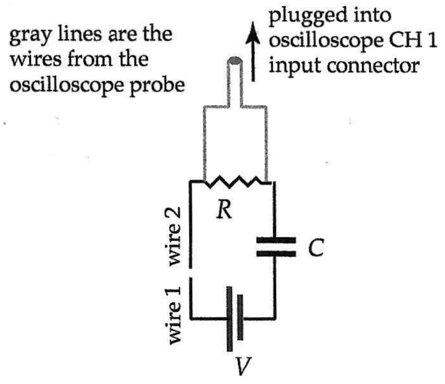
Technical stuff

Adjust the oscilloscope as shown here.



- Set SEC/DIV to .5 seconds.
- Set CH 1 VOLTS/DIV to .5 volts.

In all of the experiments, you'll build a simple circuit, and then use the oscilloscope probe to measure the voltage (potential difference) across a circuit element as a function of time. For instance, this set-up shows how you'd measure the voltage across the resistor in an RC circuit. Notice that the circuit starts out "open"; current cannot yet flow around it. You'll "close" the circuit by touching wire 1 to wire 2.

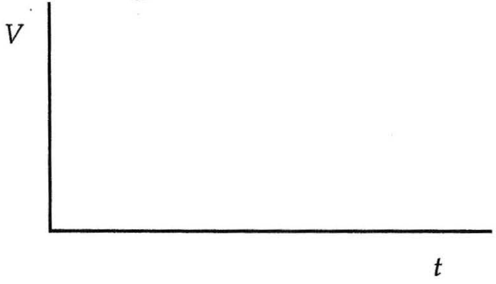


1. Consider a simple RC circuit, with the battery, resistor, and capacitor hooked up in series. Suppose you want to use the oscilloscope to measure the <u>current</u> through this circuit as a function of time. *How can you do it?* (Remember, the oscilloscope can only be used to graph the *voltage* across one or more circuit elements.) We want the graph to have the right general shape; but it need not be scaled properly. In other words, it can be "too tall" or "too short," as long as it has the right shape.

2. For this RC circuit, how can you get the oscilloscope to measure the *charge* on the capacitor as a function of time?

3. Suppose the capacitor is initially uncharged, and the circuit is closed at time $t = 0$. As your prediction, draw a rough sketch of the voltage across the *resistor* as a function of time, and <u>explain</u> your reasoning.

RC CIRCIT WITH BATTERY
Voltage across **resistor**



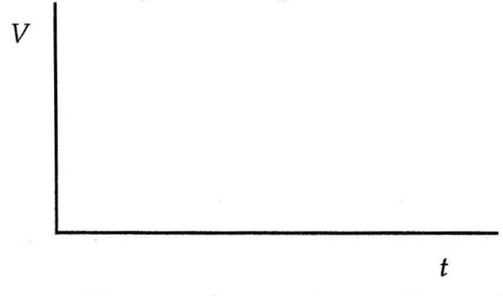
Now do the experiment, using a 1.5-volt battery, a microfarad (10^{-6} F) capacitor, and a megaohm (1 MΩ = 10^6 Ω) resistor. A 1 MΩ resistor is marked with color bands that are **brown, black, and <u>green</u>.** (There are other resistors that have brown, black and brown bands that we will use later in the lab. Don't use this now, since it is only a 100 Ω resistor.)

If the actual result differs from your prediction, sketch it on the graph as a dashed line, and explain what's going on below. **Before closing the circuit, make sure the capacitor is discharged, as demonstrated by your GSI. Each time you redo the experiment, discharge the capacitor again, so that it starts out with zero charge.**

TECHNICAL NOTE: because the oscilloscope has a 1 MΩ resistor at its input, which is in parallel with the 1 MΩ resistor in your circuit, the equivalent resistance of your circuit with the scope attached is (1/2)MΩ. Hence the time constant for your circuit will be half of what you were expecting. We are not concerned with this for the experiment.

4. Same as question 3, but now consider the voltage across the *capacitor* as a function of time. Graph and explain your prediction.

RC CIRCIT WITH BATTERY
Voltage across **capacitor**



Now run the experiment. Re-graph and re-explain, if the results differ from your prediction.

How is the voltage across the capacitor related to the voltage across the resistor as a function of time? Explain.

5. Suppose you place two 1-μF capacitors in series. Is the total capacitance now 2 μF or 0.5 μF? Don't just plug in a formulas; explain your answer conceptually, using diagrams and words. Hint: remember that $Q = C\,\Delta V$.

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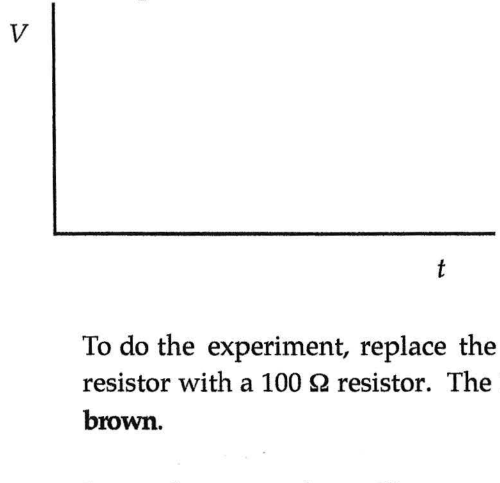
6. Now consider an LR circuit, in which a battery, a resistor, and an inductor are hooked up in series. As you saw in question 1 above, graphing the voltage vs. time across the *resistor* tells you the current through the circuit as a function of time. That's because the voltage across the resistor is proportional to the current ($V = iR$). If the circuit is closed at time $t = 0$, what does the voltage vs. time graph across the resistor look like? Sketch and explain your prediction.

LR CIRCIT WITH BATTERY
Voltage across **resistor**



To do the experiment, replace the capacitors with a 4 H inductor, and replace the mega-ohm resistor with a 100 Ω resistor. The 100 Ω resistor is marked with bands that are **brown, black, and brown.**

Remember to put the oscilloscope probe across the resistor, not across the inductor. For best results, you may want to change the SEC/DIV setting to .1 seconds or even 50 milliseconds (ms). Also, lower the VOLTS/DIV setting to 50 millivolts. Does the graph come out as you expected?

7. Your inductor has an inductance of 4 H and a resistance of about 330 Ω. As you saw in question 6, the circuit's current eventually "settles" to some final value. If you replaced this inductor with a 330 Ω resistor, how would the graph of current vs. time differ from the one in question 6? Specifically,

(a) would the current shoot up to its final value more abruptly or less abruptly than it did in question 8? Explain.

(b) Would the current settle at the same final value as it did in question 8? Or would it settle at a higher or lower final value? Explain.

You need not test your predictions.