

Lab Guide *Cathode-Ray Tube*

I. Objectives

After completing this simulation, the student will be able to:

1. Visually identify the direction of an electric field between two charged conducting plates
2. Visually identify the direction of the magnetic field produced by a coil of conducting wire carrying an electric current
3. Describe the motion of a charged particle in uniform electric fields of different strengths
4. Describe the deflection of a moving charged particle in uniform magnetic fields of different strengths
5. Quantify electric force and magnetic force on a moving charged particle

II. User Interface and Simulation Features

Each particle that is accelerated by the anode represents a “stream” of many particles. This stream will leave a green trail as it travels in the plane of a virtual phosphorescent screen from the anode toward the screen of the cathode ray tube (CRT). The grid represents this virtual phosphorescent screen. It is not the same as the screen on which the CRT display would be seen. The grid is positioned vertically, bisecting the cathode-ray tube from top to bottom. The left side of the grid represents the point at which the particle enters the deflection region. The right side of the grid represents the CRT screen itself. A green line or series of dots on the grid represents the straight or curved path that the stream of particles takes under the conditions specified. The “Clear” button will clear the path from the grid, even during a run. The horizontal bars at the top and bottom of the grid represent the plates. They are separated by a distance of 0.14 m. They display their respective signs if the anode voltage $V_{anode} \neq 0$. The two gray circles represent the Helmholtz coils that produce the magnetic field. They have a radius of 0.099 m and contain a total of 800 turns of wire. The simulation speed “slows down” time so that accurate measurements of Δt can be made. Finally, the particle charge and mass can be varied independently.

III. Questions

In each case when you start a simulation for the following questions, reset the values using the icon in the control panel at the left side of the screen. Each question assumes that you have done this. If you wish to explore further on your own (we greatly encourage this!) it is not necessary to reset the values.

a. Introductory Level

1. What is the value of electric field strength \vec{E} in the deflection region if the plate voltage is zero?
2. If the particles are electrons being accelerated from the cathode by an anode voltage of 5.0 kV, how long does it take for them to reach the fluorescent screen?

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3. Set the simulation speed to a slider value of 50. Set the anode voltage to 4 kV and run the simulation. Observe the path of the particle. Now set the anode voltage to 0.5 kV and repeat the simulation. What change do you observe?

4. What happens when you run the simulation if the potential difference between the cathode and the anode is zero, i.e., the anode voltage is zero?

b. Intermediate Level

5. Set the anode voltage to 2.0 kV . Set the plate voltage to +2.0 kV . Run the simulation and observe the path of the particle. Without clearing the grid, run the simulation again with the plate voltage at +4.0 kV . How does the path change? Now change the sign of the plate voltage to -4.0 kV . What is different about the path now? Describe why this happens, in terms of electric force.

6. What is the magnitude of the electric field strength E when the plate voltage is -4.0 kV ? What is the direction of the electric field vector \vec{E} ?

7. Set the plate voltage V_{plate} to -4 kV . Run the simulation. Use the right-hand rule to determine the direction of the magnetic field \vec{B} necessary for \vec{F}_B to oppose \vec{F}_E in direction.

c. Advanced Level

8. Set the anode voltage to 0.2 kV and run the simulation. From the control panel, pause the charged particle as it enters the deflection region. Record the time, t_i , in nanoseconds. Play the simulation until the particle reaches the CRT screen. Record the final time, t_f . Each increment on the grid represents one centimeter. What is the speed of the charged particle in the deflection region? How does this compare with the speed of light in a vacuum? Now change the anode voltage to 2.0 kV . You may have to reduce the simulation speed to take accurate measurements. Run the simulation again and calculate the speed of the charged particle in the deflection region.

9. J. J. Thomson used a CRT to calculate charge-to-mass ratio in 1897, thus first showing the electron to be an elementary particle. Find the plate voltage that produces no deflection of the charged particle when the Helmholtz current is 0.1 A . Magnetic field strength B is given by $B = kI$ where $k = 2.02 \times 10^{-6}$ T/A , a constant dependent on the geometry of the coils. What are the strengths of the electric and magnetic fields under these conditions? What is the magnitude and direction of each of the electric and magnetic forces? Now change the particle mass and charge by the same factor. Run the simulation. Describe why there is no change in the path in terms of the two forces.

10. Suppose you constructed a cathode-ray tube in an antimatter universe. Would the deflection of a negatively charged particle change? If so, how would it change?

Lab Guide *Electric Fields*

I. Objectives

After completing this simulation, the student will be able to:

1. Describe the electric field produced by a single point charge
2. Describe the electric field produced by a line or sheet of charge
3. Describe the electric field produced by two point charges of the same and opposite charges
4. Describe the electric field produced by different arrays of charges

II. User Interface and Simulation Features

Any point charge on the left side of the screen can be dragged onto the grid where the charge will be used to determine the electric field. Point charges can be placed on top of one another for an additive effect. Each increment on the grid represents 10 meters. The green vector represents the magnitude and direction of the electric field. There are a variety of preset configurations available which can be accessed by clicking on the small picture icons on the left side of the screen. The array of virtual detectors allow you to visualize the electric field. Each virtual detector displays the direction and magnitude (as indicated by its width) of the electric field at its particular location.

III. Questions

In each case when you start a simulation for the following questions, reset the values using the icon in the control panel at the left side of the screen. Each question assumes that you have done this. Then set only the values indicated in the question.

a. Introductory Level

1. Place one positive charge in the center of the grid (preset 1). Relative to the charge, which direction does the electric field point? Examine the field strength by moving the cursor around. Can you find any point on the grid where the electric force is zero?
2. Place one negative charge in the center of the grid (preset 2). Relative to the charge, which direction does the electric field point? Can you find any point on the grid where the electric force is zero? Place the cursor on a point representing 20 m from the charge. What is the magnitude of the electric force vector? Now place the cursor at a point representing 40 meters from the charge. How has the electric force vector changed at this new point?
3. Place all eight positive charges uniformly on the left side of the grid with one charge covering each of the virtual receptors on the far left. Does the electric field point generally horizontally toward the right? Does the direction vary more the farther you are away from the line of charge? Can you find any point on the grid where the electric force is zero?
4. Place all eight negative charges in a horizontal line (Preset 7). Which direction does the electric field generally point? What happens to the direction of the field at the ends of the line of charge?

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b. Intermediate Level

5. Place a positive charge in the center of the upper right quarter of the grid (quadrant I) and a negative charge in the center of the lower left quarter of the grid (quadrant III). Which direction does the field point between the two charges? How does the direction change if you move to one side of the line segment connecting the two charges? Can you find any point where the electric field strength is zero?

6. Place a negative charge in the center of the upper right quarter of the grid (quadrant I) and a second negative charge in the center of the lower left quarter of the grid (quadrant III). Which direction does the field point between the two charges? How does the direction change if you move to one side of the line segment connecting the two charges? Can you find any point where the electric field strength is zero?

7. Form two horizontal lines of opposite charge (Preset 9). What is the direction of the electric field? If you use Preset 9, what is the approximate field strength equidistant from the two lines? What physical device does this arrangement of charges model?

c. Advanced Level

8. Illustrate the shielding effect of inner electrons in an atom on the outer electrons. Place all eight positive charges in the center of the grid, as in the nucleus of an atom. Now place six negative charges (representing electrons) equally spaced around the “nucleus” in a circle, with a radius of about 10 scale divisions. A somewhat more compact version of this is Preset 16. Move the cursor in a small circle around the “nucleus.” What do you observe about the direction and magnitude of the electric field? Now use the cursor to examine the electric field further from the nucleus but inside the circle of electrons. Can you find any place where the direction of the field is toward the nucleus? Is the field strength smaller the farther you get from the nucleus? Now test the field outside the circle of electrons. Is the field strength larger or smaller than it is closer to the nucleus? Would the electric field produced by the outer electrons have any effect on electrons in a higher energy level and farther from the nucleus? Place the remaining two electrons at separate locations at a distance of about 15 scale divisions from the center to test this hypothesis.

Lab Guide *Magnetic Fields*

I. Objectives

After completing this simulation, the student will be able to:

1. State the right-hand rule for magnetic fields
2. Describe the magnetic field produced by a wire carrying an electric current
3. Describe the magnetic field produced by two parallel wires carrying electric currents in the same direction or opposite directions
4. Describe the magnetic field produced by a solenoid
5. Describe the magnetic field produced by a coaxial cable carrying an electric current

II. User Interface and Simulation Features

This simulation models the magnetic fields produced by various arrays of conducting wires carrying currents. The wires are directed in and out of the plane of the screen using the conventional notation of \otimes (the tail of the arrow) representing current flowing into the screen and \odot (the point of the arrow) representing current flowing out of the screen toward you. A grid of Cartesian coordinates has virtual magnetic field receptors with small line segments radiating away from the receptor in the direction of the field. You can drag and drop individual wires from the upper left of the screen to desired locations on the grid. There are also 16 preset arrays of wires carrying current. A digital display at the lower left of the screen shows the magnetic field strength, its x- and y-components, and the position of the cursor.

III. Questions

In each case when you start a simulation for the following questions, reset the values using the icon in the control panel at the left side of the screen. Each question assumes that you have done this. Then set only the values indicated in the question.

a. Introductory Level

1. Place one wire in the center of the grid carrying current out of the plane of the screen (Preset 1). Notice the direction of the virtual field receptors. Hold your right hand with your fingers curled slightly as if you were grasping the wire, with your thumb pointing away from your fingers in the direction of the current flow. Do your fingers curl in the same direction as the virtual field receptors? This is the right-hand rule for the direction of magnetic field produced by a wire carrying a current. Is a conventional current represented by a flow of positive charges or negative charges?
2. Place one wire in the center of the grid carrying current into the plane of the screen (Preset 2). Notice the direction of the virtual field receptors. Does the magnetic field curl clockwise or counterclockwise? Does this direction of current obey the right-hand rule?
3. Suppose you had a flow of electrons coming out of the plane of the screen. Is this a conventional current? Which direction would an equivalent conventional current travel? For the

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stream of electrons, does the magnetic field curl clockwise or counterclockwise as you view the screen? Does the magnetic field produced by the stream of electrons obey the right-hand rule?

4. Select Preset 1. Using the cursor and the digital display at the lower left, what is the magnetic field strength B at a distance of 1 cm from the wire? What is the field strength at a distance of 2 cm from the wire? Describe the variation of B with distance from the wire.

5. Place one wire carrying current into the screen and another wire some distance from the first, carrying current out of the screen (Preset 3). On the perpendicular bisector of the line connecting the charges, which direction does the magnetic field point? Is the right hand rule obeyed for each wire? Notice that a loop of current-carrying wire intersected at right angles by the screen would produce this effect. What type of permanent magnet might produce this field? Which direction would the north pole of such a magnet point?

b. Intermediate Level

6. Select Preset 4. What is the magnetic field strength exactly in the center between the two wires? Now drag one additional wire for each current direction and drop it onto the present wire with the same direction, doubling the current flow. Now measure the magnetic field strength in the center. What is its value? Describe the variation of B with current flow.

7. Select Preset 5. Examine the strength of B near the center. What value do you find? Explain this in terms of Ampere's Law. What is the strength of B at a distance of about 6 cm from one of the wires, outside the array? Explain this in terms of Ampere's Law

8. Select Preset 13. This represents a hollow conductor carrying a current. What is the approximate value of B inside the conductor? What is the value of B at a distance of 7.0 cm from the center of the hollow conductor? What is the value of B at twice this distance? Describe the variation of B with the distance from the center of a hollow conductor.

c. Advanced Level

9. Select Preset 9. What is the direction of the magnetic field between the two lines of wires? Is the right-hand rule obeyed for the individual wires? Notice that a hollow solenoid will produce this same magnetic field. In which direction does the north pole of an equivalent permanent magnet point?

10. Select Preset 16, which represents a coaxial cable. In a coaxial cable, the current flows in one direction through the center conductor (here, into the screen) and in the other direction through the outer sheath conductor. What is the order of magnitude of the magnetic field strength B between the two conductors? What is the approximate value of B outside the coaxial cable? Explain this in terms of Ampere's Law.

Lab Guide

Magnetic Field of a Bar Magnet

I. Objectives

After completing this simulation, the student will be able to:

1. Describe the magnetic field produced by a bar magnet.
2. Use magnetic field lines to draw a magnetic field
3. Describe how the strength of a magnet affects magnetic field strength
4. Describe the effect of length of a bar magnet on the shape of its magnetic field
5. Describe what effect the orientation of the magnet in space has on its magnetic field.

II. User Interface and Simulation Features

This simulation shows the two poles of a bar magnet. You can drag the poles marked N and S to change the length of the magnet, and to change its orientation in space from vertical, through an angle to horizontal. The simulation models placing a sheet of transparent plastic over the bar magnet, and then slowly dropping iron filings onto the plastic. The iron filings align themselves lengthwise with the magnetic field lines. The simulation defaults to having the Strength Dependence button unchecked. In this case, all of the filings will align with the magnetic field, no matter how weak it is. If you check the Strength Dependence button, then the Magnet Strength slider becomes active, and the strength of the bar magnet can be varied from very weak to moderate.

III. Questions

In each case when you start a simulation for the following questions, reset the values using the icon in the control panel at the left side of the screen. Each question assumes that you have done this. Then set only the values indicated in the question.

a. Introductory Level

1. Accept the default values and run the simulation. As the iron filings fall, describe the pattern that you see developing. After about two minutes, pause the simulation and print the pattern.
2. Click the Strength Dependence button. Using the slider bar, select a value of 10 for Magnet Strength. Run the simulation. After about two minutes, pause the simulation and print the pattern. How is this pattern different from the pattern in Item 1?
3. Click the Strength Dependence button. Using the slider bar, select a value of 10 for Magnet Strength. Drag the north pole upward as far as possible and the south pole downward as far as possible. Run the simulation. After about two minutes, pause the simulation and print the pattern. How is this pattern different from the pattern in Item 2?
4. Click the Strength Dependence button. Using the slider bar, select a value of 3 for Magnet Strength. Drag the north pole upward as far as possible and the south pole downward as far as possible. Run the simulation. After about two minutes, pause the simulation and print the pattern. How is this pattern different from the pattern in Item 3?

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b. Intermediate Level

5. Click the Strength Dependence button. Using the slider bar, select a value of 10 for Magnet Strength. Drag the north pole down to the center and then to the right as far as possible. Drag the south pole up to the center and then to the left as far as possible so that the magnet is horizontal. Run the simulation. After about two minutes, pause the simulation and print the pattern. How is this pattern different from the pattern in Item 3? Does the orientation of the bar magnet make a difference in the shape of the magnetic field with respect to the magnet itself? Does the orientation affect the shape of the field with respect to the surroundings of the magnet?

6. Repeat Item 5, but place the north pole at the left and the south pole at the right. Click the Strength Dependence button. Using the slider bar, select a value of 10 for Magnet Strength. Run the simulation. Observe the pattern. After about two minutes, pause the simulation and print the pattern. Does reversing the poles of the magnet affect the shape of the magnetic field with respect to the magnet itself? Does reversing the poles of the magnet affect the shape of the magnetic field with respect to the surroundings of the magnet?

c. Advanced Level

7. Accept the default values and run the simulation. Observe the pattern. After about two minutes pause the simulation and print the pattern. Then stop the simulation, check the Strength Dependence button and set the Magnet Strength slider to a value of 10. Run the simulation again. After about two minutes, pause the simulation and print the pattern. Is the maximum value of 10 for Magnet Strength equivalent to unchecking the Strength Dependence button? How can you tell?

8. Move the poles of the bar magnet so that the south pole appears to be just above the north pole on the screen. Run the simulation. How is this similar to the magnetic field of the Earth?

Lab Guide

Trajectory in E & B Fields

I. Objectives

After completing this simulation, the student will be able to:

1. Describe the path of a charged particle in a magnetic field
2. Describe the path of a charged particle in an electric field
3. Describe the path of a charged particle in crossed electric and magnetic fields.
4. Model a particle velocity selector

II. User Interface and Simulation Features

In this simulation, you can generate and vary the strength of a uniform magnetic field. The field can point into or out of the plane of the screen (the z-axis). You can simultaneously generate and vary the strength of a uniform electrical field that points parallel to the y-axis, either in the positive or negative direction. You can select either a positively- or negatively-charged particle that moves in the plane of the screen (the x-y plane). The particle leaves a trail that remains visible after you stop the simulation. You may clear the trail if you wish. You can give the particle an initial velocity component in either or both the x- and y-directions. You can choose to show or hide a vector guide, three lines that display radius, r , drift velocity of the center of the circular path of the particle v_d and angular speed of the particle, ω_c . Lastly, you can choose to show or hide the purple instantaneous (tangential) velocity vector for the particle.

III. Questions

In each case when you start a simulation for the following questions, reset the values using the icon in the control panel at the left side of the screen. Each question assumes that you have done this. Then set only the values indicated in the question.

a. Introductory Level

1. Set the magnetic field strength $B = 0$. Run the simulation. What is the shape of the path of the particle?
2. Set the magnetic field strength $B = 0$. Change the charge of the particle to negative. Run the simulation. What is the shape of the path of the particle? How does it differ from Item 1?
3. Set the magnetic field strength $B = 0$. Set the electric field strength $E = 5.0 \text{ N/C}$. Run the simulation. What is the shape of the path of the particle? How does it differ from Item 1?
4. Set the magnetic field strength $B = 0$. Set the electric field strength $E = -5.0 \text{ N/C}$. Run the simulation. What is the shape of the path of the particle? How does it differ from Item 1? How does it differ from Item 2?

Exploration of Physics: Simulation Library Vol. I**b. Intermediate Level**

5. Set the electric field strength $E = 0$. Run the simulation. What is the shape and direction of the particle's path? In what direction is the particle accelerating in circular motion relative to its instantaneous velocity? In what direction is the particle accelerating relative to the direction of B ?
6. Set the electric field strength $E = 0$. Set the charge of the particle to negative. Run the simulation. What is the shape of the particle's path? In what direction is the particle accelerating in circular motion relative to its instantaneous velocity? In what direction is the particle accelerating relative to the direction of B ?
7. Set the electric field strength $E = 0$. Set the charge of the particle to negative. Set $B = +0.5 \text{ T}$. Run the simulation. What is the shape of the particle's path? In what direction is the particle accelerating in circular motion relative to its instantaneous velocity? In what direction is the particle accelerating relative to the direction of B ?

c. Advanced Level

8. The direction of the drift velocity is given by $\vec{E} \times \vec{B}$. This is best illustrated by the use of the right-hand rule for cross-products. Point the thumb of the right hand in the direction of the electric field. Point the index finger in the direction of the magnetic field. Extend the third finger normal to the palm of the hand, perpendicular to both the thumb and index finger. This indicates the direction of the cross-product and in this simulation, the direction of the drift velocity. For a negative charge, the direction is from the tip of the third finger toward the palm. Notice that for cross-products, the order is important to maintain the "handedness" of the rule. Run the simulation. Test the right-hand rule. Which direction should your third finger point?
9. In a magnetic field, the particle maintains circular motion about a point. The point itself has velocity $v = E/B$. What is the physical meaning of the particle having velocity $v = E/B$? What value would the radius of circular motion have in this circumstance? Set $E = 2.5 \text{ N/C}$ and $B = +0.5 \text{ T}$. Now set $v_x = 5.0 \text{ m/s}$. Run the simulation. What is the path of the particle? Does the motion of the particle obey the right-hand rule? This is a velocity selector, in which all particles not having a velocity close to $v = E/B$ can be screened out by passing the beam through an aperture of small diameter.

Lab Guide *Coulomb Forces*

I. Objectives

After completing this simulation, the student will be able to:

1. Describe the electric force between two positively charged particles
2. Describe the electric force between two oppositely charged particles
3. Qualitatively predict the path of a positive charge through an array of charges
4. Force a moving charge along a desired path
5. Explain Rutherford's gold foil experiment in terms of Coulomb forces

II. User Interface and Simulation Features

This simulation features a Cartesian coordinate grid on which you can place up to four positive and four negative stationary charges of 1 C each at desired locations. A positive charge representing a proton is located on the grid. It can be moved to any desired location and its initial velocity vector can be varied. Running the simulation releases the proton and subjects it to the electric forces of the other charges on the grid. A digital display of the components of velocity and acceleration is shown in the upper left. This display can be turned on or off. You may choose to show or hide the velocity and acceleration vectors of the proton, a trail of the path of the proton, and to allow the proton to bounce off the sides of the grid. There are 11 preset combinations of charges to experiment with. In addition, there is a game mode in which you place charges so that the proton will follow an indicated path. A timer is provided, which is synchronized with the velocity values, but runs faster than real time.

III. Questions

In each case when you start a simulation for the following questions, reset the values using the icon in the control panel at the left side of the screen. Each question assumes that you have done this. Then set only the values indicated in the question.

a. Introductory Level

1. Allow the proton to bounce off the walls. Run the simulation. Are there any forces on the proton except during collisions with a wall? Does the proton ever change direction except when it hits a wall?
2. Place one positive charge at the origin. Run the simulation. In which direction relative to the positive charge does the acceleration vector point? How does the proton move relative to the positive charge?
3. Place one negative charge at the origin. Run the simulation. In which direction relative to the negative charge does the acceleration vector point? How does the proton move relative to the negative charge?
4. Choose Preset 1. Does the proton have an initial velocity? Does the proton start moving? Is there a force acting on the particle?

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5. Choose Preset 2. Does the proton have an initial velocity? Does the proton start moving? Is there a force acting on the particle? How does the motion differ from that of Preset 1

b. Intermediate Level

6. Place one negative charge at the origin. Change the blue initial velocity vector so that $v_{y,i} = 8.0$ m/s and $v_x = 0$. How does the proton move relative to the negative charge? Turn the trails on. Does the proton ever escape the negative charge?

7. Select Preset 4. This is an example of a “trapped charge.” Turn the Vectors off and Trails on. Run the simulation for at least 300 s on the timer. Does the proton escape from the “cage”? Now move the initial position of the proton to $y = 40.00$ m. Run the simulation as before. Does the proton escape from the cage? Do the initial position and velocity of the proton make a difference?

8. Select Preset 5. This is another example of a trapped charge. Run the simulation. How does the proton move? Does the proton escape? Stop the simulation. Remove the two negative charges at the sides. Does the proton move differently now, or the same? Stop the simulation. Select Preset 5 again to recover the two negative charges. Turn off Grid Snap. Move the tip of the initial velocity vector the slightest amount to the left. Run the simulation. What happens to the proton?

c. Advanced Level

9. Model Rutherford’s gold foil experiment! Place all 4 positive charges at the origin. This represents the gold nucleus. Place the proton at the point $(-150, 50)$ with an initial velocity of 150 m/s in the positive x-direction. This represents an α -particle. Run the simulation. How does the proton move? Change the initial position of the proton to $(-150, 40)$ with the same initial velocity vector. How does the proton move? Move the initial position of the proton 10 m in the negative y-direction each time. Run the simulation after each change. How does the proton move?

10. Play the game. Select Game B. Move the proton to the lower left (beginning) of the green path with its initial velocity vector pointing in the direction of the path (just a bit above the positive x-axis). Place two negative charges at the point $(-30, -40)$. Place one negative charge at the point $(20, 20)$. Place one negative charge at the point $(40, 20)$. Run the simulation. Does the proton follow the green path? If so, you’re done; go on to a more challenging problem. If not, you’re out of negative charges. Try nudging it back on track with one or more of the positive charges, strategically placed.

Lab Guide

Parallel-Plate Capacitor

I. Objectives

After completing this simulation, the student will be able to:

1. Describe the construction of a simple circuit with a parallel-plate capacitor in series.
2. Describe the qualitative effect of voltage, plate spacing and plate area on capacitance
3. Describe the effect of a dielectric material between capacitor plates
4. Calculate capacitance, given plate area and spacing
5. Calculate electric potential energy, given voltage and capacitance
6. Calculate electric field strength between plates

II. User Interface and Simulation Features

The simulation provides a schematic or a parallel-plate capacitor connected in series with a battery. Within limits, you are able to vary the area of the plates, the spacing between the plates, the voltage of the battery, and the dielectric constant of a material. You may choose whether or not to insert the dielectric material between the plates of the capacitor.

III. Questions

In each case when you start a simulation for the following questions, reset the values using the icon in the control panel at the left side of the screen. Each question assumes that you have done this. Then set only the values indicated in the question.

a. Introductory Level

1. Vary the battery voltage. First decrease it, then increase it. Look at the values on the bar graph. What happens to the values for charge, electric field strength, and electric potential energy? Do these three values change in the same direction at the same time?
2. Vary the plate area up and down through its entire range. Which quantities change on the bar graph? Which quantity remains constant? Why is this so?
3. Vary the plate spacing up and down through its entire range. Which quantities change on the bar graph? Which quantity remains constant? Why is this so?
4. Observe the values on the bar graph. Check the Dielectric In/Out button. What do you observe about the variables in the bar graph?

b. Intermediate Level

5. Set the dielectric constant for 2.0. Check the Dielectric In/Out button. Record or print the values for the quantities shown in the digital display at the upper left of the screen. Now change the dielectric constant to 4.0. By what factor do the variables change?

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6. What is the value of the largest capacitance you are able to produce in this simulation without using a dielectric material? Which of the quantities will you vary to do this? Based upon the directions in which you had to vary these quantities, can you come up with an expression for capacitance in terms of these quantities?

c. Advanced Level

7. Set the battery voltage to 12.0 V ; how much charge is on the plates? Now reduce the voltage to 6.0V . How much charge is on the plates now? Is the amount of charge on the capacitor affected by the battery voltage? Is it a linear relationship?

8. What is the largest amount of electrical energy that you can store in the capacitor in this simulation, using all the resources that are available to you? Which quantity must you minimize to achieve this?

Lab Guide

Lenz's Law

I. Objectives

After completing this simulation, the student will be able to:

1. Explain the operation of an electrical generator
2. Describe the effect of the number of coils on the current produced
3. Describe the effect of coil speed on the current produced
4. Explain the effect of magnetic field strength on the current produced
5. Described the effect of changing coil area on the current produced

II. User Interface and Simulation Features

This simulation consists of a coil of wire through which moving magnetic field lines pass. A current is induced in the coil. You can change the strength of the magnet, the number of loops in the coil and the area of the coil. You can drag the magnet vertically along the axis of the coil. There is a provision for moving the magnet automatically while making observations. A galvanometer is wired in series with the coil to indicate the magnitude of the induced current. The greater the deflection of the pointer of the galvanometer, the greater the current in the coil.

III. Questions

In each case when you start a simulation for the following questions, reset the values using the icon in the control panel at the left side of the screen. Each question assumes that you have done this. Then set only the values indicated in the question.

a. Introductory Level

1. Observe the galvanometer. Is any current flowing in the coil? Drag the magnet upward toward the center of the coil. While you are moving the magnet, is any current flowing? After you stop moving the magnet, is any current flowing? Does current flow depend on the position of the stationary magnet? Does current flow depend on the motion of the magnet?
2. Observe the galvanometer while you move the magnet slowly upward. Reset the simulation, and observe the galvanometer while you move the magnet quickly upward. Was the current greater when you moved the magnet faster or when you moved the magnet slower?
3. Check the magnet motion button. Watch the pointer on the galvanometer to see how far it deflects left and right as the magnet moves. While the magnet is moving, change the number of loops in the coil to 1. Does the magnet move up and down with the same speed? Does the pointer deflect farther left and right with only one loop, or not as far? How does the current flow depend on the number of coils?
4. Check the magnet motion button. Watch the pointer on the galvanometer to see how far it deflects left and right as the magnet moves. While the magnet is moving, change the magnet strength to 3. Does the magnet move up and down with the same speed? Does the pointer deflect farther left and right with a lower magnet strength, or not as far? Change the magnet

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strength to 10. Does the magnet move up and down with the same speed? Does the pointer deflect farther left and right with a lower magnet strength, or not as far? How does the current flow depend on the magnet strength?

5. Check the magnet motion button. Watch the pointer on the galvanometer to see how far it deflects left and right as the magnet moves. While the magnet is moving, change the loop area in the coil to 1. Does the magnet move up and down with the same speed? Does the pointer deflect farther left and right with less loop area, or not as far? Now change the loop area in the coil to 10. Does the magnet move up and down with the same speed? Does the pointer deflect farther left and right with less loop area, or not as far? How does the current flow depend on the loop area?

b. Intermediate Level

6. Observe the galvanometer while you move the magnet slowly upward (but not past the center of the coil). Does the current flow in the positive direction or the negative? Now stop the magnet and move it slowly back downward. Does the current flow in the positive direction or the negative? Start the magnet just above the center of the coil, and move it upward. Does the current flow in the positive direction or the negative? Now stop the magnet and move it slowly back downward. Does the current flow in the positive direction or the negative? Does the direction of current flow depend on which pole is producing the magnetic field lines that pass through the coil?

7. Visualize the magnetic field lines around the bar magnet. Check the magnet motion button. Watch the pointer on the galvanometer. How much current is flowing the instant the center of the bar magnet is in the plane of the coil? Which direction do the magnetic field lines point at that instant with respect to the plane of the coil? At that instant, are any magnetic field lines passing through the wires of the coil?

8. Visualize the magnetic field lines around the bar magnet. Away from which pole do they point? Toward which pole do they point? Lenz's law states that the induced current flows in a direction that produces a magnetic field that opposes the applied (bar magnet) field. Inside the coil, in which direction must a magnetic field point in order to oppose the field of the bar magnet? Use the right-hand rule for magnetic fields around a wire. To produce this opposing magnetic field, does the current in the coil flow clockwise or counterclockwise?

c. Advanced Level

9. Electrical generators work on the principle of Lenz's law. Where does the electrical energy come from in a generator? Why do the magnets not "run down"?

Lab Guide

Conducting Wire: Motion of Charge Carriers

I. Objectives

After completing this simulation, the student will be able to:

1. State the effect of potential difference on velocity, current and dissipated power.
2. State the effect of changing the mean free path of charge carriers on velocity, current and dissipated power.
3. Describe the path of charge carriers moving through a potential difference
4. Describe how Ohm's law can be deduced experimentally

II. User Interface and Simulation Features

This simulation shows the paths of charge carriers through a magnified conducting wire. The charge carriers are subject to a potential difference (voltage) that you can vary. You can also vary the mean free path of the charge carriers. This is the average distance the charge carriers travel before colliding with the ions of the wire substance. You can choose to show or hide the trail of a charge carrier. Only one trail is shown, but after the charge carrier leaves the end of the wire, another begins to show a trail at the left end of the wire. Three graphs at the bottom of the screen display the time-dependency of horizontal displacement, charge, and energy. The slopes of these graphs represent drift velocity, current and power dissipated by ions.

III. Questions

In each case when you start a simulation for the following questions, reset the values using the icon in the control panel at the left side of the screen. Each question assumes that you have done this. Then set only the values indicated in the question.

a. Introductory Level

1. Run the simulation. Watch the path of the charge carriers. In a solid wire, it is usually helpful to consider the metallic bonding model, which contains fixed metal ions surrounded by a proverbial "sea of valence electrons." Turn the trails on. What do you observe about the path of the charge carrier? What does the simulation report for drift velocity in the lower left graph?
2. Now change the mean free path to 20 nm and run the simulation again. How is the path different this time compared to your results in Item 1? What does the simulation report for drift velocity? What is the effect of mean free path on drift velocity?
3. Run the simulation. What is the value of the current flow? Stop the simulation. Double the mean free path to 20 nm . Run the simulation again. What is the current flow now? What is the relationship between mean free path and current flow?
4. Run the simulation. How much power is dissipated by the ions with which the charge carriers collide? Stop the simulation. Double the mean free path to 20 nm . Run the simulation again. Now what is the power consumption?

b. Intermediate Level

5. Run the simulation. What is the default setting for potential difference? What is the drift velocity? Stop the simulation. Change the potential difference to $40\ \mu\text{V}$. Now what is the drift velocity? Run this Item several times to see how this value varies.

6. Set the potential difference to $40\ \mu\text{V}$. Turn the trail on. Run the simulation. What is the appearance of the path? How great is the current flow, shown in the middle graph? Stop the simulation. Change the potential difference to $160\ \mu\text{V}$. Run the simulation again. Now how great is the current flow? What is the relationship between increasing potential difference and current flow?

7. Set the potential difference to $40\ \mu\text{V}$. Turn the trail on. Run the simulation. What is the appearance of the path? How great is the power dissipated by the ions with which the charge carriers collide, shown in the right graph? Stop the simulation. Change the potential difference to $160\ \mu\text{V}$. Run the simulation again. Now how great is the dissipated power? What is the relationship between increasing potential difference and power dissipation?

c. Advanced Level

8. Using Ohm's law, $E = iR$, calculate the resistance from potential difference and current flow in Item 6. Use both the low and high values for E .

9. Using the power law, $P = i^2R$, calculate the resistance from current flow and power dissipation in Items 6 and 7. Use both the low and high values of i .

Lab Guide *Resistive Circuits*

I. Objectives

After completing this simulation, the student will be able to:

1. Calculate the resistance equivalent to resistors in series
2. Calculate the resistance equivalent to resistors in parallel
3. Calculate the resistance equivalent to resistors in complex combinations
4. Estimate the relative amount of current flowing through different resistors

II. User Interface and Simulation Features

This simulation allows you to select one of five resistive circuits and analyze it for current flow through each resistor, potential difference across each resistor and power consumption by each resistor. The circuits are number left to right in this Guide. Each circuit contains up to four resistors, wired in some combination of series and parallel connection. You can vary the resistance of each resistor and the applied battery voltage using slider bars. A histogram in the lower left of the screen shows the voltage, current and power consumption by the resistors in use in the chosen circuit. In the upper right is a digital display of the same data.

III. Questions

In each case when you start a simulation for the following questions, reset the values using the icon in the control panel at the left side of the screen. Each question assumes that you have done this. Then set only the values indicated in the question.

a. Introductory Level

1. Select Circuit 1. Observe the values on the histogram while you move the slider for Resistor 1 back and forth through its entire range. As you change the resistance, how does the current flow change? Do you expect this behavior from Ohm's law?
2. Select Circuit 1. What is the battery voltage? What is the value of the resistor (the resistance) in ohms? Using Ohm's law, calculate the current flow. Using the power law, calculate the power dissipated and lost as heat in this circuit. Do your calculations agree with the displayed values?
3. Select Circuit 2. What are the values of the two resistors? What is their sum? Is the current flow the same value through both resistors? What is the value? Must this same current flow through the entire circuit? Why is this so? Using the value for current flow and Ohm's law, calculate the total resistance. How does this value compare with the sum of the two resistors?
4. Select Circuit 2. What is the value of the battery voltage? What is the voltage loss (potential difference) in the entire circuit? Are the two resistors wired in series or parallel? Are R_1 and R_2 the only sources of potential difference in the circuit? Use Ohm's law to calculate the potential differences across R_1 and R_2 . What are their values and their sum? How does the sum compare with the potential difference in the entire circuit?

b. Intermediate Level

5. Select Circuit 3. What is the value of the battery voltage? What is the voltage loss (potential difference) in the entire circuit? Are the two resistors wired in series or parallel? What are the potential differences across R_1 and R_2 ? Use Ohm's law to calculate the current flows through each of R_1 and R_2 . What are their values and their sum? How does the sum compare with the current flow in the entire circuit? Start with Ohm's law. Write an expression for the total current flow through the circuit in terms of R_1 and R_2 .

6. Select Circuit 4. What is the resistance of R_1 ? Are R_2 and R_3 connected in series or parallel? Based on your answers to Items 3 and 5, what is the equivalent resistance to the combination of R_2 and R_3 ? If you drew this equivalent resistance into the circuit as only one resistor $R_{equivalent}$, would R_1 and $R_{equivalent}$ be connected in series or parallel? What is the sum of R_1 and $R_{equivalent}$? Using Ohm's law, what is the total resistance in the circuit? How are these related?

c. Advanced Level

7. Select Circuit 3. What is the current flow across R_1 ? What is the resistance value of R_1 ? How much power, in watts, is dissipated by R_1 ? What happens to the power consumed by R_1 if you double the battery voltage? Explain why this happens in terms of current flow. Would the power consumed by R_2 and R_3 be greater or less if these two resistors were connected in series?

8. Select Circuit 5. What is the equivalent resistance for R_2 and R_3 ? What is the equivalent resistance for R_2 , R_3 and R_4 ? What is the total (equivalent) resistance of the entire circuit? Using Ohm's law, how much current should flow through the circuit? How much of this current flows through R_1 ? Using this value, what is the potential difference across R_1 ? Does your value agree with the value reported by the simulation?

Lab Guide *Capacitor Circuits*

I. Objectives

After completing this simulation, the student will be able to:

1. Calculate the capacitance equivalent to capacitors in series
2. Calculate the capacitance equivalent to capacitors in parallel
3. Calculate the capacitance equivalent to capacitors in complex combinations
4. Estimate the relative amount of current flowing through different capacitors

II. User Interface and Simulation Features

This simulation allows you to select one of five capacitive circuits and analyze it for charge and energy stored in each capacitor, and potential difference across each capacitor. The circuits are number left to right in this Guide. Each circuit contains up to four capacitors, wired in some combination of series and parallel connection. You can vary the capacitance of each capacitor and the applied battery voltage using slider bars. A histogram in the lower left of the screen shows the voltage, charge and energy storage by the capacitors in use in the chosen circuit. In the upper right is a digital display of the same data.

III. Questions

In each case when you start a simulation for the following questions, reset the values using the icon in the control panel at the left side of the screen. Each question assumes that you have done this. Then set only the values indicated in the question.

a. Introductory Level

1. Select Circuit 1. Observe the values on the histogram while you move the slider for Capacitor 1 back and forth through its entire range. As you change the capacitance, how do the charge and energy stored in the capacitor change?
2. Select Circuit 1. What is the battery voltage? What is the value of the capacitor (the capacitance) in microfarads (μF)? Calculate the charge on the capacitor. Using $U = Q^2/2C$, calculate the energy stored in this circuit. Do your calculations agree with the displayed values?
3. Select Circuit 2. What is the value of the battery voltage? What is the voltage loss in the entire circuit? Are the two capacitors wired in series or parallel? Are C_1 and C_2 the only sources of potential difference in the circuit? Use $Q = CV$ to calculate the potential differences across C_1 and C_2 . What are their values and their sum? How does the sum compare with the potential difference in the entire circuit?
4. Select Circuit 2. What are the values of the two capacitors? Are the charges the same on both capacitors? What is the charge? Is the voltage drop (potential difference) the same across each capacitor? Why is this so? Using the formula for capacitors in series, calculate the total

(equivalent) capacitance. How does this value compare with the values of each of the two individual capacitors?

b. Intermediate Level

5. Select Circuit 3. What is the value of the battery voltage? What is the voltage loss (potential difference) in the entire circuit? Are the two capacitors wired in series or parallel? What are the potential differences across C_1 and C_2 ? Using $Q = CV$, calculate charge on each of C_1 and C_2 . What are their values and their sum? How does the sum compare with the charge stored in the entire circuit? Starting with $Q = CV$, write an expression for the total charge stored in the circuit in terms of C_1 and C_2 .

6. Select Circuit 4. What is the capacitance of C_1 ? Are C_2 and C_3 connected in series or parallel? Based on your answers to Items 3 and 5, what is the capacitance equivalent to the combination of C_2 and C_3 ? If you drew this equivalent capacitance into the circuit as only one capacitor $C_{\text{equivalent}}$, would C_1 and $C_{\text{equivalent}}$ be connected in series or parallel? What is the sum of C_1 and $C_{\text{equivalent}}$? What is the total capacitance in the circuit? How are these related?

c. Advanced Level

7. Select Circuit 3. What is the charge on C_1 ? What is the capacitance value of C_1 ? How much energy is stored in C_1 ? What happens to the energy stored in C_1 if you double the battery voltage? Explain why this happens in terms of charge. Would the energy stored by C_2 and C_3 be greater or less if these two capacitors were connected in series?

8. Select Circuit 5. What is the equivalent capacitance for C_2 and C_3 ? What is the equivalent capacitance for C_2 , C_3 and C_4 ? What is the total (equivalent) capacitance of the entire circuit? How much energy should be stored in the circuit? How much of this charge is stored in C_1 ? Using this value, what is the potential difference across C_1 ? Does your value agree with the value reported by the simulation?

Lab Guide *RC Circuits*

I. Objectives

After completing this simulation, the student will be able to:

1. Describe charging a capacitor with a battery through a resistor
2. Describe the effects of capacitance and resistance on charging a capacitor
3. Describe discharging a capacitor through a resistor
4. Describe the effects of capacitance and resistance on discharging a capacitor

II. User Interface and Simulation Features

This simulation provides a circuit in which you can place a capacitor in one of two branches by means of a single-pole double-throw switch. You throw the switch by clicking on it. With the switch thrown in one direction, the capacitor becomes charged. It is wired in series with a battery and a resistor. The resistor limits the current flow in the circuit. With the switch thrown in the other direction, the capacitor is disconnected from the battery and connected in series to a second resistor, commonly called a "load." The accumulated charge on the capacitor flows through the resistor. The battery voltage, the capacitance of the capacitor, and the resistance of the two individual resistors can be set by means of slider bars. A histogram in the upper right corner of the screen graphs current through the resistor, potential difference (voltage) across the resistor, voltage across the capacitor and charge on the capacitor as functions of time. Each vertical division represents a value of 1.0 of one of the four units shown on the sliders. A line graph at the lower right plots the voltage on the capacitor vs. time. A timer operates a bit slower than real time, but synchronized with the time constant of the charge/discharge cycle.

III. Questions

In each case when you start a simulation for the following questions, reset the values using the icon in the control panel at the left side of the screen. Each question assumes that you have done this. Then set only the values indicated in the question.

a. Introductory Level

1. What is the battery voltage? Run the simulation. After about 25 s on the timer, what value does the voltage across the capacitor V_C approach? When the voltage on the capacitor is at this value, what is the charge on the capacitor in coulombs? Does the capacitor charge as a linear function of time?
2. Run the simulation. What is the initial voltage across the resistor, V_R ? What value does V_R approach after a long time?
3. Set the capacitance to 0.10 F. Run the simulation. At full charge, will this capacitor have more charge or less charge than the capacitor of 0.65 F in Item 1? Does this capacitor charge faster or slower than the capacitor in Item 1?

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4. Run the simulation for about 30 s . Observe the amount of charge on the capacitor. Stop the simulation. Set the resistance of Resistor A to 2.0Ω . Run the simulation again. Will the capacitor have the same amount of charge or a different amount when it is fully charged? Will it take a longer or shorter period of time to charge?

b. Intermediate Level

5. What voltage represents 90% of full charge? Run the simulation. Pause the simulation at 90% of full charge. How long did this take? What voltage represents 99% of full charge? Do not stop the paused simulation. Run (continue) the simulation. How much longer does it take the capacitor to charge to 99% of full charge? How much longer than this do you think it would take to charge the capacitor to 99.9% of full charge?

6. Set the battery voltage to 5.0 V . Set both Resistors A and B to 4.0Ω . Run the simulation for about 14 s and then click the switch to discharge the capacitor. Let the simulation run to the end of the graph, 30 s . Compare the shape of the discharge curve to that of the charging curve.

7. Set the battery voltage to 5.0 V . Set the capacitance to 0.50 F . Set Resistor A to 1.0Ω . Set Resistor B to 4.0Ω . Run the simulation. At $t = 5.0 \text{ s}$ pause the simulation and throw the switch to discharge. What is the voltage across the capacitor? What is the charge on the capacitor? Run (continue) the simulation. Why is the shape of the discharge curve (after “flipping” around a horizontal axis) different than the charging curve?

c. Advanced Level

8. The value RC is called the “time constant” in the equations describing the charging and discharging of an RC circuit. Set Resistor A to 10.0Ω and the capacitance to 1.0 F . Run the simulation and watch the rate of charging. Stop the simulation. Now change Resistor A to 1.0Ω and the capacitance to 0.10 F . Run the simulation again. Does a large time constant mean that the capacitor charges faster or slower?

9. Set both Resistors A and B to 2.0Ω . Set the capacitance to 0.5 F . Set the battery voltage to 5.0 V . Run the simulation. As soon as the capacitor appears nearly charged (at about 8 s), throw the switch to discharge. At about 9 s , before the capacitor has had time to discharge, throw the switch again to the charging position. What was the highest voltage across the capacitor during the original charge? To what voltage did you discharge it? Can you get the capacitor to charge to a higher voltage because it did not lose all of its charge during discharge? Why or why not?