PY 106

Section: Name: BU ID: .

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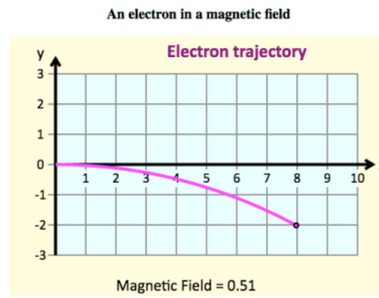
Lab 4: Charge to Mass Experiment

Part I: **Theory.**

For this part use a Java applet: go to the following URL (it should be an HTML5 version, do not use Java version): **http://physics.bu.edu/ulab/prelabs/prelab_eoverm_1new.html**. If you pause the applet you should see a picture similar to the one on the right (Click Play to start and Reset to restart the applet).



In this simulation a *negative* charge follows a circular path when exposed to a magnetic field which is uniform and *perpendicular* to the screen. At the origin negative charge is given an initial horizontal velocity which points to the right (the origin is at the point where charges enter the region with the magnetic field). When you adjust the magnetic field with the slider, the path followed by the charges will change. The grid is marked in integer units (assume SI units for all quantities involved in the "experiment").

You can use the slider to control the magnetic field.

You can also measure X and Y coordinates of a charge if the trajectory passes a clear intersection of one vertical and one horizontal lines of the grid.

1. Which statement(s) does correctly describe the direction of the Lorentz's force? Check all that apply.

[ ] The force is parallel to both the velocity of the particle *v* and the direction of the magnetic field *B*.

[ ] The force is parallel to the velocity of the particle *v*, but perpendicular the direction of the magnetic field *B*.

[ ] The force is perpendicular to both the velocity of the particle *v* and the direction of the magnetic field *B*.

[ ] To find the direction of a magnetic force *F* acting on a *negative* charge you *should not* use your left hand.

[ ] To find the direction of a magnetic force *F* acting on a *positive* charge you *should not* use your left hand.

[ ] To find the direction of a magnetic force *F* acting on a *negative* charge you *should not* use your right hand.

[ ] To find the direction of a magnetic force *F* acting on a *positive* charge you *should not* use your right hand.

2. Finish the statement: When a charge enters a magnetic field, its kinetic energy …

[ ] decreases [ ] remains constant [ ] increases

3. Check all the statement ending(s) which can ***never*** be correct.
The trajectory of a particle moving in a magnetic field (with no other fields and forces acting on it) is …

[ ] a straight line [ ] a circle

[ ] a square [ ] a spiral

4. Choose all statements that are *correct*.

[ ] A particle which velocity is parallel to the magnetic field will move in a circle.

[ ] A particle which velocity is parallel to the magnetic field will move in a straight line unaffected by the field.

[ ] If a particle is launched in a direction perpendicular to the magnetic field it will move in a circle.

[ ] If a particle is launched in a direction perpendicular to the magnetic field, it will move in a straight line unaffected by the field.

5. Copy the picture from the screen, show the trajectory of a charge, draw a free body diagram for the charge at the origin and then at some other location on the path, show the velocity and the acceleration of the charge.

6. In this applet, positive values for the magnetic field correspond to a magnetic field in a particular direction, while negative values correspond to the field with the reverse direction. Which direction of the field corresponds to the positive values of the field in the simulation?

[ ] to the right [ ] to the left [ ] up along the page

[ ] down along the page [ ] into the page [ ] out of the page

7. Write an expression for the magnitude of the magnetic *force* acting on the charge in the applet.

F_B =

8. To relate the magnetic force acting on the charge and the radius of the trajectory we must use … (select all that apply)

[ ] the law of conservation of charge [ ] the Coulomb's law [ ] the Newton's second law

[ ] the law of conservation of energy [ ] the law of conservation of linear momentum

[ ] the expression for the tangential acceleration of the charge

[ ] the expression for the centripetal acceleration of the charge

[ ] the expression for the Lorentz's force

9. Using appropriate equations, derive the expression for the charge-to-mass ratio e/m in terms of v, B, and r. and also the expressions for the radius and for the speed (in terms of other variables).

10. Predict, what should happen to the period of the motion if you double the initial speed (but use the same magnetic field acting on the same particle)?

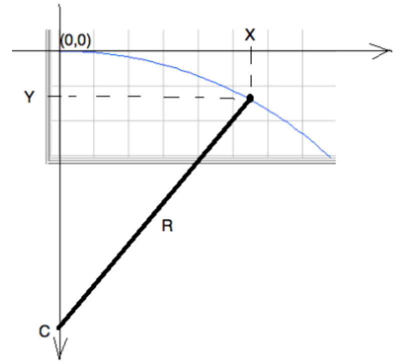
11. Predict what should happen to the period of the motion if you double the magnitude of the magnetic field (but use the same particle traveling with the same speed)?

12. Predict what should happen to the radius of the motion if you double the initial speed (but use the same particle traveling in the same magnetic field)?

13. If you double the speed of the charge, what should you do to the magnetic field in order to keep the radius the same as it was before the speed was changed?

14. Assume that the initial speed of the charge is 2 m/s, and T is the period of its motion. What is the *speed* of the charge at $t = T/4$, and at $t = 2T/3$, at $t = 1.234567890{\cdot}T$? Why?

15. You do not need to see the full circle in order to find its radius. The picture on the right shows the trajectory of a charge, the instantaneous position of the charge, its X and Y coordinates, the center of the circular trajectory it is making, and the radius of the circle R. Derive algebraically an expression which gives the value of the radius R in terms of X and Y coordinates.



16. Set the magnitude of the magnetic field to 0.67, in this case the trajectory of the charge should pass the point (7, -2). Calculate the radius of the circular trajectory of the particle.

17. Use the magnetic filed with different magnitudes, and then switch the direction of the magnetic field and try again; describe the result of your observations (in all experiments particles enter the magnetic field with the same speed).

Part II: Measuring charge to mass ratio of the electron (like Lord Thompson did!)

Physical constants are necessary for solving many physics problems. Some examples of such constants are the speed of light, c, and the electron mass, m_e. Fundamental physical constants are universal since their values are believed to be the same regardless of the time or place in the Universe. Some constants can be measured individually, but experiments usually yield only the values of combinations of constants (for example e/m_e or e/hc). In this experiment, you will measure the combination e/m_e. The technique involves the motion of charged particles in a magnetic field. It should be noted that the value of e/m_e is very precisely known to be $(1.7588047 \pm 0.0000049) \times 10^{11}$ C/kg (Coulomb/kilogram). Although the magnetic field used in this lab is known to a far smaller precision, you should be able to obtain correctly the first few decimal places of e/m_e.

In the following experiment (measuring the charge-to-mass ratio e/m_e for an electron), the apparatus is arranged so that the force is always perpendicular to *v* and *B*. As a result, the charged particle moves in a curved path in a plane perpendicular to *B*.

APPARATUS

⚐ Helmholtz coils ⚐ 35V power supply
⚐ e/m tube ⚐ DPDT switch
⚐ High voltage power supply ⚐ Keithley Multimeter (or equivalent)

The apparatus consists of a cathode ray tube (CRT) mounted between a set of Helmholtz coils which produce the magnetic field. The CRT contains an "electron gun" which shoots out a stream of electrons along the axis of the CRT as shown in Figure 1.

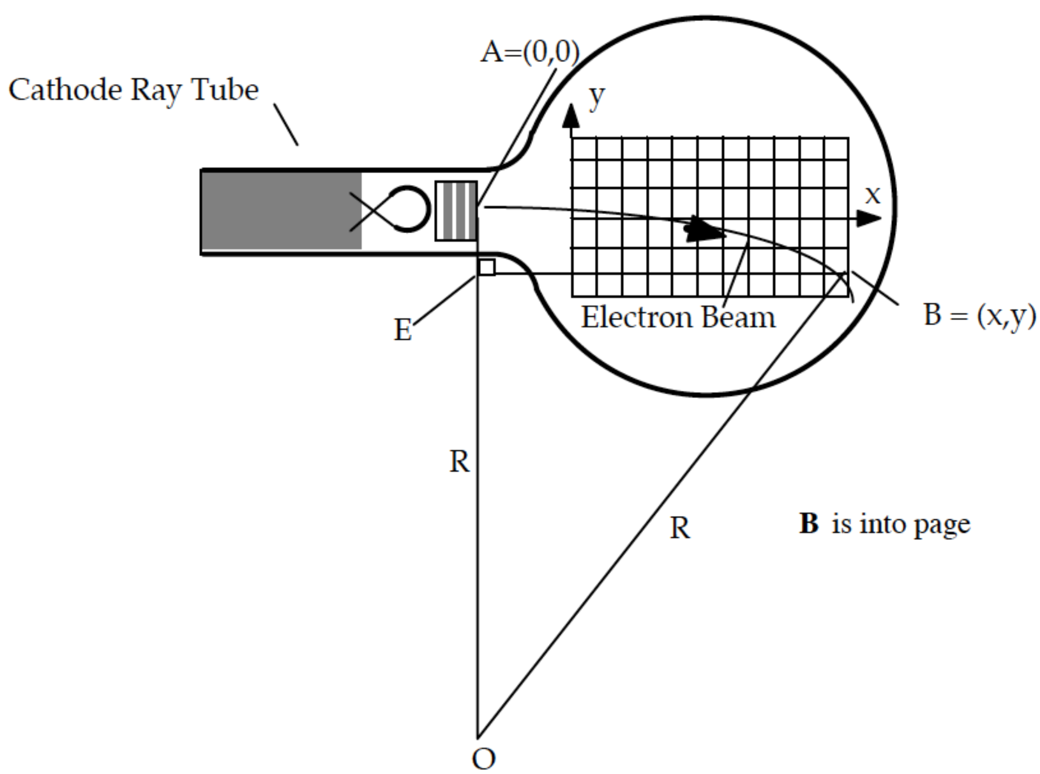


Figure 1. Schematic of Cathode Ray Tube (CRT).

The electrons are accelerated inside the gun by a potential difference, V, which is applied to the CRT by a power supply.

1. From this point forward we will use just V to label ΔV. The potential difference $\Delta V = V$ between the electrodes creates the electric field which accelerates the electrons. To relate the potential difference and the kinetic energy of the electrons you will use … (select <u>one</u> statement which *fits the best*)

[ ] the law of conservation of charge [ ] Coulomb's law [ ]Newton's first law

[ ]Newton's second law [ ]Newton's third law [ ]Newton's law of gravity

[ ] the law of conservation of energy (or work-kinetic energy theorem)

[ ] law of conservation of linear momentum

[ ] law of conservation of angular momentum

[ ] the expression for the tangential acceleration of the charge

[ ] the expression for the centripetal acceleration of the charge

2. Assume that the initial kinetic energy of the electrons is zero and derive the expression for the speed of the electrons v as a function of the potential difference V. This expression allows you to regulate the speed of the electrons as they travel in the magnetic field by adjusting the potential difference between the electrodes of the CRT (note: this expression also involves e, and m_e).

The stream of electrons passes through a phosphorescent screen creating a luminous line along its path.

The magnetic field of the Helmholtz coils is perpendicular to the screen and causes the path of the electrons to be an arc of a circle. The (x, y) grid markings on the screen are used to determine the radius of the electron path.

Refer to Figure 1 for the geometry used to convert (x, y) values along the electron's path into its radius.

Assume that the electron enters the magnetic field at point A with coordinates (0,0) and exits at point B with coordinates (x, y).

3. Write the expression you can use to find the radius of the trajectory R.

4. Using all of the expression above (starting from the ones in part 9 on page 3), derive the equation for the charge-to-mass ratio e/m_e of the electron ***only*** in terms of R, B, and V (***only***!!) Here: B is the magnetic field of the Helmholtz coils, e and m_e are the electron's charge and mass, V is the potential difference applied to the CRT, and R is the radius of the trajectory which is related to selected coordinates of the electron's path on the CRT grid, (x, y**). In SI units, B will be in Teslas, R, x and y in meters, and V in volts.** Use the symbol e for the magnitude of the electron charge.

A schematic of the Helmholtz coil geometry is shown in Figure 2.

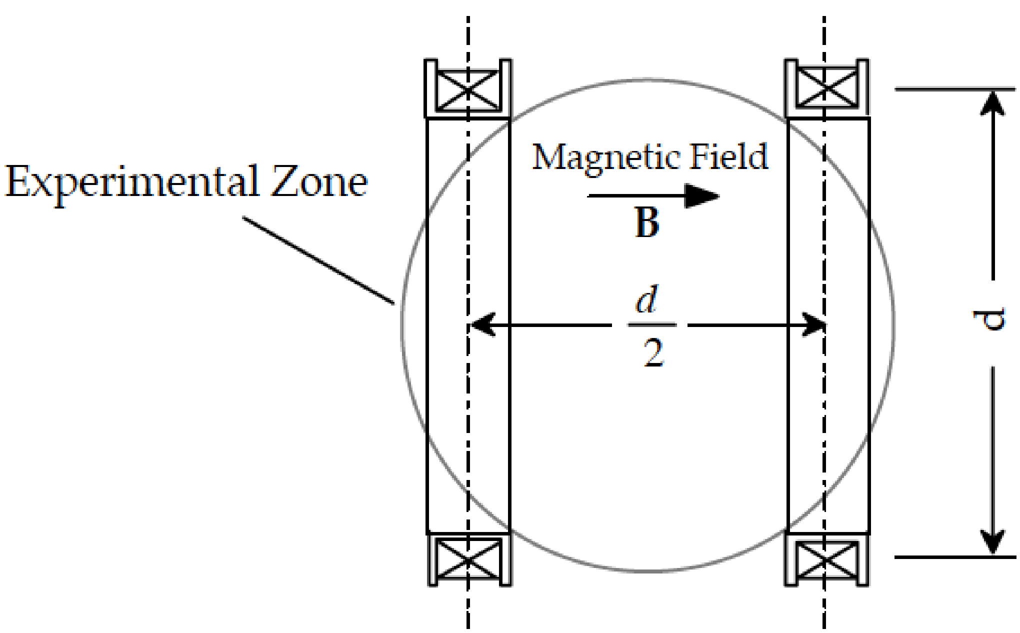


Figure 2. The Helmholtz Geometry (end view of coils).

As current passes through the Helmholtz coils, a magnetic field is generated. The field in a region near the center is nearly uniform (if the separation of the coils is equal to half of their diameter). Such an arrangement is named after its inventor, Helmholtz. Although the magnetic field strength decreases with distance along the axis from one coil, the sum of the fields from the two coils is nearly constant in the region between them. Variation in the field off the axis may have a small effect on your results. **The magnetic field (in the unit of Tesla!)** at the center of these particular Helmholtz coils is given by

$$|\boldsymbol{B}| = 4.23 \times 10^{-3} \times \boldsymbol{I} \quad \text{(assume SI units)}$$

where ***I* is current through the coils in amperes** (in the lab you are able to measure and regulate this current).

The magnetic field strength, *B*, can be changed by adjusting the current passing through the coils. The direction of the magnetic field can be reversed by reversing the direction of the current (using the switch).

PROCEDURE

Examine your apparatus and check the Helmholtz geometry. Are the coils aligned parallel with each other? Do they have the correct separation, i.e. 1/2 the coil diameter? If not, loosen the plastic knobs at the coil bases, align, and re-tighten the knobs to hold coils in position.

Connect the Helmholtz coils, ammeter, current direction switch, and the TEL 800 power supply (select dc) as shown in Figure 3 (if the apparatus is already wired up, please do not change the connections).

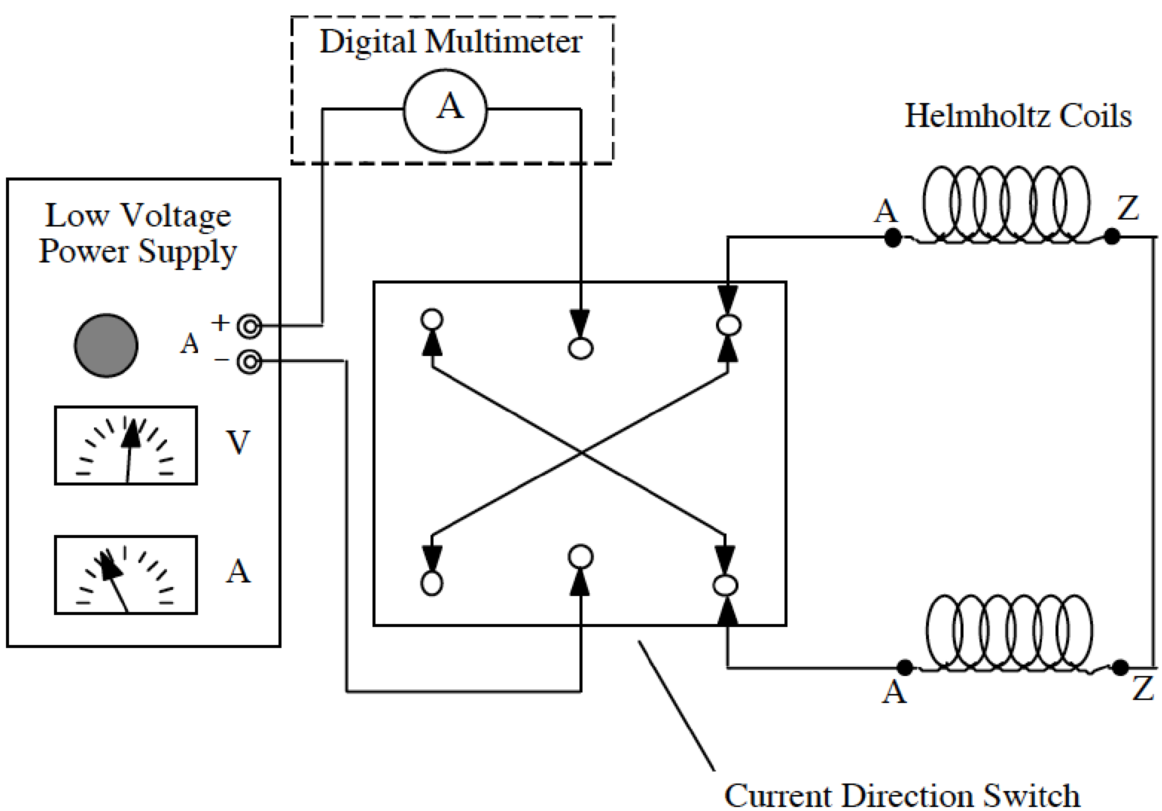


Figure 3. Wiring Diagram for Helmholtz Coils

Be sure the switch is wired as shown.
Since you want the current in both coils to be in the same direction, make sure that the “A” and “Z” connections are wired properly. The Keithley multimeter (or another type of a multimeter , but not a power supply) should be used as the ammeter in this circuit to obtain accurate current readings.

Connect the CRT and TEL 813 high voltage power supply as shown in Figure 4.

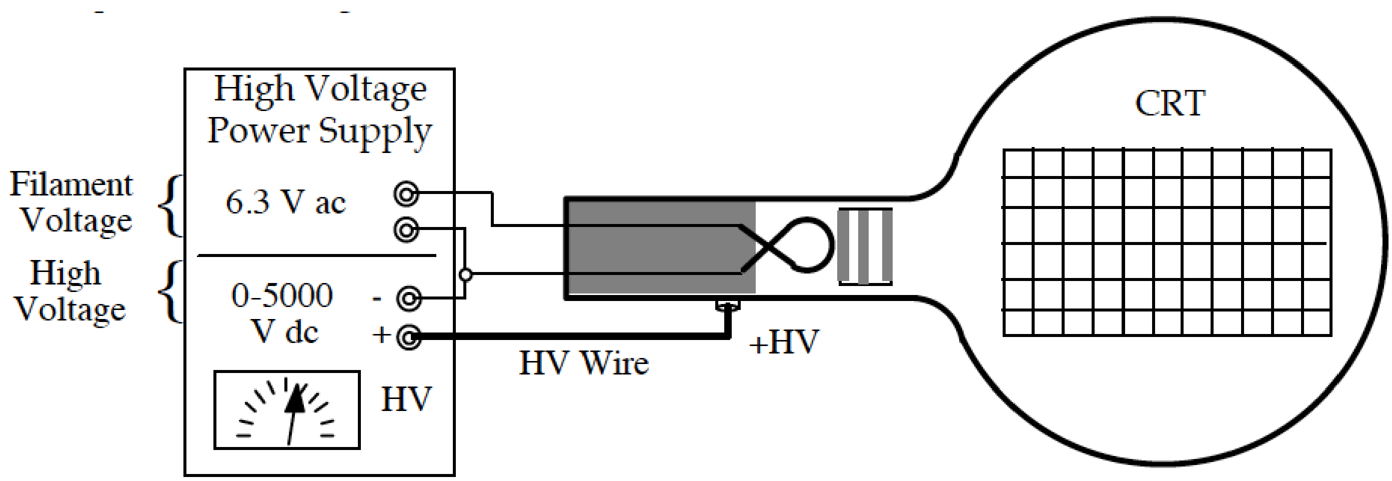


Figure 4. CRT-Power Supply Connections.

The 6.3V connection provides the heat required for electron emission from the tube filament. Be sure to use a high voltage wire in connecting the (+) HV terminal to the CRT. Do not use the Center Tap (CT) terminal. The two negative (—) terminals (-HV and -6.3 V) of the TEL 813 power supply should be connected together and to the (—) side of the CRT filament. When applying high voltage to the CRT, always start from low voltage and then slowly increase the voltage until the electron beam becomes visible. Watch the meter on the high voltage power supply and try do not exceed 3.5 kV, or you may damage the CRT. Keep the high voltage set at minimum except when making measurements.

Have the TF check your circuit wiring before proceeding. Turn on the TEL 813 high voltage supply and increase the voltage across CRT (voltage across CRT is measure relative to 0, and will be also called a CRT potential, *V*) until the electron beam is visible. **The Helmholtz coils should be off for now.**

5. Take a bar magnet and bring one of each poles close to the tube. Describe the shape of the beam. Explain the shape of the beam, provide a diagram which clearly shows the direction of the magnetic field from the magnet, the velocity of electrons, the acceleration of electrons, and state which pole (N, or S) is close to the tube. Flip the magnet and observe how does it effect the beam now.

Turn on the TEL800 power supply connected to the Helmholtz coils. Increase the current in the coils until the electron beam passes exactly through a convenient point (x, y) on the CRT grid. A coordinate around (10, 2) works well, but you may find a different point more convenient. Record the CRT potential, *V*; the current in the Helmholtz coils, *I*, measured with the Keithley multimeter; and your selected (*x*, *y*) coordinates.

$V =$ $\qquad$ $I =$ $\qquad$ $x =$ $\qquad$ $y =$

6. Calculate *R*, *B* and the charge-to-mass ratio e/m_e of the electron.

7. Now change the direction of the current in the Helmholtz coils (and thus the magnetic field direction) by reversing the switch. Do NOT change the CRT potential.

Adjust the current until the electron beam passes through *exactly the corresponding (symmetrical) point*, e.g. **(*x*,-*y*)**, on the opposite half of the grid. Record the CRT potential, *V*; the current in the Helmholtz coils, I, measured with a multimeter (usually the Keithley multimeter); and your selected (x,y) coordinate.

$V =$ $\qquad$ $I =$ $\qquad$ $x =$ $\qquad$ $y =$

8. Calculate again the charge-to-mass ratio e/m_e of the electron.

12. Compare the two values you have found for the charge-to-mass ratio e/m_e of an electron. Is there some difference? If yes, explain what may be causing the difference (think of *other* possible sources of a magnetic field).

Calculate the average value of e/m_e, compare with the currently accepted value.

Set the CRT potential to 2 kV.

13. Changing the current in Helmholtz coils also changes the magnetic field B and the radius of the trajectory, *R*. Derive an algebraic expression which relates these two variables. Sketch the graph you would expect for the radius, *R*, of the trajectory as a function of the magnetic field, *B*. Then sketch the graph you expect for the radius, *R*, of the trajectory as a function of the *inversed* magnetic field, B^{-1}.

14. For <u>*four*</u> different values of current *I*, measure the (*x*, *y*) coordinates of the beam.

I	*x*	*y*

15. For <u>*four*</u> measured values of current *I and* (*x*, *y*) coordinates calculate the corresponded values of *R*, $|B|$, and $|B|^{-1}$. On a "graph paper" on the next page plot the graph for radius *R* as a function of the inversed magnetic field strength $|B|^{-1}$ and compare with your prediction.

I	*x*	*y*	*R*	$\|B\|$	$\|B\|^{-1}$

Equipment

Unit 4: (12 tables): a computer, e/m apparatus, computer, a bar magnet

Unit layout

L4: 140 min;

PI: 70 min;

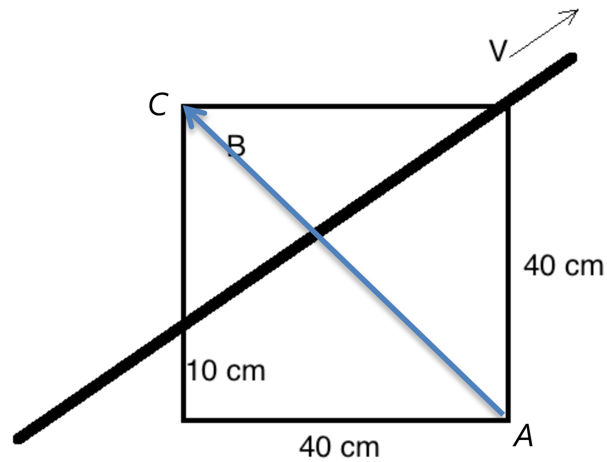
PII**:** 70 min;

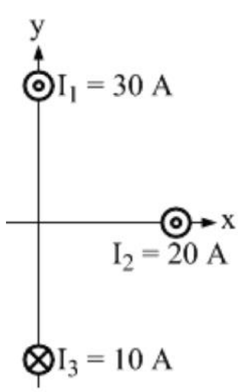
PE4: 60 min.

Breaks when needed

Practice Exercise 4:

(A) A copper wire is 2 m long and is partly placed in region with a uniform magnetic field as shown in the picture on the right (the region with the magnetic field is a square 40 cm on each side and the magnetic field points *in the direction of a long diagonal arrow from point A to point C*; $|B| = 0.5$ T). There are $50 \cdot 10^{18}$ electrons traveling through the wire each minute. Arrow *V* indicates the *velocity* of the electrons in the wire. Find the magnitude and direction of the force acting on the wire from the magnetic field.





(B) In the picture on the left each wire is located 50 cm from the origin. Calculate the magnitude of the net magnetic field at the location of wire 2 (hint, wire 2 does not act on itself), and then calculate the magnitude of the net force acting on 1 m of wire 2.