

## VIIA. THE E/M EXPERIMENT

### Equipment List:

Pasco E/M set-up  
 Cenco power supply  
 assorted permanent magnets  
 tensor lamp  
 assorted bananas  
 meter sticks

**Purpose:** To explore the trajectory of moving charge in a uniform magnetic and to calculate the ratio of the charge of an electron to its mass.

**Background:** This experiment duplicates the results obtained in 1897 by J.J. Thomson, the "discoverer" of the electron. At that time no one could measure the value of the charge of an electron or its mass as isolated quantities, but by a relatively simple experiment one could measure the *ratio* of the electron's charge to its mass,  $E/M$ , and knowing this much is useful and better than nothing.

**Theory:** A detailed discussion of the theory of a similar experiment can be found in Tipler's 5th edition physics text, page 837.

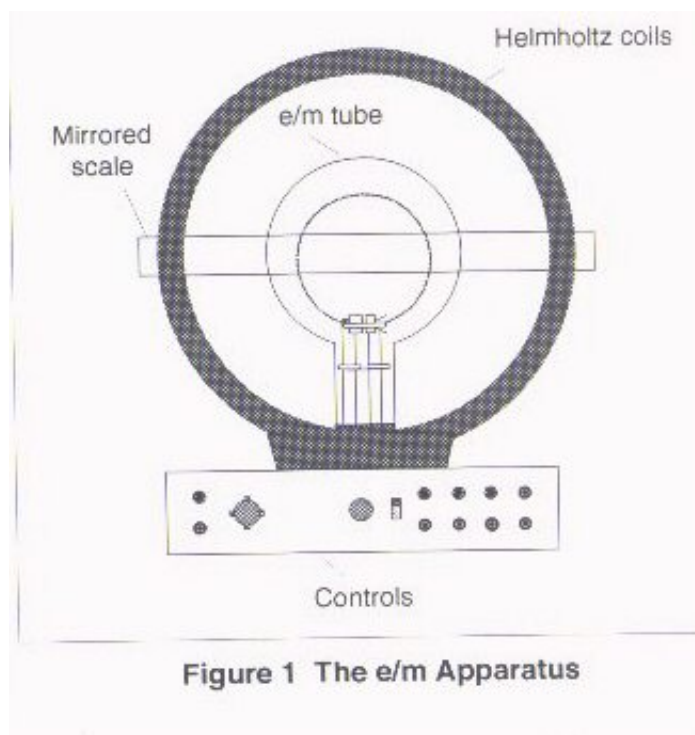


Figure 1 The e/m Apparatus

Refer to the figure above during the following discussion.

If all three vectors are mutually perpendicular to one another, the magnitude of the force on a moving charge

within a magnetic field is given by:

$$F_B = evB$$

The kinetic energy gained by a charge,  $e$ , after moving through a potential difference  $V$  is:

$$KE = eV$$

From the definition of kinetic energy, you should show that the final speed of the charge after moving through the potential difference is:

$$v = (2eV/m)^{1/2}$$

The magnitude of the magnetic field produced by the Helmholtz coils in terms of the current  $I$ :

$$B = [\mu_0 I] / [(5/4)^{3/2} a]$$

where  $\mu_0$  is the magnetic permeability and  $a$  is the radius of the the Helmholtz coil,  $N$  is the number of turns (130).

From Newton's laws and circular motion we know:

$$F_{\text{net}} = mv^2/r$$

In this case the net force acting on the charge is only one force, the magnetic force  $F_B$  (why can we ignore gravitational effects?).

Supply the necessary steps to show that:

$$e/m = [2V(5/4)^3 a^2] / [\mu_0 I r]^2$$

### Introduction:

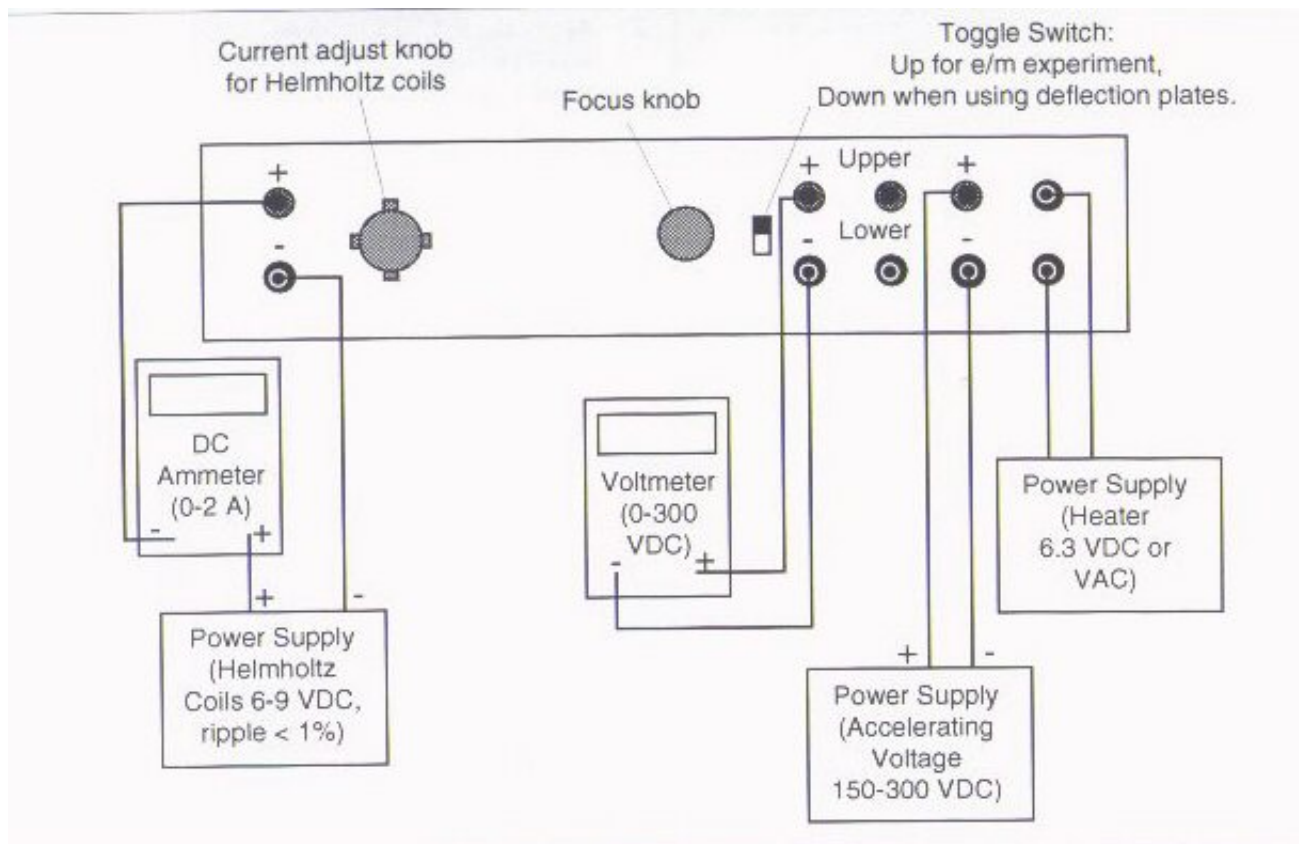
In this experiment two devices are used, a CRT (cathode ray tube) also known as an "electron gun" and a special arrangement of two identical coils of wire separated by a distance equal to their radii, Helmholtz coils. The CRT produces a beam of electrons within a glass tube filled with low pressure Helium gas ( $10^{-2}$  mm Hg). The kinetic energy of the electrons in the beam (and therefore their speed) can be determined by knowing the "accelerating voltage" of the CRT tube. The special geometrical arrangement of the Helmholtz coils produces a uniform magnetic field when a current passes through the coils.

The apparatus provided by Pasco contains the CRT *and* the Helmholtz coils together on one stand. In this experiment *both* of these devices, the CRT and Helmholtz coils, are controlled by the Cenco power supply.

The CRT needs two sources of power; one source supplies a small AC voltage of about 6.3 volts to the heater element which "boils" the electrons from the cathode plate (this process is called "thermionic emission"). The electrons are next focused into a beam by the second power supply for the CRT, the accelerating voltage, which is a DC source of between 150 and 300 volts. The higher the accelerating voltage the longer the beam becomes.

### Procedure:

1. Connect your Cenco power supply to the E/M apparatus as shown in the diagram below. The Cenco power supply sends two voltages to the CRT and one voltage to the Helmholtz coils.



## THINGS TO BE CAREFUL ABOUT!

**The heater element for the CRT must not exceed 6.3 volts AC.**

**The accelerating voltage for the CRT should not exceed 300 volts DC.**

**The current through the Helmholtz coils must not exceed 2 amps.**

**The electron beam from the CRT heater element must not be allowed to touch the glass containing bulb for an extended time.**

2. **Make sure all the power dials are turned to their zero level and then** turn the Cenco power supply on. The AC heater voltage is automatically turned on to the correct voltage; after about two minutes you should see the heater filament inside the tube glow red indicating that it is heating up correctly. Note that you can rotate the tube by *gently* turning it at its base; do not be afraid of holding the tube, as long as you don't grab it too tightly you will not break it and there is no danger of an electrical shock around the tube. **Do not remove the bulb by lifting it from its holder!**

NOTE: There are two meters on the front of the Cenco power supply. The meter on the left is a voltmeter and measures the accelerating voltage. The meter on the right is an ammeter and measures the current through the Helmholtz coils. Remember, **these two meters measure different power supplies.**

3. After you have observed the reddish glow of the heater filament, you can turn up the accelerating voltage to about 150 volts and produce a bluish colored, straight beam. If you apply enough voltage the beam will hit the side of the glass tube; **don't let the beam strike the glass for a long time as it will eventually wear a hole in the glass tube! (And the glass tube is quite expensive.)**

4. Rotate the glass tube so the beam moves out toward you. Take the permanent magnet and move it near the beam. Note how the beam deviates under the influence of a magnetic . Increase the accelerating voltage (**but no further than 300 volts!**) and continue to play with the permanent magnet. Knowing the structure of the magnetic for a permanent magnet, see if you can confirm the three step right hand rule relation between the magnetic field, the velocity of the charge, and the magnetic force on the charge.

5. Now you will create a magnetic field with the Helmholtz coils and this will deviate the beam; you no longer need the permanent magnet. **Make sure the slide switch near the focus knob on the E/M apparatus is pushed up to the E/M position.** Turn up the power to the Helmholtz coils (no more than 2 amps on the meter). There are two dials that control the current to the Helmholtz coils. One dial is on the left front of the E/M apparatus and is labeled "current adjust knob for Helmholtz coils"; turn this dial to a "nine o'clock" position and leave it there (turn it back to zero when you are finished with the experiment). The second dial is found on the left front of the Cenco power supply; this is the dial you will use to adjust the current to the coils. After you turn the current up to about 1 amp, the beam should deviate from its normally straight line path. **Do not turn this current to more than 2 amps.** Rotate the tube and note the helical trajectory of the beam; see if you can explain the nature of this trajectory.

### Performing the experiment:

1. Rotate the glass tube so that the circular beam is parallel to the mirrored ruler behind it. When this is so, the beam will not have a helical trajectory, only a circular one.

2. Adjust the accelerating voltage and the Helmholtz current until you achieve a full circle beam trajectory where the horizontal diameter of the circle is just in front of the mirrored ruler. **The zero value on the ruler should be at the center of the circular beam**, if that is not so, adjust the accelerating voltage and Helmholtz current until it is correct. You may also use the focus knob on the E/M apparatus to enhance the visual quality of the beam. Record the values of the accelerating voltage and the Helmholtz current that produce the best circular trajectory.

3. Now measure the radius of the circular beam. This is not easy because the beam disperses and is not just a thin line. To increase the accuracy of your measurement, measure the radius on the right side of the center of the circle and the left side and take an average value. Due to the sum of many systematic errors, it turns out that you should try to measure a larger radius than a smaller one if you have the choice.

Use the mirrored properties of the ruler to minimize parallax error. To use the mirror, align the image of the beam with the real beam *and then* read the position on the ruler.

4. Measure the radius of one Helmholtz coil,  $a$ , with the meter stick.

### Calculations:

Given the value of the charge of an electron  $e = 1.60 \times 10^{-19}$  coulombs and the electron's mass  $m = 9.11 \times 10^{-31}$  kilogram, calculate the value of  $E/M$  to three significant figures. Call this value the accepted value.

Using the equation derived in the theory section above, calculate the value of  $E/M$  from your four measurements: the accelerating voltage, the Helmholtz current, the average radius of the beam, and the radius of one Helmholtz coil.

As well, calculate the value of the magnetic field in teslas. Compare this value to the earth's average magnetic strength, 0.5 gauss (where 1 gauss =  $10^{-4}$  tesla). Does the Helmholtz magnetic field *have* to be greater than the earth's in this experiment?

**Conclusion:**

Discuss the accuracy of your results and ways to minimize or eliminate any systematic errors.

**Tips:**

Measure the outside radius of the beams trajectory to minimize systematic errors.

Keep the accelerating potential above 250 volts.

Try for a beam radius of around five centimeters.

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Below is a schematic for the more technically inclined.

