Phys 112L
Spring 2020

Laboratory 6: Moving Charges and Magnetic Forces – Prelab

1 Accelerating electron

An electron is initially at rest on a metal plate. Another plate is parallel to this and contains a hole through which the electron can pass. The potential difference between the plates is ΔV. Show that the speed with which the electron passes through the hole satisfies

$$v^2 = \frac{2e\Delta V}{m}.$$

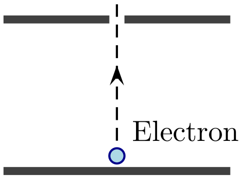

Figure 1: Electron accelerator

2 Electron moving perpendicular to a magnetic field.

At one instant an electron in a uniform magnetic field moves as illustrated in Fig. 2. Determine the direction of the force exerted by the magnetic field on the electron. Describe the trajectory of the electron (e.g. straight, curved, parabolic, circular, etc, . . .).

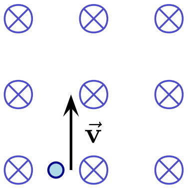

Figure 2: Electron in a magnetic field.

3 Electron orbit in a uniform magnetic field

An electron moves in a circle, with radius r, perpendicular to a magnetic field with speed v and centripetal acceleration given by $a = v^2/r$. Apply Newton's second law to eventually show that

$$\frac{e}{m} = \frac{v}{Br}$$

where B is the magnitude of the magnetic field.

Laboratory 6: Moving Charges and Magnetic Forces – Activity

1 Forces Exerted by Magnets on Currents: Qualitative Investigations

Much of this exercise is based on a similar exercise in *Tutorials in Introductory Physics* by McDermott and Shaffer.

a) A pivoting wire can be connected to an insulating stand and support as illustrated in Fig. 3. The wire is connected to a battery and switch. Connect this circuit **without closing the switch.**

b) **Predict** (i.e. do not use the apparatus) the direction of the force exerted by the magnet on the wire, provided that the wire is connected to the battery as illustrated and that the switch is closed. Explain your answer.

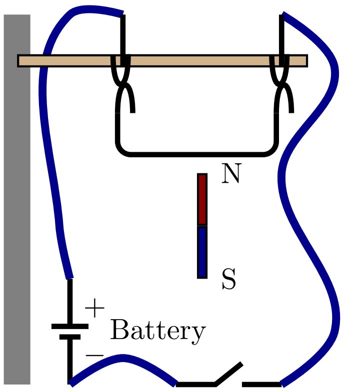

Figure 3: Current and magnet apparatus.

Connect the circuit above and use it to check your prediction. If your prediction was incorrect explain how to correct it.

c) Suppose that the battery in Fig. 3 was reversed (this can be done by reversing the connections). **Predict** the direction of the force exerted by the magnet on the wire. Explain your answer.

Check your prediction by building the circuit and observing the force. If your prediction was incorrect explain how to correct it.

d) The circuit is reconnected as before but the magnet is reversed as illustrated in Fig. 4. **Predict** the direction of the force exerted by the magnet on the wire. Explain your answer.

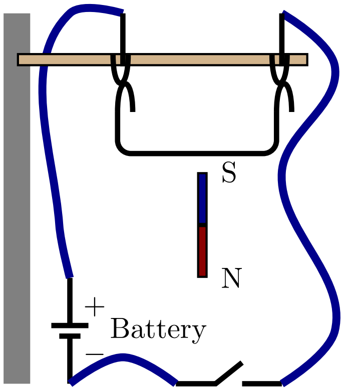

Figure 4: Current and magnet apparatus.

Check your prediction by building the circuit and observing the force. If your prediction was incorrect explain how to correct it.

e) The circuit is reconnected as before but the magnet is reversed as illustrated in Fig. 5. **Predict** the direction of the force exerted by the magnet on the wire. Explain your answer.

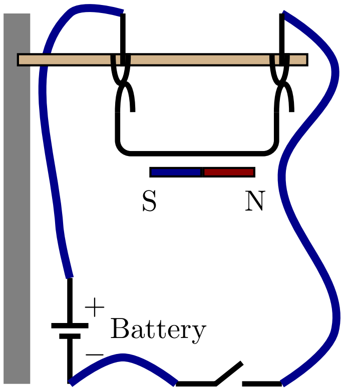

Figure 5: Current and magnet apparatus.

Check your prediction by building the circuit and observing the force. If your prediction was incorrect explain how to correct it.

2 Charge to Mass Ratio for an Electron: Theory

Whenever a subatomic particle, such as the electron, has been discovered, an immediate question has been what its charge and mass are. Almost always these questions are partly addressed by firing the particle into a region in which there is a known uniform magnetic field. It emerges that with relatively elementary physics one can easily determine the ratio

$$\frac{\text{particle charge}}{\text{particle mass}}$$

based on the particle trajectory as it passes through the magnetic field. In this experiment you will apply this technique to electrons and will determine the ratio e/m where e is the magnitude of the electron charge and m the electron mass.

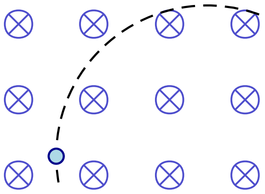

Figure 6: Electron orbit in a magnetic field.

In this experiment you will accelerate an electron through a known potential difference. The electron enters a region of approximately uniform magnetic field with its velocity perpendicular to the magnetic field as illustrated in Fig. 6. Applying Newton's second law to the situation predicts that the electron will follow a circular path with constant speed. This satisfies

$$\frac{e}{m} = \frac{v}{Br} \tag{1}$$

where v is the electron's speed, r is the orbital radius of the circle and B is the magnitude of the magnetic field.

Unfortunately it will not be possible to measure the electron speed directly; this will be inferred indirectly by knowing the potential difference, ΔV, through which the electron is accelerated prior to undergoing circular motion. However, applying conservation of energy to this situation gives

$$v^2 = \frac{2e\Delta V}{m}. \tag{2}$$

Combining Eqs. (1) and (2) gives

$$\boxed{\frac{e}{m} = \frac{2\Delta V}{B^2 r^2}.} \tag{3}$$

The approximately uniform magnetic field is produced by providing an adjustable and measurable current I through a pair of Helmholtz coils and has magnitude

$$\boxed{B = \frac{\mu_0 8NI}{5\sqrt{5}\,a}} \tag{4}$$

where $\mu_0 = 4\pi \times 10^{-7}\,\mathrm{N/A^2}$, N is the number of turns in each coil, I the current through the coils and a is the radius of the coils. For this apparatus, the number of turns is 130.

a) Predict what will happen to the electron's path if the current to the Helmholtz coil is increased while the accelerating electric potential difference is held constant.

b) Predict what will happen to the electron's path if the accelerating electric potential difference is increased while the current to the Helmholtz coil is held constant.

3 Charge to Mass Ratio for an Electron: Experiment

The instructor will set up the apparatus with an accelerating potential difference is between 250 V and 350 V.

a) Adjust the coil current so that the electrons are deflected in a circle. Keep the accelerating potential difference constant and increase the current through the Helmholtz coils. Observe the radius of the path followed by the electrons. Is this consistent with your earlier prediction? Keep the current through the Helmholtz coils constant and increase the accelerating potential difference. Observe the radius of the path followed by the electrons. Is this consistent with your earlier prediction?

b) Measure and record the radius of the Helmholtz coils.

c) Adjust the accelerating potential difference to 250 V. Adjust the Helmholtz coil current so that the radius of the electron path is 4 cm (to the outer edge of the circle). Measure and record the Helmholtz coil current and the accelerating potential difference.

d) Increase the accelerating potential difference by 20 V and adjust the Helmholtz coil current so that the radius of the electron path is 4 cm. Measure and record the Helmholtz coil current and the accelerating potential difference. Repeat this three more times.

e) For each value of Helmholtz coil current, compute the magnetic field produced by the Helmholtz coils. Use this and the data for the radius and accelerating potential difference to determine e/m.

f) Determine the average value for e/m. Express your result in standard scientific form,

$$\frac{e}{m} = \underline{x}.\underline{xx} \times 10^{\underline{zz}} \text{ units.}$$

Determine the ratio using the best known values for e and m. How does your result compare to this?

4 Conclusion

Briefly describe the main finding of the experiment of part 3. When answering this imagine that prior to the experiment no-one knew either the electron charge or its mass.