MAGNETIC DEFLECTION OF ELECTRONS

In this experiment we shall study magnetic deflection of electrons using the same CRT as was used to study electric deflection. Instead of applying a deflecting potential to the plates we will place solenoids nearby to provide a magnetic field and study the relationship between the solenoid current and deflection of the electron beam. We shall also measure the Earth's magnetic field. However, expect only good approximate agreement with the literature value of about 5 x 10^{-5} T for the Earth's magnetic field in Mississippi because of possible modifications by nearby steel and magnets in the building.

As in the experiment on electric deflection, electrons are accelerated through a potential difference $V_{acc} = V_B + V_C$, and thus obtain kinetic energy

$$\frac{1}{2} mv^2 = eV_{acc}$$

from which we may compute speed.

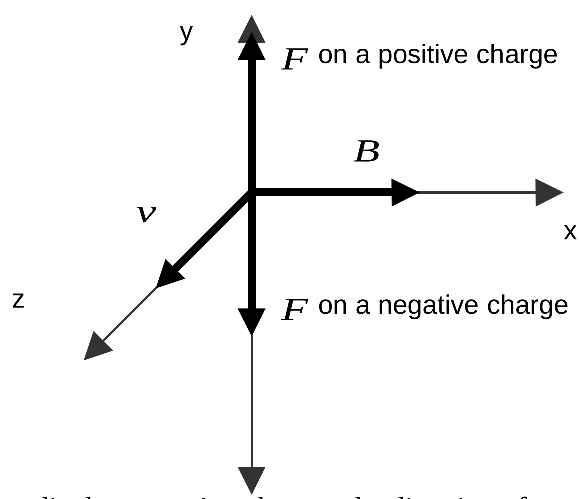
The magnetic force (F) acting on a charge (q) moving (v) in a magnetic field (B) is given by the vector equation

$$\mathbf{F} = q\,(\mathbf{v} \times \mathbf{B})$$

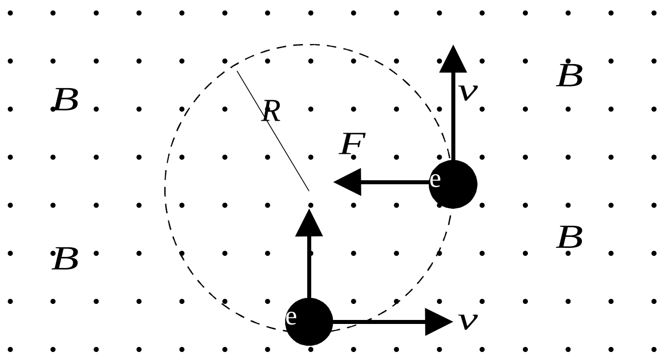
The magnitude of this force is $F = qvB\sin\theta$ where θ is the angle between the velocity vector and the magnetic field vector. The direction of this force is perpendicular to the plane containing the velocity vector and the magnetic field vector. Of course there are two directions perpendicular to this plane; the following rule applies.

Rotate the velocity vector into the magnetic field vector through the angle less than 180°. The direction of advance of a right-handed screw is the direction of force on a positive charge. The force on a negative charge is opposite this. (See your text for other statements of the right-hand rule.)

Figure 1:
Right Hand Rule



The force being perpendicular to motion changes the direction of motion but not the speed. We can see this from the fact that work changes kinetic energy but no work is done since force is perpendicular to displacement at all times. If the velocity is perpendicular to the magnetic field, the resulting motion is circular, as shown in figure 2.



Magnetic Field ($\boldsymbol{B}$)
is out of the page

Figure 2:
Circular Motion Effect

Using Newton's second law, F = ma, and the acceleration expression for circular motion, a = v^2/R, we get (since sin 90° = 1)

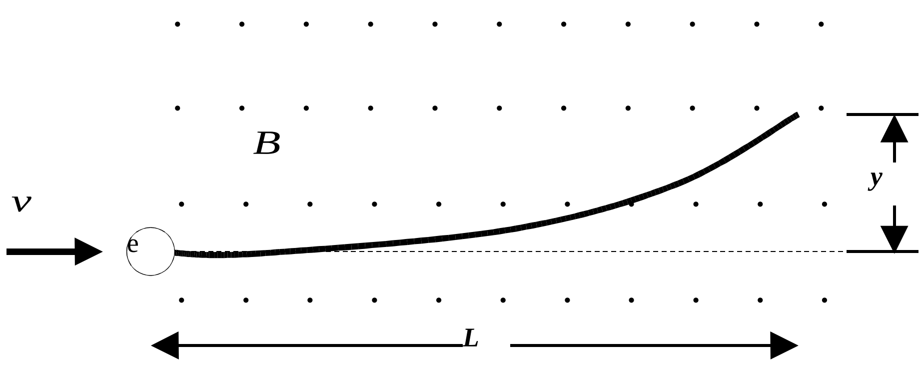
$$Bev = \frac{mv^2}{R}.$$

In this experiment we shall restrict motion to a very small fraction of the circle. For such restrictions the direction of motion doesn't change much, consequently the direction of force doesn't change much. We shall approximate the direction of force, and consequently acceleration, to be unchanged. With these approximations the lateral displacement y = ½ at^2.

From Newton's second law we get acceleration: $$a = \frac{F}{m} \quad \frac{Bev}{m}$$

and time from the expression: $$t = \frac{L}{v}.$$

Figure 3:
Electron's Movement



Magnetic field is out of page

Putting in these expressions for a and t we obtain:

$$y = \frac{ebL^2}{2mv}. \quad \text{(Equation 1)}$$

The magnetic field inside a long solenoid is given by

$$B = \frac{\mu_0 NI}{l}$$

where μ_0 is the magnetic constant ($4\pi \times 10^{-7}$ T m/amp), N is the number of turns of wire, I is the current, and ℓ is the length of the solenoid.

This experiment will be carried out between two solenoids instead of inside a long solenoid, consequently this magnetic field expression is approximate. It does, however, give the correct order of magnitude and the magnetic field is proportional to current. Now, since y is proportional to B and since B is proportional to I, y is proportional to I

$$y = (\text{constant})\ I.$$

The electrical connections to the CRT are shown in Figure 5 on the next page; they are the same as those in Figures 4 and 5 in ELECTRIC DEFLECTION OF ELECTRONS with the exception that the deflecting power supply is not used and both sets of deflecting plates are grounded.

You will recall from the experiment in electric deflection that the electron beam didn't hit the center of the screen when no deflecting potential was applied. This is a magnetic deflection due to the earth's magnetic field. If the axis of the CRT is along the earth's magnetic field this deflection is zero. ($F = evB \sin\theta$ [= 0 if $\theta = 0$]). Find this orientation by tilting and rotating the tube; then rotate the axis of the tube 90° to get maximum deflection. Measure the deflection and use Equation 1 to compute the earth's magnetic field. Here L is the distance from the second anode to the screen 14.5 cm for the tube type 3 BP1.

Next place the solenoids on opposite sides of the CRT as shown in Figures 4 and 5. Record deflection of the electron beam for several different solenoid potentials.

Remember that current is proportional to potential in most common metal conductors. Produce deflections in both directions. Plot deflection versus potential and comment on your experimentally determined relationship between current and deflection.

CAUTION: If your high voltage power supply is Model No. IP-32 (the older grey model), be sure to use the alternate connections.

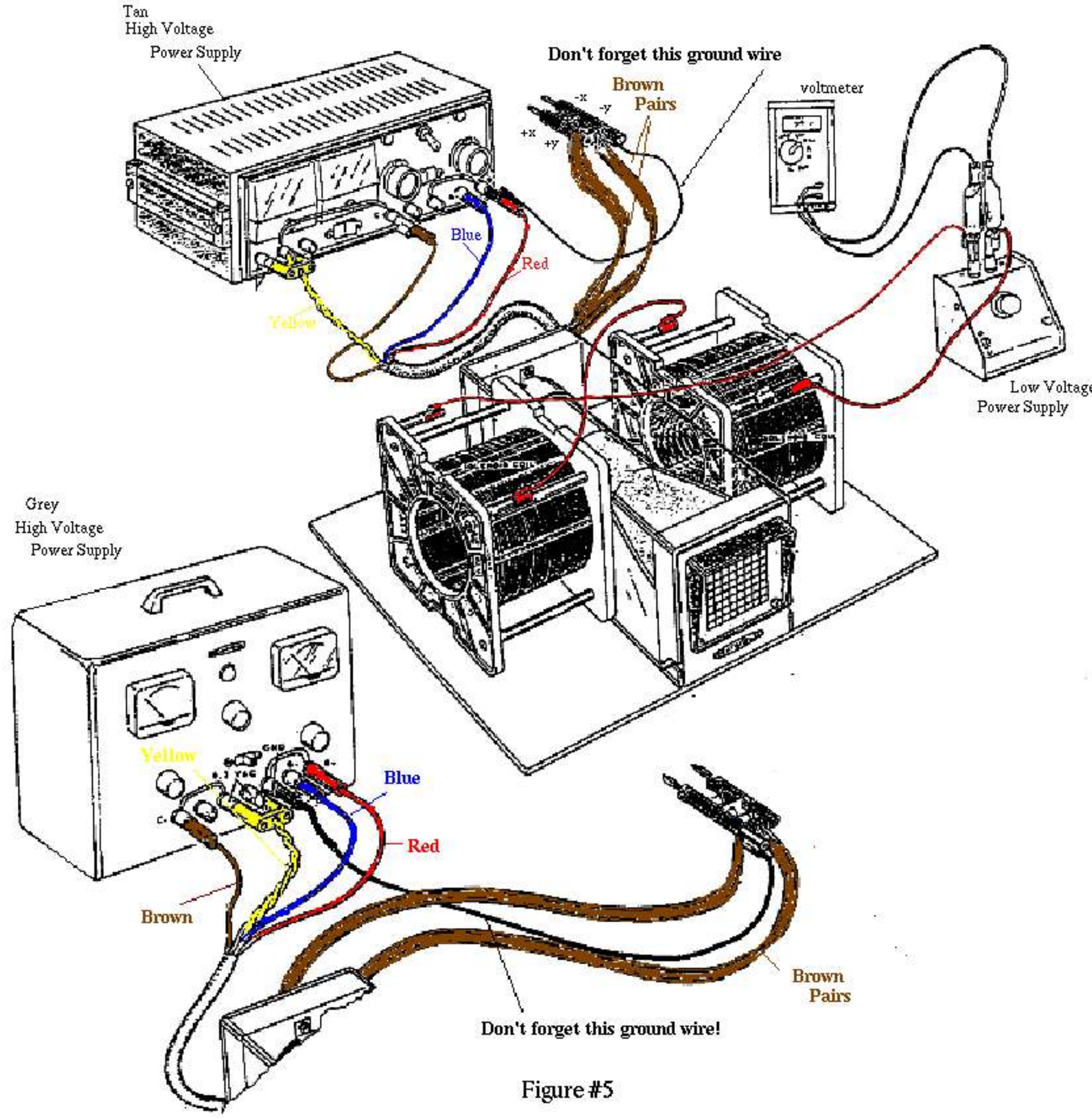


Figure #5

Note: In the production of these laboratory setups, Heath produced some solenoids that are wound in opposite directions to others. Their colors are slightly different. If two unlike solenoids are used, you should reverse electrical connection to one.

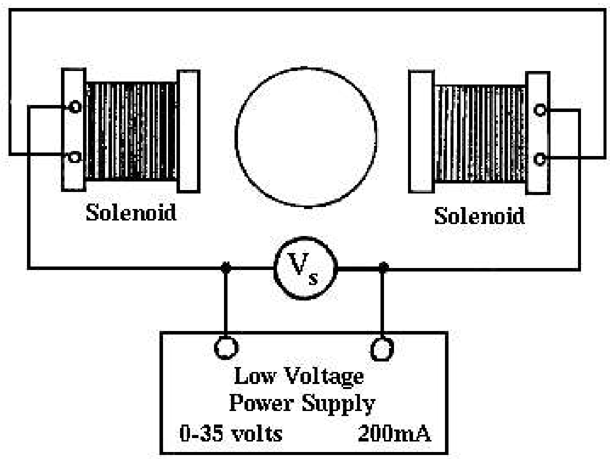


Figure #4