Magnetic Deflection of Electrons

Objective

Materials

1. Banana leads
2. Cathode ray tube
3. Fisher 1V/30V power supply (set to 30V)
4. Fluke digital multimeter
5. High voltage power supply
6. Solenoid coil

Introduction

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 Earth's magnetic field. However, expect only good approximate agreement with the literature value of about 5×10^{-5} T for Earth's magnetic field in Mississippi, because of possible modifications by nearby steel and magnets in the building.

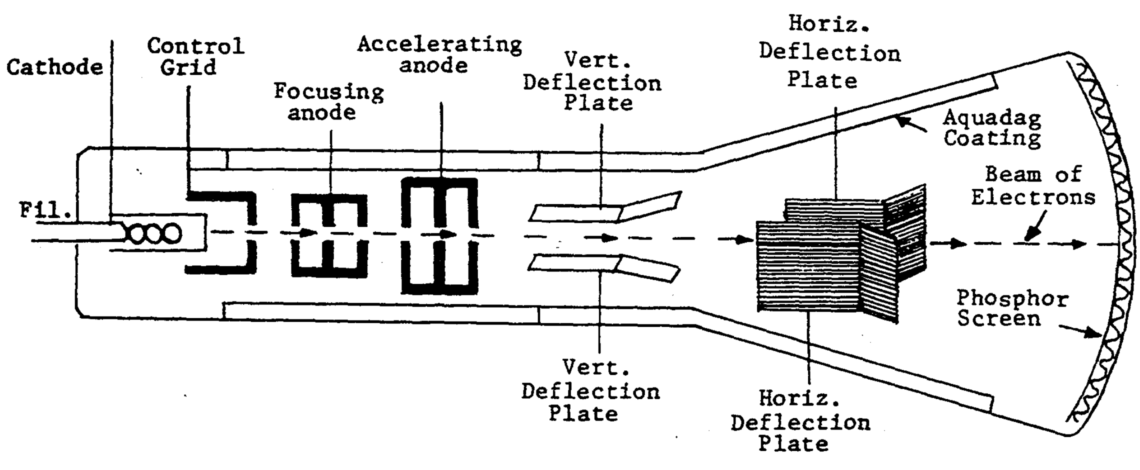

Figure 1: *CRT, as shown in the lab "Electric Deflection of Electrons".*

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

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

where e is the magnitude of the electron charge, from which we may compute speed. The magnetic force $\vec{F}$ acting on a charge of magnitude q moving with velocity $\vec{v}$ in a magnetic field $\vec{B}$ is given by the vector equation

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

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.

Right-Hand Rule

Rotate the velocity vector into the magnetic field vector through the angle that is 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”.)

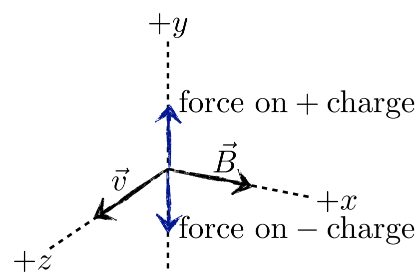

Figure 2

Because the force is perpendicular to the motion of the charge, the direction of motion changes but not the speed. We can see this from the fact that work changes kinetic energy but no work is done because force is perpendicular to displacement at all times. If the velocity is perpendicular to the magnetic field, the resulting motion is circular, as illustrated in Figure 3a.

Using Newton’s Second Law, $\vec{F} = m\vec{a}$, and the expression for centripetal acceleration under uniform circular motion, $a = v^2/R$. Now because $\sin 90° = 1$ we get

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

In this experiment we shall restrict motion to a very small fraction of the circle (see Figure 3b). 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 (thus acceleration) to be unchanged. With these approximations the lateral displacement $y = \frac{1}{2}at^2$.

From Newton’s Second Law we get the magnitude of the acceleration

$$a = \frac{F}{m} = \frac{evB}{m},$$

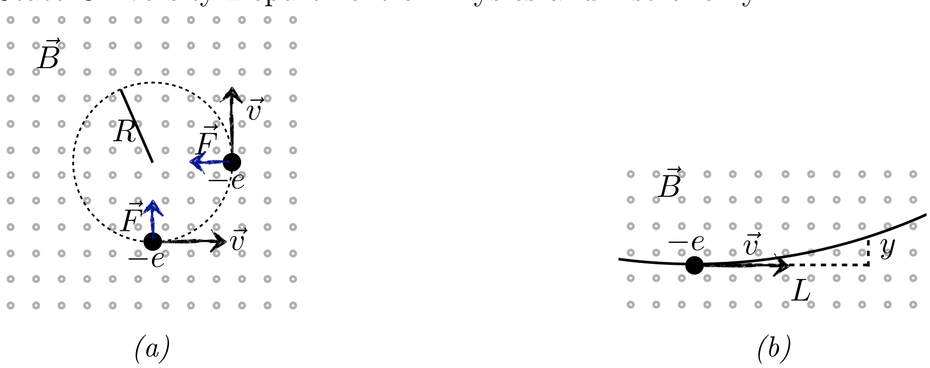

Figure 3: *The magnetic field $\vec{B}$ is out of the page.*

and we get the time from

$$t = \frac{L}{v}.$$

Substituting these expressions for a and t into ... we obtain

$$y = \frac{eBL^2}{2mv}. \tag{1}$$

The magnetic field inside a long solenoid is given by

$$B = \frac{\mu_0 N I}{\ell},$$

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

Procedure

This experiment will be carried out between two solenoids instead of inside a long solenoid, so 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 B is proportional to I, and (by Ohm's Law) I is proportional to the voltage V across the solenoids, y is therefore proportional to V:

$$y = (constant)V.$$

The electrical connections to the CRT are shown in Figure 5. *Note*: Connect all wires as shown, *except* the single brown wire that connects directly to the high voltage power supply; leave this wire unplugged until the power supply has warmed and the power supply has been switched from STANDBY to DC ON[1]. The electrical connections are the same as those in Figures 4 and 5 from "Electric Deflection of Electrons" with the exception that the deflecting power supply is not used and both sets of deflecting plates are grounded.

[1] This subtlety has nothing to do with the concepts involved in the experiment but is due to the equipment.

Caution: Use of the 400-V power supply comes with a risk of electric shock. To minimize this risk use the two following precautions: (a) switch the power supply to "Standby" before you interact with the wires at the front of the power supply, and (b) when circumstances prevent you from following precaution (a), only use one hand to interact with the wires at the front on the power supply (keep your other hand in your pocket!). Precaution (b) is intended to prevent any current from passing through your heart, should it pass through your body at all. Don't worry, just respect the equipment, and mind what you're doing.

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 Earth's magnetic field. If the axis of the CRT is along 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 by 90° to get maximum deflection. Measure the deflection, and use equation (1) to compute 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.

When you're finished, disconnect the single brown wire from the power supply *first*, before turning off the power.

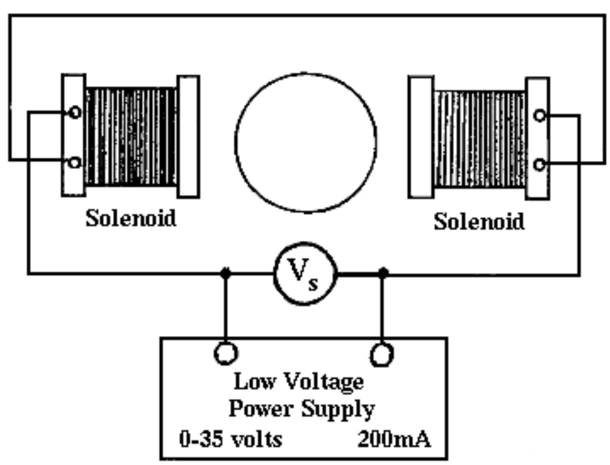

Figure 4

Note: In the production of these laboratory setups, Heath Company produced some solenoids that are wound in opposite directions to others; their colors are slightly different. If possible, use two coils of the same color; otherwise, if two unlike solenoids are used,

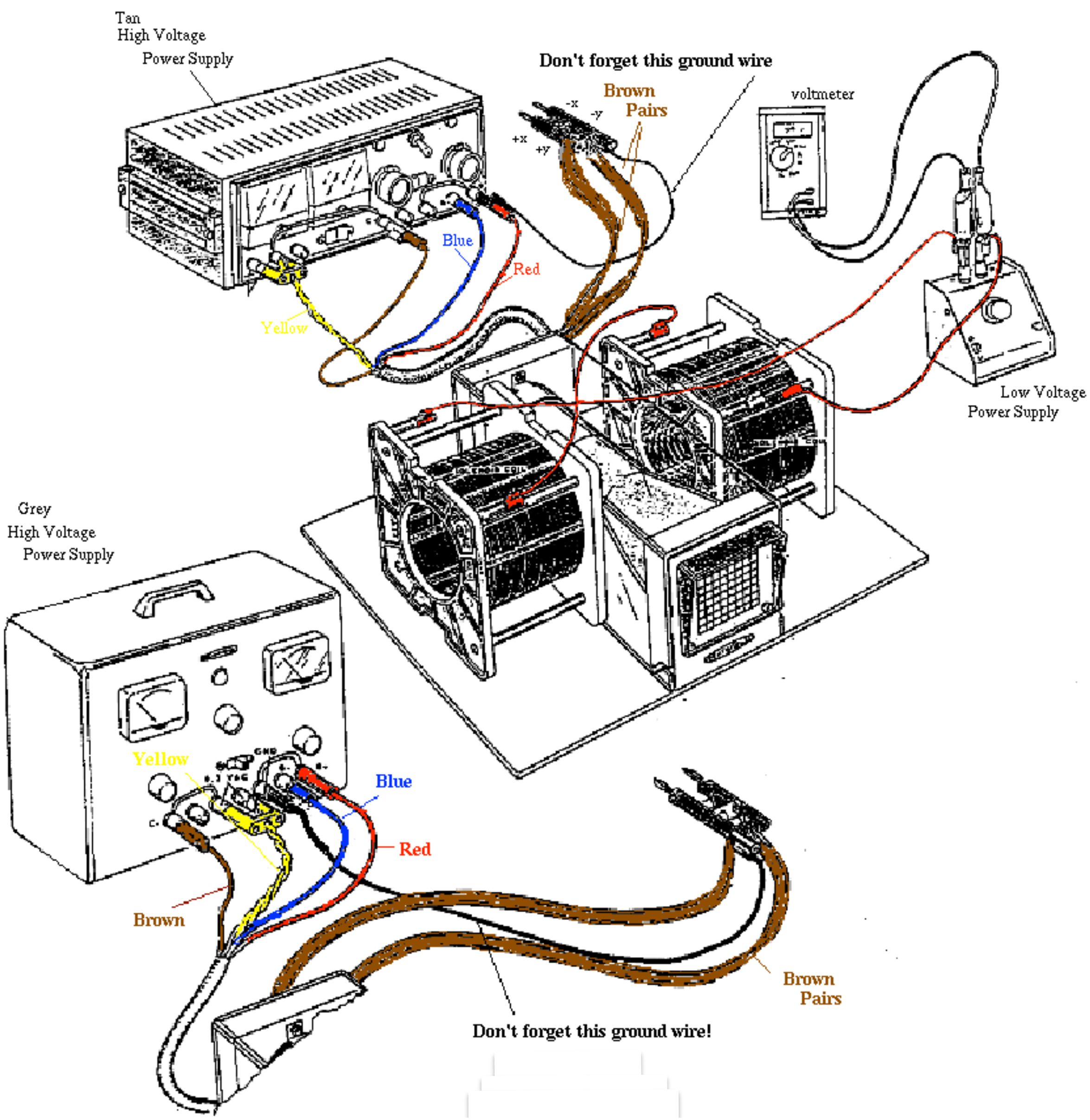

Figure 5: *CAUTION: If your high voltage power supply is Model No. IP-32 (the older grey model), be sure to use the alternate connections.*

you should reverse electrical connection to one.