Homework on Velocity Selector, Charge to Mass Ratio, Hall Effect Solutions

1. An beam of electrons are moving horizontally through a horizontal magnetic field with magnitude 3 T that makes an angle of $35°$ with the path of motion. The beam is being fired between two large conducting plates placed above and below the beam with a potential difference of 700 V that are spaced at 1 mm apart. The beam is not deflected either up or down. What is the speed of the electrons in the beam?

First calculate the electric field strength between two large (infinite) planes:

$$dE = V$$
$$E = \frac{V}{d}$$

This field could point up or down, we are not given enough information to determine which. However, we do know that since the velocity and magnetic field are both horizontal, the magnetic force on the electrons will be entirely vertical. Since the electrons are not accelerating, the electric and magnetic forces must be equal and in opposite directions:

$$F_B = F_E$$
$$qv \times B = qE$$
$$v \times B = E$$
$$vB\sin(\theta) = \frac{V}{d}$$
$$v = \frac{V}{Bd\sin(\theta)} = \frac{(700)}{(3)(0.001)\sin(35°)} = 4.07 \times 10^5\ m/s$$

2. A Thompson apparatus for measuring the charge-to-mass ratio of electrons is set up, with conducting plates that are 5.0 cm long and separated by 0.9 cm. From the end of the plates to the screen of the tube is 25.0 cm. The electrons are fired with a velocity of 2.97×10^7 m/s. If a potential of 30 V is applied across the deflection plates, by how much will the beam deflect? What is the magnitude of a crossed magnetic field that will allow the beam to pass through the plates undeflected?

The magnitude of the electric field is

$$V = Ed$$
$$E = \frac{V}{d} = \frac{30}{0.009} = 3330\ N/C$$

The total deflection is then

$$y=\frac{q}{m}\left(\frac{Ex_1^2}{2v_x^2}+\frac{Ex_1x_2}{v_x^2}\right)=\frac{\left(1.602\times10^{-19}\right)}{\left(9.109\times10^{-31}\right)}\left(\frac{(3330)(0.05)^2}{2\left(2.97\times10^7\right)^2}+\frac{(3330)(0.05)(0.25)}{\left(2.97\times10^7\right)^2}\right)=9.13\ mm$$

For the electrons to be undeflected,

$$v=\frac{E}{B}$$

$$B=\frac{E}{v}=\frac{(3330)}{2.97\times10^7}=1.12\ G$$

3. The number density of free electrons in gold is 5.90×10^{28} electrons per cubic meter. If a metal strip of gold 2 cm wide carries a current of 10 A, how thin would it need to be to produce a Hall Voltage of at least one 1 mV. What would the drift velocity of the electrons be in this case? (Assume a perpendicular field of 5000 Gauss)

$$V_H=\frac{IB}{tnq}$$

$$t=\frac{IB}{V_Hnq}=\frac{(10)(0.5)}{(0.001)\left(5.90\times10^{28}\right)\left(1.602\times10^{-19}\right)}=5.29\times10^{-7}\ m=529\,nm$$

$$V_H=v_dwB$$

$$v_d=\frac{V_H}{wB}=\frac{(0.001)}{(0.02)(0.5)}=0.1\,m/s$$