Module 07 Homework

1. Determine the direction of the magnetic force on a positive charge that moves as shown in each of the six cases shown in Figure 1.

2. Determine the direction of the magnetic force on a negative charge that moves as shown in each of the six cases shown in Figure 1.

3. For each case in Figure 2, determine the direction that a negatively charged particle must be traveling in order to have the magnetic force indicated, exerted on it. Assume that the charge moves perpendicular to $\vec{B}$.

4. An electron is traveling through a uniform magnetic field $\vec{B} = 1\,\mathrm{T}\hat{x} + 4\,\mathrm{T}\hat{y} + -2\,\mathrm{T}\hat{z}$. At $t = 0$, the velocity of the electron is $\vec{v} = 40\,\frac{\mathrm{m}}{\mathrm{s}}\hat{x} + -30\,\frac{\mathrm{m}}{\mathrm{s}}\hat{y} + 90\,\frac{\mathrm{m}}{\mathrm{s}}\hat{z}$.

    1. What is the acceleration of the electron at $t = 0$?

    2. It is possible to create a uniform electric field such that the electron would not be accelerated. Determine the components of this field, and its magnitude.

    3. If the electron where traveling in the same direction as the magnetic field, it would not be accelerated. Determine the velocity vector for the electron if it were traveling with the same speed, but in the direction of the magnetic field.

5. Consider the simple mass spectrometer show in Figure 3. A single positive ion (missing 1 electron) is emitted from a source and accelerated by an emf toward a detector that uses a uniform magnetic field to steer the particle into a detection screen, where its position is measured. Assume that all of the parameters shown in the figure can be measured and are known.

    1. The kinetic energy of the particle is zero as it leaves the source. What is its kinetic energy when it enters the detector?

    2. What is the radius of the particles circular motion inside the detector?

    3. What is the speed of the particle inside the detector?

    4. What is the magnitude of the radial acceleration of the particle inside the detector?

    5. How long after the particle enters the detector does it hit the detection screen?

    6. What is the mass of the particle?

    7. If the position x on the detection screen can only be measured with an uncertainty Δx, what is the smallest difference in mass that can be detected?

    8. To achieve the best resolution in our mass measurement, is it best to have a strong magnetic field or a weak magnetic field?

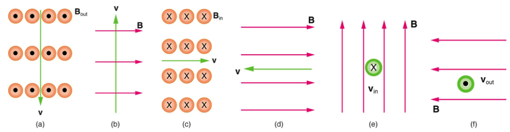

Figure 1: Various configuration of charged partilces moving through a uniform magnetic field.

9. To achieve the best resolution in our mass measurement, is it best to have a large emf or a small emf?

10. Assume we are able to turn on a uniform electric field inside the detector. What would the magnitude and direction of the electric field have to be in order to make the particle travel in a straight line inside the detector?

6. We would like to build a medical device for proton beam therapy. The device will emit a beam of protons with a minimum 100 MeV energy, and will use a cyclotron accelerator.

   1. How fast will the protrons leaving the accelerator be traveling?

   2. The device will use a 0.9 T field to steer the beam inside accelerator. What will the diameter of the accelerator be?

7. **Example Problem Write-up:** A small compass needle (5 cm long with a mass of 1 g) is observed to align with Earth's magnetic field and it is determined that it experiences a $6.283\,18\,\frac{1}{\mathrm{s}^2}$ angular accelertion when the needle starts perpindicular to Earth's magnetic field. Recall that the moment of interial for a rod rotating about its center is $I = \frac{mL^2}{12}$. If the strength of Earth's magnetic field in the lab were these observations are made is 50 µT, what is the magnitude of the magnetic dipole moment of the needle?

8. Recall that our classical model of an atoms treats electrons as charges in orbit around the nucleus. In a previous module, you used this classical model to derive the current associated with a single electron in orbit around a single proton (a Hydrogen atom). This current will produce a magnetic dipole moment.

   1. Derive the magnitude of the magnetic dipole moment vector for an electron in orbit around a proton as a function of the orbital distance, R.

   2. If a hydrogen atom is placed in a uniform magnetic field, a torque will be exerted on the atom. What is the maximum torque that will be exerted on the atom in a field of stringth B?

   3. If a hydrogen atom is placed in a uniform magnetic field, it will store potential energy depdencing on the direrction of the magnetic moment vector with respect to the unform magnetic field. What will the difference between the minimum and maximum potential energy of the atom in a field with strength B be?

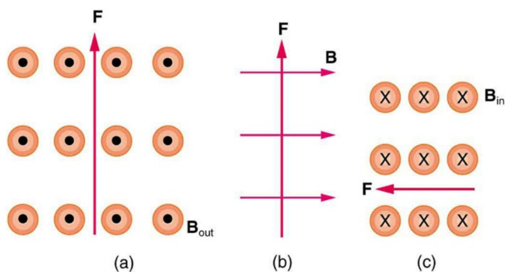

Figure 2: The magnetic force exerted on charged particles moving through a uniform magnetic field.

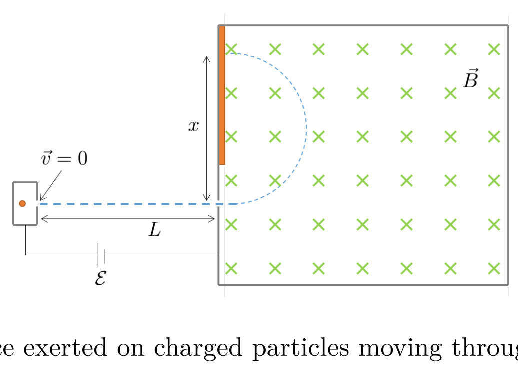

Figure 3: The magnetic force exerted on charged particles moving through a uniform magnetic field.