Solutions
Chapter 8

Problem 1

Part a

The magnitude of the force is

$$F = |q\vec{\mathbf{v}} \times \vec{\mathbf{B}}| = qvB\sin\theta$$

Hence,

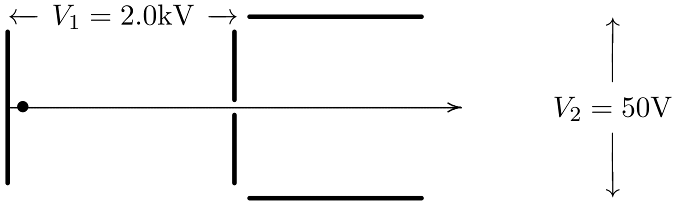
$$v = \frac{F}{qB\sin\theta} = \frac{8.00 \times 10^{-17}}{1.60 \times 10^{-19} \times 4.00 \times 10^{-3} \times \sin 30^\circ} = 2.50 \times 10^5 \text{ m/s}$$

Part b

Kinetic energy is

$$K = \frac{1}{2}mv^2 = \frac{1}{2} \times 1.67 \times 10^{-27} \times (2.50 \times 10^5)^2 = 5.22 \times 10^{-17} \text{ J} = 326 \text{ eV}$$

Problem 2



The figure above shows two vertical plates with the voltage $V_1 = 2.0$kV between them. The electron starts at zero speed at the negative plate on the left and accelerates towards the positive right plate. From the definition of potential we see that the potential energy difference between the plates is

$$U = qV_1 = -1.6 \times 10^{-19} \times 2.0 \times 10^3 = -3.2 \times 10^{-16} J.$$

As total energy is conserved, this loss in potential energy is the gain in kinetic energy. So, the kinetic energy of the electron on reaching the right plate must be

$$K = 3.2 \times 10^{-16} J.$$

As $K = mv^2/2$, this gives:

$$v = \sqrt{\frac{2K}{m}} = \sqrt{\frac{2 \times 3.2 \times 10^{-16}}{9.1 \times 10^{-31}}} = 2.65 \times 10^7 \text{ m/s}$$

With this velocity, the electron moves through the opening in the right plate and enters the second region with the two horizontal plates with a voltage $V_2 = 50$V between them. If the electric field between these plates is uniform, it will have the magnitude of $E = V_2/d$ where d is the distance between the plates (equation 4.15 of textbook). This, by itself, would make the electron go in a parabolic path in the plane of the paper. To make it continue in its straight line trajectory, a magnetic field perpendicular to the plane of the paper is applied to neutralize the electric force. The magnitude of such a magnetic field must be (equation 8.23 of textbook):

$$B = E/v.$$

So one gets:

$$B = \frac{E}{v} = \frac{V_2}{vd} = \frac{50}{2.65 \times 10^7 \times 0.002} = 9.4 \times 10^{-4} \text{ T}$$

Problem 3

The total electric and magnetic force is:

$$\vec{\mathbf{F}} = q\vec{\mathbf{E}} + q\vec{\mathbf{v}} \times \vec{\mathbf{B}}$$

So,

$$\vec{\mathbf{E}} = \frac{\vec{\mathbf{F}}}{q} - \vec{\mathbf{v}} \times \vec{\mathbf{B}}$$

From Newton's second law: $\vec{\mathbf{F}} = m\vec{\mathbf{a}}$. Hence,

$$\vec{\mathbf{E}} = \frac{m\vec{\mathbf{a}}}{q} - \vec{\mathbf{v}} \times \vec{\mathbf{B}} = \frac{9.1 \times 10^{-31} \times 4.0 \times 10^{12}\hat{\mathbf{i}}}{-1.6 \times 10^{-19}} - (5.0\hat{\mathbf{j}} + 2.0\hat{\mathbf{k}}) \times (2.0\hat{\mathbf{i}}) = -23\hat{\mathbf{i}} - 4.0\hat{\mathbf{j}} + 10\hat{\mathbf{k}} \quad \text{N/C}$$

Problem 4

Part a

The kinetic energy is

$$K = mv^2/2$$

So the speed is (remember to convert keV to J)

$$v = \sqrt{\frac{2K}{m}} = \sqrt{\frac{2 \times 5.0 \times 10^3 \times 1.60 \times 10^{-19}}{9.1 \times 10^{-31}}} = 4.2 \times 10^7 \text{ m/s}$$

Part b

For the circular orbit

$$\frac{mv^2}{r} = qvB$$

Hence,

$$B = \frac{mv}{qr} = \frac{9.1 \times 10^{-31} \times 4.2 \times 10^7}{1.6 \times 10^{-19} \times 0.20} = 1.2 \times 10^{-3} \text{ T}$$

Part c

The angular frequency is

$$\omega = \frac{v}{r}$$

Frequency is

$$f = \frac{\omega}{2\pi} = \frac{v}{2\pi r} = 3.3 \times 10^7 \text{ Hz}$$

Part d

The time priod is

$$T = 1/f = 3.0 \times 10^{-8} \text{ s}$$

Problem 5

The radius of orbit in a uniform magnetic field is $r = mv/(|q|B)$. Hence,

$$r_p = \frac{m_p v_p}{q_p B},$$

and

$$r_u = \frac{m_u v_u}{q_u B},$$

where the subscripts p, and u are used to denote the corresponding paramaters for the proton and the unknown particle. For the first experiment, $v_p = v_u$ and $r_u = 2r_p$. So, we get

$$2 = \frac{r_u}{r_p} = \frac{m_u q_p}{m_p q_u}.$$

Alternatively,

$$\frac{m_u}{q_u} = 2\frac{m_p}{q_p}$$

This condition is satisfied by the deuteron and the alpha particle. But it is not satisfied by the proton. So the unknown particle is either a deuteron or an alpha particle.

In the second experiment, the kinetic energy K is the same for both particles. Hence,

$$K = m_p v_p^2/2 = m_u v_u^2/2$$

So,

$$v_p = \sqrt{\frac{2K}{m_p}}$$

and

$$v_u = \sqrt{\frac{2K}{m_u}}$$

Putting this into the equations for radius gives

$$r_p = \frac{m_p}{q_p B}\sqrt{\frac{2K}{m_p}},$$

and

$$r_u = \frac{m_u}{q_u B}\sqrt{\frac{2K}{m_u}}$$

As in this experiment $r_u = r_p$

$$1 = \frac{r_u}{r_p} = \frac{q_p\sqrt{m_u}}{q_u\sqrt{m_p}}$$

Alternatively,

$$\frac{\sqrt{m_u}}{q_u} = \frac{\sqrt{m_p}}{q_p}$$

This condition is satisfied by the alpha particle and the proton. So the only possibility that satisfies both experimental results is the alpha particle.

Problem 6

The force is

$$\vec{\mathbf{F}} = i\vec{\mathbf{L}} \times \vec{\mathbf{B}}$$

Using the right-hand-rule gives the direction of $\vec{\mathbf{F}}$ to be east-to-west. The magnitude is

$$F = iLB\sin\theta = 2000 \times 100 \times 60 \times 10^{-6} \times \sin 70^\circ = 11.3 \text{ N}$$

Problem 7

The force is

$$\vec{\mathbf{F}} = i\vec{\mathbf{L}} \times \vec{\mathbf{B}} = 5.00 \times 0.100\hat{\mathbf{i}} \times (0.200\hat{\mathbf{j}} + 0.800\hat{\mathbf{k}}) = -0.400\hat{\mathbf{j}} + 0.100\hat{\mathbf{k}} \text{ N}$$

Problem 8

The torque is

$$\vec{\tau} = \vec{\mu} \times \vec{\mathbf{B}}$$

Using the right hand rule we find that $\vec{\mu}$ is in the -z direction. So, it is

$$\vec{\mu} = -iNA\hat{\mathbf{k}} = -0.10 \times 20 \times \pi(4.0)^2\hat{\mathbf{k}} = -100\hat{\mathbf{k}}.$$

Hence,

$$\vec{\tau} = (-100\hat{\mathbf{k}}) \times (0.40\hat{\mathbf{i}} + 0.50\hat{\mathbf{k}}) = -40\hat{\mathbf{j}}.$$