Chapter 29

1

Magnetic Fields

1

Lecture 02

2

Charged Particle In A Magnetic Field

2

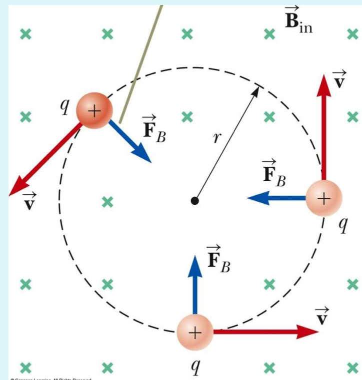
Charged Particle in a Magnetic Field

3

Consider a particle moving in an external magnetic field with its velocity perpendicular to the field.

The force is always directed toward the center of the circular path.

The magnetic force causes a centripetal acceleration, changing the direction of the velocity of the particle.



3

Force on a Charged Particle

4

- Use the particle under a net force and a particle in uniform circular motion models.
- Equating the magnetic and centripetal forces:

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

- Solving for r:

$$\boxed{r = \frac{mv}{qB}}$$

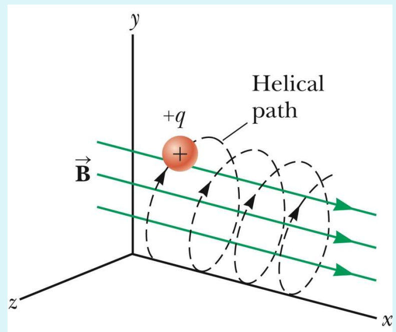
  - r is proportional to the linear momentum of the particle and inversely proportional to the magnetic field.

4

Motion of a Particle, General

5

- If a charged particle moves in a magnetic field at some arbitrary angle with respect to the field, its path is a helix.



5

Charged Particles Moving in Electric and Magnetic Fields

6

In many applications, charged particles will move in the presence of both magnetic and electric fields.

In that case, the total force is the sum of the forces due to the individual fields.

The total force is called the Lorentz force.

In general:

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

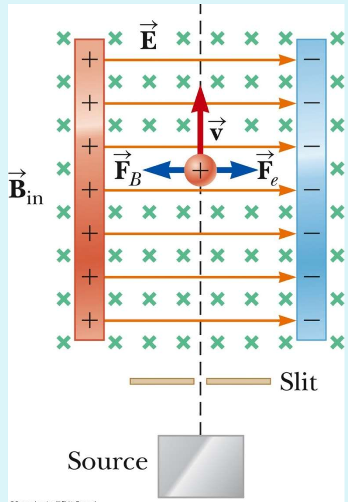
6

Velocity Selector

7

- Used when all the particles need to move with the same velocity.
- A uniform electric field is perpendicular to a uniform magnetic field.
- When the force due to the electric field is equal but opposite to the force due to the magnetic field, the particle moves in a straight line.
- This occurs for velocities of value.

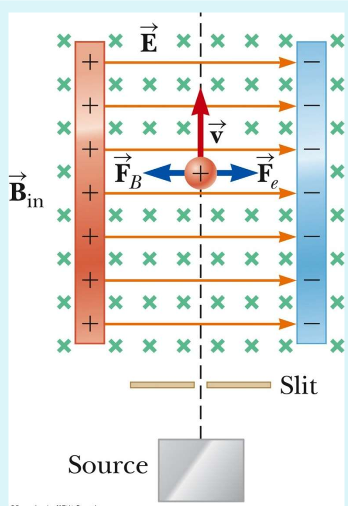
$$\boxed{v = \frac{E}{B}}$$



Velocity Selector, cont.

8

- Only those particles with the given speed will pass through the two fields undeflected.
- The magnetic force exerted on particles moving at a speed greater than this is stronger than the electric force and the particles will be deflected to the left.
- Those moving more slowly will be deflected to the right.



A Proton Moving Perpendicular to a Uniform B

Thursday, 4 February, 2021 15:55

Lecturer: Mustafa Al-Zyout, Philadelphia University, Jordan.

- [x] R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.
- [ ] J. Walker, D. Halliday and R. Resnick, *Fundamentals of Physics*, 10th ed., WILEY,2014.
- [ ] H. D. Young and R. A. Freedman, *University Physics with Modern Physics*, 14th ed., PEARSON, 2016.
- [ ] H. A. Radi and J. O. Rasmussen, *Principles of Physics For Scientists and Engineers*, 1st ed., SPRINGER, 2013.

A proton is moving in a circular orbit of radius $14\ cm$ in a uniform $0.35 - T$ magnetic field perpendicular to the velocity of the proton.

- Find the period of the proton.
- Find the frequency of the proton.
- Find the angular speed of the proton.
- Find the speed of the proton.
- Find the magnitude of the magnetic force on the proton.

SOLUTION

From our discussion in this section, we know the proton follows a circular path when moving perpendicular to a uniform magnetic field.

the period is:

$$T = \frac{2\pi m}{qB} = \frac{2\pi \times 1 \cdot 67 \times 10^{-27}}{1 \cdot 6 \times 10^{-19} \times 0 \cdot 35} = 1.87 \times 10^{-7} s$$

the frequency is:

$$f = \frac{qB}{2\pi m} = \frac{1 \cdot 6 \times 10^{-19} \times 0 \cdot 35}{2\pi \times 1 \cdot 67 \times 10^{-27}} = 5.34 \times 10^{6}\ s^{-1}$$

the angular speed is:

$$\omega = \frac{qB}{m} = \frac{1 \cdot 6 \times 10^{-19} \times 0 \cdot 35}{1 \cdot 67 \times 10^{-27}} = 3.35 \times 10^{7} rad/s$$

the speed is:

$$v = \frac{qBr}{m_p} = \frac{1.60 \times 10^{-19} \times 0.35 \times 0.14}{1.67 \times 10^{-27}} = 4.7 \times 10^{6}\ m/s$$

the magnitude of the magnetic force is:

$$F = qvB \sin\theta = 1.6 \times 10^{-19} \times 4 \cdot 7 \times 10^{6} \times 0.35 \times \sin 90^{0} = 2 \cdot 6 \times 10^{-13} N$$

What if an electron, rather than a proton, moves in a direction perpendicular to the same magnetic field with this same speed? Will the radius of its orbit be different?

An electron has a much smaller mass than a proton, so the magnetic force should be able to change its velocity much more easily than that for the proton. Therefore, we expect the radius to be smaller. r is proportional to m with $q, B,$ and v the same for the electron as for the proton. Consequently, the radius will be smaller by the same factor as the ratio of masses m_e/m_p.

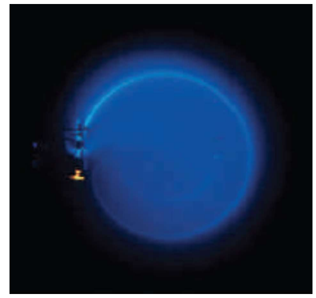
Bending an Electron Beam

Thursday, 4 February, 2021 15:57

Lecturer: Mustafa Al-Zyout, Philadelphia University, Jordan.

- [x] R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.
- [ ] J. Walker, D. Halliday and R. Resnick, *Fundamentals of Physics*, 10th ed., WILEY,2014.
- [ ] H. D. Young and R. A. Freedman, *University Physics with Modern Physics*, 14th ed., PEARSON, 2016.
- [ ] H. A. Radi and J. O. Rasmussen, *Principles of Physics For Scientists and Engineers*, 1st ed., SPRINGER, 2013.

In an experiment designed to measure the magnitude of a uniform magnetic field, electrons are accelerated from rest through a potential difference of $350\,V$ and then enter a uniform magnetic field that is perpendicular to the velocity vector of the electrons. The electrons travel along a curved path because of the magnetic force exerted on them, and the radius of the path is measured to be $7.5\,cm$.



- What is the magnitude of the magnetic field?
- What is the angular speed of the electrons?
- What is the period of the electrons?

SOLUTION

we need the speed v of the electron to find the magnetic field magnitude, and v is not given. Consequently, we must find the speed of the electron based on the potential difference through which it is accelerated.

Write the appropriate reduction of the conservation of energy equation, for the electron– electric field system:

$$\Delta K + \Delta U = 0$$

Substitute the appropriate initial and final energies:

$$\frac{1}{2}m_e v^2 - 0 + q\Delta V = 0$$

Solve for the speed of the electron:

$$v = \sqrt{\frac{-2q\Delta V}{m_e}}$$

Substitute numerical values:

$$v = \sqrt{\frac{-2 \times -1.60 \times 10^{-19} C \times 350 V}{9.11 \times 10^{-31} kg}} = 1.11 \times 10^{7} m/s$$

Now imagine the electron entering the magnetic field with this speed. The magnitude of the magnetic field:

$$B = \frac{m_e v}{er}$$

Substitute numerical values:

$$B = \frac{9.11 \times 10^{-31} kg 1.11 \times 10^{7} m/s}{1.60 \times 10^{-19} C \times 0.075 m} = 8.4 \times 10^{-4} T$$

SOLUTION

the angular speed

$$\omega = \frac{v}{r} = \frac{1.11 \times 10^{7} m/s}{0.075 m} = 1.5 \times 10^{8} rad/s$$

The angular speed can be represented as:

$$\omega = \left(1.5 \times \frac{10^{8} rad}{s}\right)\left(\frac{1 rev}{2\pi rad}\right) = 2.4 \times \frac{10^{7} rev}{s}.$$

The electrons travel around the circle 24 million times per second!

Lorentz force

Monday, 1 March, 2021 21:38

Lecturer: Mustafa Al-Zyout, Philadelphia University, Jordan.

- [x] R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.
- [ ] J. Walker, D. Halliday and R. Resnick, *Fundamentals of Physics*, 10th ed., WILEY,2014.
- [ ] H. D. Young and R. A. Freedman, *University Physics with Modern Physics*, 14th ed., PEARSON, 2016.
- [ ] H. A. Radi and J. O. Rasmussen, *Principles of Physics For Scientists and Engineers*, 1st ed., SPRINGER, 2013.

A particle with positive charge $q = 3.2 \times 10^{-19} C$ moves with a velocity $\vec{v} = (2\hat{\imath} + 3\hat{\jmath} - \hat{k})\, m/s$ through a region where both a uniform magnetic field and a uniform electric field exist.

- Calculate the total force on the moving particle (in unit-vector notation), taking $\vec{B} = (2\hat{\imath} + 4\hat{\jmath} + \hat{k})\, T$ and $\vec{E} = (4\hat{\imath} - \hat{\jmath} - 2\hat{k})\, V/m$.
- What angle does the force vector make with the positive x axis?

The net force is the Lorentz force given by

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

$$\vec{F} = (3.2 \times 10^{-19})\left[(4\hat{\imath} - \hat{\jmath} - 2\hat{k}) + (2\hat{\imath} + 3\hat{\jmath} - \hat{k}) \times (2\hat{\imath} + 4\hat{\jmath} + \hat{k})\right]$$

Execute $\vec{v} \times \vec{B}$

$$\vec{v} \times \vec{B} = (2\hat{\imath} + 3\hat{\jmath} - \hat{k}) \times (2\hat{\imath} + 4\hat{\jmath} + \hat{k}) = \begin{vmatrix} \hat{\imath} & \hat{\jmath} & \hat{k} \\ 2 & 3 & -1 \\ 2 & 4 & 1 \end{vmatrix}$$

$$= +[(3 \times 1) - (-1 \times 4)]\hat{\imath} - [(2 \times 1) - (-1 \times 2)]\hat{\jmath} + [(2 \times 4) - (3 \times 2)]\hat{k}$$

$$\vec{v} \times \vec{B} = 7\hat{\imath} - 4\hat{\jmath} + 2\hat{k}$$

Then:

$$\vec{F} = (3.2 \times 10^{-19})\left[(4\hat{\imath} - \hat{\jmath} - 2\hat{k}) + (7\hat{\imath} - 4\hat{\jmath} + 2\hat{k})\right] = (3.2 \times 10^{-19})(11\hat{\imath} - 5\hat{\jmath})$$

$$\vec{F} = (3.52\hat{\imath} - 1.6\hat{\jmath}) \times 10^{-18}\, N$$

the direction of $\vec{F}$ with respect to the positive x-axis is:

$$\varphi = cos^{-1}\left(\frac{\vec{F} \cdot \hat{\imath}}{|\vec{F}||\hat{\imath}|}\right) = cos^{-1}\left(\frac{3.52 \times 10^{-18}}{\sqrt{3.52^2 + (-1.6)^2} \times 1 \times 10^{-18}}\right) = 24.4°$$

Since the sign of F_x is positive and the sign of F_y is negative, the resultant force lies in the fourth quadrant of the coordinate system. That is,

$$\theta = 360° - 24.4° = 335.6°$$

Velocity selector

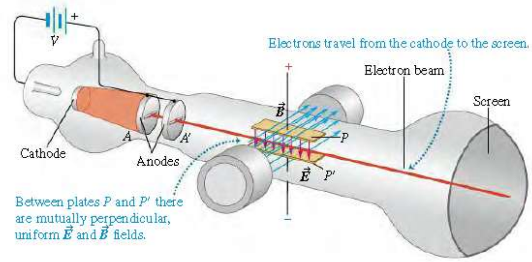
Monday, 1 March, 2021 21:38

Lecturer: Mustafa Al-Zyout, Philadelphia University, Jordan.

- [ ] R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.
- [ ] J. Walker, D. Halliday and R. Resnick, *Fundamentals of Physics*, 10th ed., WILEY,2014.
- [x] H. D. Young and R. A. Freedman, *University Physics with Modern Physics*, 14th ed., PEARSON, 2016.
- [ ] H. A. Radi and J. O. Rasmussen, *Principles of Physics For Scientists and Engineers*, 1st ed., SPRINGER, 2013.

The figure shows the essentials of a mass spectrometer, with an accelerating potential of $150\,V$ and a deflecting electric field of magnitude $6\times10^{6}\,N/C$.

- How fast do the electrons move?
- What magnetic-field magnitude will yield zero beam deflection?
- With this magnetic field, how will the electron beam behave if you increase the accelerating potential above $150\,V$?



When the ion emerges from the source, its kinetic energy is approximately zero. At the end of the acceleration, its kinetic energy is $\frac{1}{2}mv^2$. Also, during the acceleration, the positive ion moves through a change in potential of $-V$.Thus, because the ion has positive charge q, its potential energy changes by $-qV$. If we now write the conservation of mechanical energy as:

$$\Delta K+\Delta U=0$$

$$\frac{1}{2}mv^2-qV=0$$

$$v=\sqrt{\frac{2qV}{m}}$$

$$v=\sqrt{\frac{2\times1\cdot6\times10^{-19}\times150}{9.11\times10^{-31}}}=7\cdot26\times10^{6}\,m/S$$

the required field strength is

$$B=\frac{E}{v}=\frac{6\times10^{6}}{7.26\times10^{6}}=0.83T$$

Increasing the accelerating potential V increases the electron speed v. In the figure shown, this doesn't change the upward electric force, but it increases the downward magnetic force. Therefore the electron beam will turn downward and will hit the end of the tube below the undeflected position.

Mass spectrometer

Monday, 1 March, 2021 21:38

Lecturer: Mustafa Al-Zyout, Philadelphia University, Jordan.

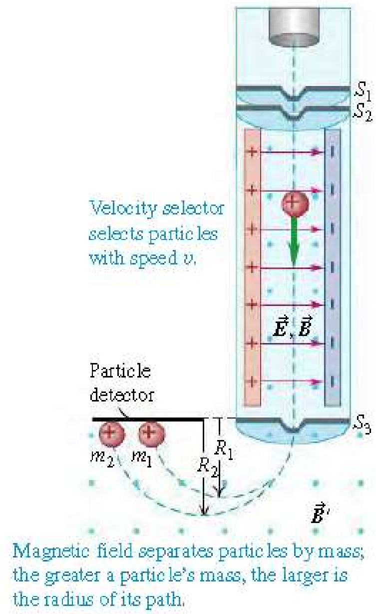
R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.

J. Walker, D. Halliday and R. Resnick, *Fundamentals of Physics*, 10th ed., WILEY,2014.

H. D. Young and R. A. Freedman, *University Physics with Modern Physics*, 14th ed., PEARSON, 2016.

H. A. Radi and J. O. Rasmussen, *Principles of Physics For Scientists and Engineers*, 1st ed., SPRINGER, 2013.

You are designing a leak detector that uses a mass spectrometer to detect He^+ ions (charge $q = 1.6 \times 10^{-19} C$, mass $m = 6.65 \times 10^{-27} kg$). Ions emerge from the velocity selector with a speed of $1 \times 10^5\, m/s$. They are curved in a semicircular path by a magnetic field B' and are detected at a distance of $10.16\, cm$ from the slit S3. Calculate the magnitude of the magnetic field B'.



The distance given is the diameter of the semicircular path shown, so the radius is:

$$r = \frac{1}{2} \times 10.16 \times 10^{-2} = 5.08 \times 10^{-2} m\ .$$

From $r = \frac{mv}{qB'}$, we get:

$$B' = \frac{mv}{qr} = \frac{6 \cdot 65 \times 10^{-27} \times 1 \times 10^5}{1.6 \times 10^{-19} \times 5.08 \times 10^{-2}} = 0.0818T$$