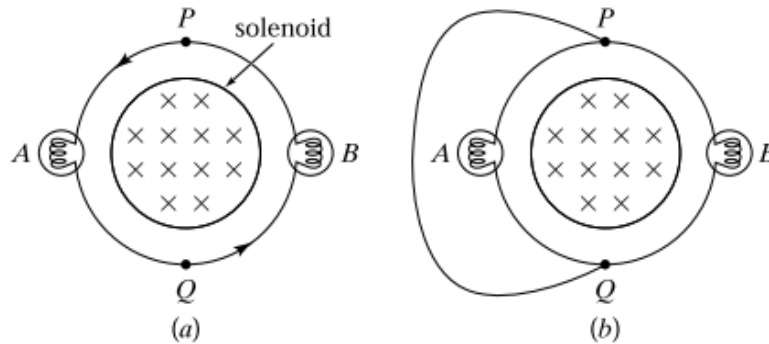## Conceptual Questions

1. In figure (a), a solenoid produces a magnetic field whose strength increases into the plane of the page. An induced current is established in a conducting loop surrounding the solenoid which lights bulbs **A** and **B**. In figure (b), points P and Q are shorted. After the short is inserted,[1]


P   solenoid

A   B

Q

(a)

P

A   B

Q

(b)

a) bulb **A** goes out; bulb **B** gets brighter

b) bulb **B** goes out; bulb **A** gets brighter

c) bulb **A** goes out; bulb **B** gets dimmer

d) bulb **B** goes out; bulb **A** gets dimmer

e) both bulbs go out

f) none of the above

ANS: A

A counter-clockwise current must flow from **P** to **Q** and back again as per Lenz's law. Since this current passes through **A** and **B**, the bulbs turn on. When the loop is connected, the same current must flow, but now it only passes through **B**. Without A in the circuit, the overall resistance decreases, the current (as mentioned) is the same, to the potential drop across **B** increases 9as per Ohm's law), so it glows brighter.

2. The drawing shows a top view of four interconnected chambers. A negative charge is fired into chamber **1**. By turning on separate magnetic fields in each chamber, the charge can be made to exit from chamber **4**, as shown. (a) Describe how the magnetic field in each chamber should be directed. (b) If the speed of the charge is v when it enters chamber **1**, what is the speed of the charge when it exits chamber **4**? Why?[2]
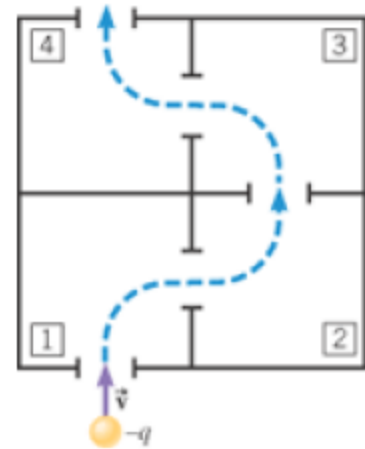
Since the particle is negatively charged, the left-hand rule is used.

a) 1-down , 2- up, 3-up, 4-down

b) Same speed. The direction of the magnetic force is always perpendicular to the direction the charged particle travels. Therefore it does not and cannot affect it.

3. A charged particle is moving in a circular path under the influence of a uniform magnetic field. Describe how the path would change in response to each of the following factors, considered separately:[3]

a) The strength of the magnetic field is increased.

When the strength of the magnetic field increases, **r** decreases and the charged particle moves in a smaller circle.

b) An electric field is added, in the same direction as the magnetic field.

The circular path will become a spiral path parallel to the magnetic field.

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[1] Peer Instruction – A User's Guide, Mazur, Magnetism CT 12

[2] Physics, 7th Edition, Cutnell & Johnson, Chapter 21 Conceptual Questions, #7

[3] Physics 12, Nelson Education, Chapter 8 Review, #4

c) The magnetic field is removed.
When both fields are switched off simultaneously, the charged particle will move off at a constant speed tangent to the spiral at the point where the fields are removed.

4. A $CuSO_4$ solution is placed in a container housing coaxial cylindrical copper electrodes. Electric and magnetic fields are set up as shown. Uncharged pollen grains added to the solution are carried along by the mobile ions in the liquid. Viewed from above, the pollen between the electrodes circulates clockwise.
The pollen is carried by ions that are[4]

cross-sectional view

copper electrodes
magnet
container

side view
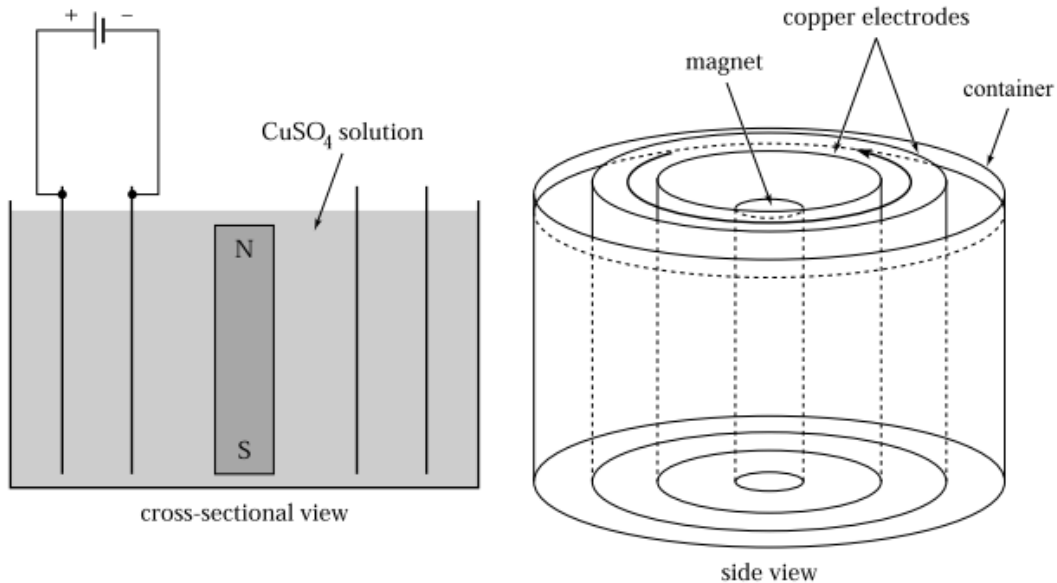
a) positive   b) negative   c) both positive and negative   d) need more information
ANS: A
Charged ions will move, creating an electric current, such that a magnetic field will also be created to oppose the magnetic field of the magnet. In order to do so, the created current must be clockwise. Since the pollen grains are moving clockwise, this means the ions are also moving clockwise. Since conventional current assumes positive moving charges, the ions are positively charged.

5. A hydrogen atom, a helium nucleus, a Na^+ ion and an F ion enter the magnetic field below. Identify the path of each particle. [5]

Hydrogen: __c__ The atom is neutral so it travels without deflection.

Helium: __a__ Positively charged, it turns left, and being lighter than sodium, it accelerates more.

Na^+:   __b__ Positively charged, it turns left, and being the heaviest, it accelerates least of all.

F^-:   __d__ Negatively charged, it turns right.
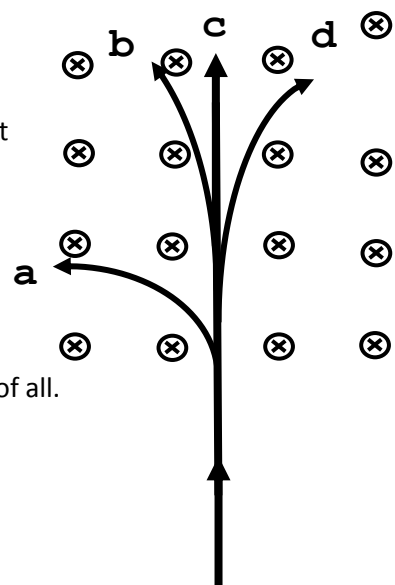
[4] Peer Instruction – A User's Guide, Mazur, Magnetism CT 5
[5] Almeida, F., Physics Department, Victoria Park C.I.

Problems

6. A conductor 45 cm long, with a mass of 15 g, lies in a horizontal position at a 90° angle to a uniform horizontal magnetic field of magnitude 0.20 T. What must the current in the conductor be if the magnetic force is to support the weight of the conductor?[6]

$l = 45$ cm $= 0.45$ m
$m = 15$ g $= 1.5 \times 10^{-2}$ kg
$\theta = 90°$
$B = 0.20$ T
$I = ?$

First we must calculate the force:
$$F = mg$$
$$= (1.5 \times 10^{-2} \text{ kg})(9.8 \text{ N/kg})$$
$$F = 0.147 \text{ N}$$

To calculate the current:
$$F = IlB \sin\theta$$
$$I = \frac{F}{lB \sin\theta}$$
$$= \frac{(0.147 \text{ N})}{(0.45 \text{ m})(0.20 \text{ T})\sin 90°}$$
$$I = 1.6 \text{ A}$$
The current in the conductor is 1.6 A.

7. Calculate the magnitude and direction of the force on an electron moving horizontally westward at 3.2 x 10^6 m/s through a uniform magnetic field of 1.2 T directed horizontally southward.[7]

$v = 3.2 \times 10^6$ m/s
$B = 1.2$ T [S]
$\vec{F} = ?$

$$F = qvB \sin\theta$$
$$= (1.6 \times 10^{-19} \text{ C})(3.2 \times 10^6 \text{ m/s})(1.2 \text{ T})(\sin 90°)$$
$$\vec{F} = 6.1 \times 10^{-13} \text{ N [vertically down]}$$

The force s 6.1×10^{-13} N [vertically down] according to the right-hand rule.

8. What is the charge-to-mass ratio of a particle accelerated to 6.0 x 10^6 m/s, moving in a circular path of radius 1.8 cm perpendicular to a uniform magnetic field of magnitude 3.2 x 10^{-2} T?[8]

$v = 6.0 \times 10^6$ m/s
$r = 1.8$ cm $= 0.18$ m
$B = 3.2 \times 10^{-2}$ T

$\dfrac{q}{m} = ?$

$$\frac{q}{m} = \frac{v}{Br}$$
$$= \frac{(6.0 \times 10^6 \text{ m/s})}{(3.2 \times 10^{-2} \text{ T})(1.8 \times 10^{-2} \text{ m})}$$
$$\frac{q}{m} = 1.0 \times 10^{10} \text{ C/kg}$$

The charge-to-mass ratio is 1.0×10^{10} C/kg.

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[6] Physics 12, Nelson Education, Chapter 8 Review, #7
[7] Physics 12, Nelson Education, Chapter 8 Review, #8
[8] Physics 12, Nelson Education, Chapter 8 Review, #16

9. A proton, of mass 1.67×10^{-27} kg, moves in a circle in the plane perpendicular to a uniform magnetic field of magnitude 1.8 T. The radius of curvature is 3.0 cm. What is the speed of the proton?[9]

$m = 1.67 \times 10^{-27}$ kg
$B = 1.8$ T
$r = 3.0$ cm $= 3.0 \times 10^{-2}$ m
$v = ?$

$$v = \frac{qBr}{m}$$

$$= \frac{(1.6\times10^{-19}\,C)(1.8\ T)(3.0\times10^{-2}\,m)}{1.67\times10^{-27}\,kg}$$

$$v = 5.2\times10^{6}\,m/s$$

The speed of the proton is 5.2×10^{6} m/s.

10. What is the minimum radius of curvature for an alpha particle, $^{4}_{2}He^{2+}$, moving at 2.0×10^{6} m/s in a magnetic field of 2.9×10^{-5} T?[10]

$q_{alpha} = 2(1.602 \times 10^{-19}\ C)$
$q_{alpha} = 3.204 \times 10^{-19}\ C$
$v = 2 \times 10^{6}\ m/s$
$B = 2.9 \times 10^{-5}\ T$
$m_{alpha} = 2(protons) + 2(neutrons)$
$m_{alpha} = 4(1.67 \times 10^{-27}\ kg)$
$m_{alpha} = 6.68 \times 10^{-27}\ kg$

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

$$r = \frac{(6.68 \times 10^{-27}\ kg)(2 \times 10^{6}\ m/s)}{(3.204 \times 10^{-19}\ C)(2.9 \times 10^{-5}\ T)}$$

$$r = 1.4 \times 10^{3}\ m$$

11. A singly ionized atom ($q = +e$) moves at 1.9×10^{4} m/s perpendicular to a uniform magnetic field of magnitude 1.0×10^{-3} T. The radius of curvature is 0.40 m. What is the atom's mass?[11]

$q = +e = 1.6 \times 10^{-19}\ C$
$v = 1.9 \times 10^{4}\ m/s$
$B = 1.0 \times 10^{-3}\ T$
$r = 0.40$ m
$m = ?$

$$m = \frac{qBr}{v}$$

$$= \frac{(1.6\times10^{-19}\,C)(1.0\times10^{-3}\,T)(0.40\ m)}{1.9\times10^{4}\,m/s}$$

$$m = 3.4\times10^{-27}\,kg$$

The mass of the ion is 3.4×10^{-27} kg.

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[9] Physics 12, Nelson Education, Chapter 8 Review, #17
[10] Physics Book Two, Irwin Publishing, Chapter 9 Problems, #34
[11] Physics 12, Nelson Education, Chapter 8 Review, #18

12. An electron moving through an electric field of 475 V/m and a magnetic field of 0.1 T does not accelerate. If the electron's direction and the directions of the electric and magnetic fields are all mutually perpendicular, what is the speed of the electron?[12]

$\varepsilon = 475$ V/m

$B = 0.1$ T

The electron experiences no net force because the forces from both the electric and magnetic fields are equal in magnitude but opposite in direction.

If all the directions are mutually perpendicular, both the electric and magnetic fields will move the electron in the same direction (based on the right-hand rule #3). Therefore,

$$F_{mag} = F_e$$
$$qvB = q\varepsilon$$
$$v = \frac{\varepsilon}{B}$$
$$v = \frac{(475 \text{ V/m})}{(0.1 \text{ T})}$$
$$v = 4750 \text{ m/s}$$

13. A mass spectrometer is being used to monitor air pollutants. It is difficult, however, to separate molecules with nearly identical mass such as carbon monoxide (CO, 28.0106 u, colourless, odourless, tasteless and highly toxic) and nitrogen gas (N_2, 28.0134 u, the major constituent of Earth's atmosphere). How large a radius of curvature must a spectrometer have if these two molecules are to be separated on the film by 0.50 mm?[13]

The particles in the mass spectrometer follow a semicircular path as shown in Fig. 20-39. A particle has a displacement of $2r$ from the point of entering the semicircular region to where it strikes the film. So if the separation of the two molecules on the film is 0.50 mm, the difference in radii of the two molecules is 0.25 mm. The mass to radius ratio is the same for the two molecules.

$$qvB = mv^2/r \rightarrow m = qBr/v \rightarrow m/r = \text{constant}$$

$$\left(\frac{m}{r}\right)_{CO} = \left(\frac{m}{r}\right)_{N_2} \rightarrow \frac{28.0106 \text{ u}}{r} = \frac{28.0134 \text{ u}}{r + 2.5 \times 10^{-4} \text{m}} \rightarrow r = 2.5 \text{ m}$$

14. The velocity selector of a mass spectrometer uses parallel plates that are 1.0 cm apart and a perpendicular magnetic field of strength 5.0×10^{-2} T. What potential difference should be applied to the plates to permit singly charged ions of only 5.0×10^6 m/s to pass through the selector?[14]

$B = 5.0 \times 10^{-2}$ T

$d = 0.01$ m

$v = 5 \times 10^6$ m/s

$q = 1.602 \times 10^{-19}$ C

$$F_{mag} = F_e$$
$$qvB = q\varepsilon$$
$$qvB = q\frac{V}{d}$$
$$V = dvB$$
$$V = (0.01 \text{ m})(5 \times 10^6 \text{ m/s})(5.0 \times 10^{-2} \text{ T})$$
$$V = 2500 \text{ V}$$

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[12] Physics Book Two, Irwin Publishing, Chapter 9 Problems, #39
[13] Physics 6th Edition, Giancoli, Chapter 20 Problems, #63
[14] Physics Book Two, Irwin Publishing, Chapter 9 Problems, #40

15. A particle of mass 6.0 x 10⁻⁸ kg and charge +7.2 x 10⁻⁶ C is travelling west. The particle enters a magnetic field of magnitude 3.0 T where it completes one-half of a circle before exiting the field moving east. How much time does this charge spend inside the magnetic field? [15]

$m = 6.0 \times 10^{-8} \text{ kg}$

$q = 7.2 \times 10^{-6} \text{ C}$

$B = 3.0 \text{ T}$

$t = \frac{1}{2}T$

$t = \left(\frac{1}{2}\right)\left(\frac{2\pi m}{Bq}\right)$

$t = \frac{\pi(6.0 \times 10^{-8} \text{ kg})}{(3.0 \text{ T})(7.2 \times 10^{-6} \text{ C})}$

$t = 8.7 \times 10^{-3} \text{ s}$

16. A 3.40-g metallic projectile moves with a speed of 160 m/s perpendicular to the Earth's magnetic field of 5.00 x 10⁻⁶ T. If, due to air friction, the projectile acquires a charge of 5.0 x 10⁻⁶ C, by what distance will it be deflected from its path due to the Earth's magnetic field after it has travelled 1.00 km? [16]

The magnetic force produces an acceleration that is perpendicular to the original motion. If that perpendicular acceleration is small, it will produce a small deflection, and the original velocity can be assumed to always be perpendicular to the magnetic field. This leads to a constant perpendicular acceleration. The time that this (approximately) constant acceleration acts can be found from the original velocity v and the distance traveled L. The starting speed in the perpendicular direction will be zero.

$$F_\perp = ma_\perp = qvB \rightarrow a_\perp = \frac{qvB}{m}$$

$$d_\perp = v_{0\perp}t + \tfrac{1}{2}a_\perp t^2 = \tfrac{1}{2}\frac{qvB}{m}\left(\frac{L}{v}\right)^2 = \frac{qBL^2}{2mv} = \frac{\left(13.5\times10^{-9}\text{C}\right)\left(5.00\times10^{-5}\text{T}\right)\left(1.00\times10^3\text{m}\right)^2}{2\left(3.40\times10^{-3}\text{kg}\right)\left(160\text{m/s}\right)}$$

$$= \boxed{6.2\times10^{-7}\text{m}}$$

This small distance justifies the assumption of constant acceleration.

[15] Physics Book Two, Irwin Publishing, Chapter 9 Problems, #46

[16] Physics 6th Edition, Giancoli, Chapter 20 Problems, #23