Open-Access

PHYSICS FOR THE LIFE SCIENCES

Solution Manual

Created by WebStraw

Physics for the Life Sciences – Magnetism Solutions

Introduction:

Dear student,

Thank you for opening this solution manual for the Magnetism chapter of the Physics for the Life Sciences Question Manual. This resource has been created by members of the Education Team at WebStraw who have previously taken an introductory university physics course.

Purpose:

This resource is meant to supplement the Physics for the Life Sciences Question Manual, by providing solutions to select questions. To access the full question manual, please click here.

Instructions

We recommend first trying to complete the problems in the question manual on your own. If you get stuck, you can use this resource to view the solution provided by one of our Education Team members. Once you are confident you understand how to solve that question, we recommend solving additional related problems in order to successfully master the topic.

Disclaimer

This resource assumes that you have a basic understanding of key concepts related to the Magnetism unit in physics. If you are looking to improve your understanding of specific physics content, check out the additional resources provided at the end of the question manual.

Note: There may be more than one correct method to solve some of the problems outlined in the question manual. Thus, the solutions provided may not represent the only acceptable solution.

If you have any comments or feedback regarding this resource or the solutions contained in it, please do not hesitate to contact us at team@webstraw.ca

We wish you the best of luck on your learning journey!

- The WebStraw Education Team

E1.

$I = 6A$
$B = 0.8T$
$R = 0.06\,m$

$$B = \frac{\mu_o N I}{2R}$$

$$0.8T = \frac{(4\pi \times 10^{-7}\ \frac{T \cdot m}{A}) \cdot N \cdot (6A)}{2(0.06\,m)}$$

$$(0.8T)(0.12m) = (4\pi \times 10^{-7}\ \frac{T \cdot m}{A}) \cdot N \cdot (6A)$$

$$\boxed{N = 1.3 \times 10^{4}}$$

$\therefore$ There are 1.3×10^{4} loops in the wire.

E3.

$N = 410$
$L = 0.17\,m$
$I = 1.7A$
$B = ?$
$R = ?$

① $B = \mu_o n I$

$$B = \mu_o \cdot \frac{N}{L} \cdot I$$

$$B = (4\pi \times 10^{-7}\ \frac{T \cdot m}{A})(\frac{410}{0.17m})(1.7A)$$

$$\boxed{B = 5.2 \times 10^{-3}\ T}$$

② 

410 loops = 410 equivalent circumferences (c).

$L = 410C$

$0.17\ m = 410\ C$

$C = 4.146 \times 10^{-4}\ m$

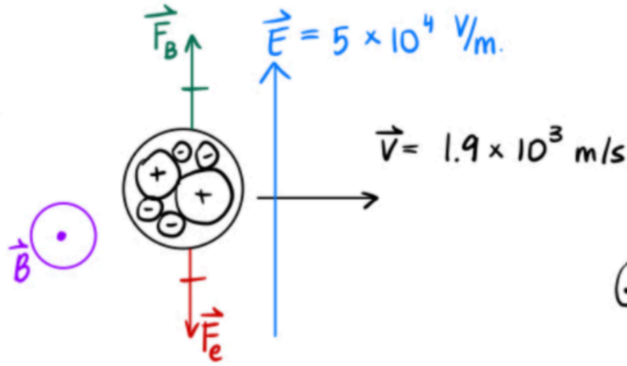
$c = 2\pi r$

$4.146 \times 10^{-4} m = 2\pi r$

$$\boxed{r = 6.6 \times 10^{-5}\ m}$$

$\therefore$ The magnitude of the magnetic field of this solenoid is $5.2 \times 10^{-3}\ T$.
The radius of the solenoid is $6.6 \times 10^{-5} m$.

E5.



① The force exerted on the negative particle by the electric field is opposite in direction to the electric field itself.

② If the particle is moving perfectly horizontally, then F_B must be equal in magnitude and opposite in direction.

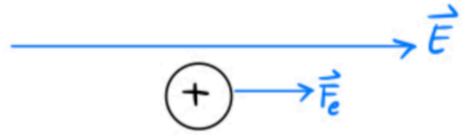
③ In the diagram above, $\vec{F}_B$ is drawn pointing directly upwards. Since the particle is negatively charged, the direction of the magnetic field must be opposite to what the right hand rule indicates $\therefore$ $\vec{B}$ points out of the page.

$$F_{net\,y} = 0 = \vec{F}_B + \vec{F}_E$$
$$0 = +(qv\vec{B}) - (qE)$$
$$\cancel{q}\vec{E} = \cancel{q}v\vec{B}$$

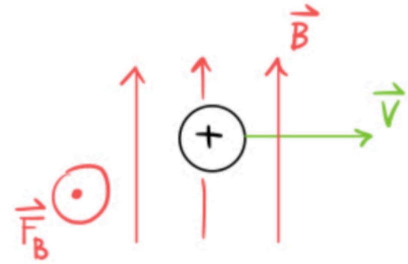
$$\vec{B} = \frac{\vec{E}}{v} = \frac{5 \times 10^{-4}\,\frac{V}{m}}{1.9 \times 10^3\,\frac{m}{s}} = \boxed{2.6 \times 10^{-7}\,T}$$

$\therefore$ the magnetic field must be directed out of the page and have a magnitude of 2.6×10^{-7} T in order for the particle to continue moving horizontally.

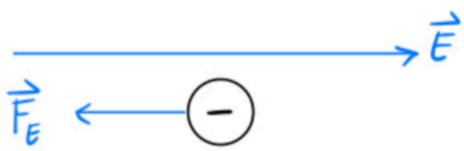
E7.



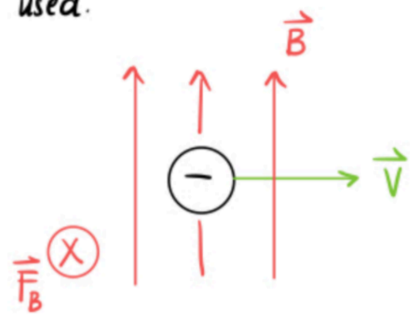
The force exerted on a <u>positively-</u> charged particle by an electric field will act in the <u>same direction</u> as the electric field.



The force exerted on a <u>positively-</u> charged particle by a magnetic field will act perpendicular to both $\vec{V}$ and $\vec{B}$. The right hand rule can be used.



The force exerted on a <u>negatively-</u> charged particle by an electric field will act in the <u>opposite direction</u> as the electric field.



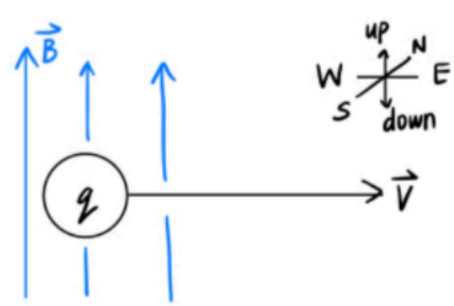
The force exerted on a <u>negatively-</u> charged particle by a magnetic field will act perpendicular to both $\vec{V}$ and $\vec{B}$. The right hand rule will indicate a direction directly opposite to the direction $\vec{F_B}$ acts on.

$\therefore$ negative and positive charges will always experience forces acting in opposite directions if they are placed in a given electric or magnetic field.

E9.

<u>Given :</u>

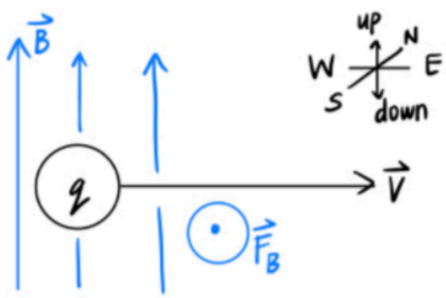
$q = 0.4\,\mu C = 0.4 \times 10^{-6}\ C$
$\vec{V} = 800\ m/s$
$\vec{B} = 0.006\ T$



$$\vec{F}_B = q\vec{v} \times \vec{B}$$
$$= q \cdot \vec{v} \cdot \vec{B} \cdot \sin\theta$$
$$= (0.4 \times 10^{-6}\ C)(800\ m/s)(0.006\,T)(\cancelto{1}{\sin 90^\circ})$$
$$\boxed{\vec{F}_B = 1.9 \times 10^{-6}\ N}$$

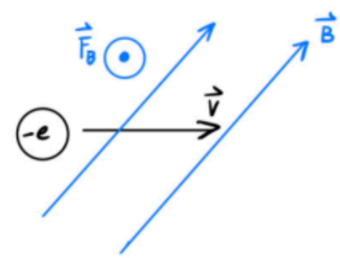
By RHR, $\vec{F}_B$ is directed south.

∴ The magnetic force acting on this charged particle is $1.9 \times 10^{-6} N$ [s].



E11. Given:

$q = +2e - 3e = -e$
$v = 2800\ m/s$
$B = 1.4\,T$
$\vec{F}_B = 1.70 \times 10^{-16}\ N$



$$\vec{F}_B = q\vec{v} \times \vec{B}$$
$$\vec{F}_B = |q| \cdot \vec{v} \cdot \vec{B} \cdot \sin\theta$$
$$1.70 \times 10^{-16} N = |-1.60 \times 10^{-19} C|\,(2800\,m/s)(1.4\,T)(\sin\theta)$$
$$\sin\theta = 0.2710$$
$$\boxed{\theta = 16^\circ}$$

Therefore, the angle the magnetic field makes with the moving particle is 16°.

E13.

<u>Given:</u>

$\vec{V} = 35.0 \text{ m/s}$

$\vec{F_B} = 5.00 \times 10^{-10} \text{ N}$

$\vec{B} = 1.00 \text{ Gauss} = 1.00 \times 10^{-4} \text{ T}$

$\theta = 34.0^\circ$

$$\vec{F_B} = q \vec{V} \times \vec{B}$$

$$\vec{F_B} = |q| \cdot \vec{V} \cdot \vec{B} \cdot \sin\theta$$

$$|q| = \frac{\vec{F_B}}{\vec{V} \cdot \vec{B} \cdot \sin\theta}$$

$$|q| = \frac{5.00 \times 10^{-10} \text{ N}}{(35.0 \text{ m/s})(1.00 \times 10^{-4} \text{ T})(\sin 34.0^\circ)}$$

$$\boxed{|q| = 2.55 \times 10^{-7} \text{ C}}$$

$\therefore$ the charge of the particle is 2.55×10^{-7} C.

E15.

$\vec{B} = 1.4 \text{ T}$

$q = +1.60 \times 10^{-19} \text{ C}$

$r = 0.010 \text{ m}$

$m = 1.673 \times 10^{-27} \text{ kg}$

$$r = \frac{m\vec{v_\perp}}{q\vec{B}}$$

$$V_\perp = \frac{rq\vec{B}}{m}$$

$$V_\perp = \frac{(0.010 \text{m})(1.60 \times 10^{-19} \text{C})(1.4 \text{T})}{(1.673 \times 10^{-27} \text{ kg})}$$

$$\boxed{V_\perp = 1.3 \times 10^6 \text{ m/s}}$$

$\therefore$ The proton is moving at a speed of 1.3×10^6 m/s.

E17.

$m = 2.76 \times 10^{-26}$ kg

$r = 0.275$ m

$\vec{B} = 1.5$ T

$q = +2e = 2(1.60 \times 10^{-19}$ C$)$

$= 3.20 \times 10^{-19}$ C

$$r = \frac{m\vec{v}_\perp}{q\vec{B}}$$

$$V_\perp = \frac{rq\vec{B}}{m}$$

$$V_\perp = \frac{(0.273\,m)(3.20 \times 10^{-19}\,C)(1.5\,T)}{(2.76 \times 10^{-26}\,kg)}$$

$$\boxed{V_\perp = 4.7 \times 10^{6}\ m/s}$$

$\therefore$ The ion moves with a speed of 4.7×10^6 m/s.

E19.

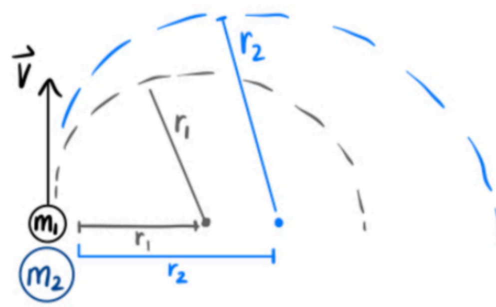
$m_1 = 2.66 \times 10^{-26}$ kg

$m_2 = 2.99 \times 10^{-26}$ kg

$B = 1.40$ T

$V = 4.50 \times 10^5$ m/s

$q = 1e = 1.60 \times 10^{-19}$ C



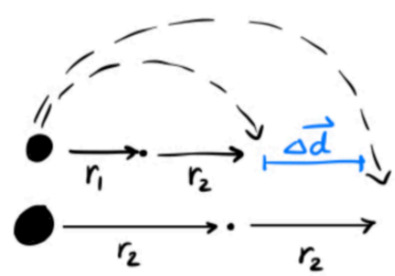
① radius of smaller ion

$$r_1 = \frac{m\vec{v}}{q\vec{B}} = \frac{(2.66 \times 10^{-26}\,kg)(4.50 \times 10^5\,m/s)}{(1.60 \times 10^{-19}\,C)(1.40\,T)} = 0.0534\ m$$

② radius of larger ion

$$r_2 = \frac{m\vec{v}}{q\vec{B}} = \frac{(2.99 \times 10^{-26}\,kg)(4.50 \times 10^5\,m/s)}{(1.60 \times 10^{-19}\,C)(1.40\,T)} = 0.0601\ m$$

③ separation



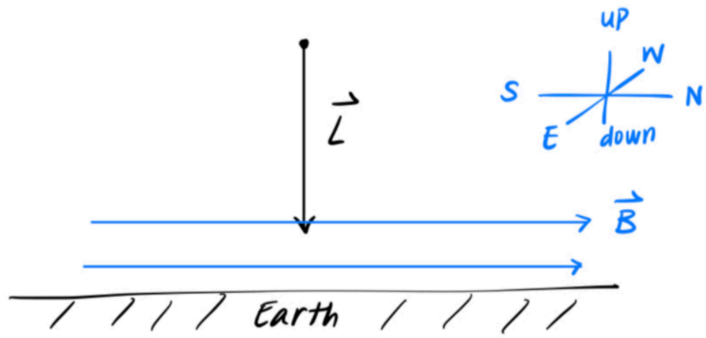
$\Delta\vec{d} = 2r_2 - 2r_1$

$\Delta\vec{d} = 2(0.0601\,m) - 2(0.0534\,m)$

$$\boxed{\Delta\vec{d} = 0.0134\ m}$$

∴ The two ions will be separated by 0.0134 m (1.34 cm) after they travel half a circle.

E21.



$I = 18\ 000A$

$\vec{L} \perp \vec{B}$

$\vec{B} = 5.00 \times 10^{-5} T$ [North]

$\vec{F}_B = ?$

$$\vec{F}_B = I\vec{L} \times \vec{B}$$

$$\vec{F}_B = I L B \sin\theta$$

$$\vec{F}_B / 1m = I B \sin\theta$$

$$\vec{F}_B / 1m = (18000A)(5.00 \times 10^{-5}T)(\overset{1}{\cancel{\sin 90°}})$$

$$\vec{F}_B = 0.90\ N$$

∴ The force per meter is 0.90 N in magnitude. By the right hand rule, the magnetic force acts East in direction.

E23. a) $B = 10T$

$r = 10m$

$$B = \frac{\mu_0 I}{2\pi r}$$

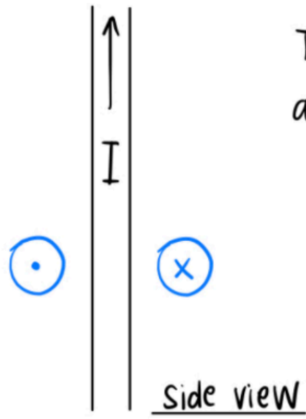
$$I = \frac{2\pi r B}{\mu_0}$$

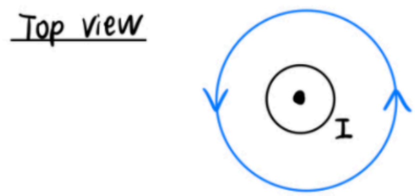
$$I = \frac{2\pi (10m)(10T)}{4\pi \times 10^{-7} \frac{T \cdot m}{A}}$$

$$\boxed{I = 5.0 \times 10^8 A}$$

∴ A current of $5.0 \times 10^8 A$ is needed to produce a magnetic field of 10T at 10m away from the wire.

b) The magnetic field lines form concentric circles around the straight, current-carrying wire.





The right hand rule indicates the magnetic field lines are directed counter clockwise when assessing the wire from a top view.

c) $\vec{F} = ILB \sin\theta$, where L is the length of the wire.

d) From the equation above, it can be seen that $\vec{F} \propto I$. Therefore, if the current is halved, the force is likewise halved.

E25.

$L = 0.14\,m$

$I = 15.0\,A$

$B = 2.1\,T$

$F_B = 3.1\,N$

$$F_B = ILB\sin\theta$$

$$\theta = \sin^{-1}\left(\frac{F_B}{ILB}\right)$$

$$\theta = \sin^{-1}\left(\frac{3.1\,N}{(15.0A)(0.14m)(2.1T)}\right)$$

$$\theta = 45^\circ$$

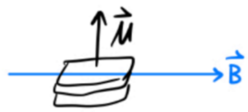
$\therefore$ The angle between the wire and the magnetic field is 45°.

E27.

$N = 20$

$B = 1.1\,T$

$\tau = 8.0\ Nm$



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

$$\tau = INAB\sin\theta$$

$$8.0\,Nm = I\,(20)(0.06\,m^2)(1.1\,T)\,\cancel{\sin\theta}^{\,1}$$

$$\boxed{I = 1.0 \times 10^2\ A}$$

$\therefore$ A current of $1.0 \times 10^2\ A$ is needed.

E29.

$$\vec{F}_{total} = \sum_{\text{all } q} \vec{F}_B$$

The total force exerted by a magnetic field is just the sum of the magnetic forces exerted by all charges in a current-carrying wire.

$$\vec{F} = \sum_{\text{all } q} (q\vec{v} \times \vec{B})$$

$$\vec{F} = (\vec{v}_d \times \vec{B})(\Delta Q_L)$$

all charges, q, in a length of wire.

$$\vec{F} = (\vec{v}_d \times \vec{B})(I \cdot \Delta t)$$

recall that $I = \dfrac{\Delta Q}{\Delta t}$

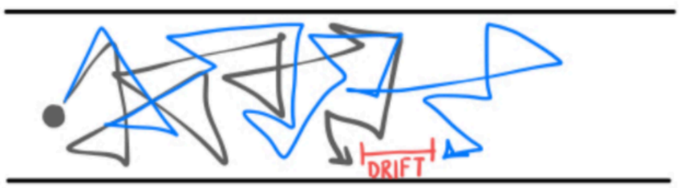
$\therefore\ \Delta Q = I \cdot \Delta t$

$$\vec{F} = I\,(\vec{v}_d\,\Delta t)\vec{B}\sin\theta$$

$\because\ \vec{F} \propto \vec{v}_d$, which means that the magnetic force of a current-carrying wire is proportional to the drift velocity of electrons in a wire, and not to the velocity of an individual electron.

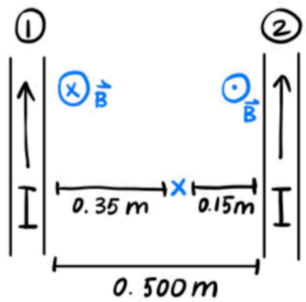
The reason for this is that electron motion in a current-carrying wire is not linear but rather random and chaotic. Only a gradual "drift" movement in <u>all</u> the electrons in a wire makes up current.

Therefore, the identity of an individual electron is lost in a wire. Individual velocities can vary from electron to electron, and even in one electron from time to time.



an electron can move in any direction and at any velocity in a wire. only drift velocity will have an influence on the production of a magnetic field and a magnetic force.

E31. $I_1 = I_2 = 90.0\,A$



From perspective of I_1

$$\frac{F_B}{L} = \frac{\mu_0 I_1 I_2}{2\pi d} = \frac{(4\pi\times10^{-7}\,\frac{T\cdot m}{A})(90.0A)^2}{2\pi(0.350\,m)} = 0.004629\ N\ [\leftarrow]$$

ignore

From perspective of I_1

$$\frac{F_B}{L} = \frac{\mu_0 I_1 I_2}{2\pi d} = \frac{(4\pi\times10^{-7}\,\frac{T\cdot m}{A})(90.0A)^2}{2\pi(0.150\,m)} = 0.0108\ N\ [\longrightarrow]$$

ignore

$$\vec{F}_{B\,net} = 0.0108\ N - 0.004629\ N$$
$$\vec{F}_{B\,net} = 0.0062\ N\ [\rightarrow]$$

Therefore, the magnetic force at a point 35.0 cm away from one of the wires is 0.0062 N towards the wire it is closer to.

E33:

Given: $I_1 = 1200\,A$ $\quad \dfrac{F}{\ell} = 11\,\dfrac{N}{m}$ $\quad r = 38\,cm = 0.38\,m$

Required: I_2

Solve: $\dfrac{F}{\ell} = \dfrac{\mu_0 I_1 I_2}{2\pi r} \longrightarrow I_2 = \dfrac{F(2\pi r)}{\ell(\mu_0 I_1)}$

$$= \frac{11\,(2\pi)(0.38)}{(4\pi \cdot 10^{-7})(1200)}$$

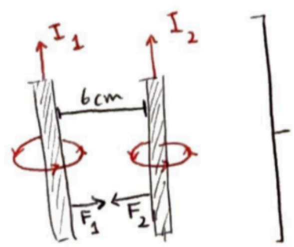
$$\boxed{= 17416.67\,A}$$

E35:

Given: $d = 6\,cm = 0.06\,m$ $\quad I = 5\,A$ each

Required: Nature of force (attractive or repulsive), average force per unit length, max force per unit length

Solve:



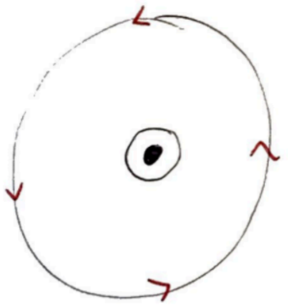
– based on RHR; force will be attractive

For force per unit length: with current carrying cables in this type of question, we assume the wires are thin (no radius) so force per unit length is constant (there is <u>no</u> "max" force per unit length).

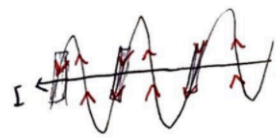
force per unit length $= \frac{F}{\ell} = \frac{\mu_0 I_1 I_2}{2\pi d} = \frac{(4\pi \cdot 10^{-7} \frac{N}{A^2})(5A)(5A)}{2\pi \cdot 0.06m}$

$$\boxed{= 8.33 \cdot 10^{-5} \frac{N}{m}}$$

E37:



$\vec{B}$ should be CCW



$\vec{B}$ is pointing down behind the coil, up in front (do RHR with your thumb pointing left; fingers curl in direction of $\vec{B}$)

$\vec{B}$ is pointing up behind the coil, down in front

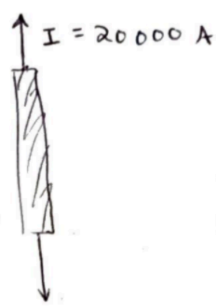
No solution for E39 provided.

E41a:

Given: $I = 20{,}000\,A$ $d = 1\,m$

Required: $\vec{B}$ strength 1m away from wire

Solve:



$$\vec{B} = \frac{\mu_0 I}{2\pi d} = \frac{(4\pi \cdot 10^{-7})(20{,}000)}{2\pi\,(1m)}$$

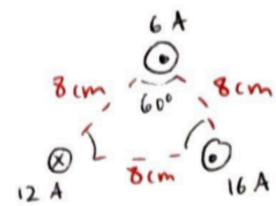
$$\boxed{= 0.004\,T}$$

E41b:

The magnetic field is CCW or CW depending on what direction the current is travelling; it will never be pointing "up". On the left side of the pole, it will be pointing out of the page (towards the observer) if the current is moving up, or into the page if the current is moving down

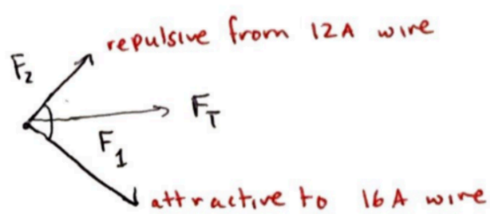
E43:

Given: $I = 5\,A$



Required: Force magnitude & direction on 6 A wire

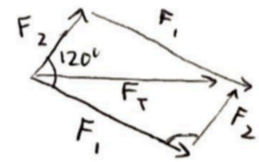
Solve: Wire will be attracted to 16 A wire and repelled by 12 A wire (check this yourself using RHR!)



$$\frac{F_1}{l} = \frac{\mu_0 (6A)(16A)}{2\pi (0.08m)} = 0.00024 \, \frac{N}{m}$$

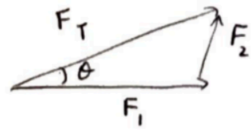
$$\frac{F_2}{l} = \frac{\mu_0 (6A)(12A)}{2\pi (0.08m)} = 0.00018 \, \frac{N}{m}$$

Use parallelogram rule to find F_T



$$|F_T| = \sqrt{F_1^2 + F_2^2 + 2F_1F_2\cos 120°}$$
$$= 0.00022 \frac{N}{m}$$

To find direction:



$$\theta = \tan^{-1}\left(\frac{F_2}{F_1}\right)$$
$$= 36.87°$$

The force felt by the 6A wire (per unit Length) is $0.00022 \frac{N}{m}$, directed 36.87° ccw from the line connecting it to the 16A wire

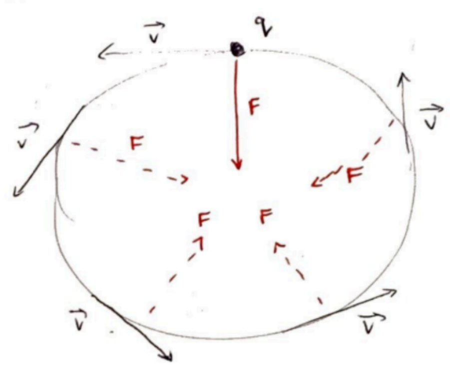
---

<u>E45</u>:

Given: $q = 1.6 \cdot 10^{-19}$ C (proton) $\vec{B} = 1.3T$ Travels in circular path

Required: Direction of $\vec{B}$ relative to proton & radius of circle

Solve: The proton is undergoing circular motion so the force must be directed to the center of the circle (remember your uniform circular motion concepts!)



Using RHR at any point in the circle (with corresponding tangential velocity & inwardly directed $\vec{F}$), the $\vec{B}$ must be going into the page relative to the proton's plane of travel.

Given $v = \frac{1}{2}c = \frac{1}{2}(3 \cdot 10^8 \frac{m}{s})$, we find r using $r = \frac{mv}{qB}$

m of proton

$$r = \frac{mv}{qB} = \frac{(1.67 \cdot 10^{-27}\ kg)(1.5 \cdot 10^8 \frac{m}{s})}{(1.6 \cdot 10^{-19}\ C)(1.3\ T)} = \boxed{1.2\ m}$$

E47:

$r = \frac{mv}{qB}$ ⟶ a proton & electron in this case have the same charge (just + and −), speed, & experience the same field

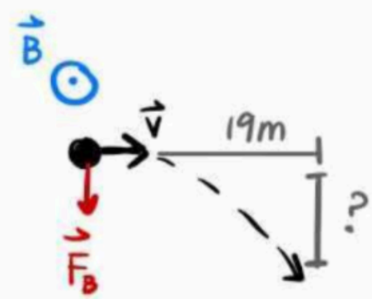
BUT: a proton's mass is roughly 1840x greater than an electron, so the radius of travel for the proton will also be roughly 1840 times greater

---

E49.

$m = 1.55\ kg$
$q = 8.0 \times 10^{-9}\ C$
$\vec{V} \perp \vec{B}$
$\Delta d_x = 19\ m$
$B = 3 \times 10^{-5}\ T$
$V = 21\ m/s$

Top view



① $F_B = q\vec{V} \times \vec{B}$

$F_B = (8.0 \times 10^{-9}\ C)(21\ m/s)(3 \times 10^{-5}\ T)\cancel{\sin 90°}^{1}$

$\boxed{F_B = 5.04 \times 10^{-12}\ N}$

② $\vec{F_B} = ma$

$5.04 \times 10^{-12}\ N = (1.55\ kg)(a)$

$\boxed{a = 3.25 \times 10^{-12}\ m/s^2}$

③ $v_{1y} = 0$ $\quad v_{1x} = 21\,m/s$

need Δt $\quad \Delta t = \frac{\Delta d}{v_{1x}} = \frac{19m}{21\,m/s} = \boxed{0.905s}$

④ $\Delta d_y = \frac{1}{2} a \Delta t^2 + \cancel{v_{1y} \Delta t}^{\,0}$

$\Delta d_y = \frac{1}{2}(3.25 \times 10^{-12}\ m/s^2)(0.905\,s)^2$

$\boxed{\Delta d_y = 1.3 \times 10^{-12}\ m}$ //

the pebble is deflected only 1.3×10^{-12}m from its original path. This is infinitesimal.

E51:

Given: speed = $30\,\frac{m}{s}$ $\quad F = 0.75N$ $\quad B = 2.5 \cdot 10^{-5}\,T$

Required: Charge on ball

Solve: $F = qvB \longrightarrow q = F/vB = \frac{0.75}{(30)(2.5 \cdot 10^{-5})} = 1000\ C$

E53:

Given: emf = 25V $\quad \ell = 3m$ $\quad B = 6 \cdot 10^{-5}\,T$ $\quad \theta = 90°$

Required: speed that wire must travel at

Solve: $emf = vB\ell \sin\theta \longrightarrow v = \frac{emf}{B\ell\sin\theta} = \frac{25\,V}{(6 \cdot 10^{-5}\,T)(3m)(\sin 90)}$

$= 138888.9\,\frac{m}{s}$

E55:

Given: $r = 40m$ $V = 40{,}000\,V$ $B = 1 \times 10^{-5}\,T$

Required: What current is in the wire?

Solve: $B = \dfrac{\mu_0 I}{2\pi r} \longrightarrow I = \dfrac{B(2\pi r)}{\mu_0} = \dfrac{(1\cdot 10^{-5})(2\pi)(40)}{4\pi \cdot 10^{-7}}$

$\boxed{= 2000\,A}$

No solution provided for E57

E59:

Given: $\vec{B} = 1.5T$ $v = 4 \cdot 10^5 \frac{m}{s}$ $q = \pm e = 1.6 \cdot 10^{-19}\,C$

Required: Force felt by the proton & electron

Solve: $F = qvB \longrightarrow$ proton & electron have same $|q|$ (just + for proton and − for electron so will experience same force)

$F = (1.6 \cdot 10^{-19})(4 \cdot 10^5)(1.5)$

$\boxed{= 9.6 \cdot 10^{-14}\,N}$

No solution provided for E61

E63:

	Electric field	Magnetic field
+ charged	Moves in direction of field lines	Moves in direction dictated by RHR (if charge already has $\vec{v}$; no movement if still)
− charged	Moves in direction opposite to field lines	Moves in direction opposite to that given by RHR (if charge already has $\vec{v}$)
uncharged	No movement	No movement

E65:

If the magnetic field is 0, the flux has to be zero since the equation is $\Phi = BA\cos(\omega t)$. However, the field does not have to be zero if flux is 0 (you may be trying to measure flux parallel to the field, or if you're measuring flux over a closed surface (Gauss' Law).

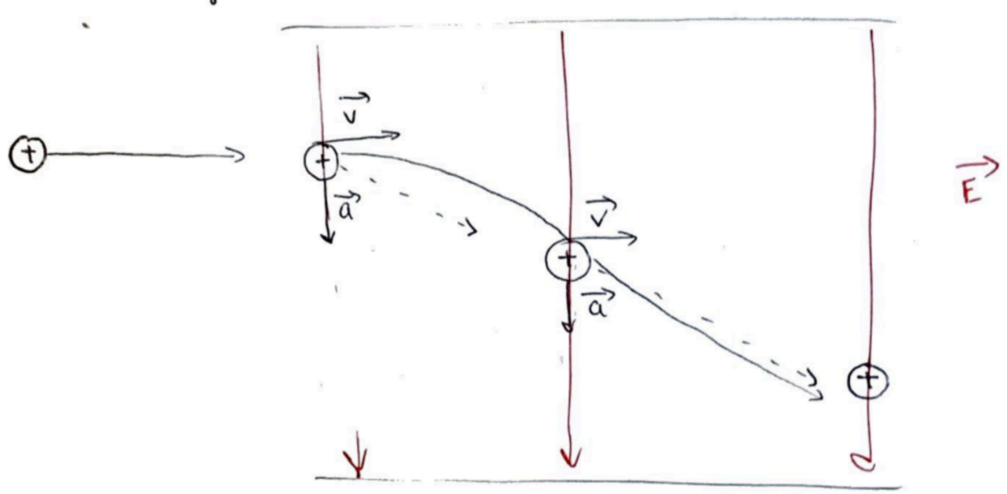
E67:

EM waves are produced by accelerating charges. DC current usually is close to constant (no acceleration of electrons) so it is unlikely to emit EM waves. In AC current, the direction of current is changing (change is velocity direction so acceleration is occurring) & are likely to emit EM waves

---

E69:

Proton = + charge = moves in direction of $\vec{E}$ field lines



$\vec{E}$ adds vertical component (accelerative force) to initial horizontal velocity, causing parabolic movement (just like gravity on a horizontally launched projectile)

No solution provided for E71