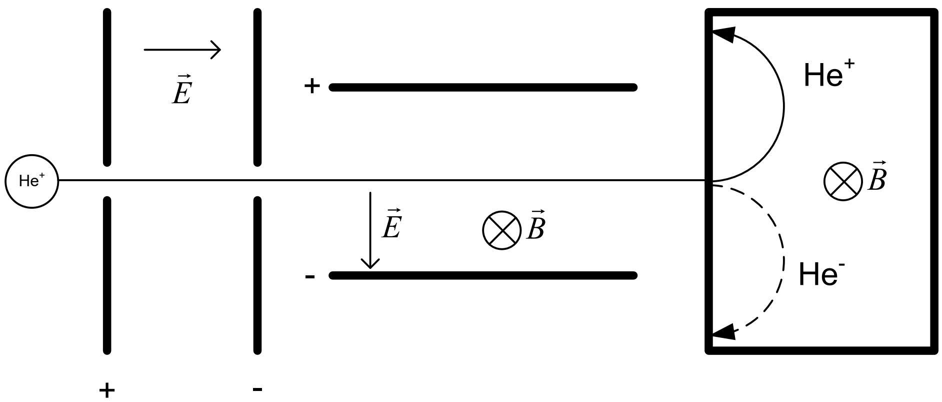
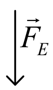
# CONCEPTUAL QUESTIONS

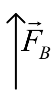
**A.**




For part B, the electric force points down




Which means that the magnetic force points up




And by the right hand rule, (shown below) the magnetic field is in the page.

**B.** A magnetic field can only exert a force on a moving particle, as we can see in the formula $\vec{F} = q\vec{v} \times \vec{B}$. So if a particle is initially at rest (i.e. not moving) the magnetic field cannot exert a force, which means it cannot accelerate the particle, which means it cannot set the particle in motion.
*Now I ask you: can a magnetic field* ***stop*** *a particle? (That would be a good one for a test, don't you think?)*

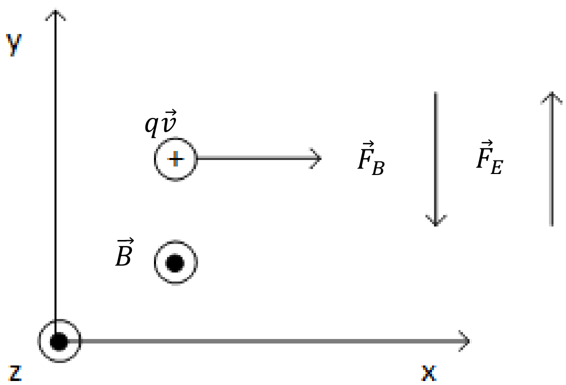
**C.** If we hang a current loop from a thread, the magnetic field will exert a torque on the current loop ( $\vec{\tau} = \vec{\mu} \times \vec{B}$). This torque will cause the loop to turn until its magnetic dipole moment is aligned with the magnetic field.
*Now I ask you: what will be the torque at that moment, and what happens if the current loop is very light?*

**D.**

$q_p v_p B = q_\alpha v_\alpha B$

$q_\alpha = 2q_p$ therefore $v_p = 2v_p$

Ans: C)

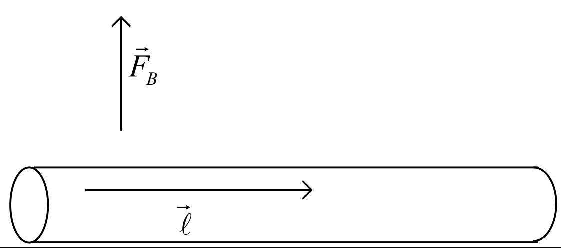



**E.**

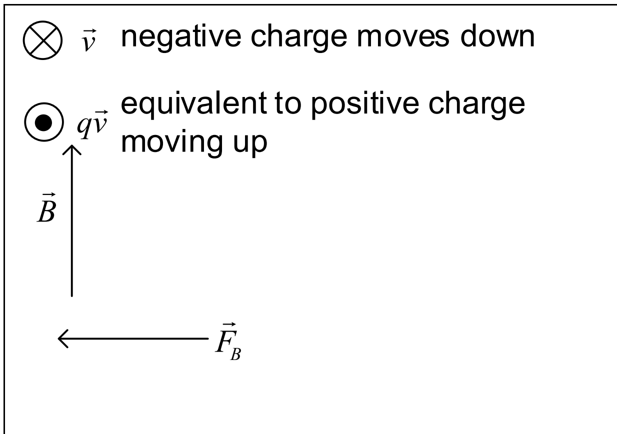
$\vec{F}_B$ points down so the electric force, $\vec{F}_E$, must point up and the electric field must point up as well.

Ans: A)

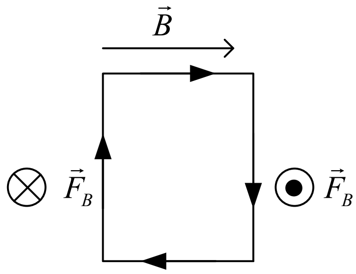
**F.**

| | |
|---|---|
|   | According to the right-hand rule as shown, the magnetic field must point into the page $\otimes \vec{B}$ |

**G.**

| | |
|---|---|
|   | The force points West. |

**H.**




Ans : A

**I.**

a) The Earth's magnetic field exerts a force on incoming charged particles, deflecting them perpendicular incoming charged particles, deflecting them perpendicular to their velocity. As a result, the particle becomes trapped as it spirals around a magnetic field line. (Particles trapped in the Earth magnetic field form the "van Allen radiation belts")

b) The Earth's magnetic field curve downward and become most dense as they approach the magnetic poles. It is here that the spiralling charged particles are brought closest to the planet; under certain conditions they come low enough to collide with atoms and molecules in the upper atmosphere, producing light.

**J.** Yes, if the charge moves parallel to the magnetic field lines there will be no force. $F = qvb\sin\theta$

**K.** No $\vec{F} = q\vec{v} \times \vec{B}$ the force is always perpendicular to the particle's motion.

**L.** Let's do an order of magnitude estimate

$I \approx 10^5$ A

$B \approx 10^{-4}$ T

So the total force on the 10 m pole (assume $\perp$ to $\vec{B}_E$)

$$F \propto I\ell B \approx \left(10^5\ \text{A}\right)\left(10\ \text{m}\right)\left(10^{-4}\ \text{N/Am}\right)$$

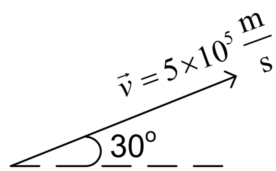
$$F \propto I\ell B \approx 100\ \text{N}$$

100 N is the weight of 100 apples, that force is unlikely to bend a flagpole.

# PROBLEMS

## Question 1

a)




$$\vec{v} = v\cos 30\hat{i} + v\sin 30\hat{j}$$

$$\vec{v} = \left(4.33\times10^5\,\hat{i} + 2.50\times10^5\,\hat{j}\right)\frac{m}{s}$$

$$\vec{F} = q\vec{v}\times\vec{B} = \left(-1.6\times10^{-19}\right)\begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 4.33\times10^5 & 2.50\times10^5 & 0 \\ 6.00 & \text{-}2.00 & 1.00 \end{vmatrix}$$

$$\vec{F} = \left(-1.6\times10^{-19}\right)\left(\left(2.50\times10^5\times1.00\right)\hat{i} + \left(-1.00\times4.33\times10^5\right)\hat{j} + \left(4.33\times10^5\times\left(-2.00\right) - 6.00\times2.50\times10^5\right)\hat{k}\right)$$

$$\vec{F} = \left(-1.6\times10^{-19}\right)\left(2.50\times10^5\,\hat{i} - 4.33\times10^5\,\hat{j} - 24.3\times10^{-5}\,\hat{k}\right)$$

| |
|---|
| $\vec{F}_B = \left(-4.00\hat{i}+6.93\hat{j}+38.9\hat{k}\right)\times10^{-14}\,\text{N}$ is the resultant magnetic force |

b) $\vec{F} = q\vec{E}$

We want the electric force to be $\vec{F}_E = \left(+4.00\hat{i}\text{-}6.93\hat{j}\text{-}38.9\hat{k}\right)\times10^{-14}\,\text{N}$ so that $\vec{F}_E + \vec{F}_B = 0$

$$\vec{E} = \frac{\vec{F}}{q} = \frac{\left(4.00\hat{i} - 6.43\hat{j} - 38.4\hat{k}\right)\times10^{-14}}{-1.60\times10^{-19}}$$

| |
|---|
| $\vec{E} = \left(-2.50\hat{i} + 4.33\hat{j} + 24.3\hat{k}\right)\times10^5\,\frac{\text{N}}{\text{C}}$ is the electric field we need to make the net force on the electron zero. |

## Question 2

$\vec{E} = 8.00\times10^{2}\ \frac{\text{N}}{\text{C}}$

$\vec{B} = 0.800\text{T}$

$m$ = 1.16×10$^{-26}$ kg

"particle is singly charged" therefore: $q$ = ±1.6×10$^{-19}$ C (*Can you explain why that is so? Do you think we might ask that on a test?*)

a)

First we find the velocity of the particle in the velocity selector:

$$v = \frac{E}{B} = \frac{8\times10^{2}}{0.8} = 1.00\times10^{3}\ \frac{\text{m}}{\text{s}}$$

This is the final velocity of the accelerating stage.

The particle starts from rest so $v_i$ = 0 m/s

$$U_i + K_i = U_f + K_f$$

$$U_i - U_f = K_f - K_i$$

$$-\Delta U = \Delta K$$

$$-q\Delta V = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$\Delta V = \frac{\frac{1}{2}\times1.16\times10^{-26}\times\left(1\times10^{3}\right)^{2} - 0}{-\left(-1.6\times10^{-19}\right)} = 36.2\times10^{-3}V$$

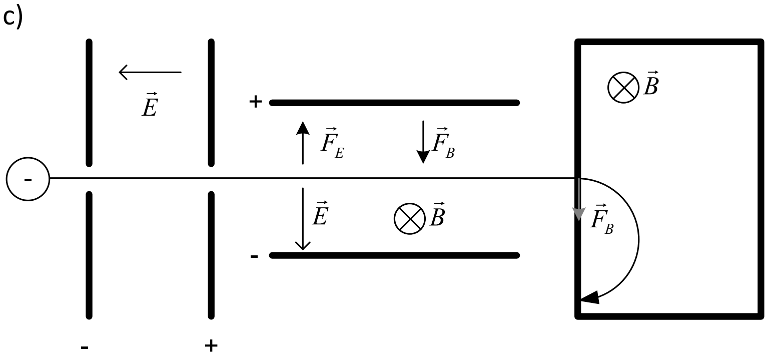
| |
|---|
| We need to accelerate the particle through a potential difference of 36.2mV |

b)

$$r = \frac{mv}{qB} = \frac{1.16\times10^{-26}\times1\times10^{3}}{1.6\times10^{-19}\times0.8} = 9.06\times10^{-5}\text{m}$$

| |
|---|
| The radius of the circular path followed by the particle once it is inside the chamber is: 9.06×10$^{-5}$m |

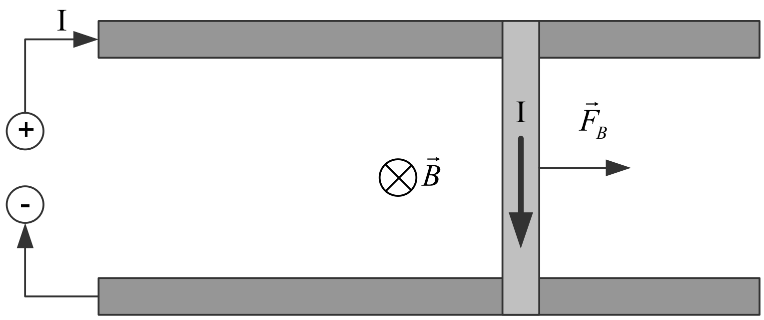
c)



## Question 3

a)

The magnetic force is to the right (see picture)




b)

*Given :*

I=0.5kg

$\ell$ =0.1 m

B=5.00T

$v_o$ =0 m/s

t = 3 s

*Objective* : a

*Strategy :* calculate $F_B$, find acceleration and use kinematics to find the final speed

$F = I\ell B \sin\theta$ where θ = 90°

$F = 4 \times 0.1 \times 5 = 2.00\text{N}$

$F = ma$

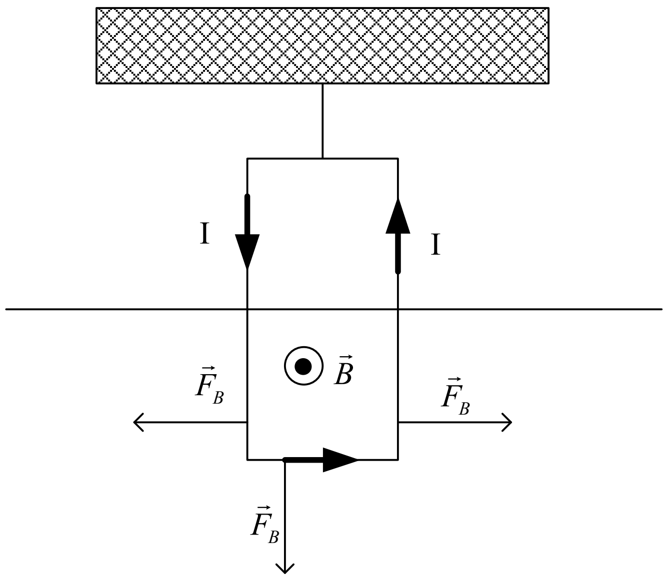
$$a = \frac{F}{m} = \frac{2\text{N}}{0.5\text{kg}} = 4.00\frac{\text{m}}{\text{s}^2}$$

$$v = v_o + at = 0 + 4 \times 3 = 12.0\frac{\text{m}}{\text{s}}$$

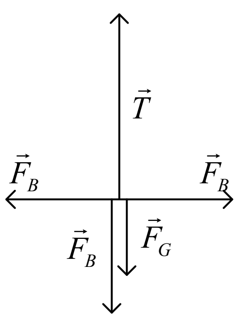
| The bar will have a speed of 12 m/s 3 seconds after starting from rest |
| --- |

## Question 4

The forces on the sides are:




Free body diagram




List of forces on the y axis :

*T = ?*

$F_G = mg$

$F_B = IlB\sin\theta$

By Newton's second law , the sum of the forces should be zero

$T - F_G - F_B = 0$

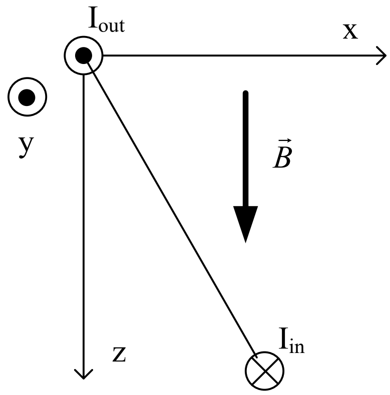
$T = F_G + F_B = mg + I\ell B\sin\theta = 0.3\times 9.8 + 3\times 0.1\times 2.5\times \sin 90$

$T = 3.69\text{N}$

The tension in the string supporting the loop is 3.69 N in positive *j* direction.

## Question 5

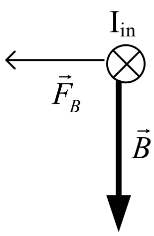
This problem will be easier if we look at the diagram from the positive y-axis:




a)

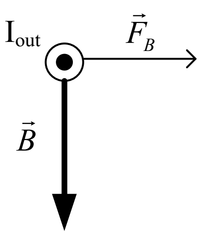
$F_{ab}$ = IlBsinθ = 5×0.05×0.5×sin90°

$F_{ab}$ = 0.125 N towards the left which we can also write as : $\vec{F}_{ab} = -0.125\hat{\imath}$ N



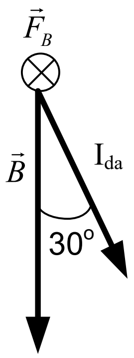

$F_{cd}$ = IlBsinθ = 5×0.05×0.5×sin90°

$F_{cd}$ = 0.125 N towards the right which we can also write as: $\vec{F}_{cd} = 0.125\hat{\imath}$ N



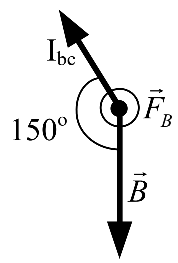

$F_{da}$ = IlBsinθ = 5×0.05×0.5×sin30°

$F_{da}$ = -0. 625 N into the page which we can also write as: $\vec{F}_{da} = -0.0625\hat{\jmath}$ N



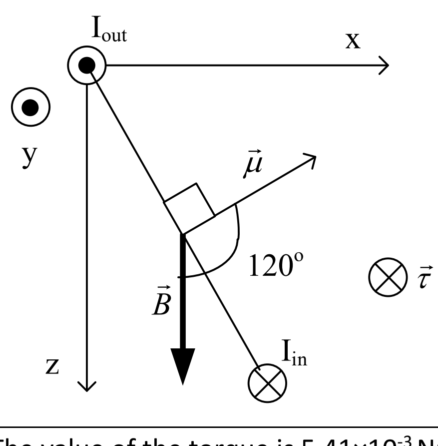

$F_{bc}$ = IlBsinθ = 5×0.05×0.5×sin150°

$F_{bc}$ = 0.0625 N out of the page which we can also write as: $\vec{F}_{bc} = 0.0625\hat{\text{j}}$ N




b)

$$\mu = NIA = 1\times 5\times 0.05^2 = 0.0125\text{Am}^2$$
$$\tau = \mu B \sin\theta$$
$$\tau = 0.125\times 0.5\times \sin 120° = 5.41\times 10^{-3}\,\text{Nm}$$
$$\vec{\tau} = -5.41\times 10^{-3}\,\hat{\text{j}}\ \text{Nm}$$




The value of the torque is $5.41\times10^{-3}$ Nm pointing in the negative y-direction.

## Question 6

Given :

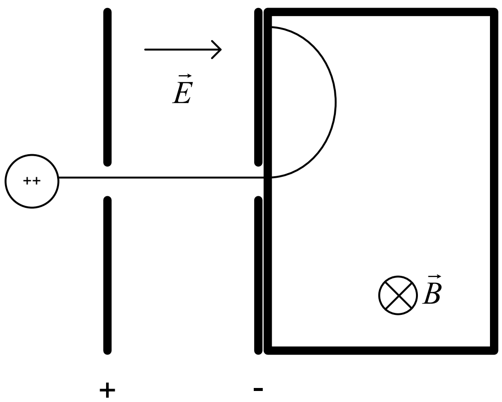
« doubly charged positive ion means » q = 2 ×1.6 ×10$^{-19}$C

d = 0.2000 m

E = 5.00 ×10$^{4}$ V/m

B = 0.5 T

r = 0.500 cm




In the magnetic field, the radius of the particle's trajectory is : $r = \frac{mv}{qB}$

We know r, q, B so we need to find v to get m

$$\Delta K = -\Delta U$$

$$\Delta K = -q\Delta V$$

$$\frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 = qEd$$

$$\frac{1}{2}mv_f^2 = qEd$$

$$v^2 = \frac{2qEd}{m}$$

$$r^2 = \frac{m^2v^2}{q^2B^2}$$

$$r^2 = \frac{m^2 2qEd}{q^2B^2m}$$

$$m = \frac{r^2q^2B^2}{2qEd} = \frac{\left(5\times10^{-3}\right)^2\times\left(2\times1.6\times10^{-19}\right)\times0.5^2}{2\times5\times10^4\times0.2} = 1.00\times10^{-28}\,kg$$

So the mass of the particle is 1.00×10$^{-28}$kg

## Question 7

a) $K = \frac{1}{2}mv^2$

$$v = \sqrt{\frac{2K}{m}} = \sqrt{\frac{2\times 3.52\times 10^{-12}}{1.67\times 10^{-27}}} = 6.50\times 10^{7}\ \frac{m}{s}$$

This speed is about 20% the speed of light, so we really should be using special relativity to find the speed, which is really closer to $6.38\times10^7$m/s. You will learn more about this in NYC. We will continue the problem with speed found with classical kinetic energy.

$$r = \frac{mv}{qB} \rightarrow B = \frac{mv}{qr} \rightarrow B = 0.678T$$

b) $f = \frac{v}{2\pi r} = \frac{6.50\times 10^{7}}{2\times 3.14\times 1} = 1.03\times 10^{7}\ Hz$

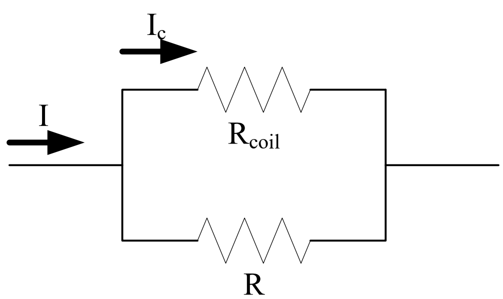
c)

$$I = \frac{\Delta Q}{\Delta t} \rightarrow \Delta Q = I\Delta t \rightarrow n\cdot e = I\Delta t \rightarrow n = \frac{I\Delta t}{e}$$

$$n = \frac{160.0\times 10^{-6}\times 1}{1.60\times 10^{-19}} = 1.00\times 10^{15}\ protons$$

d) In a cyclotron the particles travel in an outward spiral (r increases as the particles speed up.

## Question 8




*Strategy*: R and the coil are in parallel. If we find $I_C$, the current in the coil, we will know the voltage across the coil $V_C$ and therefore across the combination. From V and I we will get $R_{EQ}$.

$$\tau = 5\times 10^{-6}\,\frac{\text{N m}}{\text{deg}}\,40\,\text{deg} = 2.00\times 10^{-4}\,\text{Nm}$$

$$\tau = NI_C AB\sin 90$$

$$I_C = \frac{\tau}{NAB} = \frac{2\times 10^{-4}}{500\times 0.01^2\times 7.5\times 10^{-2}} = 5.33\times 10^{-2}\,\text{A}$$

$$V_C = I_C R_{COIL} = 5.33\times 10^{-2}\times 14 = 0.746\ \text{V}$$

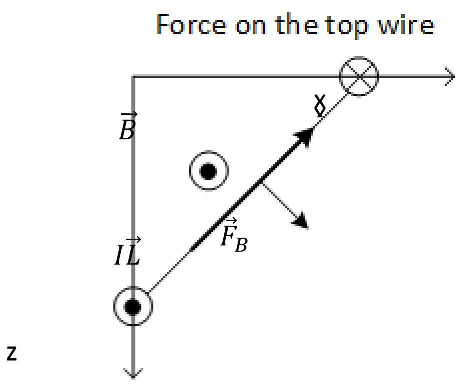
$$V_C = IR_{EQ}$$

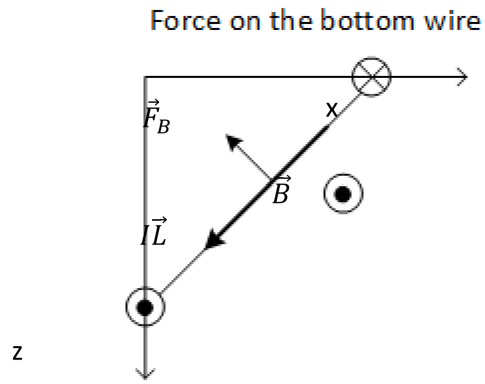
$$R_{EQ} = \frac{V}{I} = \frac{0.746}{0.500} = 1.49\ \Omega$$

| The total resistance of the ammeter 1.49 Ω |
|---|

## Question 9

a) The magnetic force on sides cd and ab is zero, because the current is parallel and anti-parallel to the magnetic field in these segments.




The magnitude for both remaining forces is as follows (the distance of the diagonal wire is $0.707 = \frac{\sqrt{2}}{2}$):

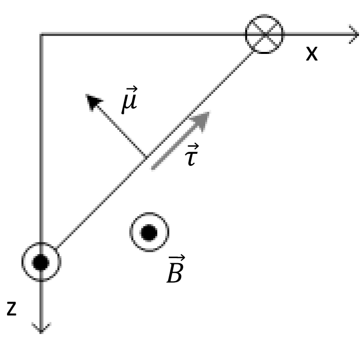
$$F_B = ILB\sin\theta = 2 \cdot \frac{\sqrt{2}}{2} \cdot 0.04 \cdot \sin 90° = 5.66\text{E-}2\ \text{N}$$

The force on wire *da* is at 45° in the x-z plane
The force on wire *bc* is at 225° in the x-z plane

b) The total force on the loop is zero.

c) the magnitude of the torque is:

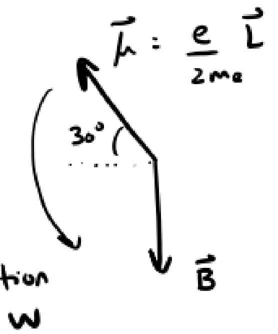
$$\tau = \mu B\sin\theta = 1 \cdot 2 \cdot 0.5 \cdot \frac{\sqrt{2}}{2} \cdot 0.04 \cdot \sin 90° = 0.0283\ \text{Nm}$$




So the torque is 0.0283 N·m at -45° or 315° in the x-z plane

d) The loop rotates so that $\vec{\mu}$ lines up with $\vec{B}$, i.e. so that the loop is parallel with the x-z plane. Side *da* will rotate down and side *cd* will rotate up. (Now think about it: the loop will gain kinetic energy as it rotates. Then, the loop will overshoot the point when $\vec{\mu}$ is lined up with $\vec{B}$ . After that, the torque will be in the opposite direction. The loop will oscillate in the magnetic field.)

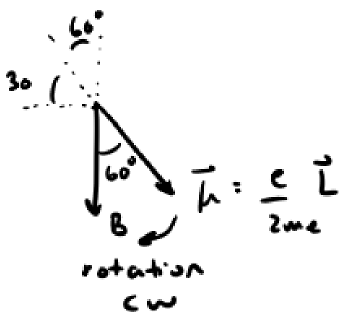
## Question 10




$$|\vec{\tau}| = |\mu||B|\sin\theta = \frac{|-1.602\times10^{-19}||6.626\times10^{-34}||5T|\sin 120°}{2\cdot 9.11\times10^{-31}\,kg}$$

so $|\vec{\tau}|$ = 2.52E-22 Nm ccw

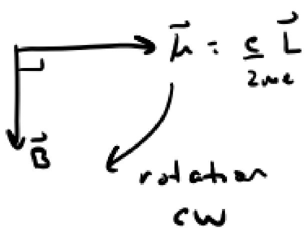
↳ rotation direction




$$|\tau| = |\mu||B|\sin\theta = \frac{|-1.602\times10^{-19}||6.626\times10^{-34}||5T|\sin 60°}{2\cdot 9.11\times10^{-31}\,kg}$$

so $|\vec{\tau}| = 2.522\times10^{-22}$ Nm cw

↳ rotation direction




$$|\tau| = |\mu||B|\sin\theta = \frac{|-1.602\times10^{-19}||6.626\times10^{-34}|5T\cdot\sin 90°}{(2)\,9.11\times10^{-31}}$$

So $|\tau| = 2.91\times10^{-22}$ Nm cw

↳ rotation direction

b) After the $\vec{B}$-field is turned on, all electron spins line up with the magnetic field in the direction of rotation indicated

c) For an MRI, the signal produced is proportional to the time it takes electrons to line up with $\vec{B}$. Therefore the larger the angle, the longer it takes and the more signal is produced.

Therefore Signal (a) > signal (c) > signal (b)

150° 90° 60°