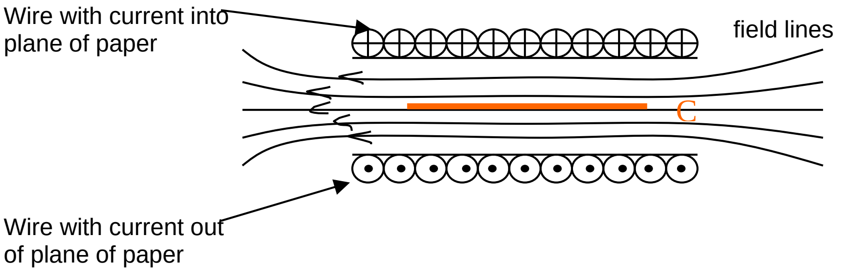
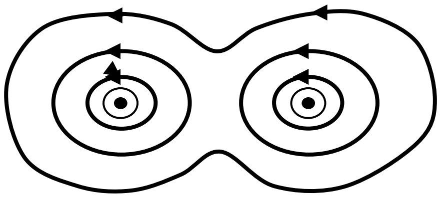
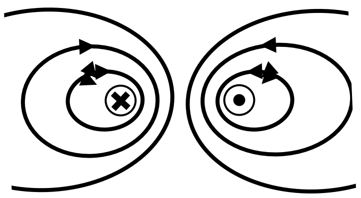
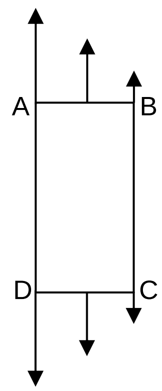
TUTORIAL 16: ELECTROMAGNETISM SOLUTIONS

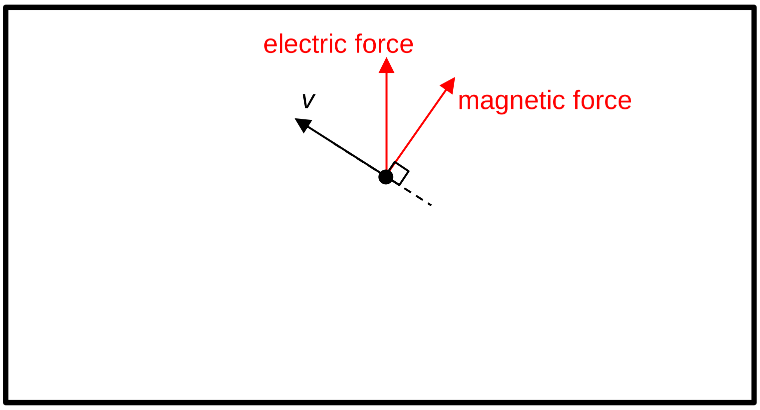
<u>Level 1 Solutions</u>

1(i) & (ii)	 • field lines are evenly-spaced & parallel to axis of solenoid • C parallel to field lines (deduced fr FLHR)	[1] [1]
2(a)	 [1m for correct shape] [1m for correct direction and <u>*increasingly spread out*</u>; **why?**]	[1] [1]
(b)	 [1m for correct shape] [1m for correct direction and increasingly spread out]	[1] [1]
8	**C** Use Fleming's left-hand rule, the force points towards point X, the current flows out of the paper, and thus the B field must point towards arrow C.	
9	**B** $F_1 = BIL \sin 90°$ $8.0 \times 10^{-3} = BIL$ ------ (1) After rotation: angle between B & current is 60° (**NOT** 30°). $F_2 = (\frac{B}{2})(I)(L \sin 60°) = ½ (8.0 \times 10^{-3})(\sin 60°) = 3.5$ mN	
13	**B** (Refer to sect. 16.5.2 for explanation in terms of RHGR & FLHR) X and Y are "like currents", so X attracts Y to the left. Z and Y are "unlike currents", so Z repels Y to the left also. Thus resultant: to left. **Note:** Not allowed to explain using following mnemonic in non-MCQ questions: mnemonic: "Like currents" (in direction) attract; Unlike currents repel"	

14	**B** Use FLHR. Current should be pointing upward since electron is moving downward as the wheel turns.	
15	**D** The standard formula F = BIL sin θ applies only if θ is the angle between B and I. However, in this question, θ is NOT the angle between B and I. Hence, the correct formula to apply in this case is F = BIL sin (90° - θ) = BIL cos θ. Thus answer is a cosine graph.	

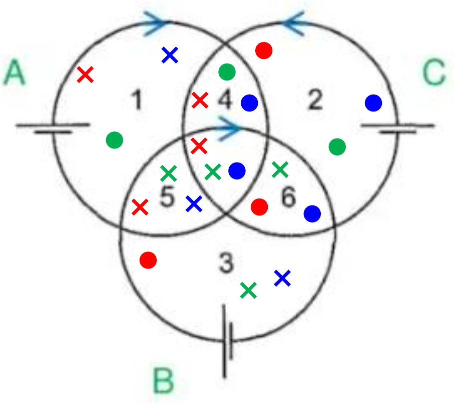
Solutions to Additional Questions

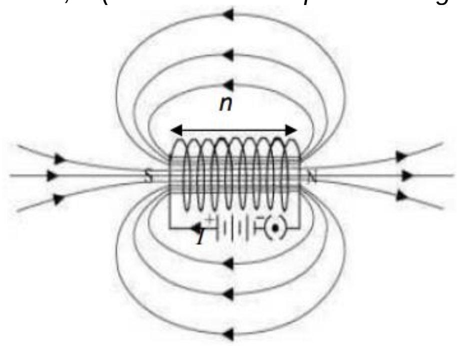
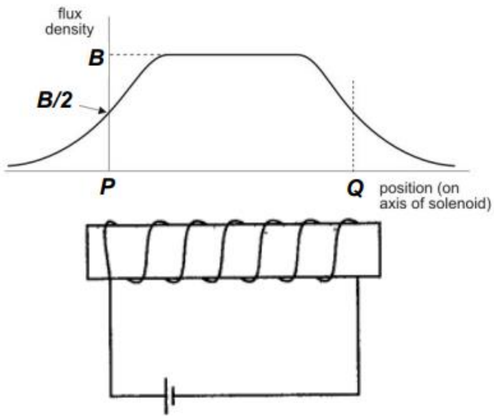
1(a)(i)	$B_{AD} = \dfrac{\mu_0 I}{2\pi r}$ $= \dfrac{(4\pi \times 10^{-7})(30)}{2\pi(0.010)}$ $= 0.00060$ T	
(a)(ii)	$B_{BC} = \dfrac{\mu_0 I}{2\pi r}$ $= \dfrac{(4\pi \times 10^{-7})(30)}{2\pi(0.090)}$ $= 0.0000667$ T	
(b)	Resultant force $= B_{AD}IL - B_{BC}IL$ $= (0.00060)(20)(0.30) – (0.0000667)(20)(0.30)$ $= 0.0032$ N Direction = towards the left (force on AD is repulsive and on BC is attractive since like current attracts and unlike current repel, respectively)	
(c)	The magnetic flux induced by XY acting on the loop ABCD is perpendicularly into the page, decreasing in magnitude further away from XY. Using Fleming's Left hand rule, magnetic force acting on AB will be upward while magnetic force acting on CD will be downward, but equal in magnitude. Hence, there is no resultant force acting on the loop along the direction XY even though there are forces acting on AB and CD individually. 	
2(a)(i)	The magnetic flux density of a magnetic field is numerically equal to the <u>force per unit length</u> of a <u>long straight conductor</u> carrying a <u>unit current</u> at <u>right angles</u> to a <u>uniform</u> magnetic field.	
(ii)	The particle is <u>positively charged</u>.	
(b)(i)	<u>Magnetic force provides for the centripetal force</u>. $Bqv = \dfrac{mv^2}{r}$ $B = \dfrac{mv}{rq}$	

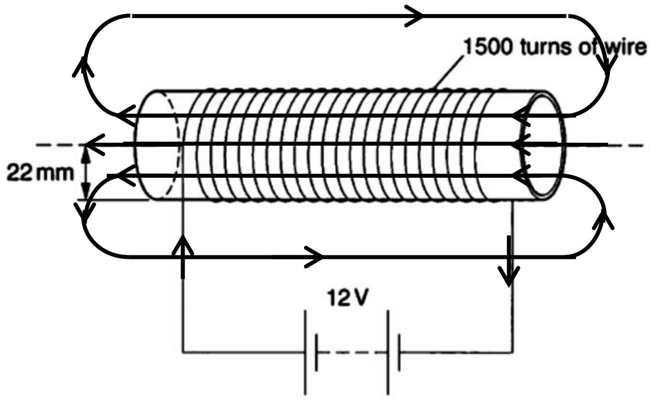
(ii)	From $B = \dfrac{mv}{rq}$, since the radius has increased, B has decreased.	
(iii)	$v = \dfrac{Brq}{m}$ $= \dfrac{(7.6\times10^{-3})(34\times10^{-2})(3.2\times10^{-19})}{6.6\times10^{-27}}$ $=1.253\times10^{5} = 1.25\times10^{5}$ m s^{-1}	
(c)(i)	Since the magnetic force is directed to the right of the particle's path, the electric force will have to be to the left of its path (so that resultant force equals zero). Electric force on a positively charged particle is in the same direction as the electric field. Hence the electric field is to the left of the path of the particle. (allow using "upwards" / "downwards" but direction has to be consistent with the drawing in **(c)(ii)**.)	
(c)(ii)	 • Forces labelled • Electric force in the correct direction • Magnetic force perpendicular to v, in the correct direction • Length of $F_E = F_B$	
3(a)(i)	1. face: PQRS, polarity: positive face: JKLM, polarity: negative	[1] [1]
	2. Using Fleming's Left Hand Rule, force on electrons is downward / electrons will accumulate on the face JKLM.	[1]
(ii)	(As charges separates,) an electric field is created between PQRS and JKLM Maximum value is reached when electric force on electron is equal and opposite to magnetic force on electron.	[1] [1]
(iii)	Using $I = nAvq$ $6.3\times10^{-4} = (1.3\times10^{29})(d)(0.10\times10^{-3})(E / B)(1.6\times10^{-19})$ $3.0288\times10^{-10} = (d)(E)(1 / B)$ $3.0288\times10^{-10} = (d)(\Delta V / d)(1 / B)$ $\Delta V = (3.0288\times10^{-10})(B)$ $= (3.0288\times10^{-10})(4.6\times10^{-3})$ $= 1.4\times10^{-12}$ V	[1] [1] [1]

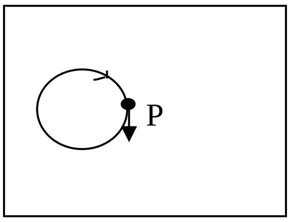
4(a)(i)	Magnetic force provides for the centripetal force. $Bqv_y = \frac{mv_y^2}{r}$ $(3.0 \times 10^{-5})(1.6 \times 10^{-19})(6.7 \times 10^6 \times \sin 40°) = (9.11 \times 10^{-31})(6.7 \times 10^6 \times \sin 40°)^2 / r$ $r = 0.817$ m	
(ii)	$v_y = r(2\pi / T)$ $6.7 \times 10^6 \times \sin 40° = (0.81737)(2\pi / T)$ $T = 1.19 \times 10^{-6}$ s	
(iii)	Using $s_x = u_x t$, $p = (6.7 \times 10^6 \times \cos 40°)(1.19249 \times 10^{-6})$ $p = 6.12$ m	
(b)	With the parallel plate, a uniform E-field will set up such that there is now a horizontal electrical force acting on the electron towards the right. Hence, the electron will now accelerate horizontally, resulting in increasing horizontal component of its velocity. With *T* being constant, the pitch *p* will increase.	
5(a)	B due to WX $= \frac{\mu_0 I}{2\pi d}$ $= \frac{(4\pi \times 10^{-7})(9.0)}{2\pi(50 \times 10^{-3})}$ = 0.000036 T, out of the page B due to YZ $= \frac{\mu_0 I}{2\pi d}$ $= \frac{(4\pi \times 10^{-7})(12.0)}{2\pi(50 \times 10^{-3})}$ = 0.000048 T, vertically upward Resultant B $= \sqrt{0.000036^2 + 0.000048^2}$ $= 6.0 \times 10^{-5}$ T Direction $= \tan^{-1}\left(\frac{0.000048}{0.000036}\right)$ = 53.1° above the horizontal	
(b)	Since P is still 50 mm away from YZ, B due to YZ remains at 0.000048 T. To get resultant B = 0 at point P, B due to WX must be equal to 0.000048 as well. Hence, B due to WX $= \frac{\mu_0 I}{2\pi d}$ $0.000048 = \frac{(4\pi \times 10^{-7})(9)}{2\pi(d)}$ d = 37.5 mm Therefore, distance of WX away from YZ = 50 + 37.5 = 87.5 mm away from YZ orientation of WX should be parallel to YZ direction of current to be in the same direction as current in YZ	

Level 2 Solutions

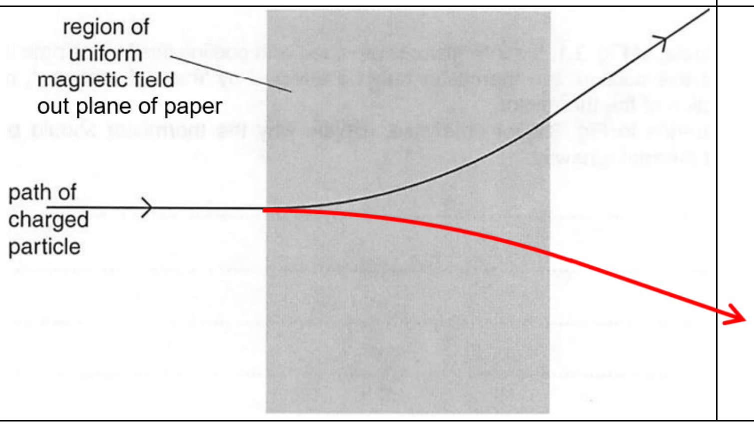
3	**A** Use right hand grip rule at each wire to find the direction of magnetic field due to each wire on point O. Then use vector summation of all 4 vectors to confirm that the resultant field points to the left.	
4	**B**  Note that B field within and outside of a coil are opposite in directions. Using RHGR, we can deduce the direction of the B field within the coil and hence outside the coil as well. B-field in red is due to coil A B-field in green is due to coil B B-field in blue is due to coil C Only in region 2 and 5 where B field are all in the same direction.	
5	Similar to Q3 Using RHGR, - the direction of flux density at P **due to A** is $\overrightarrow{PB}$, i.e ↙ 45° to vertical - the direction of flux density at P **due to B** is $\overrightarrow{PD}$, i.e. ↘ 45° to vertical - the direction of flux density at P **due to C** is $\overrightarrow{PD}$, i.e. ↘ 45° to vertical - the direction of flux density at P **due to D** is $\overrightarrow{PB}$, i.e ↙ 45° to vertical Distance between 1 wire to the centre P = $\sqrt{0.1^2+0.1^2}=\sqrt{0.02}$ B due to each wire = $\frac{\mu_o I}{2\pi d}=\frac{(4\pi\times10^{-7})(5.00)}{2\pi(\sqrt{0.02})}=7.071\times10^{-6}$ T Component of B due to each wire = $(7.071 \times 10^{-6})(\cos 45°)$, vertically downwards. Resultant B due to all 4 wires = $4 \times (7.071 \times 10^{-6})(\cos 45°)$ = 20.0×10^{-6} T, vertically downwards in plane of paper	
6	**C** Since the current in Y reduces the resultant magnetic field at O, we deduce by using the right hand grip rule that the current in Y is opposite in direction to current in X. Suppose we now assume I_X is anticlockwise & (thus) I_Y is clockwise. Therefore, the magnetic field at point P (which is outside of coil Y and inside coil X) will be increased, as the magnetic fields from both coils are in the same direction at P (by applying RHGR). Hence magnetic field at point Q (outside of both coils X and Y) will be decreased, as the magnetic fields from both coils oppose each other at Q.	

7	Magnitude of B at the ends is <u>smaller</u> compared with at the centre There is <u>greater spreading of the field lines</u> at the ends of the solenoid hence the density of field lines is less at the ends. *(in fact, B field is roughly halved at the end.* *Imagine a point at the centre of the solenoid, there are turns on both LHS and RHS of the point.* *However, a point at the end of the solenoid, there are turns only on 1 side of the point.* *Hence, n (number of turns per unit length) is halved at the ends)* 	
10	**B** Deduce the **reduction in the balance reading (of 0.02 g)** is due to the "appearance" of an (**upward) magnetic force** (= BILsin90^0) when current flows in the loop. $\Rightarrow$ BIL = Δmg where Δm = decrease in effective mass = 0.02 x 10^{-3} kg Substituting, B = 1.3 x 10^{-3} T	
11	**A** With a current of 2.0 A in the wire from X to Y, a magnetic force F_B acts upwards on the wire XY, and downwards on the horseshoe magnet: $F_B = (144.6 - 142.0) \times 10^{-3} \times 9.81 = BIL \sin 90°$ $(144.6 - 142.0) \times 10^{-3} \times 9.81 = B(2.0)L$ $BL = 0.0127$ When a current of 3.0 A flows from Y to X, the magnetic force on the horseshoe magnet acts upwards. $F_B' = B(3.0)L$ $(142.0 - m)\ ) \times 10^{-3} \times 9.81 = 3 \times 0.0127$ $m = 138.1$ g **Comments:** When a force acts on the wire, there is an equal and opposite force acting on the horseshoe magnet. These forces can be attractive or repulsive, which explains why the balance's reading can be higher or lower than 142.0 g, depending on the direction of current in the wire.	

12(a)(i)	Total length of wire = $2\pi r \times 1500$ (Note the significance of 'tightly wound') $= 2\pi(22 \times 10^{-3}) \times 1500$ = 207 m (3 sf)	[1] [1]
(ii)	total resistance $R = \dfrac{\rho l}{\pi r^2}$ $= \dfrac{1.7 \times 10^{-8} \times 207.345}{\pi\left(0.86 \times 10^{-3}\right)^2}$ $= 1.52\ \Omega$	[1] [1] [1]
(iii)	total current $= \dfrac{V}{R} = \dfrac{12}{1.52}$ = 7.89 A	[1] [1]
(b)	Given that current is as shown, use the **right-hand grip rule** to sketch out the magnetic flux pattern.  [1m for correct direction of B] [1m for correct <u>parallel field lines and evenly-spaced within solenoid</u>] [1m for correct pattern outside of solenoid] (Pattern similar to that for a bar magnet)	[1] [1] [1]
(c)(i)	The currents in CB & DE are <u>parallel to the magnetic field produced by the solenoid.</u> By FLH Rule, $F_B = BIL\sin 0° = 0$; hence, no force is experienced by the wire segments CB and DE; (hence there is no turning effect.)	[1]
(ii)	The current in the wire CD is perpendicular to the magnetic field. By Fleming's left-hand rule, a downward magnetic force acts on the wire CD. This force has an anticlockwise moment about pivot BE.	[1] [1] [1]
(iii) 1.	Direction of current in CD: from C to D { apply FLHR }	[1]
2.	Applying the principle of moments about pivot BE: Anti-clockwise moment = Clock-wise moment $BIL\sin 90° \times (106 \times 10^{-3}) = (5.7 \times 10^{-4}) \times (77 \times 10^{-3})$ $B(4.9)(25 \times 10^{-3})(106 \times 10^{-3}) = (5.7 \times 10^{-4}) \times (77 \times 10^{-3})$ $B = 3.38 \times 10^{-3}$ **Tesla** [1m for correct CW moment, 1m for correct ACW moment, 1m for Unit]	[1] [2] [2]

16	**A** Since angle betw B & velocity is 23° (and NOT 0°, 90° or 180°), shape is helical. Using $F = Bqv \sin\theta$, $7.3 \times 10^{-16} = (0.084)(1.6 \times 10^{-19})(v)(\sin 23°)$ $v = 1.4 \times 10^5$ m s^{-1} Note: Examiner used the term "magnetic field ***strength***" in place of "magnetic flux density" in this question. However, students should NOT use this term magnetic field strength in any qualitative answer.	
17	**C**. Using Fleming's left-hand rule at P: ▪ Force F finger points towards centre of circular path ▪ Magnetic flux density B finger points out of the plane of paper ▪ We get Current I finger pointing in the same direction as the tangential velocity of the particle in the diagram. Since the particle (of unknown charge) is travelling in the direction of conventional current, we can conclude the particle is positively charged. From the figure, we observe that the radius is decreasing. With $Bqv = mv^2/r$, it implies that $v = Bqr/m$. So with a decreasing r, it means that the speed is also decreasing as B, q and m are constants. (Quoting a formula is a good way to explain how v varies with r. However, students frequently fail to state that the rest of the quantities (B, q and m) are constants.)	
18 (a)	 Apply FLHR to the electron (-ve charge) where current finger points opposite to the motion of electron [1m for direction, 1m for circular path] **Note:** The path can <u>only</u> be a <u>complete circle</u> provided that the electron already <u>inside the B field</u> like in this case.	[2]
(b)(i)	$F = Bqv \sin\theta = (1.5 \times 10^{-3}) \times (1.60 \times 10^{-19}) \times (2.9 \times 10^7) \sin 90°$ $= 6.96 \times 10^{-15}$ N	[1] [1]
(ii)	$r = \dfrac{m\,v}{B\,Q} = \dfrac{(9.11\times10^{-31})\times(2.9\times10^{7})}{(1.5\times10^{-3})(1.60\times10^{-19})}$ $= 0.11$ m	[1] [1]
(iii)	Distance (half a rev.) = π r Time for half period = dist ÷ speed $= (\pi \times 0.11) \div (2.9 \times 10^7)$ $= 1.19 \times 10^{-8}$ s	[1] [1]
(iv)	K.E. = $\frac{1}{2}m v^2 = 0.5 \times (9.11 \times 10^{-31}) \times (2.9 \times 10^7)^2 = 3.83 \times 10^{-16}$ J	[1]
(c)	Gain in KE = Loss in EPE $\frac{1}{2} mv^2 - 0 = q\Delta V$ ΔV = (Change in KE) ÷ q $= (3.83 \times 10^{-16}) \div (1.60 \times 10^{-19})$ = 2400 V (2 sf)	 [1]

19	**B** If a charged particle enters <u>perpendicularly</u> to E-Field, motion is <u>parabolic</u> (curved path that is NOT the arc of a circle). If a charged particle enters <u>perpendicularly</u> to B-Field, motion is <u>circular</u>.	
20	**A** For charged particles to move through undeflected, F_B must be equal to F_E. $Bqv = qE$ $B = \frac{E}{v}$ Regardless the sign of the charge, B must be into the page if E is pointing vertically downward. For example, if charge is positive and E is pointing vertically downward, ▪ F_E points downward ▪ F_B must point upward ▪ Using FLHR, F_B can only point upward for positive charge if and only if B is pointing into the plane of the paper. If charge is negative and E is pointing vertically downward, ▪ F_E points upward ▪ F_B must point downward ▪ Using FLHR, F_B can only point downward for negative charge if and only if B is pointing into the plane of the paper.	
21(a)(i)	$R = \frac{V}{I} = \frac{4.5}{2.5} = 1.8\ \Omega$	[1]
(ii)	(Given that 1 turn of wire is 8.8 cm, we can find the number of turns if we can find the total length of the wire.) From $R = \frac{\rho L}{A}$, where L= total length of wire $L = \frac{1.8\times\left(\pi\left(0.3\times10^{-3}\right)^2\right)}{1.6\times10^{-8}} = 31.8\text{ m}$ Number of turns = L ÷ circumference = $\frac{31.8}{8.8\times10^{-2}}$ = 361.4 turns = 361	[1] [1] [1]
(iii)	A length of 12.0 cm of solenoid consists of 361 turns. $\Rightarrow$ number of turns in 1 m of solenoid = $\frac{361}{12\times10^{-2}}$ = 3008 ≈ 3000 turns	[1]
(b)(i)	$B = \mu_0 nI = 4\pi\times10^{-7}\times3000\times2.5 = 9.43\times10^{-3}\text{ T}$	[1]
(c)(i)	velocity along solenoid axis = v cos 30° = $4.0\times10^7\cos 30°$ = $3.46\times10^7\text{ m s}^{-1}$	[1]
(ii)	velocity normal to the axis = v sin 30° = $4.0\times10^7\times\sin 30°$ = $2.00\times10^7\text{ m s}^{-1}$	[1]

(d)	The magnetic force provides the centripetal force. (This statement is essential, especially in a "Show" question.) Therefore, $Bqv \sin 90° = \frac{mv^2}{r}$ ($\theta = 90^0$ since v is "normal" to B) $r = \frac{mv}{Bq}$	[1] [1] [1]
(e)	▪ Only the component of the velocity **<u>normal</u>** to the axis of solenoid is affected by the magnetic force, as it is perpendicular to the magnetic field. ▪ Hence, we need to substitute the velocity <u>normal</u> to the axis of solenoid to $r = \frac{mv}{Bq}$. ▪ We would then need to compute the <u>diameter</u> of the circular motion. ▪ if the <u>diameter of the circular motion</u> exceeds the <u>radius of the solenoid</u>, it will then collide with the solenoid. $r = \frac{mv_n}{Bq}$, where v_n = velocity normal to the solenoid axis $= \frac{9.11 \times 10^{-31} \times 2 \times 10^{7}}{9.43 \times 10^{-3} \times 1.6 \times 10^{-19}}$ = 1.21 cm Hence, the diameter of the circular motion = 1.21 × 2 = 2.42 cm, which exceeds the 1.4 cm radius of solenoid. As the electron enters the solenoid at the centre, we can conclude that the electron will <u>collide</u> within its wall.	 [1] [1] [1]
22(i)	Using Fleming Left hand rule, the magnetic force will **<u>always</u>** be perpendicular to the direction of the charged particle's velocity. As the magnetic force will only change the direction of the velocity and not the magnitude of the velocity, the speed for the charged particle and the magnitude of the force will be remain constant. This magnetic force therefore will provide a constant centripetal force to allow the charged particle to move in a uniform circular motion.	[1] [1]
(ii)	Using FLHR, ▪ Force F finger points towards centre of circular path (upward) ▪ Magnetic flux density B finger points out of the plane of paper ▪ We get Current I finger pointing in the **<u>opposite</u>** direction as the tangential velocity of the particle in the diagram. ▪ Hence, sign of the particle is <u>negative</u>.	[1]
(iii)	Since $r = \frac{mv}{Bq}$, a larger momentum while B & q are constant will result in a <u>larger r</u>. Since the 2nd particle has opposite sign, then the circular arc for the 2nd particle will be in the opposite direction.  	

23(a)(i)	(by Fleming's left hand) magnetic force is right So electric force is left and so left plate is lower potential	M1 A1
(a)(ii)	Bev = eE $v = E/B = 1.50 \times 10^4 / 0.020$ $= 7.5 \times 10^5$ m s^{-1}	 C1 A1
(a)(iii)	The other ions are <u>deflected</u> (and so do not arrive at the slit). Only ions of certain "chosen" velocity can emerge from the slit.	B1 B1
(b)(i)	$Bqv = mv^2/r$ $r = mv/Bq$ $= (5.81 \times 10^{-26})(7.5 \times 10^5) / (0.020)(1.60 \times 10^{-19})$ (allow ecf for v) $= 13.6$ m	 C1 A1
(b)(ii)	1. no, no 2. no, halved	A1 A1

- End of tutorial solutions -