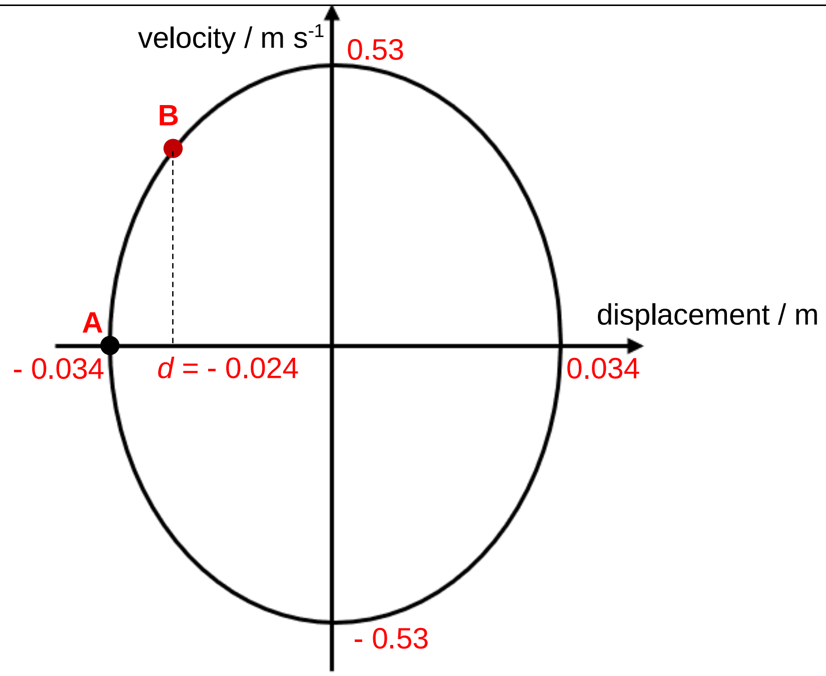
2023 H2 Physics Preliminary Examination Paper 3 Suggested Solutions

1	**(a)**	The **work done per unit mass**, by an external force, in bringing a **small test mass from infinity to that point**, without any change in kinetic energy.			B1
	(b)	**(i)**	As the satellite goes to a higher orbit, **gravitational potential energy,** $U = -\frac{GMm}{R}$ will **become less negative** as R increases, hence the **gravitational potential energy** of the satellite **increases.**		B1
		(ii)	**The gravitational force between the Earth and the satellite provides for the centripetal force that keeps the satellite of mass *m* in its circular orbit.** $\frac{GMm}{R^2} = \frac{mv^2}{R}$ $v = \sqrt{\frac{GM}{R}}$		B1 A0
		(iii)	Since G and M are constant, it follows from part (ii) that $v \propto \sqrt{\frac{1}{R}}$ Hence, $v_{\text{new}} = \sqrt{\frac{R_{\text{old}}}{R_{\text{new}}}} v_{\text{old}} = \sqrt{\left(\frac{6610 \times 10^3\ \text{m}}{6890 \times 10^3\ \text{m}}\right)} (7780)\ \text{m s}^{-1}$ $= 7620\ \text{m s}^{-1}$		M1 A0
		(iv)	1.	(Change in kinetic energy) = (final kinetic energy) – (initial kinetic energy) = ½ (120) 7620^2 – ½ (120) 7780^2 = -1.48×10^8 J	M1 A1
			2.	Let KE be the kinetic energy, GPE the gravitational potential energy, and TE the total energy. Using part (ii), we have $\text{KE} = \frac{1}{2}mv^2 = \frac{1}{2}\frac{GMm}{R}$ Furthermore, we have $\text{GPE} = -\frac{GMm}{R}$ Hence, $\text{TE} = \text{KE} + \text{GPE} = \frac{1}{2}\frac{GMm}{R} + \left(-\frac{GMm}{R}\right) = -\frac{1}{2}\frac{GMm}{R}$ Since **TE = -KE (needs to be derived)**, (change in total energy) = (negative of change in kinetic energy) = $+1.48 \times 10^8$ J	M1 A1
			Total:		8

2	**(a)**	**(i)**	*N*: the number of molecules in the ideal gas *m*: the mass of an ideal gas molecule. *V*: the volume of the ideal gas or volume occupied by the ideal gas (molecules) Note: volume of the container (holding the gas) is accepted, but discouraged, since the question does not mention any container for the ideal gas. $\langle c^2 \rangle$: mean square speed of the ideal gas molecules. "Average of the squared velocities" is accepted (-1 for each mistake, max -2 marks.) molecules/ particles/ atoms are all accepted but make sure it is used consistently throughout.	B2
		(ii)	$p = \frac{1}{3}\frac{Nm}{V}\langle c^2 \rangle \Rightarrow pV = \frac{1}{3}Nm\langle c^2 \rangle -----(1)$ Substitute $pV = NkT$ into (1): $\frac{1}{3}Nm\langle c^2 \rangle = NkT$ $\frac{3}{2}\times\frac{1}{3}m\langle c^2 \rangle = \frac{3}{2}kT$ mean kinetic energy of a molecule $\langle E_k \rangle = \frac{1}{2}m\langle c^2 \rangle = \frac{3}{2}kT$ Internal energy of the ideal gas, $U =$ total KE of ideal gas $= N\langle E_k \rangle = \frac{3}{2}NkT$ OR: $p = \frac{1}{3}\frac{Nm}{V}\langle c^2 \rangle -----(1)$ $pV = NkT \quad -----(2)$ Internal energy of the ideal gas, $U =$ total KE of ideal gas $= N\langle E_k \rangle = \frac{1}{2}Nm\langle c^2 \rangle = \frac{3}{2}pV = \frac{3}{2}NkT$	 B1 B1
	(b)	**(i)**	From Formula list, $\langle E_k \rangle = \frac{3}{2}kT$ $\frac{1}{2}m\langle c^2 \rangle = \frac{3}{2}kT$ $T = \frac{m\langle c^2 \rangle}{3k}$ $= \frac{40u\langle c^2 \rangle}{3k}$ $T = \frac{(40\times1.66\times10^{-27})(2380)^2}{3(1.38\times10^{-23})}$ *T* = 9080 K OR: $\langle E_k \rangle = \frac{3}{2}kT$ $\frac{1}{2}m\langle c^2 \rangle = \frac{3}{2}kT$ $\frac{1}{2}m_R\langle c^2 \rangle = \frac{3}{2}RT$, where $m_R =$ molar mass $T = \frac{m_R\langle c^2 \rangle}{3R}$ $= \frac{0.040\langle c^2 \rangle}{3R} = \frac{(0.040)(2380)^2}{3(8.31)}$ $= 9090$ K	 B1 B1

			(mass of the argon atom is approximately the same as mass of the argon nucleus, it does not matter whether you take into account the mass of electrons)	
		(ii)	Argon-40 is highly likely that the argon formed from the nuclear decays will be present in the Moon's atmosphere, since the **temperature on the surface of the Moon is much lower** than temperature calculated in (b)(i), the majority of argon-40 atoms would have speeds lower than the escape speed from Moon, **and are unable to escape from the surface of the Moon.**	B1 B1
			Total	8

3	(a)	 $v_{max} = \omega x_0 = 2\pi f x_0 = 2\pi(2.5)(0.034) = 0.534$ m s^{-1} Amplitude and maximum velocity values correctly indicated Point A is labelled correctly	A1 A1
	(b)	$E_T = \frac{1}{2}m\omega^2 x_0^2 = \frac{1}{2}1.2(2\pi(2.5))^2(0.034)^2$ $= 0.171$ J Or $E_T = \frac{1}{2}mv_{max}^2 = \frac{1}{2}1.2(0.534)^2 = 0.171$ J	M1 A1
	(c)	(i) **Any point in second quadrant.** (e.c.f if point A is wrongly labelled)	A1
		(ii) $E_P + E_K = E_T$ When $E_P = E_K = \frac{E_T}{2}$ $\frac{1}{2}m\omega^2 d^2 = \frac{\frac{1}{2}m\omega^2 x_0^2}{2}$ $d = \pm\frac{x_0}{\sqrt{2}} = \pm\frac{0.034}{\sqrt{2}} = \pm 0.024$ m d = - 0.024 m (no answer mark for + 0.024 m) (e.c.f if point B is wrongly labelled as + 0.024 m)	M1 A1

	(d)		$-\frac{x_0}{\sqrt{2}} = -x_0\cos(\phi) \rightarrow \cos(\phi) = \frac{1}{\sqrt{2}}$ $\phi = \frac{\pi}{4}$ rad or 0.785 rad	M1 A1
			Total:	9

4	**(a)**		Two images are **just resolved or distinguishable** when the **central maximum of one diffraction pattern coincides** with the **first minimum** of the **diffraction pattern** of the other.	B1 B1
	(b)		Applying Rayleigh criterion, $\theta = \frac{\lambda}{b} = \frac{600\times10^{-9}}{20.0\times10^{-2}} = 3.00\times10^{-6}$rad $d = 8.14\times10^{16}\times\tan(3.00\times10^{-6}) = 2.44\times10^{11}$ m	 M1 A1
	(c)	**(i)**	For second order maxima, $d\sin\theta = 2\lambda \Rightarrow \theta = \sin^{-1}\left(\frac{2\lambda}{d}\right)$ when $\lambda =$ 400 nm, $\theta = \sin^{-1}\frac{2(400\times10^{-9})}{10^{-3}\div500} = 23.578^o$ when $\lambda =$ 700 nm, $\theta = \sin^{-1}\frac{2(700\times10^{-9})}{10^{-3}\div500} = 44.427^o$ Angular spread $\Delta\theta = 48.590^o - 23.578^o = 20.84^o$	 M1 M1 A1
		(ii)	Advantage: θ is larger, so for the same $\Delta\theta$, **the fractional uncertainty / percentage uncertainty in θ is smaller.**	B1
			Total:	8

5	**(a)**	**(i)**	**Resistance of thermistor** is given by the **ratio of p.d. across thermistor, *V* to current through thermistor, *I***. In Fig. 5.2, the **ratio of *V*/*I* decreases as current or voltage increases.** As current or voltage increases, the thermistor will heat up. Thus, the **thermistor's resistance decreases with increasing temperature** indicating that it is a ntc thermistor. *Alternatively,* **Resistance of thermistor** is given by the **ratio of p.d. across thermistor, *V* to current through thermistor, *I***. In Fig. 5.2, the **gradient of the straight line that joins the origin to a point on the *I*-*V* graph of thermistor increases, the reciprocal of this gradient gives the ratio of *V*/*I*, i.e. *V*/*I* decreases as current or voltage increases.** As current or voltage increases, the thermistor will heat up. Thus, the **thermistor's resistance decreases with increasing temperature** indicating that it is a ntc thermistor.	B1 B1 Or B1 B1
		(ii)	From the graph, when current through battery is 8.0 A, 1. the current through the filament bulb = 5.5 A 2. the current through the thermistor = 2.5 A 3. the e.m.f. of the battery = 8.0 V	A1 A1 A1
	(b)	**(i)**	Correct sketch of a **straight line passing through the origin** with **gradient = 1/2.5 = 0.4.** Straight line pass through (2.5, 1.0) and (10, 4).	A1
		(ii)	the current through the filament bulb = 4.0 A	A1
		(iii)	the potential difference across the resistor = 4.0 x 2.5 = 10 V	A1
			Total marks	8

6	**(a)**	**(i)**	$\frac{V_S}{V_P}=\frac{N_S}{N_P}\rightarrow V_{S,peak}=170\left(\frac{3500}{2000}\right)=297.5\text{ V}$ $V_{S,rms}=\frac{297.5}{\sqrt{2}}=210\text{ V}$	M1 A1
		(ii)	$V_{S,rms}=I_{S,rms}R\rightarrow I_{S,rms}=\frac{210}{130}=1.62\text{ A}$ mean power output $=\langle P\rangle_{output}=V_{S,rms}I_{S,rms}=(210)(1.62)=340\text{ W}$ Power input = Power output (ideal transformer) peak power input = $2\times\langle P\rangle_{output}$ $V_{P,peak}I_{P,peak}=2\times340\Rightarrow I_{P,peak}=\frac{(2\times340)}{170}=4.00\text{ A}$	M1 M1 A1
	(b)	As **the number of turns in the secondary coil is halved** while input voltage and number of turns in the primary coil remain the same, **the induced voltage in the secondary coil is halved**. The **power output is proportional to the square of the voltage**. The resistance of the heater is unchanged, so the new mean power dissipated is $\frac{1}{4}P$.		B1 A1
		Total:		7

<table>
<tr><td rowspan="7">7</td><td>(a)</td><td colspan="2">When the energy level of atom or system (not electron) at (n = ∞) is 0 eV, this is where electron just breaks free from the atom.

When the atom is at energy level (n < ∞), its electron is bounded to the nucleus by electric attractive force since the nucleus and the electron are of oppositely charged.

The atom needs to gain energy to cause electron to break free from it.

OR

When the atom is at energy level (n < ∞), its electron is bounded to the nucleus by electric attractive force since the nucleus and the electron are of oppositely charged.

Positive work is done by external agent when the electron breaks free from it.

By conservation of energy, energy level of atom at (n < ∞) is less than the energy level at (n = ∞); i.e. energy level at (n < ∞) is of negative value.</td><td>B1

B1

B1</td></tr>
<tr><td>(b)</td><td colspan="2">Transition A.</td><td>A1</td></tr>
<tr><td>(c)</td><td colspan="2">$\Delta E_A = -0.54 - (-13.6) = 13.06$ eV

$= 13.06 \times 1.60 \times 10^{-19} = 2.0896 \times 10^{-18}$ J

$\lambda_A = \dfrac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{2.0896 \times 10^{-18}} = 9.52 \times 10^{-8}$ m = 95.2 nm (e.c.f.)

UV region. (e.c.f. is based on student’s calculated wavelength)</td><td>M1

A1

A1</td></tr>
<tr><td>(d)</td><td>(i)</td><td>The incoming electron can give up a fraction of its energy to excite the atom to energy levels (n = 3) or (n = 2).

After which, atom can de-excite from energy levels (n = 3) to (n = 2), followed by (n = 2) to (n = 1) , or (n = 3) to (n = 1) , or (n = 2) to (n = 1).</td><td>B1

A1</td></tr>
<tr><td></td><td>(ii)</td><td>No possible transition.

since photon energy does not correspond exactly to the energy interval / difference / gap between (n>1) and (n=1) .</td><td>A1

B1</td></tr>
<tr><td>(e)</td><td colspan="2">The emission spectrum can be used to <u>determine the composition of a material</u> in atomic emission spectroscopy.

It can helps to create special <u>advertisement lightings or entertainment lightings</u>.

OR any plausible applications</td><td>A1</td></tr>
<tr><td></td><td colspan="2">Total:</td><td>12</td></tr>
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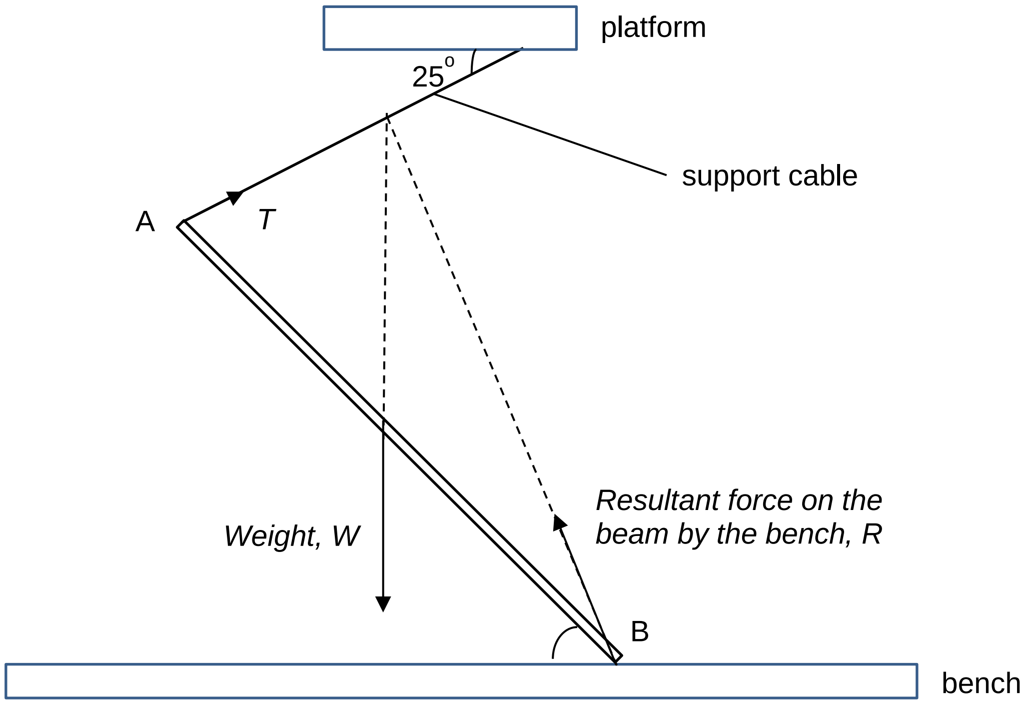
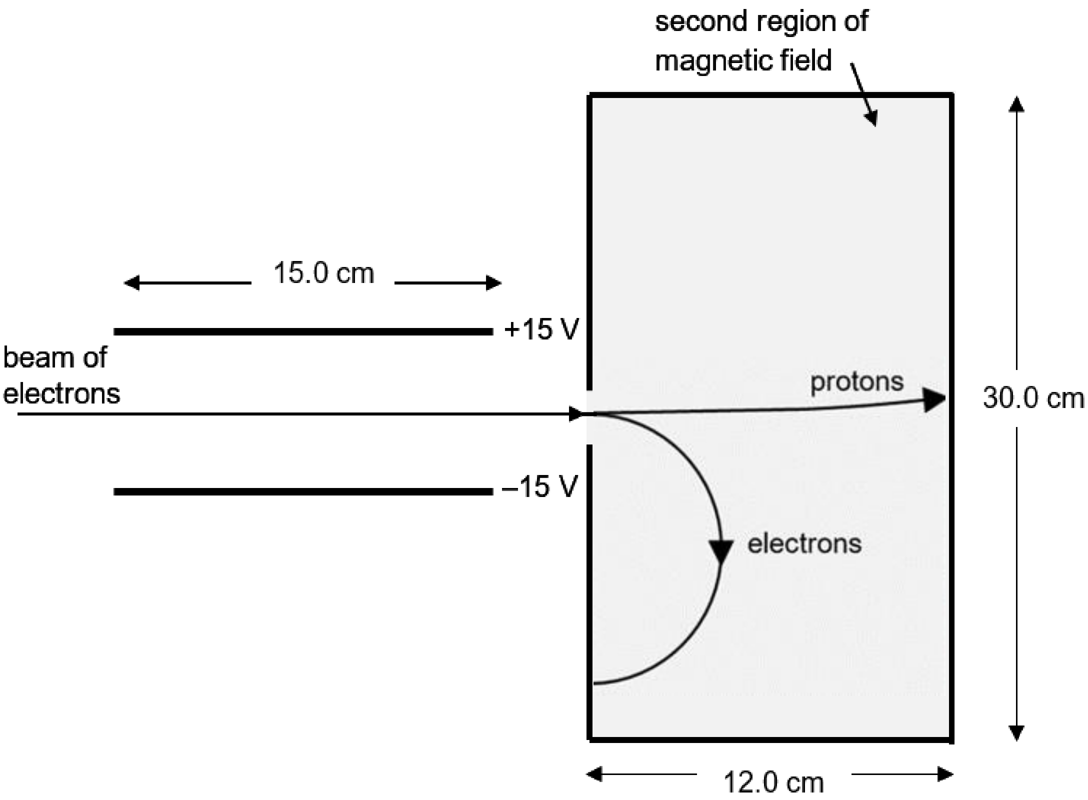
8	**(a)**	The **net external force acting on a body is zero.** The **net torque on the body about any point is zero**.		B1 B1
	(b)	**(i)**	 Correct labelling of the 3 forces and point of contact – 1 mark Correct direction (check 3 forces intersect at a common point)	M1 A1
		(ii)	Taking moments about B, and by the principle of moments Sum of clockwise moments = Sum of anti-clockwise moments $T\sin 67^o \times L = mg \times (\frac{L}{2}\cos 42^o)$ $T = \frac{mg\cos 42^o}{2\sin 67^o} = \frac{1.5(9.81)\cos 42^o}{2\sin 67^o} = 5.939\,\text{N} = 5.9\,\text{N}$	B1 M1 A0
		(iii)	$\sum F_x = 0 \Rightarrow R_x = T_x = 5.939\cos 25^o = 5.383\,\text{N}$ $\sum F_Y = 0 \Rightarrow R_Y + T_Y = W$ $R_Y = W - T_Y = 1.5(9.81) - 5.939\sin 25^o = 12.21\,\text{N}$ $\therefore R = \sqrt{(R_X)^2 + (R_Y)^2} = \sqrt{5.383^2 + 12.21^2} = 13.3\,\text{N}$ $\tan\theta = \frac{F_Y}{F_X} = \frac{12.21}{5.383}$ $\theta = 66.2^o$ Direction = 66.2° clockwise above the horizontal. (need a short description)	M1 M1 A1 A1

	(c)	**(i)**	By Newton's 2nd law, $F_{net} = ma$ $mg\sin\theta = ma$ $a = g\sin\theta = 9.81\sin 42^o = 6.56\ \text{m s}^{-2}$	M1 A1
		(ii)	Acceleration of the ball **remains the same** as it is **independent of mass or weight** as shown in the equation in (c)(i).	B1 B1
		(iii)	From start to top of circular track, Loss in GPE = Gain in KE $mg\left(0.58\sin 42^o - 0.34\right) = \frac{1}{2}mv_{top}^2 - 0$ $v_{top} = \sqrt{2\left(9.81\right)\left(0.58\sin 42^o - 0.34\right)}$ $= 0.9714 = 0.971\, m\,s^{-1}$ Consider the forces acting on the ball at the top of the circular track, $mg + N = \frac{mv^2}{r}$ To find the minimum speed at the top of the circular track, consider N→0, $v_{\min} = \sqrt{rg} = \sqrt{0.17\left(9.81\right)} = 1.29\, m\,s^{-1}$ Since $v_{top} < v_{\min}$, the ball is unable to make a complete loop around the circular track.	M1 A1 A1 A1
		(iv)	The ball will **remain in contact with the circular track at least clearing half of the height of the circular track or ¼ of the circular track** and then move in a **parabolic path when it leaves the tracks**.	B1 B1
			Total:	20

9	**(a)**		The magnetic flux linkage is defined as the **product of the number of turns** of the coil and the **component of magnetic flux density** passing **perpendicularly** through a **cross sectional area** of the coil.	B1 B1
	(b)	**(i)**	Magnetic flux density at the centre of the solenoid, $B = \mu_o n I = \left(4\pi \times 10^{-7}\right)\left(\frac{900}{30.0 \times 10^{-2}}\right)(2.0)$ $= 7.54 \times 10^{-3}$ T Magnetic flux through flat coil = magnetic flux through solenoid $\phi = BA = \left(7.54 \times 10^{-3}\right)\left(3.2 \times 10^{-4}\right) = 2.41 \times 10^{-6}$ Wb	M1 M1 A0
		(ii)1.	Magnitude of e.m.f. $\varepsilon = N\frac{d\phi}{dt} \approx N\frac{\Delta\phi}{\Delta t} = (250)\left(\frac{2.41 \times 10^{-6}}{0.45}\right)$ $= 1.34 \times 10^{-3}$ V	M1 A1
		(ii)2.	charge = current x time $= \frac{\varepsilon}{R} \times t = \left(\frac{1.338 \times 10^{-3}}{35.0}\right)(0.45)$ $= 1.72 \times 10^{-5}$ C	M1 A1
		(ii)3.	charge = (average current) x (time) $= \left(\frac{1}{2}I\right)(t) = \left(\frac{2.0}{2}\right)(0.45)$ $= 0.45$ C	M1 A1
	(c)	**(i)**	$evB = eE$ $B = \frac{E}{v} = \frac{\Delta V}{dv} = \frac{(15-(-15))}{0.040\left(4.5 \times 10^{6}\right)}$ $= 1.67 \times 10^{-4}$ T	M1 A1
		(ii)	The electrons experienced a constant **magnetic force always perpendicular to its direction of motion/velocity.** This force does **zero work** on the electrons hence the **speed remains constant**. Hence the **magnetic force provides the centripetal force** for circular motion.	B1 B1
		(iii)	The centripetal force is provided by the magnetic force. $evB = \frac{mv^2}{r}$ $r = \frac{mv^2}{evB} = \frac{mv}{eB} = \frac{\left(9.11 \times 10^{-31}\right)\left(4.50 \times 10^{6}\right)}{\left(1.6 \times 10^{-19}\right)\left(0.50 \times 10^{-3}\right)}$ $= 0.0512$ m	M1 A1

		(iv)	$evB = eE$ $v = \dfrac{E}{B} = \dfrac{7.50 \times 10^{2}}{1.6667 \times 10^{-4}} = 4.49991 \times 10^{6} = 4.50 \times 10^{6}\ \text{m s}^{-1}$ Accept if candidates just state the speed, realising that the speed of protons is the same as that of the electrons passing through the same velocity selector.	A1
		(v)	 	
			circular path of electrons in clockwise direction (semi-circle)	A1
			Relative size of radius and proton must exit on right side of magnetic field	A1
			Protons curve upwards in anti-clockwise direction	A1
			Total:	20