Answers to examination-style questions

Answers	Marks	Examiner's tips
1 (a) *the units of the quantities are*: Force F: newton (N) Current I: ampere (A) Magnetic flux density B: tesla (T) or weber metre^{-2} (Wb m^{-2}) Length l of wire in field: metre (m)	1	It is preferable to give the full name of the units in a question such as this, although the symbols normally used for them (N, A, Tand m) would be accepted. Note that units that are named after eminent physicists do not begin with a capital letter (unlike the name of the persons themselves).
The equation $F = BIl$ applies only when the magnetic field is directed at right angles to the direction of the current.	1	When B and I are not at right angles, the force is caused by the component of the magnetic flux density at right angles to the current, $B \sin\theta$, where θ is the angle between the current and the field. The more general equation is therefore $F = BIl \sin \theta$. It follows that there is no force on a wire when the current is parallel to the magnetic field.
(b) (i) Mass m of bar $= (25 \times 10^{-3})^2 \times 8900 \times l$ $= 5.56\, l$ Weight mg of bar $= 5.56l \times 9.81 = 54.6l$ Magnetic force = weight of bar $\therefore\ mg = BIl$ $BIl = 54.6l$ gives $B = \frac{54.6}{I} = \frac{54.6}{65} = 0.84$ T	1 1 1 1	For the bar, mass = volume × density, and volume = cross-sectional area × length. When the bar is supported by the magnetic force acting on it, the upwards magnetic force balances the bar's weight. The length l of the bar is a common factor, which cancels since it appears on both sides of the equation.
(ii) *Arrow drawn on diagram, labelled* M: Into the front surface of the bar, at right angles to it, and in the same horizontal plane as the bar	1	This comes from the application of Fleming's left-hand rule. The representation may not be easy on the three-dimensional diagram; a correct arrow should point almost 'north-west' on the page.
2 (a) (i) Use of $F = BIl$ gives $B = \frac{F}{Il} = \frac{180}{12 \times 10^3 \times 0.83}$ $= 1.81 \times 10^{-2}$ T	1 1	The current in **X** sets up a magnetic field around it. The current in **Y** experiences a force, because **Y** is situated in the magnetic field produced by **X**. This argument applies equally in reverse, so the forces on × and **Y** are equal and opposite, whether or not the currents in × and **Y** are the same.
(ii) Force on **X** due to **Y**: • B at **X** (due to **Y**) is unchanged because the current in **Y** is unaltered • $F = BIl$ and the current in **X** is halved, so the force on **X** is now 90 N.	2	Originally, when both bus bars carried currents of 180 A, the force between them was 180 N. Halving the current in one of them will reduce this force to 90 N.

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Force on **Y** due to **X**: • *B* at **Y** (due to **X**) is halved because the current in **X** is halved • $F = BIl$ and the current in **Y** is unchanged, so the force on **Y** is also now 90 N.	**2**	Once you have worked out the force on one bus bar, it would be acceptable to deduce that on the second by pointing out that they experience equal and opposite forces. This is really an example of Newton's 3rd law of motion.
(b) (i) *Relevant points include*: • The magnetic field due to the current in each bus bar alternates with the current in the bar • The force will be zero when the current in either wire is zero • Both current and field reverse together, so the force does not reverse direction when the current reverses • The force on each wire varies periodically, making the wires vibrate • The frequency of vibration is twice the ac frequency.	**any 3**	These two bus bars will, in fact, attract each other – because they carry currents in the same direction. (If one current alone were reversed, they would repel.) With ac, the magnitude of the force varies because the currents vary with time. But the bus bars still attract each other when the currents are reversed. In each half cycle of the ac the forces will rise from 0 to a maximum and then fall to 0 again. Hence there are two attraction cycles for every cycle of the alternating currents.
(ii) The amplitude of vibration could be reduced by: • clamping each bar along it length • attaching a damping device to each bar • moving the bars further apart.	**any 1**	Either the physical movement has to be restricted (by clamping or damping) or the wires have to be in a weaker field; the latter could be achieved by increasing their separation.
3 (a) (i) The force on the ion is directed out of the plane of the page.	**1**	Apply Fleming's left-hand rule; positive ions move in the same direction as the conventional electric current.
(ii) In the magnetic field the ion moves in a circular path . . . in a horizontal plane (or out of the plane of the page). the force equation for the circular motion is $BQv = \frac{mv^2}{r}$ $\therefore$ radius of path $r = \frac{mv}{BQ}$ $= \frac{1.05 \times 10^{-25} \times 7.8 \times 10^5}{0.28 \times 2 \times 1.60 \times 10^{-19}} = 0.914$ m or 0.91 m	**1** **1** **1** **1**	The force experienced by moving charges in a magnetic field is always at right angles to their velocity. Like a mass of the end of a string, they move in a circular path. You are required to describe the path of the ion in words, and to carry out a calculation. Since the path is circular, the obvious feature to calculate is the radius of the path. The magnetic force (*BQv*) is the centripetal force on the moving charge. The charge of the ion is + 2*e*, because it is doubly-charged. The value of *e* is given in the Data Booklet.

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(b) *Relevant points are*: When magnetic field strength is doubled • the radius of the path decreases • to half the original value. When a single charged ion is used • the radius of the path increases • to double the original value.	**any 3**	From the equation giving the radius of the path in part **(a)(ii)**, it follows that $r \propto \frac{1}{B}$ when the other factors remain constant, and that $r \propto \frac{1}{Q}$ for ions of the same isotope that travel in the same field at the same velocity. Therefore when Q is halved, r is doubled.
4 (a) (i) The flux density of a magnetic field is 1 tesla if a 1 metre length of wire carrying a current of 1 ampere experiences a magnetic force of 1 newton when placed in the field … in such a way that the magnetic field is at right angles to the current.	1 1	By rearranging $F = BIl$, the magnetic flux density of the field is given by $B = \frac{F}{Il}$ from which $1\,\text{T} = \text{N A}^{-1}\,\text{m}^{-1}$. Since $F = BIl$ is only valid when B and I are perpendicular, this condition is an essential part of the definition.
(ii) Within the velocity selector, magnetic force on ion = electric force on ion $\therefore BQv = EQ$ In this equation Q cancels, giving $Bv = E$, and velocity of ions $v = \frac{E}{B}$, meaning that v does not depend on Q.	1 1	Ions will pass through the velocity selector in a straight line only when the magnetic force on them is balanced by the electric force caused by the electric field. Only those ions which satisfy this condition will emerge through the slit directly ahead of them.
(iii) Velocity selected $v = \frac{E}{B} = \frac{2.0 \times 10^4}{0.14} = 1.43 \times 10^5\ \text{m s}^{-1}$ (which is about 140 km s^{-1})	1	The values of E and B are given at the start of part **(a)**; direct substitution into $v = \frac{E}{B}$ gives the required result.
(b) (i) Radius of circular path whilst in ion separator $r = \frac{mv}{BQ}$	1	See part **(a)(ii)** of Question 3 for the theory underlying this equation.
Mass of $^{58}_{28}\text{Ni}$ ion $= 58 \times 1.661 \times 10^{-27}$ $= 9.64 \times 10^{-26}$ kg $\therefore B = \frac{mv}{rQ} = \frac{9.64 \times 10^{-26} \times 1.43 \times 10^5}{0.14 \times 1.6 \times 10^{-19}}$ $= 0.615$ T or 0.62 T	1 1	The ion contains 58 nucleons, each of mass around 1 u. The radius r of the path is one half of its diameter (0.28 m), which is given as the distance from **P** to the point where the plate is struck.
(ii) Radius r of path $\propto$ mass m of ion $\therefore$ new radius $= \left(\frac{60}{58}\right) \times 0.140 = 0.145$ m $= 0.145$ m new diameter = 0.290 m, so separation of isotopes on plate = 0.290 – 0.280 = 0.010 m (10 mm)	1 1	This proportionality follows from the equation in part **(b)(i)**, when v, B and Q are all unchanged (a condition that is satisfied here). *Alternatively*, you could calculate the new radius by substituting into $r = \frac{mv}{BQ}$ but it would take longer.

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5 (a) The force equation for the circular motion is $BQv = \frac{mv^2}{r}$ $\therefore$ speed of particle $v = \frac{BQr}{m}$	**1**	The magnetic force acts as the centripetal force. When this is equated with $\frac{mv^2}{r}$, one v cancels, and rearrangement gives this result.
(b) Since the particles follow the same path, the radius of curvature r is the same. They have the same momentum because $r \propto mv$ when B and Q are the same. mv is the same, but m is different for the antiproton and the negative pion, $\therefore$ v must be different.	**1** **1** **1**	The radius of curvature is $r = \frac{mv}{BQ}$. An antiproton has the same charge ($-e$) as a negative pion and both types of particle are travelling through the same magnetic field, meaning that both B and Q are the same for the two particles. You should remember from *AS Physics* Unit 1 that the particles have different masses.
(c) Identify correct format for both particles: *antiproton*: 3 antiquarks *negative pion*: quark + antiquark	**1**	A baryon, such as a proton, consists of 3 quarks and an antibaryon of 3 antiquarks. A meson is a quark–antiquark combination.
antiproton: 2 up antiquarks + 1 down antiquark ($\bar{u}$, $\bar{u}$, $\bar{d}$)	**1**	3 antiquarks are needed to give a total charge of $-1e$: $-\frac{2}{3}e - \frac{2}{3}e + \frac{1}{3}e = -1e$
negative pion: 1 up antiquark + 1 down quark ($\bar{u}$, d)	**1**	The total charge has again to be $-1e$: $-\frac{2}{3}e - \frac{1}{3}e = -1e$
6 (a) (i) The magnetic field is directed into the plane of the page	**1**	Apply Fleming's left-hand rule: the force acts towards the centre of the semicircle and the arrow on the positive ion gives the direction of the conventional current.
(ii) *Relevant points include*: • The magnetic field is directed at right angles to the velocity of the ions. • The magnetic force acts at right angles toboth the magnetic field and the velocity. • Hence the magnetic force acts at right angle to the velocity of the ions. • This force changes the direction of the velocity of the ions but not its magnitude. • The force remains perpendicular to the velocity as the direction of movement ofthe ions changes … • so the force acts as a centripetal force.	**any 4**	This part of the question asks for an explanation in words of the semicircular path of the ions, rather than a mathematical derivation of the centripetal force equation. Most of the argument follows from the application of Fleming's left-hand rule, by showing that F is perpendicular to v in this case. The force therefore acts towards the centre of the semicircle and is centripetal, like the tension in a string pulling on a mass that is whirled around.

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(iii) The force equation for the circular motion is $B\,Q\,v \frac{mv^2}{r}$ $\therefore$ diameter of path $d = 2r = \frac{2mv}{BQ}$	1 1	The force equation for charges moving in a magnetic field is a regular topic in past questions. Here the **diameter** of the path is required, not its radius.
(b) Charge to mass ratio of ions $\frac{Q}{m} = \frac{2v}{Bd} = \frac{2 \times 7.5 \times 10^4}{0.34 \times 110 \times 10^{-3}}$ $= 4.01 \times 10^6$ C kg^{-1}	1 1	'Charge to mass ratio' of ions should be familiar from *AS Physics A* Unit 1. Rearrangement of the result from part **(a)(iii)**, together with substitution of the given values, leads to this result.
(c) *Relevant points include*: **(i)** Ions have a different mass Diameter d of path $\propto$ mass m of ion Due to isotopes of the same element **(ii)** Ions are doubly ionised Diameter d of path $\propto \frac{1}{Q}$; if Q is doubled then d is halved	any 3	Part **(c)** becomes a test of whether you can understand the implications of the equation in part **(a)(iii)**. A **slightly** different radius indicates either a **slight** difference in charge (which is not possible), or a slight difference in mass (which is). *Possible alternative* answer for **(i)**: Mutual repulsion of ions (all charged positively) causes smearing of the spot around **R**.
7 (a) $B\,Q\,v \frac{mv^2}{r}$ gives magnetic flux density $B = \frac{1.67 \times 10^{-27} \times 1.2 \times 10^5}{1.60 \times 10^{-19} \times 120}$ $= 1.04 \times 10^{-5}$ T	1 1 1	In this question the equation for the circular motion of charged particles has to be used to find a value for B. The **diameter** of the circle is marked on the diagram as 240m. This magnetic field must act upwards, out of the plane of the page (Fleming's left-hand rule).
(b) As the kinetic energy of the protons increases, the magnetic flux density has to increase . . . because in a path of constant radius (using the same charged particles) magnetic flux density $B \propto v$	1 1	In a **synchrotron** the radius of the path travelled by the charged particles has to remain constant as they are progressively accelerated. For this to be achieved, the increase in magnetic flux density has to be **synchronised** with the increase in velocity.