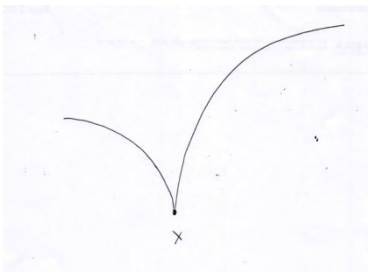
Question Number	Answer	Mark
1(a)	Use of $E_k = eV$ **and** $E_k = p^2/2m$ **(1)** Use of $\lambda = \frac{h}{p}$ **(1)** $\lambda = 2.2 \times 10^{-11}$ (m) **(1)** **Or** Use of $E_k = eV$ **and** $E_k = \frac{1}{2}mv^2$ **(1)** Use of $\lambda = \frac{h}{p}$ **(1)** $\lambda = 2.2 \times 10^{-11}$ (m) **(1)** <u>Example of calculation</u> $v = \sqrt{\frac{2 \times 3000\ \text{V} \times 1.6 \times 10^{-19}\ \text{C}}{9.11 \times 10^{-31}\ \text{kg}}} = 3.2 \times 10^7\ \text{m s}^{-1}$ $\lambda = \frac{6.63 \times 10^{-34}\ \text{J s}}{9.11 \times 10^{-31}\ \text{kg} \times 3.2 \times 10^7\ \text{m s}^{-1}} = 2.24 \times 10^{-11}\ \text{m}$	**3**
1(b)	Compares λ to atomic gap spacing **and** makes comment consistent with their answer to (a) **(1)**	**1**
	Total for question	**4**

Question Number	Answer	Mark
2(a)	Divide by 1.6×10^{-19} **(1)** $V = 4.5 \times 10^6$ V **(1)** Example of calculation $V = \frac{7.2 \times 10^{-13}\ \text{J}}{1.6 \times 10^{-19}\ \text{C}} = 4.5 \times 10^6\ \text{V}$	**2**
2(b)	Line of best fit drawn with maximum speed $< 3 \times 10^8$ **(1)** Comment that line tends towards *c* **Or** comments that the graph levels off close to *c*. **(1)**	**2**
2(c)	The idea that as electrons travel at speeds close to the speed of light their mass increases **(1)** $E_k = \frac{1}{2}mv^2$ does not apply **Or** relativistic equations should be used. **(1)**	**2**
2(d)(i)	The time spent in each tube must remain constant (as the speed increases) **(1)** Refers to the tubes switching polarity at fixed time intervals **(1)** (For MP2 just saying frequency is constant is not sufficient)	**2**
2(d)(ii)	The speed of electrons has become a maximum/constant **Or** there can be no further increase in the speed of the electrons **(1)** (do not accept there is no acceleration)	**1**
	Total for question	**9**

Question Number	Answer		Mark
3(a)	The idea that electron(s) have been removed/added from an atom/molecule/particle.	**(1)**	**1**
3(b)	Flemings left hand (rule) **Or** FLHR	**(1)**	**1**
3(c)	**Max 5** Only charged particles leave a trail so photon is neutral **Or** the two particles produced are charged because they leave a track Particles are oppositely charged because they curve/spiral in opposite directions **Or** Particles are oppositely charged to conserve charge (Applying FLHR) , top particle is positive and bottom one negative. Because they have the same curvature/radius on the spirals **Or** because the paths have identical shape Particles have the same momentum The photon enters from the left because the (resultant) momentum afterwards is to the right.	**(1)** **(1)** **(1)** **(1)** **(1)** **(1)**	**5**
	Total for question		**7**

Question Number	Answer	Mark
4	**Diagram:** Path curves in opposite sense **(1)** With a greater radius of curvature **(1)** [For Mp2 drawn line must start at X , upwards at less than 45^{o} to vertical and go above printed line. Look at curvature close to X, do not penalise if later it curves more/less.]  **Explanation: (these marks are independent of the diagram)** (Antihelium) has opposite charge (to proton) **Or** reference to proton +ve **and** antihelium -ve **(1)** See $r = p/BQ$ **(1)** r is doubled **Or** p/Q is doubled **(1)** [equation may appear near diagram.]	**5**
	Total for question	**5**

Question Number	Answer		Mark
5(a)(i)	Straight through, zero deflection, direction fired in. (Do not accept 'through' or 'directly behind' on its own)	**(1)**	**1**
5(a)(ii)	(Atom consists) mainly/mostly of <u>empty space</u> **Or** Volume of atom very much greater than volume of nucleus. (do not credit if part of a list)	**(1)**	**1**
5(b)	Most of the mass is in the nucleus/centre [it is not enough to say that the nucleus is dense/concentrated. Looking for idea that nearly all of the atom's mass is in the nucleus] Nucleus/centre is <u>charged</u> [ignore references to the charge being positive. Just saying the nucleus is positive does not get the mark.]	**(1)** **(1)**	**2**
5(c)(i) E	Electrostatic/electromagnetic/electric/coulomb	**(1)**	
5(c)(ii)	Arrow starting on the path at closest point to the nucleus Arrow pointing radially away from nucleus (correct direction starting on the nucleus scores 2nd mark only)	**(1)** **(1)**	**2**
5(c)(iii)	Deflection starts earlier Final deflection is greater (paths should diverge)	**(1)** **(1)**	**2**
	Total for question		**9**

Question Number	Answer		Mark
6	Considers momentum	**(1)**	
	Calculates momentum of xenon or spacecraft	**(1)**	
	Calculates a second momentum **Or** calculates speed of spacecraft	**(1)**	
	A statement that the prediction is correct **Or** a statement that the increase is (about) $8 ms^{-1}$ (only award this mark if based on correct calculations)	**(1)**	**4**
	(Calculation to find the speed of the Xenon or either mass scores **max 3**) <u>Example of calculation</u> Momentum of Xenon = 0.13 kg × 30000 m s^{-1} = 3900 kg m s^{-1} Momentum of spacecraft = 486 kg × 8 m s^{-1} = 3888 kg m s^{-1} **Or** Momentum of Xenon = 0.13 kg × 30000 m s^{-1} = 3900 kg m s^{-1} Momentum of spacecraft = 486 kg × v v= 3900 kg m s^{-1} / 486 kg = 8.02 m s^{-1}		
	Total for question		**4**

Question Number	Answer	Mark
7	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) **Max5** **Electric fields** • can be used to accelerate/deflect particles **(1)** • direction of force/deflection indicates (sign of) charge. **(1)** • $a = EQ/m$ **(1)** **Magnetic fields** • produce circular motion **Or** provides a centripetal force **Or** causes spirals/arc **(1)** • Direction of force/curvature/deflection indicates (sign of) charge. **(1)** • momentum/speed/mass found from radius/curvature **(1)** • $r = p/BQ$ **Or** $Bqv = mv^2/r$ **(1)**	**5**
	Total for question	**5**

Question Number	Answer		Mark
8(a)	Disc/metal/cathode is heated (by a current) Thermionic emission (allow use of extremely high pd **and** a vacuum for 2 marks)	**(1)** **(1)**	**2**
8(b)	See $F=mv_{(v)}/t$ **Or** $F=ma$ and $v_{(v)}=at$ See $F= eE$ (accept F = EQ) See (time in field is) $t= l/v$ (This needs to be three clear statements) (Do not credit a units method)	**(1)** **(1)** **(1)**	**3**
8(c)	Find/measure horizontal distance from plates to screen Find/measure vertical displacement from centre of screen Use tan θ (this mark can be awarded if velocities are used rather than distances)	**(1)** **(1)** **(1)**	**3**
8(d)	Tan θ = vertical velocity / horizontal velocity **Or** v_v/v $v_v = \frac{Ee}{m} \times \frac{l}{v}$ and $v_H = v$ (conditional mark) (Do not credit a units method) .	**(1)** **(1)**	**2**
8(e)(i)	Magnetic rather than electric force **Or** Bev/BQv is the magnetic force **Or** $F = Bev/BqV$ (do not credit just $eE = Bev$)	**(1)**	**1**
8(e)(ii)	Mark for appreciation of magnetic force e.g. Force/acceleration now centripetal **Or** (causes) circular motion **Or** force/acceleration not vertical **Or** force/acceleration is not always in the same direction **Or** vertical force/acceleration not constant **Or** force/acceleration is at right angles to direction of motion, Mark for consequence Horizontal velocity no longer constant **Or** l/v = t not true	**(1)** **(1)**	**2**
	Total for question		**13**

Question Number	Answer		Mark
9(a)	Identifying the equations $E_k = p^2/2m$ and $\lambda = h/p$ **OR** $\lambda = h/p$, $p = mv$ and $E_k = ½ mv^2$	**(1)**	**2**
	Any combination or rearrangement (conditional mark)	**(1)**	
	(do not give 2nd mark just for quoting equation given in question) (Do not credit a reverse argument i.e. starting with the given equation.) <u>Example of derivation</u> $p = 2mE_k$ $\lambda = h/\sqrt{(2mE_k)}$		
9(b)	Correct sub of h^2 and m	**(1)**	**3**
	Use of $E_k = eV$	**(1)**	
	$\lambda = 2.5 \times 10^{-11}$ m	**(1)**	
	OR Use of $E_k = ½ mv^2$ (to find v =3.0 x10^7 (m s^{-1}))	**(1)**	
	Use of $\lambda = h/p$ with correct substitution for h and m	**(1)**	
	$\lambda = 2.5 \times 10^{-11}$ m	**(1)**	
	<u>Example of calculation</u> $\lambda = \sqrt{\frac{(6.63x10^{-34}\text{ J s})^2}{2(9.11\text{ x }10^{-31}\text{ kg})(2500\text{ V})\,(1.6\times10^{-19}\text{ C})}}$ $\lambda = 2.46 \times 10^{-11}$ m **OR** $v = \sqrt{\frac{2(2500\text{V})(1.6x10^{-19}\text{ C})}{9.1\text{ x }10^{-31}\text{ kg}}} = 3.0\text{ x}10^7$ $\lambda = 6.63 \text{ x } 10^{-34}\text{ J s} / (9.1 \text{ x } 10^{-31}\text{ kg})(3.0\text{x}10^7\text{ m s}^{-1})$		
	Total for question		**5**