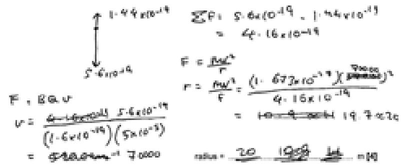
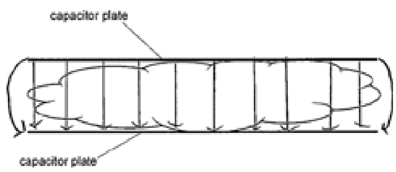
Mark scheme

Question			Answer/Indicative content	Marks	Guidance
1	a		F (= EQ) = 0.90 × 1.60 × 10^{-19} = 1.4(4) × 10^{-19} (N)	B1	Working and answer must both be shown Answer must be given to 2sf or more Unit need not be given but, if given, must be correct **<u>Examiner's Comments</u>** This was an easy introduction to the question, which used the definition of electric field strength; $E = F_E / Q$. Being a 'show that' question, candidates needed to show their working in full, including writing the value for the electronic charge (rather than simply 'e') and giving the answer to at least 2 s.f.
	b	i	($F = BQv$ but B and Q are constant, so) (the magnitude of) the velocity is different /changes	B1	**Allow** speed **Ignore** the direction is different **<u>Examiner's Comments</u>** The force on a charged particle moving at right angles to a magnetic field is given by the formula $F_{mag} = BQv$. Since B and Q are constants in this case, the reason for the different magnitude of F must be that the proton has a different velocity, v. **Common problems in 6(b)(i)** • using the formula $F = BIl\sin\theta$ and suggesting that the proton might be travelling at a different angle to the field, not realising that the proton is always travelling at right angles to the magnetic field in this question • suggesting that the proton may be in a weaker (or stronger) field at X than at Y, not realising that the magnetic field is uniform and so its field strength is constant throughout

•		ii	$v = (\frac{F_{mag}}{BQ} =)\frac{5.6 \times 10^{-19}}{5.0 \times 10^{-5} \times 1.60 \times 10^{-19}}$ resultant force F_R= (5.6 − 1.4) × 10^{-19} $r = \left(\frac{mv^2}{F_R} =\right)\frac{1.673 \times 10^{-27} \times (7.0 \times 10^4)^2}{4.2 \times 10^{-19}}$ *r* = 20 (m) Alternative all-in-one method: $r = \frac{mF_{mag}{}^2}{F_R B^2 Q^2}$ resultant force F_R= (5.6 − 1.4) × 10^{-19} $r = \frac{1.673 \times 10^{-27} \times (5.6 \times 10^{-19})^2}{4.2 \times 10^{-19} \times (5.0 \times 10^{-5})^2 \times (1.60 \times 10^{-19})^2}$ *r* = 20 (m)	C1 C1 C1 A1 (C1) (C1) (C1) (A1)	*v* = 7.0 × 10^4 (m s^{-1}) implies first C1 **Allow** 10^{-19} for 1.4×10^{-19} (giving $\boldsymbol{F_R}$= 4.6 × 10^{-19}) F_R = 4.2 × 10^{-19} implies second C1 Do not credit if used as F_{mag} in F_{mag} in F_{mag} = *BQv* Third C1 is for correct substitution into formula **Allow** m_p = 1.67 × 10^{-27} kg given to 3 s.f. **Not** m_p = 1.661 × 10^{-27} kg or m_p = 1.675 × 10^{-27} kg **Allow ECF** for incorrect *v* Use of $\boldsymbol{F_R}$ = 5.6 × 10^{-19} or = 1.4 × 10^{-19} is **XP** **Allow** *r* = 19 (m) $\boldsymbol{F_R}$ = **4.2 × $\boldsymbol{10^{-19}}$** (4.16 × 10^{-19} to 3sf) implies second C1 An incorrect value of F_R is **XP** from this point Third C1 is for correct substitution into formula **Allow** *r* = 19 (m) **<u>Examiner's Comments</u>** This question could not be done in one step, by equating the magnetic force to the centripetal force. This is because, at X, the centripetal force is being provided by a combination of forces from both the electric and the magnetic field. The easiest approach is to find the velocity of the proton using F_{mag} = *BQv* (the value for F_{mag} is given in the diagram as 5.6 × 10^{19} N). This velocity *v* can then be used in the formula *F* = mv^2/r in order to calculate the radius, r. *F* here is the *resultant* force towards the centre of the circle, which is found from magnetic force downwards - electric force upwards (the electric force having been calculated in part (a)). Exemplar 3 is an example of a correct

					answer, clearly written to show each stage in the calculation: Exemplar 3 
		iii	$\lvert\text{resultant force}\rvert = (\sqrt{3.9^2 + 1.4^2}) \times 10^{-19}$ |resultant force| = 4.1×10^{-19} (N)	C1 A1	**Ignore** attempt to calculate weight of proton **Allow** $F_E = 10^{-19}$ **Allow** $\lvert F\rvert = 4.0 \times 10^{-19}$ (N) using $F_E = 1.0 \times 10^{-19}$ **Allow** $\lvert F\rvert = 4.2 \times 10^{-19}$ (N) using $F_E = 1.44 \times 10^{-19}$ <u>**Examiner's Comments**</u> There are two forces acting on the proton at Y: an electric force upwards (given in (a)) and a magnetic force to the left (shown on the diagram). These two forces act at right angles to each other, and so the magnitude of their resultant can be found using Pythagoras's Theorem. Credit was given for using a value for the electric force to 1, 2 or more significant figures.
		iv	<u>resultant / net</u> force is not perpendicular to velocity work is done on proton (therefore kinetic energy changes so speed is not constant)	B1 B1	**Allow** direction of motion / path but **not** speed for velocity **Allow** acceleration / <u>resultant</u> force is not (always) towards centre (of circle) **Allow** electric force is not perpendicular to velocity / is in the same direction as velocity **Ignore** references to centripetal **Ignore** references to centripetal <u>**Examiner's Comments**</u> At Y, the proton is moving downwards, with a resultant force being the combination of an electric force upwards and a magnetic force to the left (calculated in part 1). The resultant force cannot be at right angles to the

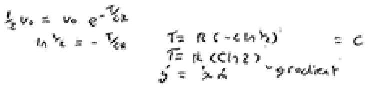
					velocity, so we cannot have circular motion. The component of the resultant force acting in the direction of the proton's motion will do work on the proton and change its speed. So, the proton cannot be travelling at a constant speed.
			Total	**10**	
2	a	i	At least 4 equidistant parallel vertical (straight) lines With arrows pointing downwards	B1 B1	By eye **Ignore** field lines outside of plates At least one line must touch top and bottom plate At least one arrow, and all arrows given must be correct **<u>Examiner's Comments</u>** Most candidates were able to score at least 1 mark on this question. The most common loss of marks was an uneven spacing between the lines. Some candidates (helpfully) wrote on the diagram that the spacing was equal. As it is apparent that most candidates know the spacing should be regular, it would be best to do this with a ruler rather than leave it judgement. Similarly, the lines should be vertical and straight, again best done with a ruler. Exemplar 3  Exemplar 3 only scored the second mark, as the spacing is unequal. At first glance it may look like the spacing is regular and this is possible what the candidate meant to do, but those at the right hand side (ignoring those outside of the plates) are definitely not equally spaced by eye. It would have been far better for the

					candidate to use a ruler to make the spacing equal.
		ii	The top and the bottom of the clouds will not be parallel / will be uneven	B1	**Allow** uneven charge distribution / charge density **Allow** the field is non-uniform **Allow** the cloud is a non-uniform shape **Ignore** cloud has non uniform density **Examiner's Comments** Although there were many ways to obtain this mark, only around half of candidates gave a suitable response. Many answers were vague such as 'the cloud is not even' or 'the cloud contains water vapour' which really needs more clarity. The best response is based on the distribution of charges, but alternatives relating to uniformity of a variety of factors are perfectly correct.
		iii	($V = Ed$) = $4.0 \times 10^5 \times 3.2 \times 10^3 = 1.3 \times 10^9$ (V)	B1	Values of E, d with correct powers of 10 and correct evaluation must be seen to at least 2sf (1.28) **Ignore** unit **Examiner's Comments** Again, a 'show that' question needs the calculation to be clear. Here it will involve the multiplication of two quantities using the correct powers. For example, 32k is not a suitable alternative to 32 x 10^3. The value calculated is not the same as the 'show that' value so needs to be given to more significant figures (at least 2) to prove the calculation was carried out. The significant majority of candidates were able to correctly score this mark.
		iv	$C = \left(\frac{\varepsilon_0 A}{d} =\right) \frac{8.85 \times 10^{-12} \times \pi \times (12 \times 10^3)^2}{3.2 \times 10^3}$ $C = 1.3 \times 10^{-6}$ (F)	C1 A1	All values (including ε_0) substituted correctly Correct evaluation to at least 2sf (1.25 × 10^{-6}) **Note:** use of $C = 4\pi\varepsilon R$ (leading to 1.3 × 10^{-6} is XP) **Examiner's Comments**

					Most candidates were able to select the correct formula and make an attempt at a substitution. The main error came from an incorrect calculation of the area, either by using an incorrect method for the circle or incorrectly calculating it using 24km x 3.2km. Candidates are to be reminded that if the working is correct and the calculation wrong, then marks may still be given. Without this working, there is likely to be no credit. Several candidates used the formula for charge on a sphere which gave the same answer (to 2sf) but is a physics error so scores no marks.
		v	Q (= CV) = $1.25 \times 10^{-6} \times 1.28 \times 10^{9}$ Q = 1600 (C)	C1 A1	Ecf from (a)(iii) and (a)(iv) Correct evaluation to at least 2sf **Allow** 2sf answer of 1700 C for 2sf values used in calculation **Allow** answer of 1250C for p.d. value of 1 x 10^9 **<u>Examiner's Comments</u>** This response could produce a wide variety of correct answers depending on the rounding of the numbers used, although most candidates used at least 2sf for their values, which is recommended. A noticeable number of candidates correctly evaluated the change then divided it by 2, presumably due to it asking for the charge on one of the plates. **Assessment for learning** Error carried forward. In general, error carried forward can only be applied when the working is clearly seen and the error value is correctly used. In this question, there are two values to be used, each of which may have been incorrectly calculated. It is therefore vital that the calculation is seen, so that the credit

					can be given. It is, of course, good practice to always show working rather than when just an error carried forward could be applied.
	b	i	$V = \frac{Q}{4\pi \varepsilon_0 r}$ $V = \frac{155}{(4\pi\ 8.85 \times 10^{-12} \times 2 \times 10^{3})}$ $= 7.0 \times 10^{8}$ (V)	C1 A1	All values substituted correctly Correct answer to at least 2sf (6.97) **Examiner's Comments** Most candidates were able to correctly select the equation and evaluate the correct answer. Some chose the field strength equation or wrote the potential equation with a r^2. Some selected the wrong value of r, giving it as the radius of the cloud. As with Question 18(b)(iii) candidates are reminded that, in general, answers should be given to the lowest number of significant figures in the question, and that an answer of 7×10^8 will incur the significant figure penalty (applied only once per paper).
		ii	Either (I =) 155 / 25 × 10^{-3} = (6200 A) n = 6200 / 1.6 × 10^{-19} = 3.88 x10^{22} n (in 1ms) = 3.88 × 10^{22} × 10^{-3} = 3.9 × 10^{19} Or (Charge flow) = 155/25 = (6.2 C ms^{-1}) n = 6.2 / 1.6 × 10^{-19} n = 3.9 × 10^{19}	C1 C1 A1 (C1) (C1) (A1)	**Ignore** units throughout although penalise any unit on answer line Correct evaluation to at least 2sf (3.88) Correct evaluation to at least 2sf (3.88) **Examiner's Comments** This question could be answered in several ways. Most candidates chose to calculate the current in amps and then converting back to ms at the end. Very few were confused by the need to give the answer in ms. This question polarised the candidates with the vast majority scoring 0 or 3; those who got part way to solving it generally ended up with the correct answer.
			Total	**13**	
3			D	1	

					Examiner's Comments A little under half of the candidates were able to calculate and select the correct response. The most common incorrect response was **B**, although it was not entirely clear why this was the case from candidates working. A very small minority of candidates did not answer this question.
			Total	**1**	
4			D	1	**Examiner's Comments** Around two thirds of candidates were able to correctly apply Coulomb's law and obtain the correct response. Response **C** was a common distractor and this was evident for working as the charge on the helium nucleus was given as a single multiple of the fundamental charge.
			Total	**1**	
5	a	i	**1** 0.5 (C_0) **2** 2 (V_0) **3** 2 (E_0)	B1 B1 B1	**Allow** ½ **Ignore working** No ecf **Ignore working** No ecf **Examiner's Comments** Around two thirds of candidates were able to score all of these marks. Most showed some limited (but helpful) working, such as writing the equation for the parallel plate capacitor and $C = Q/V$, to assist them in appreciating how each of the factors change. For this question, there is a quite large amount of introductory text and the bold text is there as a supportive guide. The most common incorrect responses were a simple reversal of the correct responses.
		ii	Work done against attractive forces	B1	**Allow** WD for work done

					Examiner's Comments This proved to be a challenging question and only the higher end candidates were able to give a clear and correct response. The question stated, "in terms of forces" and most candidates did not explain the idea of attraction between the plates. Common incorrect responses included using $E = ½ QV$ or using $W = F \times d$ as a starting point.
	b	i	Evidence of use of $V = V_0 e^{-t/CR}$ leading to ln (½) = −T/CR or ln2 = T/CR $T = C\ln 2 \times R$ compared with $y = mx$ with gradient = Cln2	M1 A1	**Must** see exponential decay as starting point (allow Q for V) **Allow** t for T **Allow** x for V and x_0 for V_0 **Not** T/R = gradient **Examiner's Comments** The treatment of natural logs was generally well done across the ability range and those who started from a correct exponential equation were generally able to score the first mark. There was some confusion among the less successful responses about the role of the negative sign, without them appreciating that ln(2) = − ln (½) and it was evident that some simply ignored it. Although many candidates were able to get to the correct equation, few linked it appropriately to the equation of a straight line and did not show that the gradient was Cln2, as required. Exemplar 3 shows a candidate producing elegant solution.  A response that works through the logs clearly and then relates it well to the form of y = mx + c.
		ii	Best-fit line drawn correctly **1** gradient = 5.4 (× 10^{-9}) C = (gradient / ln2) = 7.8 × 10^{-9} (F)	B1 B! B1 C1	**Note** line must pass through all (vertical part of) error-bars. If more than one line drawn, all lines must pass through all error-bars (1/2 square tolerance). **Allow** ± 0.2 (× 10^{-9})

			2 $7.8 \times 10^{-9} = \frac{\varepsilon \times 3.1 \times 10^{-2}}{8.0 \times 10^{-5}}$ $\varepsilon = 2.0 \times 10^{-11}$ (Fm^{-1})	A1	**Ignore** POT **Ecf** from incorrect gradient, but penalise POT error here Possible ECF from **(b)(ii)1** **Allow** 1 mark if final answer is relative permittivity correctly calculated (ε divided by 8.85 x× 10^{-12}) **<u>Examiner's Comments</u>** In part 1, nearly all the candidates were able to draw a correct straight best-fit line which passed through all the error bars. It was actually rather difficult not to do this, although several candidates did multiple lines (assuming they were unable to remove an original) and if any fell outside of the error bars, then it could not be given marks. In calculating the gradient, misreads from the graph were common either from the vertical scale or often assuming that the horizontal scale started from zero. A common mistake among the range of abilities was to miss out the 10^6 in the denominator of the gradient. Several candidates may have interpreted the question as meaning that the gradient was *C*, as they calculated the gradient but took it no further. Part 2 was generally well done by many candidates. Some of the less successful responses were unable to rearrange the capacitance equation correctly, often swapping over the *d* and *A* values. A small proportion calculated the relative permittivity and as long as this was done correctly, it could score the first mark. A common error was to attempt to use $C = 4\pi\varepsilon r$ which proved to be unproductive. **Assessment for learning**

					Good practice for straight best-fit lines includes: • A single straight line – not a line drawn in two or more parts. • Use of a sharp pencil – once a line is drawn in pen, it is almost impossible to correct. • Aiming to have an equal number of data points above and below the line – not always possible due to potential variations in data, but this should be a general aim. • Looking for anomalous points – should not form part of the best-fit. • Being aware of a false origin – if present then the line should not necessarily be expected to go through this point. • Drawing a line through the origin – would (0,0) be expected to be a data point, and consideration of a potential systematic error in the data. • Use of error bars – if present (generally in the dependent data), then the line must pass through the vertical error bars on every point.
•			**Total**	**11**	
6	a	i	$a = \frac{VQ}{dm}$ OR $a = \frac{EQ}{m}$ OR $KE = ½ mv^2$ and $v^2 = u^2 + 2as$ OR $KE = F \times d$ and $F = m \times a$ $a = \frac{0.30 \times 1.6 \times 10^{-19}}{6.0 \times 10^{-3} \times 9.11 \times 10^{-31}}$ / $a = \frac{50 \times 1.6 \times 10^{-19}}{9.11 \times 10^{-31}}$ / (Use of $KE = ½ mv^2$) = 4.8×10^{-20} = ½ × $9.11 \times 10^{-31} \times v^2$ and (use of $v^2 = u^2 + 2as$ =) v^2 = (1.05×10^{11}) = 2 × a × 6×10^{-3} (± 0^2) (Use of $KE = F \times d$) = 4.8×10^{-20} = $F \times 6 \times 10^{-3}$ and (use of $F = m \times a$) F = (8.0×10^{-18}) = $9.11 \times 10^{-31} \times a$	C1 M1	**Allow** u and v interchangeably throughout **Allow** calculation of E = (0.30 / 6 × 10^{-3}) = 50 (V m^{-1}) or $v = 3.2 \times 10^5$ (ms^{-1}) or $v^2 = 1.05 \times 10^{11}$ $(ms^{-1})^2$ or $F = 8.0 \times 10^{-18}$ (N) for C1 mark Substitution mark – in any arrangement. Expect full substitutions including numerical value of m_e if appropriate Method 1: direct calculation of a

			$a = 8.78 \ldots \times 10^{12}$ (ms^{-2})	A1	Method 2: using $KE = \frac{1}{2} mv^2$ and $v^2 = u^2 + 2as$ Method 3: using $KE = F \times d$ and $F = m \times a$ **Note** must be more than 2 SF (not paper SF penalty) **Ignore** negative sign **<u>Examiner's Comments</u>** There were many different routes to showing the acceleration, and marks were given for each method or part method. No one method was seen significantly more than others, and some candidates used a variety of pathways to come to their answer. The main principle in the question (and the subsequent one) where the candidate is being asked to "show that" a given value is correct is that the examiner must be convinced that the candidate has clearly demonstrated that they have carried out the calculation and evaluated it on their calculator. The instructions which examiners used was: first marking point for providing one (or two) equations that would lead to the solution, or calculation of an intermediate value; second marking point for a full substitution into one or more equations; third marking point for using this full substitution to produce an answer to more sf than given in the question. As the second marking point was deemed to be an M mark, the full substitution needed to be seen to gain the A mark. A small number of (often higher end) candidates did not show the full substitution, often missing out the value of m_e in their calculation, and another common error was to not show the extra significant figure. Over half of the candidates were able to achieve full marks on this question and it generally discriminated well.

					Assessment for learning When a question asks a candidate to "show that" a given value is correct, the following two points should be considered: • Each stage of the calculation should be clearly shown. Preferably setting out any equation first, and then showing a full substitution of all values into that equation • If the value calculated by the candidate would correctly round to the given value, then the candidate should show their calculated value to at least one more significant figure than the given value. Both of these are evidence that the complete calculation has taken place and that the candidate has not somehow artificially generated the required value. This advice should be viewed as "best practice" rather than a rigid set of rules. Reverse arguments are often possible where a candidate can work backwards from their given value, however this is not the advised approach.
		ii	(Use of $KE = ½ mv^2$) = 4.8×10^{-20} = $½ \times m \times v^2$ OR ($u^2 = v^2 - 2as$) = $0^2 - [2 \times (-)\ 8.8 \times 10^{12} \times s]$ Full substitution leading to $v = 3.2… \times 10^5$ (ms^{-1})	C1 A1	**Allow** u and v interchangeably Numerical value of m_e must be used if using *KE* method **Note** must be more than 1 SF (not paper SF penalty) **Note** 3.25 is acceptable for A1, but not 3.3 **<u>Examiner's Comments</u>** The vast majority of candidates were

					able to clearly show that the speed of the photoelectron could be calculated as 3.2×10^5 ms^{-1}, most often through substitution into the kinetic energy formula. As in Question 19 (b) (i), it is important to show all variables and constants used in the equation for full marks and to give the answer to at least one more d.p. than given in the question, to show the calculation has taken place. An alternative solution using an equation of motion and the acceleration given (or calculated) in Question 19 (b) (i) would yield the same result.
		iii	$t = \frac{3.2 \times 10^5}{8.8 \times 10^{12}}$ $t = 3.6 \times 10^{-8}$ (s)	C1 A1	**Allow** correct full substitution into any suvat equation **Allow** 3×10^5 for v **Ignore** signs of substituted values **Expect** values between 3.4×10^{-8} and 3.8×10^{-8} (s) **No ecf** from (b)(i) or (b)(ii) **<u>Examiner's Comments</u>** Only around half of the candidates were able to obtain answers within the required range. Candidates used a variety of rounded or none-rounded values from prior calculations, so a generous range of responses was given to allow for this. A common error among less successful responses was to simply use speed = distance/time usually leading to 2.0×10^{-8} s. Those using $s = ut + ½ at^2$ often encountered problems in solving the equation as it could lead to imaginary roots and tended to produce solutions way outside of the accepted values. However, marks could be given for setting up the calculation correctly.
		iv	Any line with negative slope starting from 0, 4.8×10^{-20} A straight line finishing at 6.0,0	M1 A1	½ square tolerance. **ALLOW** a curve with negative gradient. **ALLOW** a region of zero gradient, but not whole line ½ square tolerance on axis intercepted **<u>Examiner's Comments</u>**

					Nearly all candidates appreciated that this line would start at 4.8×10^{-20} J and decrease to zero at 6.0 mm. However, the vast majority drew a curved line of decreasing gradient. This may well have come from a confusion from $KE \propto v^2$ and attempting to draw a parabola.
	b		Energy of photon increases (max) kinetic energy / speed (of electrons) increases / (some) electrons (now) reach **C and** there is a current or reading (on ammeter)	B1 B1	**Do not allow** increased *kinetic* energy of photons **Do not allow** explanation in terms of increased number of **emitted** electrons (per second) **Allow** photoelectrons for electrons **<u>Examiner's Comments</u>** There were several misconceptions in candidates' responses to this question. Many candidates did not appreciate that the increased frequency would result in electrons of greater KE and thought that it was the increased energy of the photons crossing the 6.0mm gap that caused an ammeter reading. A significant number of candidates also described increasing frequency causing an increase in *kinetic* energy of photons, and some also linked the increasing frequency to a greater number of photons or photoelectrons.
			Total	**11**	
7			**B**	1	**<u>Examiner's Comments</u>** This was a challenging question; candidates often drew a radial field diagram as a starting point and many candidates helpfully "ticked" the correct responses to help them eliminate these from their response. It is important that candidates read the questions carefully, as it was evident that some were looking for a correct statement.
			Total	**1**	