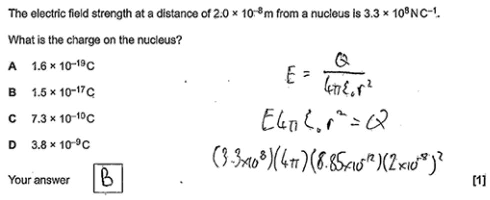
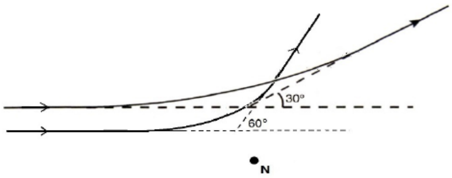
Mark scheme – Electrical Fields

Question			Answer/Indicative content	Marks	Guidance
1			**B**	1	
			Total	**1**	
2			**A**	**1**	
			Total	**1**	
3	a		Correct pattern Correct direction of the field	**B1** **B1**	**Note:** At least five field lines must be drawn and of these, two must be perpendicular (by eye) to the surface of the sphere and plate **Note:** This may be shown on just one line **Examiner's Comment** Most candidates drew decent field patterns and showed the correct direction of the electric field. It is difficult to draw curved field lines, but those who were careful and had the field lines perpendicular at both the surface of the sphere and the metal plate were rewarded.
	b		(Electric potential) is the work done per (unit) charge in bringing a positive charge from infinity (to the point).	**B1**	**Allow:** work done / energy required to bring a unit positive charge from infinity (to the point) **Examiner's Comment** This was not well-answered; the modal mark was zero. Definition for electric potential lacked precision and often made no reference to a 'unit **positive** charge' or 'per unit **positive** charge'. At times, other quantities such as electric field strength and gravitational field strength were being defined. This was a missed opportunity -definitions just need to be learnt.
	c	i	$V = Q/4\pi\varepsilon_0 r$ (Allow any subject) $Q = 4\pi \times 8.85 \times 10^{-12} \times 0.015 \times 5000$ $Q = 8.3(4) \times 10^{-9}$ (C)	**C1** **C1** **A0**	**Note** using $E = V/d$ with $E = Q/4\pi\varepsilon_0 r^2$ is wrong physics and hence scores zero **Note** if the value of ε_0 is not given here, it could be implied in the correct 3sf answer **Allow** any subject here if the answer is given to more than 2sf **Allow** the use of $1/4\pi\varepsilon_0 = 9 \times 10^9$ **Examiner's Comment** By contrast to the last question, the answers here were perfect. Correct values were substituted into the equation for electric potential to show that the charge was that stated in the question. In a 'show' question, always give the final answer to more significant figures than the required answer. It was good to see many scripts with the final answer written as $8.3\mathbf{4} \times 10^{-9}$ C.

		ii	1 (electric force =) $1.7 \times 10^{-2} \times \tan 4.0$ (Allow any subject) (electric force = 1.19×10^{-3} N) 2 $E = 1.2 \times 10^{-3}/8.3(4) \times 10^{-9}$ $E = 1.4 \times 10^{5}$ (N C^{-1})	**M1** **(A0)** **C1** **A1**	**Not** 1.7×10^{-2} sin4 or 1.7×10^{-2} cos86 **Allow** $1.7 \times 10^{-2} \times$ sin4/cos4 **Allow** 2 marks for 1.45×10^{5} (N C^{-1}), 8.3×10^{-9} used **Allow** 2 marks for 1.43×10^{5} (N C^{-1}), 1.19×10^{-3} (N) used **Examiner's Comment** This was a good discriminator with high-scoring candidates either using triangle of forces, or resolution of forces, to determine the electric force on the sphere. The value of the force was given so that it could be used to answer the next question. More than half of the candidates correctly calculated the electric field strength using the information provided in **(c)(i)** and **(c)(ii)1.** Some candidates used the elementary charge rather than the value from **(c)(i)** to calculate the field strength; this gave an incorrect answer of 7.5×10^{15} N C^{-1}.
			Total	**8**	
4			B	1	
			Total	**1**	
5			A	1	
			Total	**1**	
6			**B**	**1**	
			Total	**1**	
7			**D**	**1**	
			Total	**1**	
8			B	1	**<u>Examiner's Comments</u>** This question required knowledge of the equation $E = \frac{Q}{4\pi\varepsilon_0 r^2}$, which is in the Data, Formulae and Relationship Booklet. The key, the correct answer, is **B**. The most common mistake made by candidates was not squaring *r*, or the equivalent where the electric potential *V* equation was used instead. This gave the incorrect answer of 7.3×10^{-10} C for the most recurrent distractor **C**. The exemplar 2 below shows a plausible method for getting to the correct answer. **Exemplar 2**

					 The electric field strength at a distance of 2.0×10^{-8} m from a nucleus is 3.3×10^{8} N C^{-1}. What is the charge on the nucleus? A 1.6×10^{-19} C B 1.5×10^{-17} C C 7.3×10^{-10} C D 3.8×10^{-9} C Your answer B [1] $E = \frac{Q}{4\pi\varepsilon_0 r^2}$ $E4\pi\varepsilon_0 r^2 = Q$ $(3.3\times10^{8})(4\pi)(8.85\times10^{-12})(2\times10^{-8})^2$ This middle-grade candidate has shown all the working. A significant number of candidates wrote down the correct expression, circled the key data in the question and did the rest of the work on their calculators. A variety of techniques were use.
			Total	**1**	
9			D	1	**<u>Examiner's Comments</u>** This question was assessing the simple learning outcome 6.2.1b from the specification – *modelling a uniformly charged sphere as a point charge at its centre*. The correct key is **D**. The most popular distractor was **A** with distance being measured between the two surfaces of the sphere.
			Total	**1**	
10			c	1	**<u>Examiner's Comments</u>** This was a well-answered question with most candidates correctly recalling that charge is conserved according to Kirchhoff's first law. A significant number of candidates distracted towards **B**; perhaps because of the unit of charge is the coulomb.
			Total	**1**	
11			C	1	**<u>Examiner's Comments</u>** The correct response is **C**. Candidates often find the electric field questions challenging and this was again the case as this question was correctly answered by only one third of the candidates. Many candidates drew arrows on the diagram to assist them. Response **D** was the most common distractor; linking this to gravitational fields would produce a zero field strength at **P** which is likely to be the reason.
			Total	**1**	
12			A	1	
			Total	**1**	
13			Downward curved path Same *x*	B1 B1	**Ignore** any line outside of the plates **Expect** same x by eye **<u>Examiner's Comments</u>** Nearly all candidates appreciated that the path should be

					downwards, but many did not take the care needed for it to be clear that the deflection at the end of the plate should be the same. Some candidates drew an 'x' on their sketch, which was helpful in determining if the intention to draw it the same had been made.
			Total	**2**	
14	a		$\varepsilon = 7.2 \times 10^{-12} \times 1.2 \times 10^{-3}/4.0 \times 10^{-4}$ permittivity = 2.2×10^{-11} (F m^{-1})	**C1** **A1**	**Allow** any subject **Allow** ε_o instead of ε **Note** answer to 3 sf is 2.16×10^{-11} (F m^{-1}) **Allow** 1 mark for bald 2.4; relative permittivity calculated **Examiner's Comment** Most candidates effortlessly used the equation $C = \varepsilon A / d$ to determine the permittivity *s* of the insulator between the capacitor plates. Once again, most answers were well-structured and showed good calculator skills. The most common errors were: • Taking the prefix pico (p) to be a factor of 10^{-9}. • Confusing permittivity ε and permittivity of free space ε_0. • Calculating relative permittivity (2.4).
	b	i	capacitance of two capacitors in series = 500 (πF) *C* = 1000 + 500 *C* = 1500 (μF)	**C1** **A1**	**Examiner's Comment** The modal score here was two marks, with most scripts showing excellent understanding of capacitors in combination. Many candidates arrived at the final answer of 1500 μF without much calculation. A small number incorrect swapped the equations for series and parallel combinations and arrived at the incorrect answer of 670 μF.
		ii	$V = 1.5 \times e^{-12/15}$ $V = 0.67$ (V)	**C1** **A1**	Possible ecf from **(i)** **Allow** 1 mark for 0.83 V, $V = 1.5[1 - e^{-12/15}]$ used **Examiner's Comment** Many candidates correctly calculated the time constant of the circuit and then either determined the p.d. across the capacitors (0.83 V) or the resistor (0.67 V) - the latter being the correct answer. The most common mistake was calculating e^{-12115} rather than $1.5 \times e^{-12/15}$. Weaker candidates got nowhere by attempting to use $V = IR$ and $Q = VC$.
			Total	**6**	

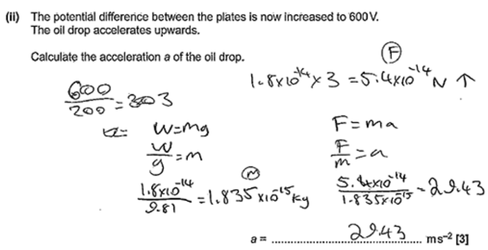
15			Flemings left hand rule / the force on the electron is in the plane of the paper, right angles to the velocity and 'downwards'.	B1	
			Circular path within field in a clockwise direction.	B1	**Note**: If drawn on Fig. 22.1, then judge 'circular' path by eye.
			Total	**2**	
16			 	B1 B1	Path is initially horizontal **and** further up the page than original Path <u>ends</u> at 30^0 to horizontal (angle must be labelled) in the direction shown **<u>Examiner's Comments</u>** The common errors here were: • not realising that, for the particle to be deflected through a smaller angle, it needed to be travelling further away from N • not labelling the final angle of 30° • not adding arrows to show the direction of travel • drawing a path that continued bending beyond the stated 30° (usually ending up parallel to the original path).
			Total	**2**	
17			The magnitude of the electric potential is the same for both particles at the midpoint but of opposite sign.	B1	
			The (total) potential at the midpoint is zero.	B1	
			Total	**2**	
18			**Similarity** The field strength or force ∝ 1 / separation^2 or both produce a radial field.	B1	
			Differences Gravitational field is linked to mass and electric field is linked to charge.	B1	
			Gravitational field is always attractive whereas electric field can be either attractive or repulsive.	B1	
			Total	**3**	
19			F = Bev **and** F = eE E = V / a **or** F = (eE) = eV / a Bev = eV / a giving V = Bva	**B1** **B1** **B1**	**allow** Q or q for e **Examiner's Comments** This was an exercise in writing basic definitions in algebraic form and then using them to derive a given equation. More than

					half of the candidates managed to gain full marks with less than one third scoring zero. The presentation was sometimes difficult to follow with the inclusion of unnecessary equations and deletions and the substitution of *d* for *a* in the last line.
			Total	**3**	
20			The charge on each plate remains the same.	B1	**Allow** other correct methods.
			$C = \varepsilon_0 A/d$, hence the capacitance is halved.	B1	
			$E = ½\, Q^2/C$, $E \propto 1/C$ and hence energy stored doubles.	B1	
			Total	**3**	
21		i	Kinetic energy (of proton) changes to potential (energy) **or** Potential energy increases as the kinetic energy (of the proton) decreases **or** Potential energy increases as work is done against the field / against repulsion / positive charge	**B1**	**Allow** 'it' / PE for (electric) potential energy **Allow** KE / E_k
		ii	energy = $0.52 \times 10^6 \times 1.60 \times 10^{-19}$ **or** $8.3(2) \times 10^{-14}$ (J) $\frac{1.60\times10^{-19}\times27\times1.60\times10^{-19}}{4\pi\varepsilon_0 R} = 8.32\times10^{-14}$ $R = 7.5 \times 10^{-14}$ (m)	**C1** **C1** **A1**	**Allow** 2 mark for 1.6×10^{-13} (m); Z = 59 used **Allow** 2 mark for 8.9×10^{-14} (m); Z = 32 used **Allow** 1 mark for 2.8×10^{-15} (m); Z = 1 used **Allow** 1 mark for 1.2×10^{-32} (m); energy = 5.2×10^5 used **<u>Examiner's Comments</u>** The above question on electric potential energy provided excellent discrimination with middle and upper quartile candidates showing how to produce immaculate answers – identify the physics, write down the correct physical equation, do any necessary conversions (e.g. MeV to J), rearrange the equation, substitute correctly and then write the final answer in standard form to the correct number of significant figures. About a third of the candidates scored full marks. Some of the missed opportunities or errors were:

					• Using an incorrect equation with the distance squared • Not correctly converting the kinetic energy 0.52 MeV into joule (J) • Using the equation $r = r_0A^{1/3}$ for the mean radius of a nucleus to determine the minimum distance
			Total	**4**	
22		i	($v^2 = u^2 + 2as$) $(2.4 \times 10^6)^2 = (7.2 \times 10^6)^2 + 2 \times a \times 1.2 \times 10^{-2}$	C1	**Allow** other correct methods
		i	$a = (-)\ 1.9 \times 10^{15}$ (m s^{-2})	A1	**Allow** 1 mark for 1.9×10^{13}; distance left in cm **Note** answer to 3 s.f. is 1.92×10^{15} (m s^{-2}) **Ignore** sign
		ii	$E = F/Q$ and $F = ma$	C1	
		ii	$E = \dfrac{1.67\times10^{-27}\times1.92\times10^{15}}{1.60\times10^{-19}}$	C1	Possible ECF from **(i)**
		ii	$E = 2.0 \times 10^7$ (N C^{-1})	A1	**Allow** 2 marks for 1.1×10^4; mass of electron used **Allow** 1 s.f. answer
			Total	**4**	
23	a	i	$F = QE = QV / d$ **or** $E = 5(.0) \times 10^4$ (Vm^{-1}) $F = 9.0 \times 10^{-9} \times 4000 / 8.0 \times 10^{-2}$ (= 4.5×10^{-4} N)	C1 A1	$F = 5.0 \times 10^4 \times 9.0 \times 10^{-9}$ **<u>Examiner's Comments</u>** Many lower ability candidates did not appreciate the uniform nature of the electric field between the plates and attempted to use Coulomb's Law.
		ii	weight; arrow vertically downwards tension; arrow upwards in direction of string electric (force); arrow horizontally to the <u>right</u> (not along dotted line)	B1 x 2	All correct, 2 marks; 2 correct, 1 mark 1 mark maximum if more than 3 arrows are drawn **Ignore** position of arrows **Allow** W **or** 0.030(N) (**not** gravity or g) **Allow** T **Allow** F **or** E or 4.5×10^{-4}(N) or electrostatic **Ignore** repulsion or attraction **Not** electric field / electric field strength / electromagnetic **<u>Examiner's Comments</u>** Most candidates scored a mark for showing the weight and tension forces accurately. Only a small proportion labelled the electric force arrow correctly and drew it as clearly perpendicular to the plates.

					AfL Do not use the word ‘gravity’ in place of ‘weight’
		ii i	$W x = F l$ 0.03 x = 4.5 x 10^{-4} x 120 **or** = 4.5 x 10^{-4} x 1.2 x = 1.8 cm **or** x = 0.018 m	M1 M1 A0	**Allow** any valid alternative approach e.g. M1 deflection angle θ = 1° M1 x = 120sinθ 1 mark for each side of the equation **Examiner’s Comments** Although most candidates knew the principle of moments, many were unable to apply it correctly in this situation. More practice at this sort of question is recommended.
	b		Electric force/field (strength) increases Ball deflected further from vertical / moves to the right / touches negative plate Ball acquires the charge of the (negative) plate when it touches (Oscillates because) constantly repelled from (oppositely) charged plate	B1 B1 B1 B1	Must be clear which force is increasing Must have the idea of a repeating cycle **Examiner’s Comments** The purpose of this question was to challenge the candidates to use their knowledge of electric fields in a novel practical situation. The word ‘oscillate’ confused many candidates, who tried to explain why the ball would perform simple harmonic motion.
	c		$I = Qf$ **or** $Q = It$ f = 3.2 x 10^{-8}/9.0 x 10^{-9} = 3.6 (Hz)	C1 A1	
			Total	**12**	
2 4			Q = 79e and q = 2e $F = (1/4\pi\varepsilon_0)Qq/r^2$ = 79 × 2 × (1.6 × 10^{-19})^2/ [4π × 8.85 × 10^{-12} ×(6.8 × 10^{-14})^2] = 7.9 (N)	C1 C1 C1 A1	**Apply ECF** for wrong charge(s), e.g. Q and / or q = e, or Q = 79 and / or q = 2, etc **Examiner’s Comments** The most common error here was to use incorrect values for the charges on the two ions. Even so, most candidates were able to gain most of the marks with ECF.

			Total	**4**	
25		i	The force is right angles to the motion / velocity.	B1	
		i	The particle describes a circle in the plane of the paper.	B1	
		ii	Particle experiences a force perpendicular to motion / velocity.	B1	
		ii	It moves to the right and either comes out or goes into the plane of the paper (in a parabolic path).	B1	
			Total	**4**	
26	a	i	*Qd* = constant At least **two** pairs of values substituted to show that *Qd* = constant	C1 A1	**Allow** straight-line graph of *Q* against 1/*d* passes through the origin **Allow** as *d* increases by a given factor (e.g. doubles) then *Q* decreases by the same factor (e.g. halves) **Allow** numbers that show when *d* doubles then *Q* halves **Ignore** prefixes and POT errors **Examiner's Comments** The question was not carefully examined by most candidates, because the reference to use **Fig. 22.2** was totally ignored. A significant number of candidates focused either on superfluous practical details or the proof of the relationship between *Q* and *d* – which was required in the next question. About a third of the candidates used at least two points on the graph to show that *Qd* = constant. The powers of ten were overlooked by examiners. A small number of candidates, mainly at the lower-end, calculated the gradient of the curve at arbitrary points to provide support for their incorrect reasoning.
		ii	*Q* = *VC* **and** *C* = $\frac{\varepsilon_0 A}{d}$ Hence $Q = \frac{V\varepsilon_0 A}{d}$ (and $Q \propto \frac{1}{d}$)	C1 A1	**Allow** ε **Note** *Q*, or *Q/V* must be the subject here **Allow** *Q* ∞ *C* and *C* ∞ $\frac{1}{d}$ **Examiner's Comments** Most candidates successfully, and elegantly, provided the proof for the relationship. Correct answers ranged from the whole space filled with algebra to a couple of succinct lines. A small number of candidates finished off their working by writing $Q = \frac{1}{d}$ instead $Q \propto \frac{1}{d}$ the 'equal' and the 'proportionality' symbols are not equivalent.
	b	i	1.8×10^{-14} (N)	B1	**Ignore** sign **Examiner's Comments**

					This question was designed to support candidates with the next question. The majority scored 1 mark for quoting the weight of the oil drop. A significant number of candidates, about 1 in 5, focused incorrectly on the term **stationary** in the question, and wrote 0 N on the answer line.
	ii	(F_E =) 3 × 1.8 × 10^{-14} (N) **or** (F_E =) 5.4 × 10^{-14} (N) **or** (mass =) $\frac{1.8 \times 10^{-14}}{g}$ (resultant force = 3.6 × 10^{-14} N) (a =) $\frac{3.6 \times 10^{-14}}{(1.8 \times 10^{-14}/g)}$ a = 20 (ms^{-2})	C1 C1 A1	**Note** this mark is for either electric force on the oil drop **or** the calculating the mass of the oil drop **Allow** for ECF from **(b)(i)** **Allow** *g* = 9.8, but not *g* = 10 **Note** answer to 3SF is 19.6 **Allow** 2 marks for *a* = 2*g* **Note** a bald answer of 20 will score 3 marks, if however, we see evidence for *g* = 10, then maximum score will be 2 mark <u>**Examiner's Comments**</u> This was a perfect question for the higher and middle ability candidates. Securing full marks was very much dependent on candidates' understanding of **resultant force**. The majority of the candidates scored 1 mark for calculating the weight of the oil drop in kg. Subsequent steps required the electric force on the oil drop to be 3 times the weight, or the resultant force being twice the weight. The key to getting the correct answer of 2*g*, or 19.6 m s^{-2}, was deducing that the resultant force was 3.6 × 10^{-14} N. The most common incorrect answer was 29.4 ms^{-2} because the resultant force was taken as 5.6 × 10^{-14} N. The exemplar 9 below shows the most common incorrect solution. **Exemplar 9**  This exemplar from a middle-grade candidate shows how lack of knowledge of resultant force on the oil drop led to just 1 mark. The only mark given was for the mass of the oil drop. Using as 5.6 × 10^{-14} N as the resultant force led to the incorrect response of 3*g* or 29.43 m s^{-2}.
			Total	**8**	

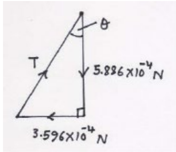
27			$eV = ½mv^2$ so $v^2 = 2eV/m$ $ma = eE$ so $a = eE/m$ $x = vt$ $d = ½at^2 = ½a(x/v)^2$ $d = (eE/2m).x^2.(m/2eV) = Ex^2/4V$ $x^2 = 4(d/E)V$	B1 B1 B1 B1 B1 A0	four equations are needed and some sensible substitution, etc. shown for the fifth mark
			Total	**5**	
28		i	Parallel and equidistant field lines.	B1	**Note**: Field lines must be right angle to the plates.
		i	Field direction is correct (from left to right).	B1	
		ii	work done = $1500 \times 1.6 \times 10^{-19} \times 1.2 \times 10^{-2}$ = 2.88×10^{-18} (J)	C1	
		ii	$\frac{1}{2} \times 9.11 \times 10^{-31} \times v^2 = \frac{1}{2} \times 9.11 \times 10^{-31} \times (5.0 \times 10^6)^2$	C1	Correct use of: final KE = initial KE − work done.
		ii	speed = 4.3×10^6 (m s^{-1})	A1	
			Total	**5**	
29		i	The direction of the electric field due to the negative charge is to the left and right for the positive charge.	B1	
		i	The magnitude of the electric field strength due to the positive charge is smaller than that for the negative charge (because of greater distance). (Hence the resultant electric field strength is to the left.)	B1	
		ii	energy = $\frac{Qq}{4\pi\varepsilon_0 r} = \frac{(1.60 \times 10^{-19})^2}{4\pi\varepsilon_0 \times 3.0 \times 10^{-10}}$	C1	
		ii	energy = $7.67(2) \times 10^{-19}$ (J)	C1	
		ii	energy = 4.8 (eV)	A1	
			Total	**5**	
30		i	(E =) $\frac{4000}{0.080}$ (F =) $\frac{4000}{0.080} \times 1.6 \times 10^{-19}$ (a =) $\frac{8.0 \times 10^{-15}}{9.11 \times 10^{-31}}$ **or** 8.78×10^{15} $a = 8.8 \times 10^{15}$	C1 C1 C1 A0	$E = 5.0 \times 10^4$ (V m^{-1}) $F = 8.0 \times 10^{-15}$ (N) **Allow** this mark if the working is shown. If only value is given, then the answer must be 3SF or more **Examiner's Comments** This question asks for a calculation to show the value of the vertical acceleration in an electric field. The magnitude of the electric field strength first needs to be calculated, followed by the acceleration from Newton's second law. Candidates are reminded that a **show** question needs to be answered in detail and that each stage should be clear. Roughly equal numbers of candidates scored full marks or zero on this question.

		ii	$(t=)\ \frac{0.12}{6.0\times10^{7}}$ (t = 2.0 × 10^{-9} s)	M1 A0	**Examiner's Comments** As with the previous question, there is the need to make sure that the calculation leading to the given answer is clearly set out.
		iii	(x =) ½ × 8.78 × 10^{15} × (2.0 × 10^{-9})^2 x = 1.8 × 10^{-2} (m)	C1 A1	**Allow** a = 8.8 × 10^{15} **Examiner's Comments** Most candidates appreciated the need to use an equation of motion in their solution, but a significant number of candidates used an initial horizontal velocity in the expression, leading to an incorrect answer. There were also an unusually large number who gave no response. Candidates should appreciate that if they have been given show questions, then it is likely that these values will be used in alter questions. **Misconception** Many candidates included an initial vertical velocity – it may be helpful to think of this process as analogous to that of projectile motion.
			Total	**6**	
31			**Level 3 (5–6 marks)** Clear description **and** correct value of C *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Clear description **and** some correct working **OR** Some description **and** correct value for C *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Some description **OR** Some working *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.*	**B1 × 6**	**Indicative scientific points may include:** **Description** • $C = \varepsilon A/d$ • A = area (of overlap) and d = separation. • Use ruler to measure the side / radius / diameter (andhence the area A) • Ensure total overlap of plates. • Measure the thickness / d of paper using micrometer /(vernier) caliper. • Take several readings of thickness and determine anaverage value for d **Calculation of capacitance** • gradient ≈ 85 • C ≈ 1.2 × 10^{-8} (F) **Examiner's Comments** This was the second of the two LoR questions in this paper. It required application of practical skills from module 1.1

			0 marks No response or no response worthy of credit		(Development of practical skills), knowledge of parallel plate capacitor and permittivity. As with the other LoR question 17, examiners expect varied responses for the criteria for the three levels to be met. Unlike some of the analytical questions, there is no one perfect model answer for a specific question. For Level 3, correct value of the capacitance *C* was required together with a clear description of how to do the additional measurements that led to the determination of the permittivity of the paper. For Level 2, it was either clear description with some correct working or some description with the correct value for *C*. Level 1 required some description or some working. As expected, there were diverse answers which demonstrated adequate experimental and practical skills. The thickness of the paper was invariably measured using a micrometer, but some candidates decided to measure the total thickness of a large number of sheets using a ruler and then calculating the thickness of each sheet. This technique was as good as using a micrometer or using Vernier calipers. Diverse answers are the characteristic of LoR questions.  The most common errors made were: • Confusing permittivity with either relative permittivity or the permittivity of free space ε_0. • Using $C = 4\pi\varepsilon R$ instead of $C = \varepsilon A/d$. • Issues with powers of ten when determining the gradient – mainly because of the milli prefix on the time axis. **Exemplar 10**

					$\frac{dy}{dx} = \frac{0.68}{8\times10^{-3}} = 85$ $85 = \frac{1}{CR}$ $R = 1\times10^{6}$ $CR = \frac{1}{85}$ $C = \frac{1}{85(1\times10^{6})}$ $= 1.18\times10^{-8}$ F $C = \frac{\varepsilon A}{d}$ - would also need the area of the plates (A) on the capacitor and the separation between them (d) - can then rearrange equation to give $\frac{Cd}{A} = \varepsilon$ - can use to figure out ε. L2 This exemplar illustrates a Level 2 performance from this top-end candidate. The analysis is perfect, but the description is basic and there are no details of the instruments needed to make the measurement. It would have taken a couple more lines to elevate this answer to Level 3. Compare and contrast this with the exemplar below for a Level 3 response. **Exemplar 11**

					$\lvert \Delta \ln(V) \rvert = 0.68$ $\lvert \Delta t \rvert = 8 \times 10^{-3}$ s $\lvert m \rvert = \frac{1}{CR} = \frac{0.68}{8 \times 10^{-3}}$ $= 85$ $85 = \frac{1}{C(10^6)}$ $C^{-1} = 8.5 \times 10^7$ $C = 1.176... \times 10^{-8}$ F $\approx$ 12nF Via the equation $C = \frac{\varepsilon A}{d}$, to dedu[illegible] the student must do is measure [illegible] of the paper) and A (Area of [illegible] aluminium plates) to give $\frac{Cd}{A} = \varepsilon$ To measure d, take 50 [illegible] of paper used and stack them ontop of [illegible] using a micrometer screw gauge or a ve[illegible] caliper, measure this distance (ensuring [illegible] crumple the paper) and divide by 50 [illegible] d value. To calculate A, simply measure [illegible] width and height of both aluminium plates with a ruler (i[illegible] use a vernier caliper). Taking an aver[illegible] of height and width, multiply these togeth[illegible] the A value. Then $\varepsilon = \frac{cd}{A}$ gives the [illegible] of pa[illegible] 18 L3 This above is a typical Level 3 answer. Correct calculation and a description that has all the right ingredients. Notice how the appropriate measuring instruments are being used and how the uncertainty in the measurements is reduced.
			Total	**6**	
3 2		i	The charges repel each other (because they have like charges).	B1	
		i	Each charge is in equilibrium under the action of the three forces: downward weight, a horizontal electrical force and an upwardly inclined force due to the tension in the string.	B1	
		ii	$F = \frac{(4.0 \times 10^{-9})^2}{4\pi\varepsilon_0 \times 0.02^2} = 3.596.... \times 10^{-4}$ (N)	C1	Correct use of $F = \frac{Qq}{4\pi\varepsilon_0 r^2}$
		ii	weight $W = 6.0 \times 10^{-5} \times 9.81 = 5.886 \times 10^{-4}$ (N)	C1	

		ii	$\tan\theta = \dfrac{3.596\times10^{-4}}{5.886\times10^{-4}}$	C1	
		ii	angle θ = 31°	A1	
			Total	**6**	
3 3		i	$V \propto 1/r$ or distance = $3R$	C1	
		i	V = 5400 (V)	A1	
		ii	**1** $5400 = \dfrac{Q}{4\pi\times8.85\times10^{-12}\times0.04}$ (Any subject)	C1	Possible ecf from **(i)**
		ii	$Q = 2.4\times10^{-8}$ (C)	A1	
		ii	**2** $E = \dfrac{2.4\times10^{-8}}{4\pi\times8.85\times10^{-12}\times0.04^2}$	C1	Possible ecf from **(ii)1**
		ii	$E = 1.35\times10^{5}$ (N C^{-1})	A1	
			Total	**6**	
3 4			**Level 3 (5–6 marks)** Clear description **and** at least two from control of variables *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Some description **and** at least one from control of variables *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Any description but no control of variables **or** Limited mention of control of variable(s) *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.*	B1× 6	Use level of response annotations in RM Assessor **Indicative scientific points may include:** **Description** • $E = V/d$ • Voltmeter used to measure p.d. • Ruler used to measure separation d plates • Plastic rod held in a stand • Safety: Do not touch the terminals of high-voltage supply / (positive) plate • Vary d or V to change E • θ determined for each value of E • Experiment repeated for several values of E • Sensible techniques used to determine θ, e.g. use a protractor • Plot tanθ against E **or** tanθ against $1/d$ graph • Straight line through origin (expected) **Control of variables** • Charge q kept constant (ignore method) • Method for keeping q constant (e.g. same V for the (positive) plate, use separate constant voltage supply, etc) • Use the same foil / keep W the same • Keep d or V constant • Foil in between plates (where the field is uniform) • Draught-free room

					• Do the experiment quickly to avoid leakage of charge **Examiner's Comments** This was the second level of response (LoR) question in this paper. This too was designed to assess practical skills of planning, implementation, analysis and evaluation. The context of the question was force experienced by a charged gold foil in the uniform electric field provided by two parallel plates. Candidates were not expected to have seen such an experiment, but they were expected to use their knowledge of electric field strength and practical skills to present plausible approaches. On occasions, the experimental methods showed poor appreciation of some basic ideas. Some candidates were charging the foil using large current that allegedly would cause heating issues for the foil, while others decided to use *Q* = *It*, ammeter and a stopwatch to determine the charge on the foil – failing to appreciate that the time constant will be too small for such a technique. However, on this occasion, such over ambitious techniques were generally overlooked by examiners. As with **16d**, a holistic approach to marking was used, with marks given according answers matching the descriptors for the various levels. There is no one perfect answer for this question, examiners were expecting an eclectic approach. The key things examiners were looking for were: - Methods for determining electric field strength *E*. - Using the right instruments for the measurements. - Plotting the correct graph to show the relationship given in the question was valid. - Correctly identifying the variables that were being controlled (kept constant). Access to higher level marks dependent on fully answering the question – and this included the last statement about control of variables. A significant number of candidates focused on the description and analysis of the data, without ever addressing the last sentence of the question. This question did discriminate well, with L1, L2 and L3 marks roughly distributed in the ratio 1:3:4.
			Total	**6**	
35		i	acceptable pattern with lines touching but not entering spheres	B1	adequate drawing for 1 mark
		i	lines perpendicular to spheres and arrows from plus ion to minus ion	B1	award second mark for detail/quality
		ii	$E = kQ/r^2$ where $k = 1/4\pi\varepsilon_0$	C1	correct formula with Q = e
		ii	$E = 9 \times 10^9 \times 1.6 \times 10^{-19}/6.25 \times 10^{-20}$	C1	correct substitution
		ii	$E = 2.3 \times 10^{10}$	C1	evaluation

		ii	$2E = 4.6 \times 10^{10}$ (N C^{-1})	A1	fields of charges add, **allow ecf** for E
			Total	**6**	
36	a	i	(force =) $\frac{(1.6 \times 10^{-19})^2}{4\pi\epsilon_0 \times (1.0 \times 10^{-15})^2}$ (F =) 230 (N) $F^2 = 230^2 + 230^2 - 2 \times 230 \times 230 \times \cos 120°$ **or** $F = 2 \times 230\cos 30°$ F = 400 (N)	C1 C1 C1	**Special case:** $F = \frac{Qq}{4\pi\epsilon_0 r^2} = \frac{2 \times 1.6 \times 10^{-19}}{4\pi\epsilon_0 \times (1.0 \times 10^{-15})^2}$ loses this C1 mark, then ECF for the rest of the marks **Not** the first two C1 marks for incorrect charge, then allow ECF for the final C1A1 marks **Note** force to 4 SF is 230.2 N **Allow** sine rule / scale drawing **Allow** this mark for 230cos30° **or** 200 (N) **Allow** ± 10 (N) if scale drawing used
		ii	F / arrow vertical up the page	B1	**Allow** correct arrow direction anywhere on the figure
		iii	Strong (nuclear) force (acts on the protons) The strong (nuclear) force is attractive	B1 B1	**Ignore** gravitational force **Allow** pulls / holds (the protons) / binds (the protons) for 'attractive'
	b	i	$12\,000 = \frac{Q}{4\pi\varepsilon_0 r}$ $12\,000 = \frac{Q}{4\pi\varepsilon_0 \times 0.19}$ $Q = 2.5(4) \times 10^{-7}$ (C)	C1 C1 A0	**Allow** $E = (V / d =)\ 6.316 \times 10^4$ **C1** and $E = 6.316 \times 10^4 = \frac{Q}{4\pi\varepsilon_0 \times 0.19^2}$ **C1**
		ii	**1** $t = 78 \times 3600$ $(I =) \frac{2.5 \times 10^{-7}}{78 \times 3600}$ $I = 8.9 \times 10^{-13}$ (A) **2** $(R =) \frac{6000}{9.0 \times 10^{-13}}$ **or** 6.7×10^{15} (Ω) **or** $V = IR$ and $R = \frac{\rho L}{A}$ $\frac{6000}{9.0 \times 10^{-13}} = \frac{\rho \times 0.38}{1.1 \times 10^{-4}}$ $\rho = 1.9 \times 10^{12}$ (Ω m)	C1 C1 A0 C1 C1 A1	There is no ECF from **(b)(i)** **Note** 2.54×10^{-7} gives an answer 9.0×10^{-13} A There is no ECF from **(b)(ii)1** **Take** 12000 V as **TE** for this C1 mark, then ECF **Note** 8.9×10^{-13} (A) gives an answer 2.0×10^{12} (Ω m)
			Total	**14**	
37		i	Proton is repelled (by nucleus) (High-speed) proton can get close to (oxygen) nucleus	**B1** **B1**	**Allow** 'proton can experience the strong (nuclear) force' **Not** 'collide / hit nucleus'
		ii	$E = [0.25 - (2.24 - 2.20)] \times 10^{-11}$ (J) **or** 0.21×10^{-11} (J)	**C1**	

			$\lambda = \dfrac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{0.21 \times 10^{-11}}$ (Any subject) $\lambda = 9.5 \times 10^{-14}$ (m)	**C1** **A1**	**Allow** 2 marks for 6.9×10^{-14}; $E = 0.29 \times 10^{-11}$ used **Allow** 1 mark for a value correctly calculated based on any other incorrect value for E (e.g. 8(.0) × 10^{-14} for $E = 0.25 \times 10^{-11}$ and 5(.0) × 10^{-13} for $E = 0.04 \times 10^{-11}$)
		ii i	Used in PET (scans) Any **one** from: Used to diagnose function of organ / brain / body Detection of cancer / tumour Non-invasive / no surgery / no infection 3D (image)	**M1** **A1**	Enter text here.
			Total	**7**	
3 8		i	22.1 ± 0.9	B1	value plus uncertainty both required for the mark allow ± 1.0
		ii	two points plotted correctly, including error bars;	B1	**ecf** value and error bar of first point
		ii	line of best fit worst acceptable straight line.	B1	**allow ecf** from points plotted incorrectly steepest or shallowest possible line that passes through all the error bars; should pass from top of top error bar to bottom of bottom error bar **or** bottom of top error bar to top of bottom error bar
		ii	gradient (= 4d / E) = 2.4 ± 0.4;	B1	**allow** 2.4 ± 0.5
		ii	$E = 4 \times 2.0 \times 10^{-2} / 2.4 \times 10^{-6} = 3.3 \times 10^{4}$	B1	
		ii	(3.3) ± 0.6 × 10^{4}	B1	0.1/4 + 0.4/2.4 = 0.192 × 3.3 = 0.63
		ii	V m^{-1} or N C^{-1}	B1	0.1/4 + 0.5/2.4 = 0.233 × 3.3 = 0.77 **allow** 3.3 ± 0.8 × 10^{4}
			Total	**7**	