Question	Answer	Marks	Guidance
1 (a) (i)	The electric field strength at a point is the force per unit charge... acting on a small positive test charge placed at the point.	1 1	Because direction matters, this must be defined for a positive test charge. One coulomb is a very large amount of charge, and a test charge of 1 C would completely distort any field in which it was placed. The definition is therefore per unit charge on a small positive test charge.
1 (a) (ii)	E is a vector quantity.	1	
1 (b) (i)	$F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$ $= \frac{(4.0\times10^{-9})\times(-8.0\times10^{-9})}{4\pi\times8.85\times10^{-12}\times(80\times10^{-3})^2}$ $= (-)4.50\times10^{-5}$ N	1 1	Coulomb's law gives an equation for the force between point charges. A negative sign in the answer indicates that the force is an attraction. This question only requires you to find the magnitude of the force; therefore the sign does not matter.
1 (b) (ii)	Let x be the distance from the + 4.0 nC charge to the point where $V = 0$ use of $V = \frac{Q}{4\pi\varepsilon_0 r}$ gives $0 = \left(\frac{4.0\times10^{-9}}{4\pi\varepsilon_0 x}\right) + \left(\frac{-8.0\times10^{-9}}{4\pi\varepsilon_0 (80\times10^{-3} - x)}\right)$ giving x = 26.7 mm or 27 mm	1 1	So far this question has been about field strength. In part (b)(ii) it now switches to potential. The sum of the potentials due to each charge must be zero. If you spotted that $V \propto \frac{Q}{r}$, you could move quickly to $\frac{4}{x} = \frac{8}{(80-x)}$ and $x = \frac{80}{3}$ = 26.7 mm.
1 (c)	*Diagram drawn to show:* • Two lines with arrows at P, one representing E_4 directed outwards away from the 4 nC charge and the other representing E_8 directed inwards towards the 8 nC charge. • E_8 twice as long as E_4. • Arrowed line R, the correct resultant of the parallelogram, drawn through the common point of E_8 and E_4.	3	If the two charges were equal in magnitude but opposite in sign the resultant electric field at P would be directed horizontally to the right. Since one charge is twice the other, the resultant is directed slightly upwards and towards the right. If the two charges were equal in both magnitude and sign, the resultant field at P would be directed vertically on the diagram.
2 (a)	Let T be the tension in the thread and resolve vertically: $T \cos 6° = mg$ resolve horizontally: $T \sin 6° = F$ Dividing these equations gives $\frac{F}{mg} = \frac{\sin 6°}{\cos 6°} = \tan 6°$ ∴ $F = mg \tan 6°$	3	Alternatively, F can be determined by drawing a closed right-angled vector triangle, in which mg acts vertically downwards, F acts horizontally to the right, and T acts along the thread at 6° to the vertical. From the sides of this triangle, $\frac{F}{mg} = \tan 6°$
2 (b) (i)	Electric field strength $E = \frac{V}{d} = \frac{4200}{60\times10^{-3}} = 7.0\times10^4$ V m^{-1} (or N C^{-1})	1	The electric field between parallel plates is uniform, allowing the equation $E = \frac{V}{d}$ to be used. The unit of E could be expressed as N C^{-1}, which is equivalent to V m^{-1}.

Question	Answer	Marks	Guidance
2 (b) (ii)	Using $E = \frac{F}{Q}$, charge on sphere $Q = \frac{F}{E} = \frac{mg\tan 6°}{E}$ $= \frac{2.1\times10^{-4}\times9.81\times\tan 6°}{7.0\times10^{4}}$ $= 3.09 \times 10^{-9}$ C	1 1	The equation $E = \frac{F}{Q}$ follows from the definition of E as the force per unit charge. When rearranged, this equation becomes $F = EQ$, which is the electric counterpart of the gravitational force equation $F = mg$.
3 (a) (i)	Electric potential is taken to be zero at infinity. A positive test charge would gain potential energy as it was moved away from the negative charge and towards infinity.	1 1	Gravitational potential is always negative, because gravitational forces are always attractive. Electric potential is defined in terms of the work done on a small positive test charge. Positive and negative charges always attract, like gravity, causing the electric potential to be negative near a negative charge.
3 (a) (ii)	Three radial straight lines drawn so that they all end on the charge at Q. Arrows marked on all of the lines, pointing inwards to Q.	1 1	A point charge produces a radial electric field. The direction of the field at a point is the direction of the force that acts on a positive charge placed at the point.
3 (b) (i)	On the diagram, which is full size, $V = -10$ V when $r = 38$ mm Use of $V = -\frac{Q}{4\pi\varepsilon_0 r}$ gives $-10 = \frac{Q}{4\pi\varepsilon_0\times38\times10^{-3}}$ $\therefore Q = -4.23 \times 10^{-11}$ C (other circles may give a slightly different, although still acceptable, value for Q) $\therefore$ the charge Q is about -4.5×10^{-11} C	1 1	Four values of potential are marked on the diagram. The corresponding radius could be measured for any of the four, but the circle with the largest radius will give the most accurate value for r. Measurement shows that the diameter of the largest circle is 76 mm; hence r = 38 mm. Any value for Q consistent with the corresponding value of r would be accepted for the second mark.
3 (b) (ii)	$E = \frac{Q}{4\pi\varepsilon_0 r^2} = \frac{4.23\times10^{-11}}{4\pi\varepsilon_0\times(38\times10^{-3})^2}$ $= 263$ V m^{-1} or 260 V m^{-1}	1 1	This calculation should make use of the values of r and Q that were obtained in part (b)(i). Answers which were consistent with these values would be accepted.
3 (c) (i)	pd $\Delta V = -10 - (-40) = 30$ V Energy transferred = $Q\Delta V$ $= 1.60 \times 10^{-19} \times 30 = 4.80 \times 10^{-18}$ J	1 1	In moving from A to B, the electron moves across a pd of 30 V, as is clear from the values of potential on the diagram.
3 (c) (ii)	Relevant points include: • The electron loses potential energy as it moves away from Q. • As it moves away its speed will increase. • Its de Broglie wavelength will decrease... • because its momentum will increase. • De Broglie wavelength = $\frac{h}{mv}$	Any 4	An electron has a negative charge and is repelled away from the negative charge Q. This repulsive force accelerates the electron, causing its kinetic energy to increase and its potential energy to decrease.

Question	Answer	Marks	Guidance
4 (a) (i)	Diagram drawn to show: • An arrow, horizontal to the right, representing v_H (or 20 m s^{-1}) and an arrow from the same point, vertically downwards, representing v_V. • An arrow from the same point, at 35° to the horizontal, along the diagonal of the parallelogram representing the resultant velocity v. From the diagram it will be seen that $\frac{v_V}{v_H} = \frac{v_V}{20} = \tan 35°$ ∴ v_V = 20 tan 35° = 14.0 m s^{-1} or 14 m s^{-1}	1 1 1 1	It may not be clear how to find the vertical component of the exit velocity until you have drawn the diagram. Simple trigonometry should then lead to an easy solution for v_V. Alternatively, the diagram can be a large scale drawing, with a horizontal vector of 20 m s^{-1}, a resultant velocity vector at 35° to it, and a vertical vector that is to be found. v_V can be determined from the scale drawing, but some tolerance would have to be allowed in the answer: (14.0 ± 0.2) m s^{-1}.
4 (a) (ii)	Time spent in field = $\frac{L}{v_H} = \frac{5.0\times10^4}{20}$ $= 2.5 \times 10^{-5}$ s Vertical acceleration = $\frac{v_V}{t} = \frac{14.0}{2.5\times10^{-5}}$ $= 5.6 \times 10^5$ m s^{-2}	1 1	At constant speed (horizontally), time = $\frac{\text{distance}}{\text{speed}}$ acceleration = $\frac{\text{change in velocity}}{\text{time}}$ and the ink droplet has no vertical velocity when it enters the field.
4 (a) (iii)	Force on droplet = ma $= 2.9 \times 10^{-10} \times 5.6 \times 10^5$ $= 1.62 \times 10^{-4}$ or 1.6×10^{-4} N	1 1	Since mass of the droplet is constant, $F = ma$ can be applied when finding the vertical force.
4 (a) (iv)	Electric field strength E $= \frac{F}{Q} = \frac{1.62\times10^4}{2\times10^{-10}}$ $= 8.1 \times 10^5$ V m^{-1} (or N C^{-1})	1 1	The vertical force (calculated above by mechanics theory) is the electric force on the ink droplet. The charge Q is given at the start of the question.
4 (a) (v)	Pd between plates = $E \times d$ $= 8.1 \times 10^5 \times 1.0 \times 10^{-3}$ = 810 V	1 1	The field is uniform between the parallel plates; field strength of a uniform field $E = \frac{V}{d}$
4 (b)	To arrive at the paper, the droplet travels a further 1.0 mm at 20 m s^{-1} Time taken for this = 5.0×10^{-5} s Distance fallen under gravity = $\frac{1}{2}gt^2$ $= \frac{1}{2} \times 9.81 \times (5.0 \times 10^{-5})^2 = 1.2 \times 10^{-8}$ m ∴ the distance fallen under gravity is insignificant	1 1 1 1	The distance from the plates to the paper is taken from the diagram as 2 × 0.5 mm. The droplets continue to move horizontally over this distance at 20 m s^{-1}. The final stage of the calculation uses $s = ut + \frac{1}{2}at^2$ from AS Physics.

Question	Answer	Marks	Guidance
5 (a) (i)	At the surface of the sphere $E = \frac{Q}{4\pi\varepsilon_0 R^2}$ and $V = \frac{Q}{4\pi\varepsilon_0 R}$ hence $\frac{E}{V} = \frac{Q}{4\pi\varepsilon_0 R^2} \div \frac{Q}{4\pi\varepsilon_0 R} = \frac{1}{R}$ $\therefore E = \frac{V}{R}$	1 1	The equations quoted for E and V apply in a radial field. A charged sphere produces the same shape of field as a point charge: it is a field radiating outwards from the centre of the sphere (if the charge is positive). Answers that make use of $E = \frac{V}{d}$ would not be acceptable, because this equation applies only to a uniform field. Note also that you are required to answer in terms of radius R, and not r.
5 (a) (ii)	$3.3\ \text{kV mm}^{-1} = \frac{3.3\times10^3\ \text{V}}{1.0\times10^{-3}\ \text{m}}$ $= 3.3 \times 10^6\ \text{V m}^{-1}$ Using the previous result, $V = ER$ $= 3.3 \times 10^6 \times 0.20$ $= 6.6 \times 10^5$ V (660 kV)	1 1 1	The question quotes the breakdown field strength of dry air in kV mm^{-1}. The first task is to change this to the fundamental unit of V m^{-1} (it would be 33000 V cm^{-1}). The potential which a sphere can reach is proportional to its radius. The larger the dome of a Van de Graaf generator, the better. Damp air has a much lower breakdown field strength; this is what usually limits the potential at which school and college Van de Graaff generators can operate.
5 (b) (i)	Peak potential $V_0 = \sqrt{2} \times V_{rms}$ $= \sqrt{2} \times 100 = 141$ kV or 140 kV	1	The relationship between ac peak and rms values was covered in AS Physics.
5 (b) (ii)	Minimum radius of sphere is given by $R = \frac{V}{E} = \frac{141\times10^3}{3.3\times10^6} = 4.29 \times 10^{-2}$ m $\therefore$ minimum diameter of sphere = 8.57×10^{-2} m or 86 mm	1 1	The sphere is required to be on the point of discharging into the air when the peak potential is applied to it. Remember to double the radius of the sphere, because the question asks for its diameter.
6 (a) (i)	Lines drawn on Figure 1: • Six or more straight, radial field lines which would pass through the centre of the sphere ... • with arrows pointing away from charge.	2	Ideally these lines should be spaced equally, because the field strength is of constant value at a particular radius, e.g. six lines drawn at 60° to each other.
6 (a) (ii)	Lines drawn on Figure 2: • Two circles outside the sphere − centred on + ... • of radii 2R and 4R, where R is the radius of the sphere	2	It would be best to use a compass. $V \propto \frac{1}{R}$, so the potential is halved when the radius is doubled, and so on.
6 (a) (iii)	ε_0 is the permittivity of free space.	1	If your memory fails you the Data Booklet reveals this name.
6 (b) (i)	Nylon is used for the thread because it is a good insulator.	1	The sphere must not lose charge during the experiment
6 (b) (ii)	Use of $mg = k\Delta L$ gives extension $\Delta L = \frac{mg}{k} = \frac{1.5\times10^{-3}\times9.81}{0.18}$ $= 8.18 \times 10^{-2}$ m or 8.2×10^{-2} m	1 1	This part revises the Hooke's law equation, as applied to the weak spring.

Question	Answer	Marks	Guidance
6 (b) (iii)	Electric field strength $E = \frac{V}{d} = \frac{8.0\times10^3}{30\times10^{-3}}$ $= 2.67 \times 10^5$ V m^{-1} (or N C^{-1}) or 2.7×10^5 V m^{-1}	1 1	The electric field will be uniform between the parallel plates, so $E = \frac{V}{d}$ can be applied.
6 (b) (iv)	$F = k\Delta L = 0.18 \times 4.5 \times 10^{-3}$ $= 8.1 \times 10^{-4}$ N $F = EQ$ gives charge $Q = \frac{F}{E} = \frac{8.1\times10^{-4}}{2.67\times10^5}$ $= 3.04 \times 10^{-9}$ C or 3.0×10^{-9} C	1 1 1	The electric field is directed downwards (from the positive upper plate to the negative lower one). This field produces an additional downwards force on the positively charged sphere, causing a further extension of the spring.
6 (c) (i)	Use of $T = 2\pi\sqrt{\frac{m}{k}}$ gives period $T = 2\pi\sqrt{\frac{1.5\times10^{-3}}{0.18}}$ $= 0.574$ s or 0.57 s	1 1 1	
6 (c) (ii)	Graph drawn to show: • Axes labelled 'amplitude' (vertically) and 'time' (horizontally) with the amplitude shown decreasing with time. • The correct shape (amplitude decreasing exponentially).	2	This is not intended to be a displacement–time graph for damped simple harmonic motion (which you might be tempted to draw).
7 (a) (i)	At **B**, field strength $E = 21$ N C^{-1} (or V m^{-1}) Line drawn on graph: • Starts at (6.4, 84) and is a curve of decreasing gradient ... • passes through (12.8, 21) and does not meet or intersect r axis	1 2	The electrical field around by a charged sphere is radial, identical to that around a point charge of the same magnitude as the charge on the sphere. The field strength E $\propto \frac{1}{r^2}$ in a radial field; when r is doubled (from 6.4 to 12.8×10^3 km) E decreases by a factor of 4.
7 (a) (ii)	The pd between A and B can be found from the graph by determining the area enclosed between the line and the r axis between $r = 6.4$ and 12.8×10^3 km	1	The area under a force–distance graph represents work done. E is equal to the force acting per unit charge. Therefore the area under a graph of E against r represents work done per unit charge, which is potential difference.
7 (b) (i)	From the graph, $E = 84$ N C^{-1} when $r =$ 6400 km, $E = \frac{Q}{4\pi\varepsilon_0 R^2}$ gives $Q = 4\pi\varepsilon_0 R^2 E$ $= 4\pi \times 8.85 \times 10^{-12} \times (6.4 \times 10^6)^2 \times 84$ $\therefore$ charge on the Earth $Q = 3.83 \times 10^5$ C	1 1	The equation giving the electric field strength in a radial field can be applied at the surface radius of a charge-carrying sphere. The value of E at the surface of the Earth is given by the marked point on the graph in the question.
7 (b) (ii)	Surface area of the Earth $= 4\pi R^2 = 4\pi \times (6.4 \times 10^6)^2$ $= 5.15 \times 10^{14}$ m^2 Charge per unit area of surface $= \frac{Q}{4\pi R^2} = \frac{3.83\times10^5}{5.15\times10^{14}}$ $= 7.44 \times 10^{-10}$ C m^{-2} or 7.4×10^{-10} C m^{-2}	1 1	The equation for the surface area of a sphere is listed in the Data Booklet. Since the question asks for the charge per square metre, either C m^{-2} or C would be acceptable as the unit in the final answer