2	**The only correct answer is D** (The inverse of the gradient of the line) A is not correct because this is energy B is not correct because this is energy C is not correct because this is the inverse of capacitance		1

7	**D is the correct answer,** as each capacitor stores a charge Q		1

6	**D is the only correct answer** because $t = \frac{-t}{\ln\left(\frac{V}{V_0}\right)}$ A is not correct because it is not $\frac{-t}{\ln\left(\frac{V}{V_0}\right)}$ B is not correct because it is not $\frac{-t}{\ln\left(\frac{V}{V_0}\right)}$ C is not correct because it is not $\frac{-t}{\ln\left(\frac{V}{V_0}\right)}$		1

5	**A is the correct answer,** as the electric field between parallel plates is uniform		1

3	**The only correct answer is B** $\left(\frac{8.99 \times 10^{9} \times (8.0 \times 10^{-6})^{2}}{0.020^{2}}\right)$ A is not correct because distance is not squared, and charge is not squared C is not correct because distance is not squared D is not correct because charge is not squared		1

9	**D is the correct answer** because $Q = Q_o e^{-\frac{t}{RC}}$ and RC = 5 s		1

3	**The only correct answer is A** $\left(\sqrt{\frac{1.6 \times 10^{-19}}{4\pi \times 8.85 \times 10^{-12} \times 0.77}}\right)$ B is not correct because the charge is squared C is not correct because quantity is not rooted D is not correct because the quantity is not rooted, and the charge is squared		1

9	**The only correct answer is B** (The area under the graph from 0.5 m to infinity.) A is not correct because area under the graph is incorrect C is not correct because the gradient does not give electric potential D is not correct because E at 0.5m divided by 0.5m does not give electric potential		1

17(a)	At least 4 radial straight lines, from surface of sphere Equal spacing Arrows outward	(1) (1) (1)	 3
17(b)(i)	Use of $V = \frac{Q}{4\pi\varepsilon_0 r}$ $Q = 1.1 \times 10^{-8}$ (C) <u>Example of calculation</u> $5000\ \text{V} = 8.99 \times 10^{9}\ \text{Nm}^{2}\text{C}^{-2} \times \frac{Q}{0.02\ \text{m}}$ $Q = 1.1 \times 10^{-8}$ C	(1) (1)	 2

17(b)(ii)	Use of $E = V/d$ Use of $F = EQ$ $F = 5.2 \times 10^{-4}$ N (e.c.f from (b)(i)) <u>Example of calculation</u> $E = 5000 \text{ V} \div 0.105 \text{ m} = 47\,600 \text{ V m}^{-1}$ $F = 47\,600 \text{ V m}^{-1} \times 1.1 \times 10^{-8}$ C $F = 5.24 \times 10^{-4}$ N	(1) (1) (1)	 **3**

17(b)(iii)	Use of $W = mg$ Use of suitable trigonometry, such as $\tan\theta = F/W$ $\theta = 1.1(°)$ (e.c.f from (b)(i) and (b)(ii)) <u>Example of calculation</u> $W = 0.0027 \text{ kg} \times 9.81 \text{ N kg}^{-1} = 0.0265$ N $\tan\theta = 5.24 \times 10^{-4} \text{ N}/0.0265 \text{ N} = 0.0198$ $\theta = 1.13°$	(1) (1) (1)	 **3**

17(c)	Use of $F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$ with $Q_1 = Q_2 = 1.2 \times 10^{-8}$ C $r = 0.051$ m <u>Example of calculation</u> 5.0×10^{-4} N $= \frac{8.99 \times 10^{9} \text{ Nm}^2\text{C}^{-2} \times 1.2 \times 10^{-8} \text{ C} \times 1.2 \times 10^{-8} \text{ C}}{r^2}$ $r = 0.051$ m	(1) (1) (1)	 **3**

20(a)	Use of $C = 4\pi\varepsilon_0 r$ Use of $Q = CV$ Use of $E = \frac{V}{d}$ Use of $F = EQ$ $F = 1.6 \times 10^{-3}$ N <u>Example of calculation</u> $C = 4\pi \times 8.85 \times 10^{-12} \text{ F m}^{-1} \times 3.5 \times 10^{-2} \text{ m} = 3.89 \times 10^{-12}$ F $Q = 3.89 \times 10^{-12} \text{F} \times 4500 \text{ V} = 1.75 \times 10^{-8}$ C $E = \frac{4500 \text{ V}}{5.0 \times 10^{-2} \text{ m}} = 9.0 \times 10^{4} \text{ V m}^{-1}$ $F = 9.0 \times 10^{4} \text{ N C}^{-1} \times 1.75 \times 10^{-8} \text{ C} = 1.58 \times 10^{-3}$ N	(1) (1) (1) (1) (1)	 **5**

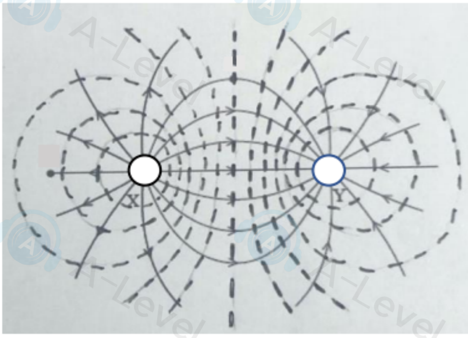
20(b)	When the sphere touches the plate it is charged with the same polarity The force on the sphere due to the electric field is away from that plate so it moves towards the opposite plate **Or** the sphere is repelled from the plate with the charge of the same sign **Or** the sphere is attracted towards the plate with opposite charge When the sphere touches the charged plate opposite the first it becomes oppositely charged and is repelled from that charged plate (and so on) **Or** When the sphere touches the oppositely charged plate it becomes oppositely charged and is attracted to the first plate (and so on)	**(1)** **(1)** **(1)**	**3**

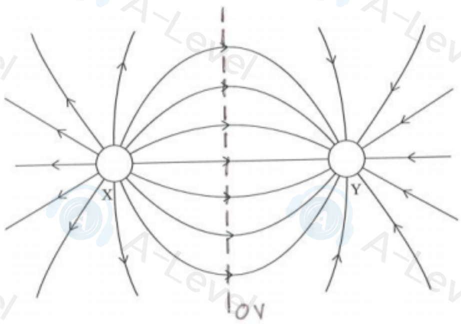
20(c)	(The bell connected to the lightning conductor becomes positively charged so) electrons are attracted to the right-hand side of the sphere The sphere is attracted to the positively charged bell [MP2 dependent on award of MP1]	**(1)** **(1)**	**2**

18(a)(i)	Corresponding pair of values read from graph line Substitution into $V = V_0\left(1 - e^{-\frac{t}{RC}}\right)$ … … with $V_0 = 6.0$ V $C = 2.2 \times 10^{-4}$ F (220 μF) (Allow answers in the range 2.1×10^{-4} to 2.3×10^{-4} F) MP4 dependent on MP3 **OR** Read time for $V_0\left(1 - \frac{1}{e}\right)$ or 63 % × V_0 from graph, Use of time constant = RC … with $V_0 = 6.0$ V $C = 2.2 \times 10^{-4}$ F (220 μF) MP4 dependent on MP3 (Allow answers in the range 2.1×10^{-4} to 2.3×10^{-4} F) MP4 dependent on MP3 Example of calculation $V = V_0\left(1 - e^{-\frac{t}{RC}}\right)$ $5.1\text{ V} = 6.0\text{ V}\left(1 - e^{-\frac{70\text{ s}}{168 \times 10^3\,\Omega \times C}}\right)$ $\frac{5.1\text{ V}}{6.0\text{ V}} = 1 - e^{-\frac{70\text{ s}}{168 \times 10^3\,\Omega \times C}}$ $e^{-\frac{70\text{ s}}{168 \times 10^3\,\Omega \times C}} = 1 - 0.85$ $\frac{70\text{ s}}{168 \times 10^3\,\Omega \times C} = 1.90$ $C = \frac{70\text{ s}}{168 \times 10^3\,\Omega \times 1.90} = 2.19 \times 10^{-4}$ F	**(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)**	**4**

18(a)(ii)	Use of $I = \frac{V}{R}$ $I = 3.6 \times 10^{-5}$ A and marked on current axis at time $t = 0$ Exponential decreasing curve <u>Example of calculation</u> $I = \dfrac{6.0\text{ V}}{168 \times 10^{3}\ \Omega} = 3.57 \times 10^{-5}$ A	**(1)** **(1)** **(1)**	**3**

18(b)	Resistance in circuit would decrease So current in circuit would increase **Or** so time constant will decrease **Or** so T = RC will decrease (Hence) capacitor would charge more quickly MP2 dependent on MP1, MP3 dependent on MP2	**(1)** **(1)** **(1)**	**3**

17(a)(i)	Central straight line equidistant from spacecraft and satellite **and** at least one of the diverging lines between spacecraft and the central line **and** at least one of the diverging lines between the central line and satellite At least one line looping spacecraft **and** one line looping satellite Line spacing between spacecraft and satellite smaller than line spacing to the left of spacecraft **and** to the right of satellite <u>Example of diagram</u> 	**(1)** **(1)** **(1)**	**3**

17(a)(ii)	Straight line equidistant from spacecraft and satellite and labelled 0 V. <u>Example of diagram</u> 	**(1)**	**1**

17(b)(i)	Use of $V = Q / 4\pi\varepsilon_0 r$ **Or** Use of $V = kQ / r$	**(1)**	
	Use of $W = QV$	**(1)**	
	Minimum energy = 1.7×10^{-15} (J)	**(1)**	**3**
	Example of calculation $V_{spacecraft}$ (= $V_{satellite}$) = 1.5×10^{-6} C / $4 \times \pi \times 8.85 \times 10^{-12}$ F m^{-1} $\times$ 2.5 m = 5400 V $W = 2 \times 5400$ V $\times 1.6 \times 10^{-19}$ J = 1.7×10^{-15} J		

17(b)(ii)	Use of $F = Q_1 Q_2 / 4\pi\varepsilon_0 r^2$ **Or** Use of $F = k\,Q_1 Q_2 / r^2$	**(1)**	
	Use of $F = ma$ **Or** Use of $Fs = ½\,mv^2$	**(1)**	
	Use of suitable *suvat* equation(s), e.g. $s = ut + ½\,at^2$	**(1)**	
	Correct value for s (270 km) or t (62.5 days), comparison and consistent conclusion	**(1)**	**4**
	Example of calculation $F = 1.5 \times 10^{-6}$ C $\times 1.5 \times 10^{-6}$ C / $4 \times \pi \times 8.85 \times 10^{-12}$ F m^{-1} $\times$ (20 m)^2 = 5.1×10^{-5} N $a = 5.1 \times 10^{-5}$ N / 2500 kg = 2.0×10^{-8} m s^{-2} 300 000 m = ½ $\times 2.0 \times 10^{-8}$ m s^{-2} $\times t^2$ $t = 5.4 \times 10^6$ s $t = 5.4 \times 10^6$ s / (24 × 60 × 60 s) t = 62.5 days is approximately 60 days, so the estimate is correct		

17(c)	A reasonable suggestion, such as • Some of the electrons / beam misses • Some of the electrons are deflected • The spacecraft is already charged from use on a previous satellite • The spacecraft emits further electrons in another direction as a fine control on the electrostatic force • UV (from Sun) leads to photoelectric emission	**(1)** **(1)** **(1)** **(1)** **(1)**	**1**