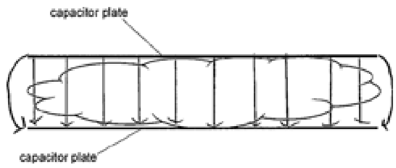
Mark scheme

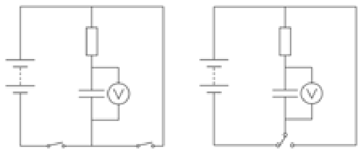
Question			Answer/Indicative content	Marks	Guidance
1			$x = x_0 e^{-t/RC}$ or $\frac{x_o}{2} = x_0 e^{-T/RC}$ **and** (total) resistance = *NR* and (total) capacitance = *NC* $\frac{1}{2} = e^{-\frac{T}{NR \times NC}}$ with clear steps leading to $T=(\ln 2)N^2RC$	M1 A1	**Allow** $x=x_0e^{-T/RC}$ **Allow** any letter for *x* except *N* **Allow** τ for *RC* **Not** $x=x_0(1-e^{-t/RC})$ **Not** $R_TC_T = N^2CR$ alone but **allow** $R_TC_T = NR \times NC$ Intermediate working must be shown in full e.g. $\ln½ = -\frac{T}{NR \times NC}$ so $\frac{T}{NR \times NC} = \ln 2$ **Do not allow** incorrect negative signs in working or in answer **<u>Examiner's Comments</u>** The initial step in this question is to use the equation $I = I_o e^{-t/RC}$ together with the fact that *N* resistors in series have a total resistance of *NR* and *N* capacitors in parallel have a total capacitance of *NC*. *T* is the time taken for I_o to fall to $I_o/2$ and so ½ = $e^{-T/NR.NC}$. Many candidates were able to navigate the tricky mathematics and were aware that ln(½) = -ln(2) It is important in this question to distinguish clearly between *t*, the general variable for time, and *T*, the time taken for I_o to fall to $I_o/2$. The statement ½ = $e^{-t/NR.NC}$ is not generally true; it is only true when *t* = *T*.
			Total	**2**	
2		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 **<u>Examiner's Comments</u>** 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)

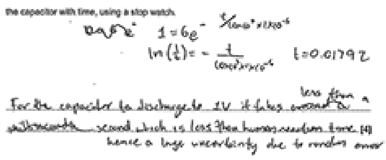
					Ignore unit **<u>Examiner's Comments</u>** Again, a 'show that' question needs the calculation to be clear. Here it will involve the multiplication of two quantities using the correct powers. For example, 32k is not a suitable alternative to 32 x 10^3. The value calculated is not the same as the 'show 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	$C = \left(\frac{\varepsilon_0 A}{d} = \right)\frac{8.85\times10^{-12}\times\pi\times(12\times10^3)^2}{3.2\times10^3}$ $C = 1.3 \times 10^{-6}$ (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) **<u>Examiner's Comments</u>** 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.
			Total	**8**	
3			B	1	**<u>Examiner's Comments</u>** Most candidates were able to correctly calculate the total capacitance, and many showed working to support a correct method. **A** was the most common distractor, being calculated as if the capacitors were resistors.
			Total	**1**	
4			D	1	**<u>Examiner's Comments</u>** Most candidates were able to correctly calculate the charge. Although not a difficult calculation, there are plenty of stages and potential for error at each. Most of the candidates filled in the table at each point which would be a helpful way of keeping on track of the charge.

			Total	**1**	
5	a	i	($W = \frac{1}{2} C V^2$ so) $400 \times 10^6 = 0.5 \times C \times (24 \times 10^3)^2$ **C = 1.4 (F)**	C1 A1	**Allow** $W = \frac{1}{2} Q V$ **and** $C = Q / V$ ($Q = 3.3 \times 10^4$(C) so) $C = Q / V = 3.3 \times 10^4 / 24 \times 10^3$ **<u>Examiner's Comments</u>** Most candidates seemed to find this quite straightforward and easily calculated the capacitance using $W = \frac{1}{2}CV^2$. A common error was using $W = QV$(then $C = Q/V$) instead of $W = \frac{1}{2}QV$. Some candidates clearly confused the use of *C* for capacitance with C for Coulombs as they had calculated charge rather than capacitance.
		ii	(putting capacitors in parallel) increases the total capacitance **ORA**	B1	**Allow** $C_T = C_1 + C_2 + ...$ **or** capacitors add together (in parallel) **Ignore c**apacitors in parallel can store more charge/ energy **<u>Examiner's Comments</u>** A few candidates lost the mark here by discussing voltage/energy across capacitors in series versus parallel without linking this idea to capacitance.
	b		power ≈ $400 \times 10^6 / 10^{-3} = 4.0 \times 10^{11}$(W) power required is equivalent to output of ≈ 400 power stations **or** time taken for power station to release stored energy $= 400 \times 10^6 / 10^9 = 0.40$s 0.4s is (much) longer than 1 ms	M1 A1 (M1) (A1)	**Allow** ECF (a)(i) for incorrect POT in 400GW **Allow** this is <u>much</u> more than could be provided by one power station **or** 4.0×10^{11}(W) » 1GW **Ignore** comments about household supply **Allow** ECF (a)(i) for incorrect POT in 400GW **Allow** it would take more time / too long **<u>Examiner's Comments</u>** Candidates were expected to link the power output of a conventional power station (1GW) given at the start of the question to the power requirement of the fusion reactor (400 MJ in less than

					1 ms). Alternative approaches which received credit were finding the energy supplied by a conventional power station in 1 ms, or calculating the time required for a conventional power station to release 400 MJ. A common incorrect approach involved attempting to calculate the time constant of a capacitor. Many candidates disregarded the instruction to use a calculation in their response and thus were unable to earn any marks despite a good understanding of the problem.
			Total	**5**	
6	a		Circuit showing (6V) supply in series with a capacitor and resistor, with a voltmeter in parallel with the capacitor. Switch/switches allowing discharging of the capacitor through the resistor.	B1 B1	No labels required. **ALLOW** any suitable symbol for d.c. supply **ALLOW** this mark if resistor and capacitor in parallel if switch will allow the discharge Examples of correct circuit for both marks e.g.  **<u>Examiner's Comments</u>** Many candidates were able to correctly draw the supply, capacitor, and resistor in series with a voltmeter in parallel for a single mark. The position of a switch/switches to allow a discharge was less simple and many candidates had a single switch in series with their components. There are several ways to correctly draw

					this, and examiners allowed the use of double throw type switches as long as the idea was clear. Placing the capacitor and resistor in parallel with the supply may have allowed access to the second marking point as it would allow the discharge but not the charging. As always, clarity of the diagram makes it easier for examiners to understand. Several candidates appeared not to know the symbol for the capacitor and used a capital C in a circle. Less than one fifth of candidates were able to correctly draw the required diagram.
	b		Charge = $1.0 \times 10^{-6} \times 6.0$ = $\mathbf{6.0 \times 10^{-6}}$ (C)	A1	**ALLOW** correct answer to 1 significant figure **<u>Examiner's Comments</u>** The vast majority of candidates were able to calculate this correctly and the main reason for not awarding the mark tended to be from a power of ten error.
	c		(CR =) $1 \times 10^{-6} \times 10 \times 10^{3}$ CR / Time constant / τ= 0.010 (s) Time constant / $\tau$is time taken to fall to 1/e (37%) of initial value The time it takes to record the variation of pd / the capacitor to discharge is far less than (human) <u>reaction time</u> OR $V = V_0 e^{-\left(\frac{t}{CR}\right)}$ to give $0.6 = 6.0 e^{-\left(\frac{t}{1.0 \times 10^{-6} \times 10 \times 10^{3}}\right)}$ t = 0.023 (s) 0.6 is the voltage when it has fallen to 10% of the initial voltage The time it takes to record the variation of pd / for the capacitor to discharge is far less than human <u>reaction time</u>	C1 A1 B1 B1 (C1) (A1) (B1) (B1) (C1) (A1) (B1) (B1)	**ALLOW** POT error for capacitance if same as in (b) **ALLOW** 1sf **ALLOW** t for τ **NOT** fallen <u>by</u> 37% Substitution into exponential decay equation to fall to a value of V less than $0.9V_0$ (<5.4V). **ALLOW** calculation in log form e.g ln 0.6 = ln 6.0 - t/0.01 Justification/explanation for using a given voltage Substitution into exponential decay equation with a time less than 0.1s (t < 0.1s). **ALLOW** calculation in log form lnV = ln 6.0 - 0.02/0.01 Justification/explanation for using a

			OR $V = V_0 e^{-\left(\frac{t}{CR}\right)}$ to give $V = 6.0e^{-\left(\frac{0.02}{1.0\times10^{-6}\times10\times10^{3}}\right)}$ V = 0.81 V 0.02 s is a very short amount of time The time it takes to record the variation of pd / for the capacitor to discharge is far less than human <u>reaction time</u>		given time **<u>Examiner's Comments</u>** Candidates were credited with calculations that produced a time or voltage that showed the time for decay was rapid. There were many possible routes to an answer and candidates were credited with any method that would produce a correct solution. As the question also included an explanation, it was often necessary to justify candidates' values for further credit rather than simply determine a numerical answer. The calculations were, in general, completed well and a good number of candidates were able to score 2 or more marks. Explanations in terms of reaction time were quite rare and often a vague answer such as 'the time is short' or 'human error' was given. Many candidates also related it to the precision of the stopwatch rather than the limitations of their use due to human reaction time. Exemplar 2  In this response the candidate has chosen to determine the time taken to fall to 1 V. The calculation has been done correctly for the first 2 marks (although there is no unit, it is clear what *t* is). The third marking point has not been satisfied – a comment would be needed (however brief) on why 1 V was chosen. The final marking point is given for the idea that this is time is less than human reaction time.
	d		Use an oscilloscope / data logger with a voltmeter probe	B1	**ALLOW** connect a voltmeter to a datalogger **<u>Examiner's Comments</u>**

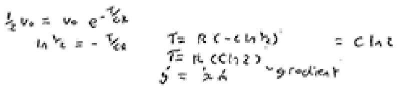
					While changing the value of the resistor or capacitor would increase the charging time, that would alter ‘this experiment’ and as such was not credited. In the context of this question, it is how the variation can be determined using the given values. Few candidates appreciated this, however there were significant numbers who knew that an oscilloscope could be used in place of the voltmeter.
	e	i	$V = V_0 e^{-(\frac{t}{CR})}$ to give $4.12 = 6.0\,e^{-(\frac{t}{1.0\times10^{-6}\times10\times10^{3}})}$ = **3.76 x 10^{-3}** (s)	C1 A1	**ALLOW** in terms of logs eg In 4.12 = In 6.0 $-\frac{t}{0.01}$ Correct to at least 2 significant figures **IGNORE** minus sign in final answer **<u>Examiner’s Comments</u>** Most candidates were able to calculate the correct time for the discharge, by taking substituting values into the logarithmic equation. Common errors included incorrect taking of logs by division rather than subtraction (depending on their original set-up) and power of ten errors or transcription errors in the values of *C* or *R*. As with many calculations, those who spent a little time setting out the working carefully were more likely to get the correct answer.
		ii	Change in energy = ½ CV_1^2 - ½ CV_2^2 = (½ x 1x10^{-6} x 6^2) – (½ x 1x10^{-6} x 4.12^2) = 9.5 x10^{-6} (J) rate = 9.5 x10^{-6} / 3.76 x 10^{-3} = **2.53 x 10^{-3}** (Js^{-1})	C1 C1 A1	**ALLOW** POT error from (e)(i) Ecf from (e)(i) Correct to at least 2 significant figures **<u>Examiner’s Comments</u>** Only around one third of candidates were able to correctly calculate this answer. By far the most common error was to calculate the change in energy using the difference in voltages (using 1.88 V) rather than calculating the separate energies and then

					subtracting. Several candidates left their answer at this point, rather than going on to divide by their value for the time.
			Total	**13**	
7	a		time taken for current (**or** charge **or** voltage) to fall to 1/e <u>of its initial value</u>	B1	**Not** capacitance **Not** to fall <u>by</u> (a factor of) 1/e **Allow** to decrease <u>to</u> 37% of its initial value **Allow** to decrease <u>by</u> 63% **Ignore** time constant = *CR* **<u>Examiner's Comments</u>** To find the time constant of a capacitor, we look at the time taken for the charge on a discharging capacitor to fall from any initial value to 37% (1/*e*) of that value. We could also take values of current or voltage. However, it is not the time taken for the <u>capacitance</u> to fall from C_o to C_o/e – the capacitance remains constant. Care is needed with wording here. Either the charge falls <u>to</u> 37% of its initial value, or it falls <u>by</u> 63% from its initial value. **Misconception** Capacitance × resistance is not the <u>definition</u> of the time constant; it is one way of calculating the time constant if the values of capacitance and resistance are known.
	b	i	f (= $1/T$) = 1 / (40 × 10^{-3}) f = 25 (Hz)	B1 B1	**Allow** $f = 1/T$ **and** $T = 40 \times 10^{-3}$ (s) **<u>Examiner's Comments</u>** It is important to show how the information from the graph has been used to calculate the frequency. The correct answer did not score full marks unless some working had been shown.
		ii	**EITHER** Calculation of Q_o / *e*	C1	**Allow** any initial value of charge e.g. 8.0 / e = 2.9 (μC) **or** 37% × 8.0 =

			time constant (read from graph) = 14 (ms) **OR** Use of $Q = Q_0 e^{-t/CR}$ time constant = 14 (ms)	A1 (C1) (A1)	3.0 (μC) **Allow** 14±1 (ms) e.g. $2.0 = 8.0e^{-0.02/CR}$ gives CR = 0.02 / ln4 Using the decay equation may incur two POT errors **Examiner's Comments** The question specifies using the discharging section of the graph. Some candidates tried to use the charging section, but this proved more difficult. Using the definition of the time constant, we need to find how long it takes for the charge to fall from any initial value to 37% (1/*e*) of that value. Many candidates chose 8μC for their initial value, but this is not vital. 37% of 8μC is 2.9μC. The charge is 8μC at 20ms and 2.9μC at 34ms, so the time taken is 34 − 20 = 14ms. A common alternative approach was to insert values from the graph into the equation $Q = Q_0 e^{-t/CR}$ This gave the same result, but sometimes resulted in a POT error because of the need to give the answer in milliseconds.
		iii	tangent drawn to graph <u>at steepest part of curve</u> maximum current in range 5.0×10^{-4} to 7.0×10^{-4} (A)	M1 A1	Judge by eye, no daylight between curve and tangent **Allow** a negative answer **Allow** answer to 1sf **Examiner's Comments** Many candidates lost marks here because they did not realise that, to calculate the *maximum* current in the resistor, they had to draw the steepest possible tangent to the graph.
		iv	vertical axis labelled as current with the correct unit **and** at least one positive and one negative	B1	For example *I* / mA, *I* (mA), *I* /10^{-4} A, current in mA etc All scale markings shown must be

			scale marking **and** scale should allow for their maximum current to be plotted		correct
			exponential decay of current in each section	M1	**Allow** any curve with a decreasing gradient in each section **Ignore** value of minimum current but **not** zero **Ignore** sign of current for this marking point
			sign of current alternates at 20, 40, 60 and 80 ms	A1	All curves should start at the correct maximum current value. However, If **B1** mark has not been scored, **allow** any value of maximum current as long as it remains consistent across all four sections **<u>Examiner's Comments</u>** Since $I = \Delta Q/\Delta t$, the graph of I against t can be found from the gradient of the graph of Q against t. The gradient is positive from 0 − 20 ms and negative from 20 − 40ms; this represents the current flowing one way around the circuit while the capacitor charges and then the opposite way while it discharges. Since the gradient is never zero, the value of the current is never zero either. **Tasks that caused problems in 6(b)(iv)** • drawing an exponential decay, particularly in the negative section of the graph (most drew a sinusoidal curve). • converting the maximum current into mA or μA. • labelling the vertical axis and drawing on a sensible scale. **Assessment for learning** Centres should consider providing more practice in drawing graphs without the aid of graph-plotting software.
			Total	**10**	

8	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 **<u>Examiner's Comments</u>** 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	<u>Work</u> done against <u>attractive</u> forces	B1	**Allow** WD for work done **<u>Examiner's Comments</u>** 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 $T = C\ln2 \times R$ compared with $y = mx$ with gradient = $C\ln2$	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 **<u>Examiner's Comments</u>** 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 *C*ln2, 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 ($\times 10^{-9}$) C = (gradient / ln2) = 7.8×10^{-9} (F) **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})	B1 B! B1 C1 A1	**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 ($\times 10^{-9}$) **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$\times 10^{-12}$) **<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**	