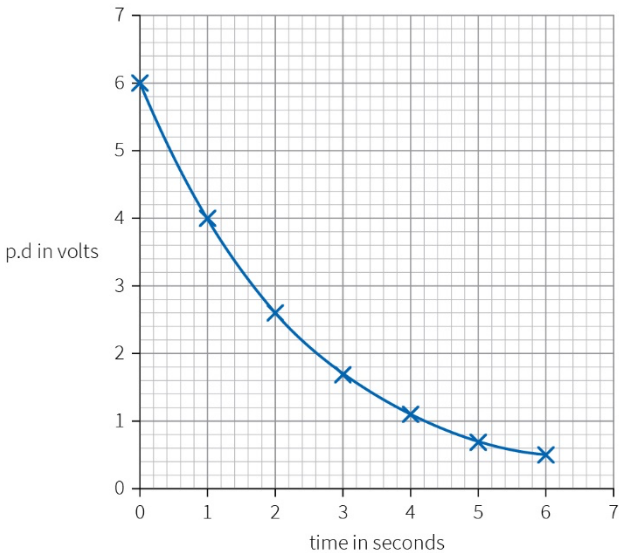
A Level OCR Physics

Chapter 20 Capacitors

Question	Answers	Extra information	Mark	AO	Spec reference
1 (a) (i)	$Q = CV = 470 \times 10^{-6} \times 6 = 2.82 \times 10^{-3}$ C $I = V/R = 6$ V/50 000 Ω $= 1.2 \times 10^{-3}$ A		1 1	2	6.1.1
(ii)	Time for p.d. to drop to half its value = $RC \ln 2 = 5000 \times 470 \times 10^{-6} \times 0.693 = 1.62$ s 	Graph with scales/labelled axes extending to 6 seconds Initial p.d. = 6 V and exponential shape by eye Evidence for p.d. halving in 1.6 s	1 1 1	2	6.1.3
(b)	Original time constant = $RC = 5000 \times 470 \times 10^{-6} = 2.35$ New time constant = $2.5 \times 2.35 = 5.88$ s Effective capacitance = $5.88/5000 = 1.12 \times 10^{-3}$ F Capacitances in parallel add so $C_{total} = C + 470 \times 10^{-6}$ F $= 1.12 \times 10^{-3}$ F $C = 0.7 \times 10^{-3}$ F = 700 μF	Calculation of new time constant/ method involving time constant Answer	1 1 1	3	6.1.3

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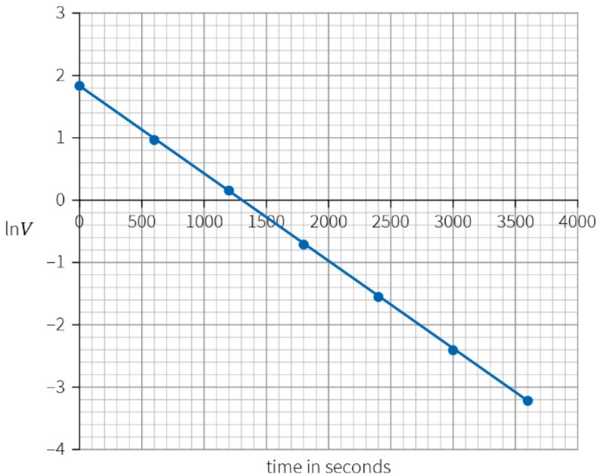
(c)	Assumption is that the voltmeter has infinite resistance If the voltmeter has a large but finite resistance this reduces the resistance of the circuit because there are now two resistances in parallel. The time constant will be smaller than it should be, so the unknown capacitance is larger than the value in **1(b)**	Effect of resistance of voltmeter on resistance of circuit Effect on capacitance	1 1	1 3	6.1.3
2 (a) (i)	From the graph, the time for the p.d. to halve is 1.4 cm = 1.4 × 0.1 ms = 1.4 × 10^{-4} s. Time to halve = RC ln2 = 0.693 RC Time constant = RC = time to halve/0.693 = 2.02×10^{-4} s	Use of graph to find time to halve Answer Accept use of time taken to drop to 1/e (2.21V) = 0.2ms	1 1	2	6.1.3
(ii)	C = time constant/R = 2.02×10^{-4} s/10^4 = 2.02×10^{-8} F	Use of time constant to find C Accept ecf from a)i)	1 1	2	6.1.3
(b)	Curve that starts at half the p.d. on the *y*-axis, and has $t_{½}$ that is double the original value If the resistance doubles the maximum current will halve, so the maximum p.d. will halve If the resistance is doubled the time constant is doubled, so the time to halve the p.d. is also doubled.		1 1 1	3	6.1.3
(c)	Use the p.d. and resistance to work out the current using $I = V/R$ The area under the graph is the charge stored, work out the charge represented by each square using $Q = It$, count squares and multiply	Conversion of p.d. to current How to find charge from area Accept find area under graph and divide by R for 2 marks	1 1	3	6.1.3
3 (a) (i)	When the switch is closed there is a potential difference across the resistor A current flows, so the charge on the capacitor decreases.	Link between p.d. and current	1	1	6.1.1

<table>
<tr><th>Question</th><th>Answers</th><th>Extra information</th><th>Mark</th><th>AO</th><th>Spec reference</th></tr>
<tr><td></td><td>As the charge decreases the p.d. decreases ($V = Q/C$), so the current decreases in the same way
The rate of change of p.d. depends on the charge, and hence p.d., so the relationship is a negative exponential</td><td>Link to charge on capacitor
Explanation of exponential</td><td>1
1</td><td></td><td></td></tr>
<tr><td>(ii)</td><td>
<table>
<tr><th>Time in minutes</th><th>P.d. in volts</th><th>Time in seconds</th><th>ln V</th></tr>
<tr><td>0</td><td>6.25</td><td>0</td><td>1.832581</td></tr>
<tr><td>10</td><td>2.6244</td><td>600</td><td>0.964852</td></tr>
<tr><td>20</td><td>1.1664</td><td>1200</td><td>0.153922</td></tr>
<tr><td>30</td><td>0.49</td><td>1800</td><td>−0.71335</td></tr>
<tr><td>40</td><td>0.2116</td><td>2400</td><td>−1.55306</td></tr>
<tr><td>50</td><td>0.09</td><td>3000</td><td>−2.40795</td></tr>
<tr><td>60</td><td>0.04</td><td>3600</td><td>−3.21888</td></tr>
</table>


</td><td>Calculations of t in seconds and ln V

Graph starting at (0,0), points plotted, linear line of best fit
Correct labels/units</td><td>1

1
1</td><td>2</td><td>6.1.3</td></tr>
</table>

Question	Answers	Extra information	Mark	AO	Spec reference
(iii)	$V = V_0 e^{\frac{-t}{RC}}$ $\ln V = \ln V_0 - \frac{t}{RC}$ So a graph of ln$V$ against t has - y-intercept = lnV_0 - gradient = $-1/RC$	Taking natural logs of both sides of equation y-intercept correct Gradient correct	1 1 1	2	6.1.3
(b)	For capacitors in series $1/C_{\text{total}} = 1/C_1 + 1/C_2$ If the capacitors have the same value the total capacitance is halved The time constant is halved so the gradient will be doubled The y-intercept is the same	Use of equation Effect on gradient Effect on intercept	1 1 1	3	6.1.1
4 (a)	$E = ½ CV^2$ $= ½ \times 330 \times 10^{-6} \times (12.0)^2$ $= 2.38\times10^{-2}$ J	Answer	1 1	2	6.1.2
(b)	Resistance of lamp = 12/0.8 = 15 Ω Time to discharge to 37% = RC = 330 × 10^{-6} × 15 = 4.95×10^{-3} s Approximately t = 5 ms × 4/3 = 6.7 ms Power = energy/time = 2.38×10^{-2} J/6.7×10^{-3} s = 3.57 W Or = 4.8 W if 5 ms used You may only just see this, as it is about half/one quarter the power the lamp used under normal conditions, where power = 12 V × 0.8 A = 9.6 W	Calculation of resistance Explicit use of RC as time for p.d. to reduce to 37% ecf from their time Answer Calculation of power Appropriate comment with numerical comparison	1 1 1 1 1	3	6.1.2
(c)	The energy stored would be multiplied by 4 as energy stored depends on V^2 The time is the same	Reference to E proportional to V^2	1	3	6.1.2

<table>
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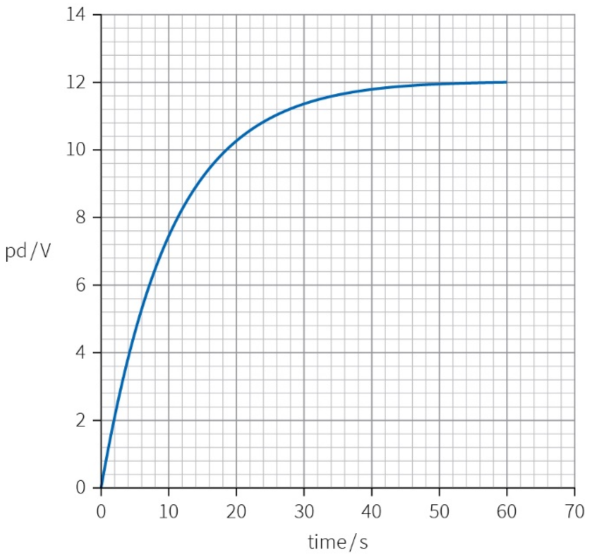
<tr><td></td><td>Power would be multiplied by 4, this would definitely be observable</td><td>Effect on what is observed</td><td>1</td><td></td><td></td></tr>
<tr><td>(d)</td><td>The energy stored is about $100/2.38\times10^{-2}$ J ~ 4 000 × the energy calculated
$E = ½\,CV^2$ so energy $\propto C$, and V^2
You would need to charge this capacitor to a p.d. of $12\,V \times \sqrt{4\,000}$ = 760 V
Or use a capacitance of 4000 × 330 μF = 1.32 F

1.39 F is a very large capacitor, so the energy stored is achieved by increasing the p.d. and increasing the capacitance.</td><td>Calculations that support increase in energy by a factor of approximately 4000
Both calculations
Precise calculation using $E = ½\,CV^2$ produces:
p.d. = 780 V
capacitance = 1.39 F

Comment on size of capacitance</td><td>1

1

1</td><td>3</td><td>6.1.2</td></tr>
<tr><td>5 (a) (i)</td><td>



Initially there is no charge on the capacitor, so zero p.d., as the capacitor charges the p.d. increases as $V = Q/C$</td><td>Exponential growth by eye
Asymptotic to 12 V

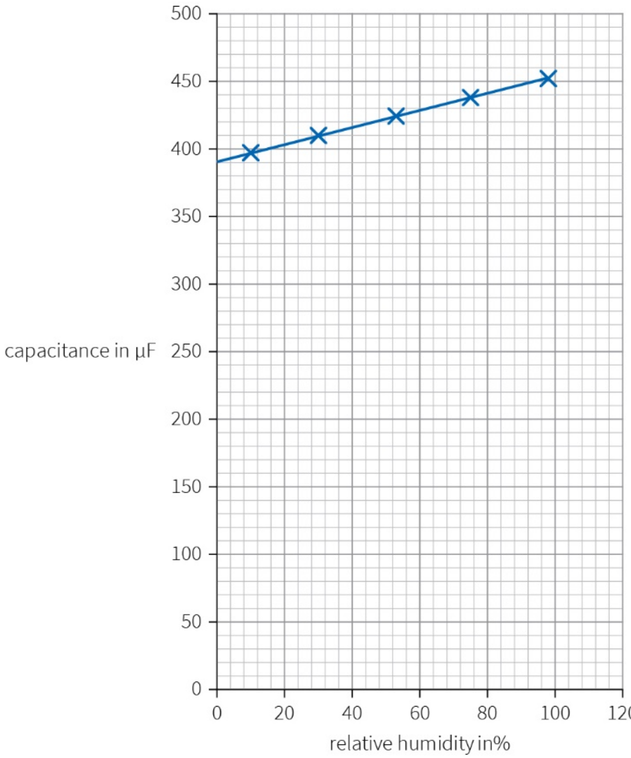
Only a sketch needed, so no values needed on x-axis

Correct description of V proportional to charge
Comment about shape</td><td>1

1

1</td><td>1</td><td>6.1.1</td></tr>
</table>

Question	Answers	Extra information	Mark	AO	Spec reference
	And increases at a decreasing rate				
(ii)	Reducing the resistance, as the current normally decreases as the capacitor charges a smaller resistance is needed to maintain the current at a constant value The graph will be a straight line through (0,0) as the p.d. increases at a constant rate The graph will be horizontal when the capacitor is fully charged	Answer and reason needed for mark	1 1 1	3	6.1.3
(iii)	Procedure described, for example: - note the capacitance of the capacitor - open the switch and short circuit the capacitor to ensure that it is uncharged - close the switch and reduce the resistance of the variable resistor to maintain the current at a constant value - when the graph on the computer is horizontal open the switch - use the graph to find the time it took to charge the capacitor from time the p.d. started to rise until the time the p.d. was constant. - multiply the current by the time to get the charge - replace the capacitor with one of a different capacitance, and repeat - repeat for a range of capacitors - repeat the experiment three times for each capacitor, and calculate the mean charge stored - plot a graph of charge against capacitance	Sufficient detail Using the graph to find the time Calculating charge from current and time Repetition/finding mean	1 1 1	1	6.1.3
(b)	Appropriate suggestion and solution, for example The reading on the ammeter will not be constant as it will be difficult to change the resistance to exactly match the exponential decay of current Repeating the experiment many more times will give a more accurate measurement		1 1	1	6.1.3
6 (a)	The water molecule aligns with the electric field between the plates so that the	Movement of molecule to align with	1	1	6.2.3

Question	Answers	Extra information	Mark	AO	Spec reference
	positive side of the molecule (H^+) is attracted to the negative plate, and the negative side (O^-)	field			
(b) (i)	The greater the humidity, the greater the capacitance The water molecules effectively reduce the distance between the plates of the capacitor, and $C = \varepsilon_0\varepsilon_\text{r}A/d$, C is inversely proportional to d, so as d decreases, C increases	Relationship Effect of water molecules on distance Link to capacitance	1 1 1	1 2	6.2.3
(ii)		Graph starting at (0,0), points plotted, linear line of best fit Correct labels/units Values between 280 μF and 285 μF acceptable Use of ratios of capacitances Method	1 1 1 1 1	2	6.2.3

Question	Answers	Extra information	Mark	AO	Spec reference
	When the humidity is zero the capacitance is 390 μF, and when it is 100% the capacitance is 450 μF, $C_{100} = \varepsilon_0(\varepsilon_{rw} + \varepsilon_r)A/d$ and $C_0 = \varepsilon_0\varepsilon_r A/d$ $\frac{C_{100}}{C_0} = \frac{\varepsilon_0(\varepsilon_r + \varepsilon_w)}{d} \times \frac{d}{\varepsilon_0\varepsilon_r}$ $\frac{C_{100}}{C_0} = \frac{\varepsilon_r + \varepsilon_w}{\varepsilon_r} = \frac{450}{390} = 1.15$ $\varepsilon_r + \varepsilon_w = 1.15\varepsilon_r$ $\varepsilon_w = 0.15\varepsilon_r$ $\varepsilon_r = \frac{80}{0.15} = 533$				
(c)	$C_0 = \varepsilon_0\varepsilon_r A/d$ $d = \varepsilon_0\varepsilon_r A/C_0$ $= \frac{8.85\times10^{-12}\times533\times(10.8\times10^{-3}\times3.81\times10^{-3})}{(390\times10^{-6})}$ $= 5.00\times10^{-7}$ m which is about 0.5×10^{-6} m.	Use of equation ecf from C_0 in b) Answer/comparison	1 1	2	6.2.3
(d)	Field strength (assuming parallel plates) = V/d, so V = field strength × d = 94 000 000 × 5×10^{-7} m = 47 V $R = \rho l/A = 10^{12}\ \Omega$ m × 5×10^{-7} /10.8×10^{-3} × 3.81×10^{-3} $= 1.22\times10^{10}\ \Omega$ $I = V/R = 47$ V/$1.22\times10^{10}\ \Omega$ $= 3.87\times10^{-9}$ A This is an extremely small current that would be very difficult to measure.	 Answer Answer Comment	1 1 1	3	6.2.3 4.2.4

Question	Answers	Extra information	Mark	AO	Spec reference
			1		
7 (a)	$C = \varepsilon_0\varepsilon_r A/d$, $\varepsilon = 1$ = 8.85×10^{-12} × 150 × 10^4/0.15 = 8.87×10^{-13} V $Q = CV$ = 8.87×10^{-13} × 5000 = 4.43×10^{-9} C	Calculation of capacitance Charge	1 1	2	6.2.3
(b)	When the ball touches the plate electrons are transferred to it giving the ball a net negative charge and is attracted to the other plate/repelled from the negative plate When it touches the positive plate the electrons are transferred to the plate so it is repelled from the plate	Transfer of electrons used Correct attraction/repulsion	1 1	3	6.2.3
(c)	$T = 2\pi\sqrt{\frac{l}{g}}$ $= T = 2\pi\sqrt{\frac{0.40}{9.8}}$ = 1.27 s So it would take about 0.63 s to travel between the plates	Use of time period Answer	1 1	2	5.3.1
(d)	Current = charge/time = 0.1 × 4.43×10^{-9} /0.63 = 7.0×10^{-10} A	 Answer	1 1	2	4.1.1
(e)	The p.d. would decrease $C = \varepsilon_0\varepsilon_r A/d$ And $Q = CV$ where Q is constant $Q = V\,\varepsilon_0\varepsilon r A/d$ $Qd = V\,\varepsilon_0\varepsilon_r A$ P.d. is proportional to d		1 1	3	6.2.3
8 (a)	The dielectric would break down/ the capacitor will conduct		1	1	6.2.3
(b)	$V = V_0 e^{-t/RC}$ $\ln V = \ln V_0 - t/RC$			2	6.1.3

Question	Answers	Extra information	Mark	AO	Spec reference
	$C = t/R(\ln V_0 - \ln V)$ t = 7200 s, V = 1.5 V, $V_0 = 3V - C$ = 7200/10 000(ln3 – ln1.5) = 1.0 F $V_0 = 6V - C$ = 7200/10 000 (ln6 – ln1.5) = 0.51 F 1.3 F capacitor chosen from table The operating p.d. for the 0.5 F capacitor is only 3 V	Expression for C, explicit or implied Values of C for both initial p.d.s Conclusion with reason	1 1 1		
(c)	$Q = It$ = 1400 × 10^{-3} × 3600 = 5040 C $E = QV$ = 5040 × 3 = 1.5×10^3 J $E = \frac{1}{2} CV^2$ = 0.5 × 0.5 × 3^2 = 2.25 J $E = \frac{1}{2} CV^2$ = 0.5 × 1.3 × 3^2 = 5.85 J The energy is much less than that stored in the battery by a factor of 500	Calculation of energy Calculations of energy Comment	1 1 1	3	4.1.1 6.1.2
(d)	The battery has an internal resistance, r, so if a current flows the p.d will be reduced by a p.d. of Ir, $V = \varepsilon - Ir$ Current in circuit $I = \varepsilon/(R + r)$ Terminal p.d. = $V = \varepsilon - Ir$ $V = \varepsilon - \varepsilon r/(R + r)$ So $r/(r + R) = \frac{1}{2}$ R is equal to the internal resistance of the battery.	Explanation involving internal resistance Use of equation Answer	1 1 1	3	4.3.2