Q	Evidence	1–4 Below Schol	5–6 Scholarship	7–8 Outstanding
ONE (a)	Material must be an insulator (have no "free" electrons), and its atoms / molecules must be easily polarised (distinct charge separation shown in an imposed electric field).	Thorough understanding of these applications of physics. OR Partially correct mathematical solution to the given problems. AND / OR Partial understanding of these applications of physics.	(Partially) correct mathematical solution to the given problems. AND / OR Reasonably thorough understanding of these applications of physics.	Correct mathematical solution to the given problems. AND Thorough understanding of these applications of physics.
(b)(i)	Work needed $= \Delta E = E_F - E_1 = \frac{1}{2}\frac{Q^2}{C_F} - \frac{1}{2}\frac{Q^2}{\varepsilon_r C_F}$ $= \frac{1}{2}\frac{Q^2(\varepsilon_r - 1)}{\varepsilon_r C_F}$ $Q = C_F V_F$ So work needed $= \frac{1}{2} C_F V^2 \left(\frac{\varepsilon_r - 1}{\varepsilon_r}\right)$			
(ii)	With the charge constant and the capacitance decreased, the voltage (potential energy per coulomb) must have increased.			
(c)	Because the voltage must remain constant across the capacitor, the stored charge must reduce, as the capacitance is reduced by the dielectric withdrawal. The excess charge is returned to the battery and work must be done (by the withdrawing dielectric) to send the charge back into the battery.			
(d)(i)	The capacitance has increased, the charge is constant, therefore voltage is reduced.			
(ii)	Because the edge field of the capacitor has a component acting perpendicular to the plates which will attract material (electrostatically upwards).			

Question	Evidence	1–4 marks	5–6 marks	7–8 marks
TWO (a)(i)	At the steady state condition, no current will flow in the branch with the capacitor present. Therefore the current in the 3kΩ resistor will be zero. The rest of the circuit becomes a simple series circuit with resistance 27 kΩ and voltage 9 V; therefore the current is $I = \frac{9.00}{27\times10^{3}} = 3.33\times10^{-4}$ A	Thorough understanding of these applications of physics. OR Partially correct mathematical solution to the given problems. AND / OR Partial understanding of these applications of physics.	(Partially) correct mathematical solution to the given problems. AND / OR Reasonably thorough understanding of these applications of physics.	Correct mathematical solution to the given problems. AND Thorough understanding of these applications of physics.
(ii)	$Q = CV$ $Q = 10.0 \times 10^{-6} \times V$ $V = IR$ (V across 15 kΩ = V across capacitor) $V = 3.33 \times 10^{-4} \times 15.0 \times 10^{3} = 5.00$ V $Q = 10.0 \times 10^{-6} \times 5.00 = 50.0$ μC			
(iii)	On opening the switch, the circuit becomes a simple series circuit, with a source voltage of 5.00 V and a resistance of 18.0 kΩ. $I = \frac{5.00}{18\times10^{3}} = 2.78\times10^{-4}$ A			
(b)	The field lines at the edge of the capacitor are not vertical. They are arced and so have a component acting parallel to the capacitor plate surface. This component will attract the polarised charges of the dielectric (in the same way as charged objects can "pick up" small objects).			
(c)	$\Delta E \text{ (capacitance)} = \frac{1}{2}\frac{Q^2}{C_i} - \frac{1}{2}\frac{Q^2}{C_F}$ $C_F = \varepsilon_r C_I$ by definition $\Delta E = \frac{1}{2}\frac{Q^2(\varepsilon_r - 1)}{\varepsilon_r C_i}$ $\Delta E = \frac{1}{2}mv^2 = \frac{1}{2}\frac{Q^2(\varepsilon_r - 1)}{\varepsilon_r C_i}$ $v = \sqrt{\frac{Q^2(\varepsilon_r - 1)}{m\varepsilon_r C_i}}$			
(d)	Capacitors store energy. They do this by way of charge separation (increasing the electric potential energy of the charges). The total unbalanced charge of any capacitor is always zero.			

Question	Evidence	1-4 marks	5-6 marks	7-8 marks
3(a)	$C = 2.8 \times 3.0 \times 10^{-6} = 8.4\ \mu\text{F}$ Assumption: The wax completely fills the distance between the plates.	Thorough understanding of these applications of physics. OR Partially correct mathematical solution to the given problems. AND / OR Partial understanding of these applications of physics.	(Partially) correct mathematical solution to the given problems. AND / OR Reasonably thorough understanding of these applications of physics.	Correct mathematical solution to the given problems. AND Thorough understanding of these applications of physics.
(b)	The dielectric material is polarised by the electric field between the plates. There is now an electric field inside the dielectric, which opposes (weakens) the field between the plates. Reduced field strength, with the same amount of charge stored, means reduced voltage (assuming not connected to battery) and therefore the capacitance has increased. (*C* = *Q* / *V)* If capacitor is connected to the battery the voltage is fixed but the capacitance still increases as more charge is able to 'fit in'.			
(c)	At distance d_1 the energy stored in the capacitor is $E = \frac{1}{2}CV^2 = \frac{1}{2}\frac{\varepsilon_0 A V^2}{d_1}$ as the capacitance is $C = \frac{\varepsilon_0 A}{d_1}$. As the distance between plates increases from d_1 to d_2, the capacitance changes to $C = \frac{\varepsilon_0 A}{d_2}$ and the energy stored is now $\frac{1}{2}\frac{\varepsilon_0 A V^2}{d_2}$. $\Delta E = \frac{V^2 \varepsilon_0 A}{2}\left(\frac{1}{d_1} - \frac{1}{d_2}\right) = \frac{V^2 \varepsilon_0 A}{2}\left(\frac{d_2 - d_1}{d_1 d_2}\right)$			
(d)	As the capacitor is still connected to the battery, the voltage across the capacitor must remain constant at *V*. As the capacitance decreases as the distance between the two plates increases $C \propto \frac{1}{d}$, the energy stored in the capacitor must decrease (as $E = \frac{1}{2}CV^2$).The amount of charge on the plates must also decrease by ΔQ (as $Q = VC$). The "lost" charge is driven back through the battery to the opposite capacitor plate by the work done to separate the plates and the potential energy removed from the capacitor. This missing energy is converted into heat of the connecting wires and into potential energy stored in the battery.			
(e)	The plates, being oppositely charged, attract each other. In separating them, they have to be dragged apart. Work must be done and this energy is stored as electric potential energy in the field between the plates. We express this by talking of an increase in the voltage between the plates. $C = \frac{\varepsilon A}{d}$ so as *d* increases, *C* reduces.Energy $= \frac{Q^2}{C_2} - \frac{1}{2}\frac{Q^2}{C_1}$. *Q* is constant so as *C* decreases, the energy must increase – work is being done to drag the plates apart. Work done $= \frac{1}{2}\frac{Q^2}{C_2} - \frac{1}{2}\frac{Q^2}{C_1}$ $\frac{1}{2}Q^2\left(\frac{1}{C_2} - \frac{1}{C_1}\right) = \frac{Q^2\left(d_2 - d_1\right)}{2\varepsilon A}$			

FOUR 6 (a)	Charge will move from C_1 to C_2 (due to the mutual repulsion of the excess charges on C_1). The voltage across C_1 will fall, while that across C_2 will rise until the two potential differences are equal. At that point, charge movement will cease, as the forces on the charges are balanced.	Shows some understanding of the underlying physics. AND/OR (Partially) correct mathematical solution to given problem.	A reasonable understanding of the underlying physics. AND (Partially) correct mathematical solution to given problem.	Thorough understanding of the underlying physics. AND Correct mathematical solution to the given problem.
(b)	$Q_{1F} = C_1V$ $Q_{2F} = C_2V$ $Q = Q_{1F} + Q_{2F}$ $Q_{1F} = \frac{C_1Q_{2F}}{C_2} = \frac{C_1Q_{2F}p}{C_1} = Q_{2F}p$ $Q_{1F}(p+1) = pQ$ $Q_{2F} = \frac{C_2Q_{1f}}{C_1} = \frac{(Q - Q_{2f})}{p}$ $Q_{2F}\frac{(p+1)}{p} = \frac{Q}{p}$			
(c)	If p tends towards zero, then C_2 is very large (tending towards ∞) and will act as a short circuit (a very large charge sink). All the charge will flow to it and none of the charge will remain on C_1. As shown by the equations (taking the limit below): $Q_{1F} = Q\frac{p}{p+1}$ tends towards 0 when $p \to 0$ and $Q_{2F} = \frac{Q(1)}{p+1}$ tends towards Q when $p \to 0$ If p tends towards ∞, then C_2 is very small (tending toward zero) and will act as a break in the circuit, so no charge will move. $Q_{1F} = \frac{Q(p)}{p+1}$ tends towards Q when $p \to \infty$ $Q_{2F} = \frac{Q(1)}{p+1}$ tends towards 0 when $p \to \infty$			
(d)	Original energy $E_0 = \frac{Q^2}{2C_1}$ Final capacitance = $C_1 + C_2 = C_1 + \frac{C_1}{p} = C_1\frac{(p+1)}{p}$ Q is conserved so Final energy $E_F = \frac{Q^2 \times p}{C_1(p+1)} = E_0\frac{p}{p+1}$ The energy change does not depend on the resistance in the circuit, only on the relative sizes (given by the value of "p") of the capacitances. The resistor provides the mechanism for the energy dissipation.			

5(a)	1 mark for 4 A.	$R_T = 1.2 + 1.5 + 0.3 = 3.0\ \Omega$ $I = \frac{V}{R} = \frac{12}{3.0} = 4.0\ \text{A}$ $Q_1 = Q_2 = VC_T$ $V = 4.0 \times 2.7 = 10.8\ \text{V}$ $\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2}$ $C_T = \frac{1}{\left(\frac{1}{0.05} + \frac{1}{0.02}\right)} = 0.014286\ \mu\text{F}$ $Q_1 = Q_2 = VC_T = 10.8 \times 0.014286\ \mu\text{F}$ $= 0.15\ \mu\text{C}$	2
6(b)	1 mark for unchanged current.	Current unchanged So $V_{C1} = V_{R1} = 1.5 \times 4.0$ $Q = CV$ $Q_1 = 6.0 \times 0.05\ \mu\text{C} = 0.3\ \mu\text{C}$ So $V_{C2} = V_{R2} = 1.2 \times 4.0$ $Q_2 = 4.8 \times 0.02\ \mu\text{C} = 0.096\ \mu\text{C}$	2
6(c)		The very top and bottom junctions are at the same potential due to symmetry so the capacitor between them can be ignored. So we are left with two sets of series capacitors each worth in total 0.5 microfarads. Finally we have three parallel branches $C_T = 0.5 + 0.5 + 1 = 2$ microfarads.	2

<table>
<tr><th>Q</th><th>Evidence</th><th>1-4 marks</th><th>5-6 marks</th><th>7-8 marks</th></tr>
<tr><td>SIX (a)(i)</td><td>Current cannot build instantaneously in inductor, so initial current is just through resistor arm: $I = \frac{V}{R}$.</td><td rowspan="5">Thorough understanding of these applications of physics.

OR

Partially correct mathematical solution to the given problems.

AND / OR

Partial understanding of these applications of physics.</td><td rowspan="5">(Partially) correct mathematical solution to the given problems.

AND / OR

Reasonably thorough understanding of these applications of physics.</td><td rowspan="5">Correct mathematical solution to the given problems.

AND

Thorough understanding of these applications of physics.</td></tr>
<tr><td>(a)(ii)</td><td>After a long time, the current reaches a steady state and the inductor voltage is zero, so the total impedance seen by the voltage source is just the two parallel resistors, with total resistance $\frac{R}{2}$. Thus $I = \frac{2V}{R}$.</td></tr>
<tr><td>(b)(i)</td><td>Electric potential energy stored in the capacitor converts by way of moving charges (a current) into the magnetic field energy. This field energy then converts into more current, driving charge onto the plates of the capacitor so that the plates now restore EPE. Then the process reverses itself.</td></tr>
<tr><td>(b)(ii)</td><td>After ¼ of a cycle (when $t = 1.57$ s), there is no charge separation on the capacitor plates, and so no work (positive or negative) need be done in moving the plates closer.</td></tr>
<tr><td>(c)</td><td>The copper feels a changing magnetic field as it enters the field region, so eddy currents are induced. Their direction of flow is such that they create a field of their own that interacts with the applied field, slowing the copper. The energy is lost to heat – the copper has finite resistance so the eddy currents are dissipative.</td></tr>
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