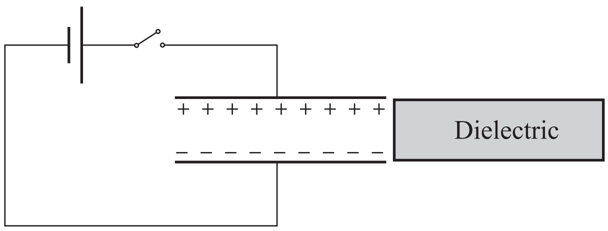
QUESTION ONE: CAPACITORS AND DIELECTRICS

(a) Describe the electrical properties required for a material to act as a dielectric.



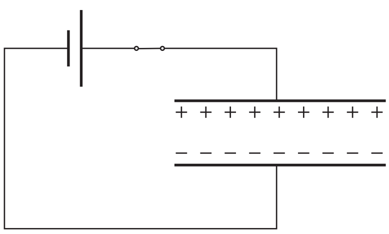
(b) A capacitor containing a dielectric is initially charged and then disconnected from a battery. The capacitor then has its dielectric removed, as in the diagram above.

(i) Show that the minimum work required to remove the dielectric is $\frac{1}{2}C_F V_F^2\left(\frac{\varepsilon_r - 1}{\varepsilon_r}\right)$

where C_F is the capacitance of the capacitor with the dielectric removed, V_F is the final potential difference, and ε_r is the dielectric constant.

(ii) Explain why work has to be done to remove the dielectric.

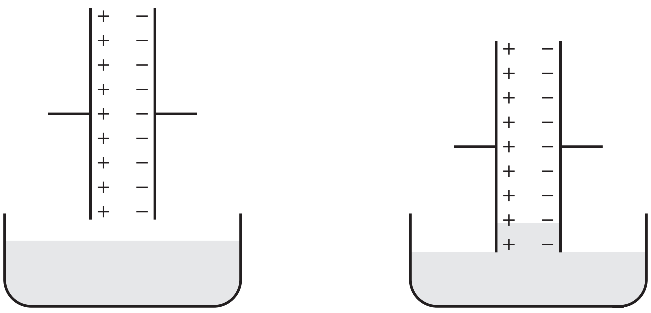
(c) If the capacitor is still connected to the battery when the dielectric is removed, as in the diagram below, the energy stored in the capacitor will decrease.



Despite this reduction in energy, work must still be done to withdraw the dielectric.

Explain this apparent contradiction.

(d) If the charged capacitor is held just touching the surface of a liquid dielectric, the dielectric will be drawn up into the capacitor.



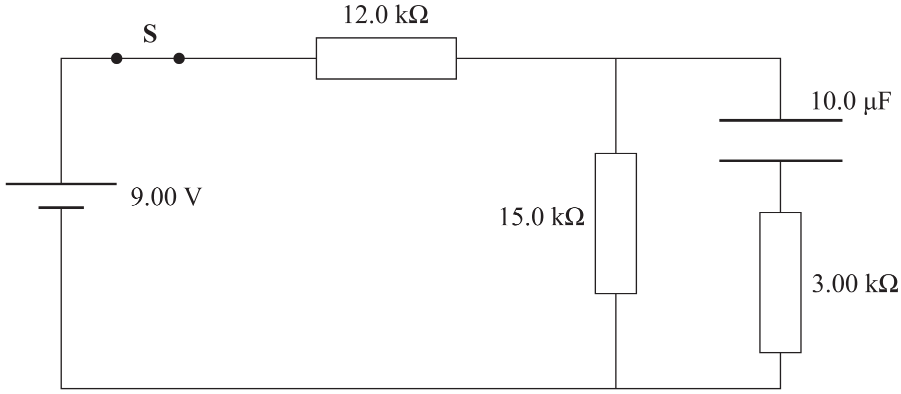
(i) Explain why the capacitor voltage decreases when this phenomenon takes place.

(ii) Explain why the liquid dielectric is drawn up into the charged capacitor.

(8)

QUESTION TWO: CAPACITORS AND DIELECTRICS

In the circuit below, the switch S has been closed for a time sufficiently long for the capacitor to become fully charged.



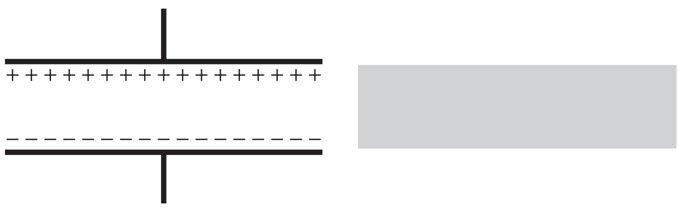
(a) (i) Calculate the steady-state current in each resistor.

(ii) Show that the charge on the capacitor is 50.0 μC.

(iii) The switch S is now opened.

Calculate the maximum value of the current through the 3.00 kΩ resistor.

In a separate experiment, a dielectric material is placed next to a charged parallel-plate capacitor, as shown in the diagram. The dielectric material experiences an electrostatic force that pulls it into the gap between the capacitor plates.



(b) Explain why the dielectric material is attracted into the gap between the plates.

(c) If the dielectric material is able to move without friction, show, by considering conservation of energy, that the maximum speed reached by the dielectric material is given by

$$v = \sqrt{\frac{Q^2}{mC_i}\frac{(\varepsilon_r - 1)}{\varepsilon_r}}$$

where

Q = original charge on the capacitor
ε_r = dielectric constant for the dielectric material
m = mass of the dielectric material
C_i = initial capacitance of the capacitor

(d) A capacitor is often referred to as a "store of charge".

Comment on this.

(8)

QUESTION THREE: CAPACITORS (8 marks)

(a) A capacitor with air between the plates has a capacitance of 3.0×10^{-6} F.

Calculate the capacitance when wax of dielectric constant 2.8 is placed between the plates. State your assumptions.

(b) Dielectric materials can increase the capacitance of a capacitor.

Explain how a dielectric material creates an increase in capacitance.

A capacitor is made of two parallel plates with air between them. A student is attempting to determine the work lost or gained when the two plates are moved apart. The plates, each of area A, are connected to a battery of potential difference V.

The student sets the initial separation of the plates to d_1, and they are to be moved further apart to a separation d_2.

(c) Show that the work done in changing the separation from d_1 to d_2 is $\frac{V^2 \varepsilon_0 A}{2}\left(\frac{d_2 - d_1}{d_1 d_2}\right)$.

(d) Explain, using physical principles, what happens to the stored energy and charge as the plate separation increases.

(e) The plates are brought back to the original separation d_1. The battery is now disconnected.

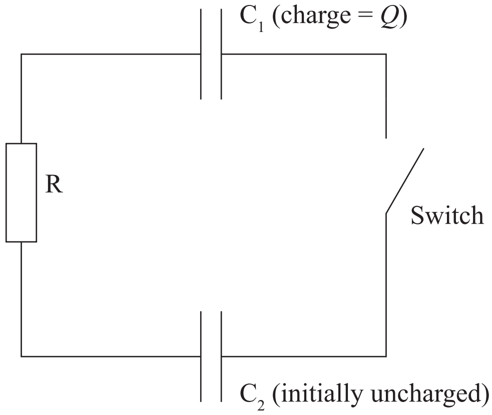
Derive an expression for the work done to, once again, increase the separation to d_2.

(8)

QUESTION FOUR: CAPACITOR ENERGY (8 marks)

In the circuit shown, a capacitor C_1, which is holding a charge Q, has an initial potential difference of V_o. Capacitor C_2 is initially uncharged.

At time $t = 0$, the switch is closed.



(a) Explain what changes will take place to the charge on each capacitor and to the potential difference across each capacitor.

(b) The value of $C_2 = \frac{C_1}{p}$ (where $p \geq 0$).

Show that the final charge on C_1 is $Q_{1f} = Q\frac{p}{p+1}$

and that the final charge on C_2 is $Q_{2f} = Q\frac{1}{p+1}$.

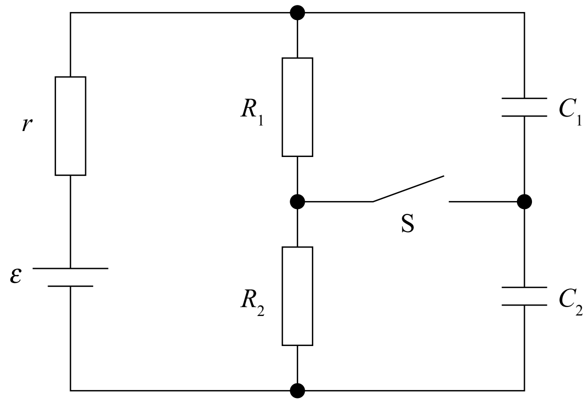
(c) Explain, using physical principles, the meaning of these results by considering the limiting cases when p approaches zero and when p tends to infinity.

(d) Show that when the switch is closed, the stored energy will change by a factor of $\dfrac{p}{p+1}$.
Comment on the role of the resistor R when the switch is closed.

(8)

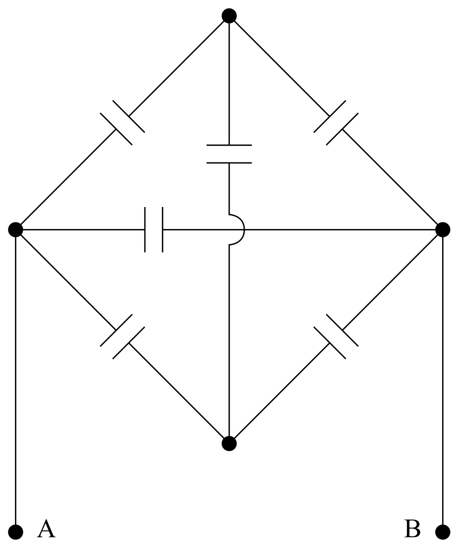
QUESTION FIVE: CAPACITORS (6 marks)

(a) In the circuit shown below, an emf source $\varepsilon = 12$ V, with an internal resistance of $r = 0.3\ \Omega$, is connected to two resistors $R_1 = 1.5\ \Omega$ and $R_2 = 1.2\ \Omega$. Two capacitors $C_1 = 0.05\ \mu$F and $C_2 = 0.02\ \mu$F are connected in parallel to the resistors, and the switch S is open. Calculate the current in the circuit and the charges Q_1, Q_2 on the capacitors once a steady state is reached. (A steady state is reached when no further charging of the capacitors takes place.)



(b) What values do the current in the circuit and charges Q_1 and Q_2 take if the switch is closed and a new steady state is reached?

(c) Calculate the capacitance between terminals A and B for the circuit shown below. Each capacitor has a capacitance of 1 μF. Explain all reasoning.



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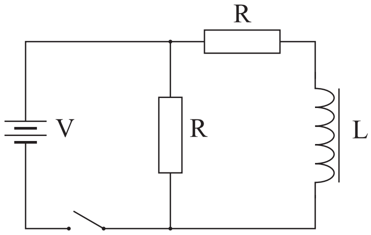
(6)

QUESTION SIX: CIRCUITS

ASSESSOR'S USE ONLY

This question uses an inductor, which is not in any A-level course



(a) In the electric circuit shown, the switch is closed at time $t = 0$.

(i) Write an expression for the current immediately after the switch is closed.

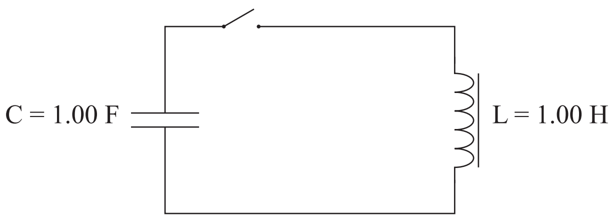
Explain your reasoning.

(ii) Write an expression for the limiting value of the current a long time after the switch is closed.

Explain your reasoning.

(b) (i) A charged capacitor (1.00 F) is connected to an inductor (1.00 H), as shown in the diagram below. When the switch is closed (at $t = 0$), the current in the circuit will oscillate sinusoidally with a period of 6.28 s.

Describe the energy changes that take place in the course of one complete cycle.



(ii) The capacitor plates can be moved closer together so that the capacitance is increased to 4.00 F.

Explain at what point in the cycle, could the plates of the capacitor be moved closer to each other so that no energy is transferred to the circuit.

(c) A slab of copper falls freely under the influence of gravity before entering the region between the poles of a strong magnet. As it enters the magnetic field, the copper slab slows considerably.

Explain why this occurs, and state what has happened to the kinetic energy of the copper slab.

(8)