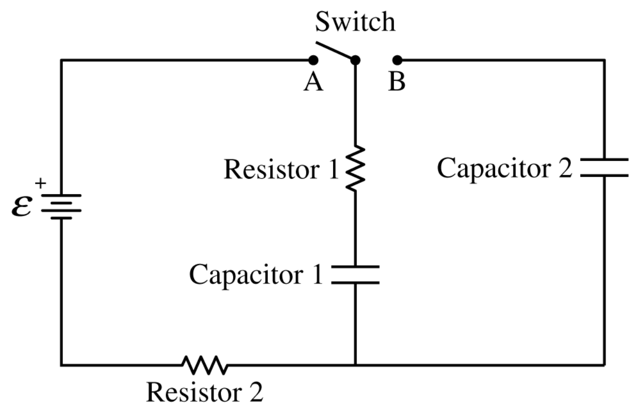
Begin your response to **QUESTION 3** on this page.



3. The circuit shown consists of an ideal battery of emf $\mathcal{E}$, resistors 1 and 2 each with resistance R, capacitors 1 and 2 each with capacitance C, and a switch. The switch is initially open and both capacitors are uncharged.

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

(a) Write, but do NOT solve, a differential equation that can be used to determine the charge Q on the positive plate of Capacitor 1 as a function of time t after the switch is closed to Position A. Express your answer in terms of $\mathcal{E}$, R, C, Q, t, and fundamental constants, as appropriate.

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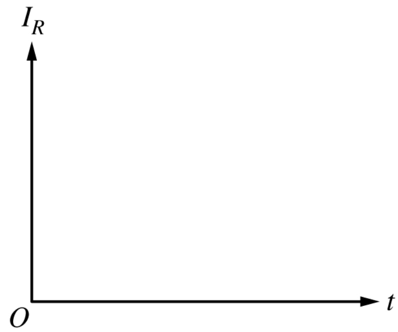
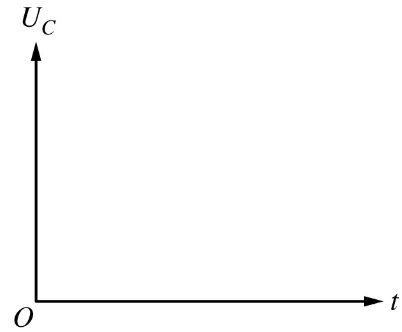
Continue your response to **QUESTION 3** on this page.

(b) On the axes shown, sketch graphs of the current I_R in Resistor 1 and the energy U_C stored in Capacitor 1 as functions of time t from time $t = 0$ until steady-state conditions are nearly reached.





A long time after the switch is closed to Position A, the total charge on the positive plate of Capacitor 1 is Q_0 and Capacitor 2 is uncharged.

(c) At time t_1, the switch is closed to Position B.

i. Immediately after t_1, is the direction of the current in Resistor 1 directed up, directed down, or is there no current? Briefly justify your answer.

ii. Determine an expression for the total charge on the positive plate of Capacitor 2 a long time after t_1. Express your answer in terms of Q_0 and fundamental constants, as appropriate.

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Continue your response to **QUESTION 3** on this page.

iii. Derive an expression for the total energy dissipated by Resistor 1 immediately after time t_1 until new steady-state conditions have been reached. Express your answer in terms of C, Q_0, and fundamental constants, as appropriate.

With the switch still closed to Position B, a dielectric material with dielectric constant $\kappa = 2$ is inserted between the plates of Capacitor 2.

(d) Determine the charge on the positive plate of Capacitor 2 a long time after the dielectric has been inserted. Express your answer in terms of Q_0 and fundamental constants, as appropriate.

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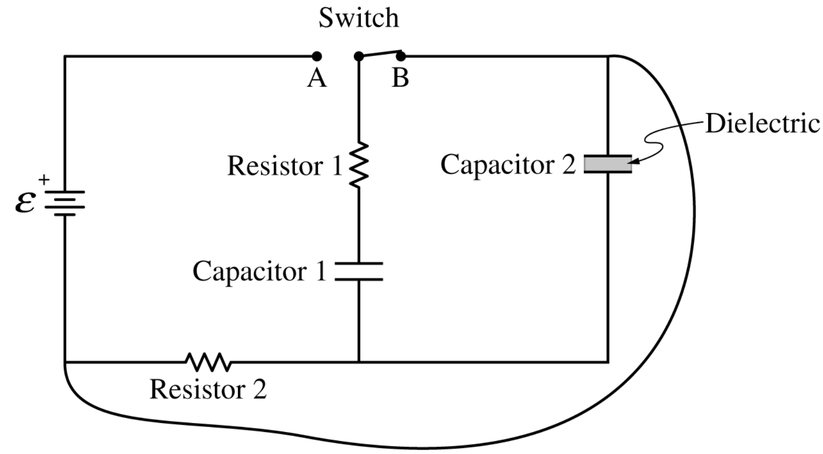
Continue your response to **QUESTION 3** on this page.



With the switch still closed to Position B, a wire of negligible resistance is connected between two corners of the circuit, as shown.

(e) Express your answers to part (e)(i) and part (e)(ii) in terms of R, C, Q_0, and fundamental constants, as appropriate.

i. Derive an expression for the current in Resistor 2 immediately after the wire is connected to the circuit.

ii. Determine the current in Resistor 2 a long time after the wire is connected to the circuit.

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(e)(i) For a loop rule equation that includes terms for the potential difference across Resistor 2 and the potential difference across Capacitor 2 with the dielectric — **1 point**

Example Response

$$\Delta V_{R,2} - \Delta V_{C,2} = 0$$
$$\Delta V_{R,2} = \Delta V_{C,2}$$

For correct substitution of IR for the potential difference across Resistor 2 — **1 point**

Example Response

$$\Delta V_{R,2} = IR$$

For correct substitutions of $2C$ for the new capacitance of Capacitor 2 with the dielectric inserted and of the charge consistent with part (d) into the expression for the potential difference across the capacitor — **1 point**

Example Response

$$\Delta V_{C,2} = \frac{Q_2}{C_2}$$
$$\Delta V_{C,2} = \left(\frac{2Q_0}{3}\right)\left(\frac{1}{2C}\right)$$

Example Solution

$$\Delta V_{R,2} - \Delta V_{C,2} = 0$$
$$\Delta V_{R,2} = \Delta V_{C,2}$$
$$IR = \left(\frac{2Q_0}{3}\right)\left(\frac{1}{2C}\right)$$
$$IR = \frac{Q_0}{3C}$$
$$I = \frac{Q_0}{3RC}$$

(e)(ii) For indicating that the current is zero — **1 point**

Total for part (e) — **4 points**

Total for question 3 — **15 points**