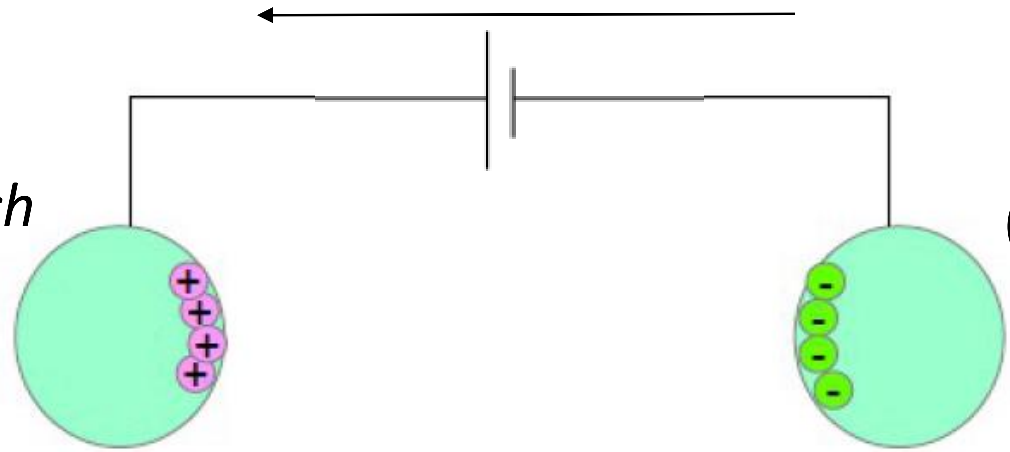
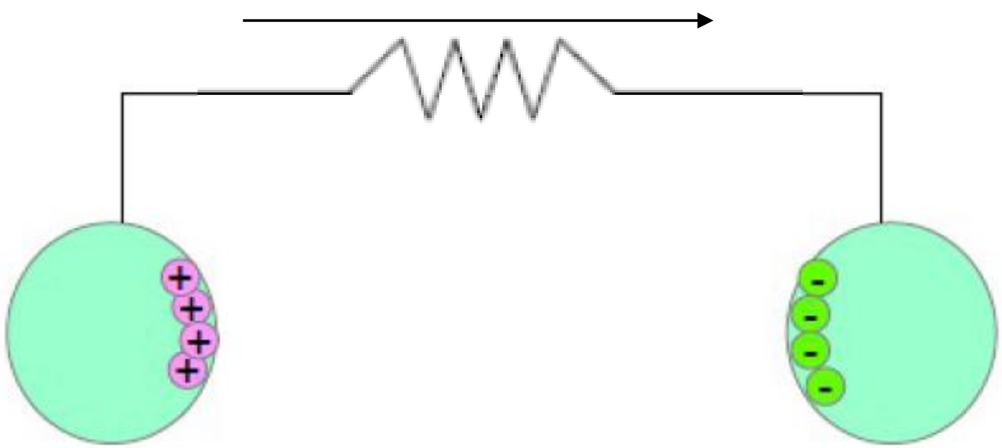
Chapter 24: Capacitance and dielectrics

- Capacitor: a device store electric energy
- How to define capacitance
- In parallel and/or in series
- Electric energy stored in a capacitor
- Dielectric materials

Capacitor: a device store electric energy





Capacitor: a device store electric energy

Any two separated conductors could be used as a capacitor (electric energy storage device)

In circuit, a capacitor is shown as:

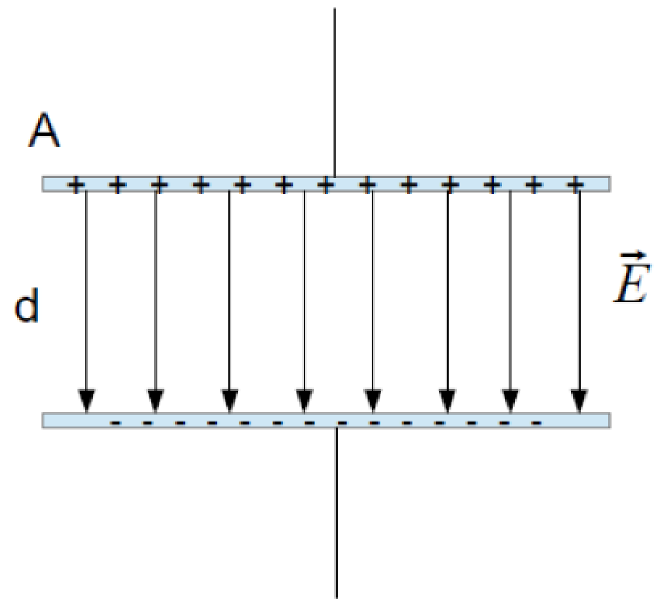
How to define capacitance

Capacitance: How much **charge** could be stored **per volt**

$$C = \frac{Q}{V}$$

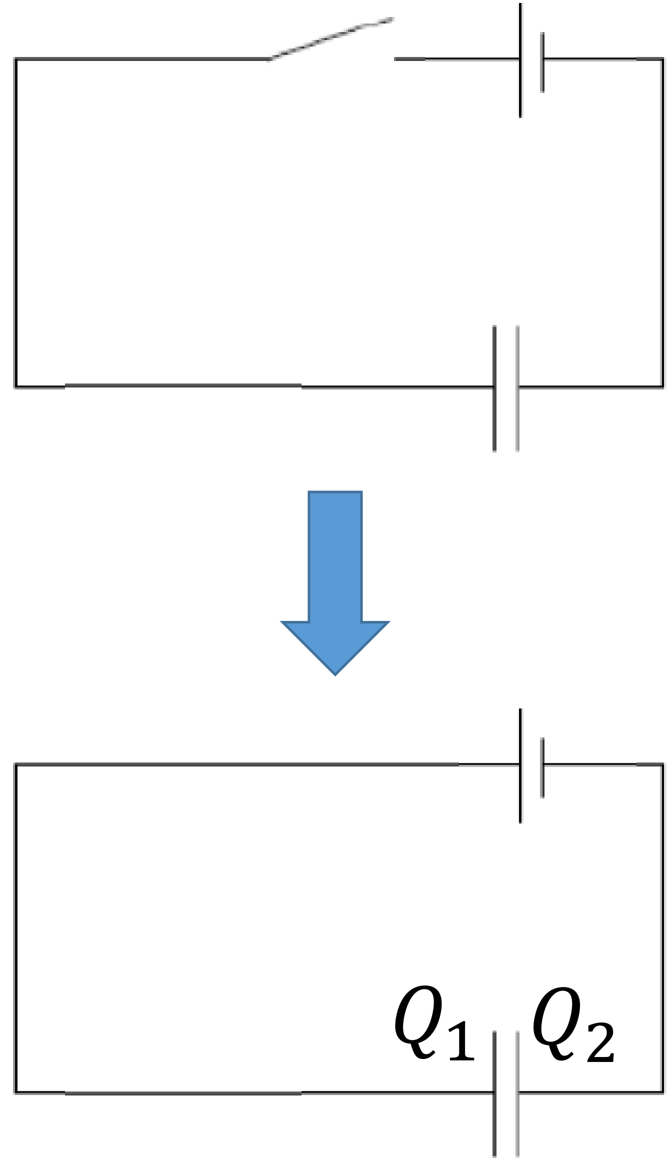
The unit of capacitance (Farad): $1\mathrm{F} = \frac{C}{V}$

Example

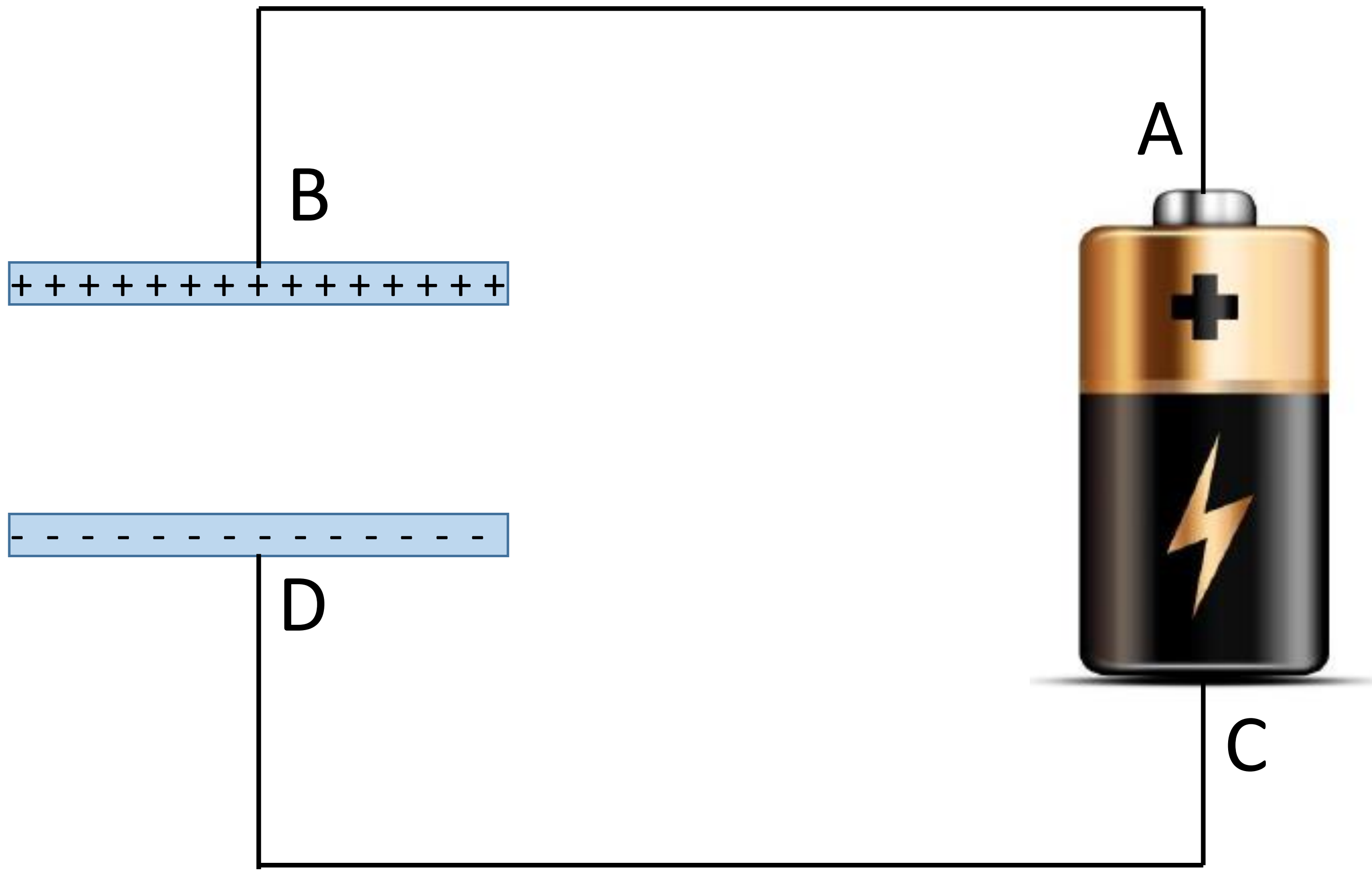


Find the capacitance of the parallel plates capacitance

When the switch is opened, the capacitor is uncharged. After the switch is closed, and all the charges reach equilibrium, the two plates of the capacitor have Q_1 and Q_2 charges. Which of the following description is correct?



A. $Q_1 > 0; Q_2 > 0;$ and $|Q_1| = |Q_2|$
B. $Q_1 < 0; Q_2 > 0;$ and $|Q_1| = |Q_2|$
C. $Q_1 > 0; Q_2 < 0;$ and $|Q_1| = |Q_2|$
D. $Q_1 > 0; Q_2 < 0;$ and $|Q_1| < |Q_2|$
E. $Q_1 > 0; Q_2 < 0;$ and $|Q_1| > |Q_2|$

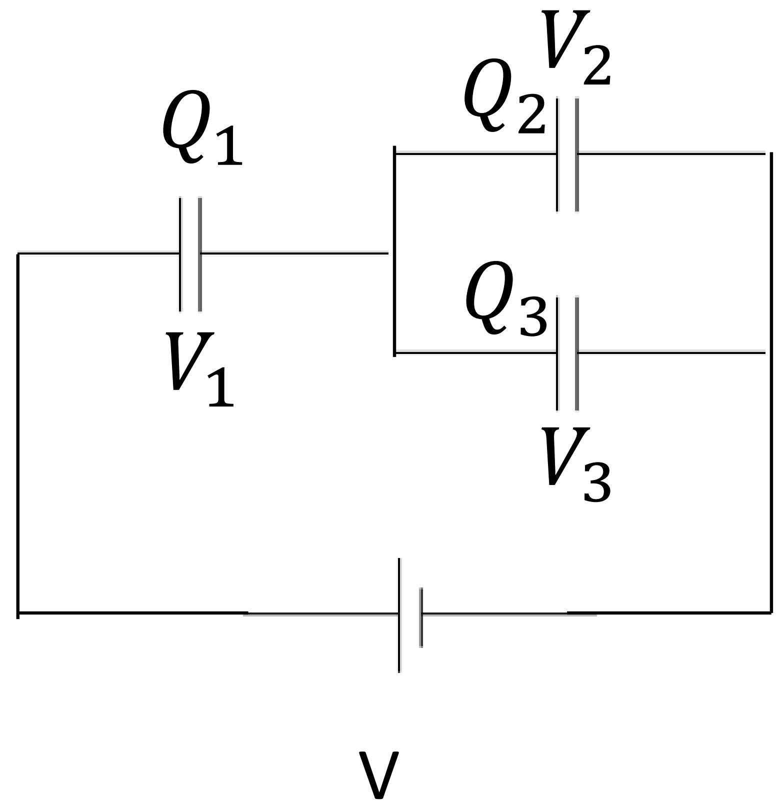


What is the relationship of the electric potential at these four positions?

A. $A>B>C>D$
B. $A>B>D>C$
C. $A=B>C=D$
D. $A>B=D>C$
E. $A>C>B=D$

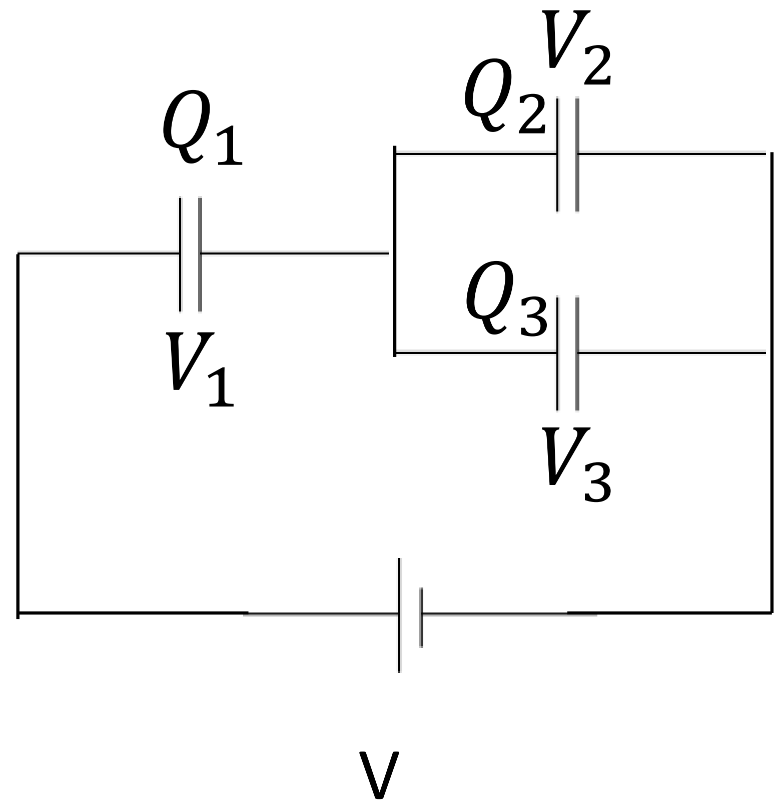
Do the working sheet

Three different capacitors are connected in a circuit shown in the figure. Which of the following is true?



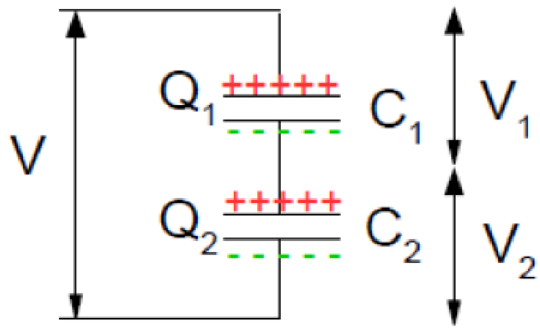
A. $V_1 = V_2$
B. $V_2 = V_3$
C. $V_1 = V_2 + V_3$
D. $V_2 = V_1 + V_3$
E. $V_3 = V_2 + V_1$

Three different capacitors are connected in a circuit shown in the figure. Which of the following is true?

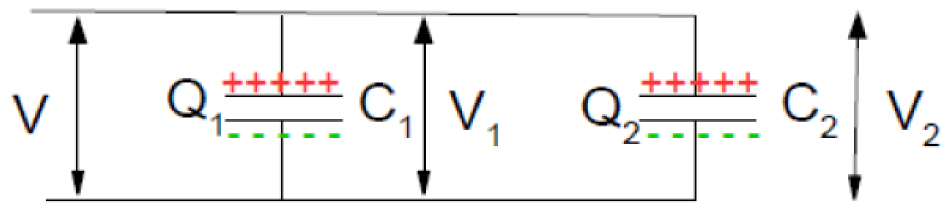


A. $Q_1 = Q_2$
B. $Q_2 = Q_3$
C. $Q_1 = Q_2 + Q_3$
D. $Q_2 = Q_1 + Q_3$
E. $Q_3 = Q_2 + Q_1$

In parallel and/or in series



in series

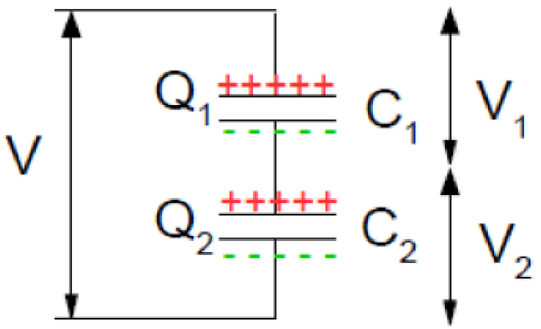


in parallel

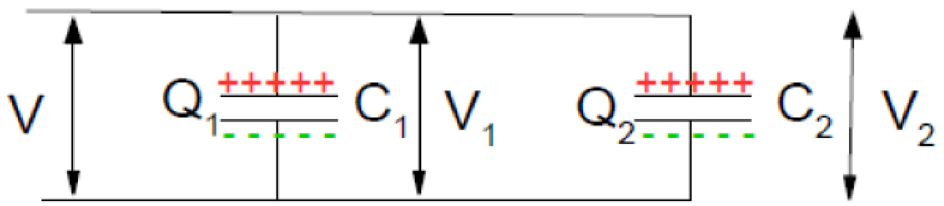
Charges are the same for the two capacitors

Potential drop are the same for the two resistor

In parallel and/or in series



in series

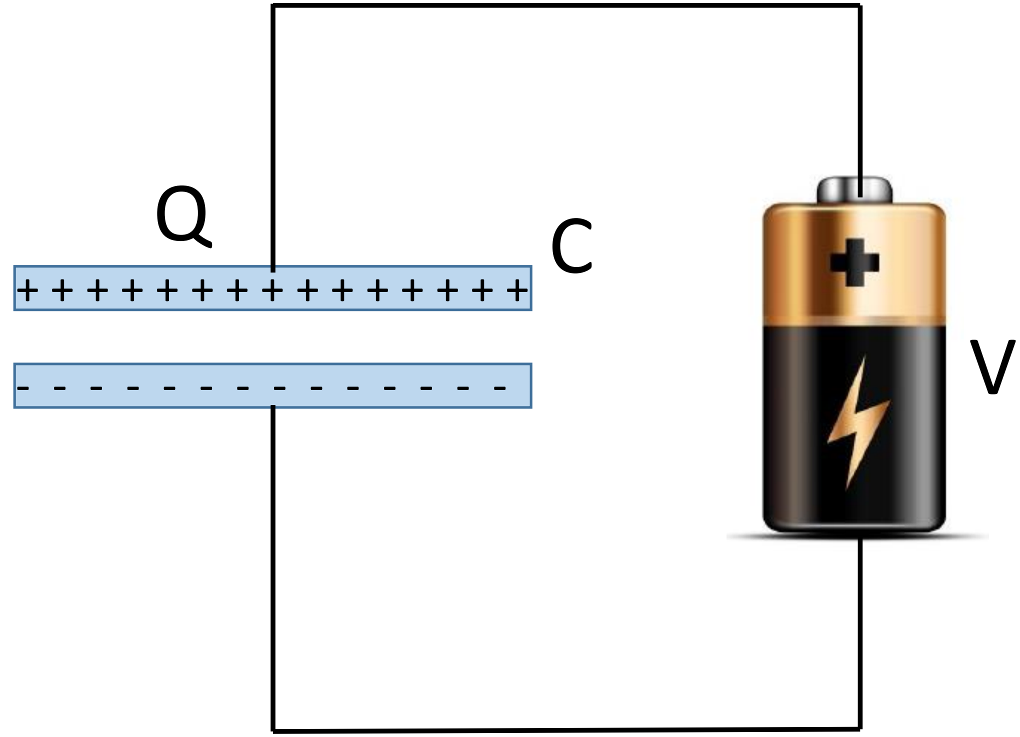


in parallel

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$C_{eq} = C_1 + C_2$$

After the capacitor is charged, how much electric energy is stored in the capacitor?

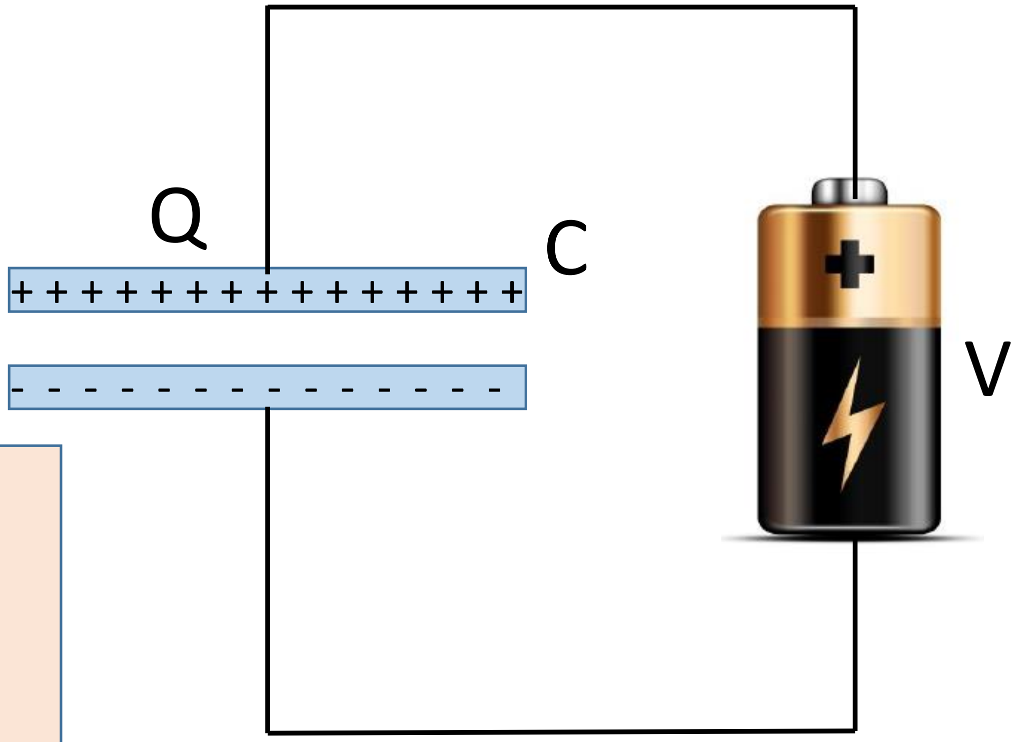


A. QV
B. $QV/2$
C. $2CV$
D. CV
E. Q/C

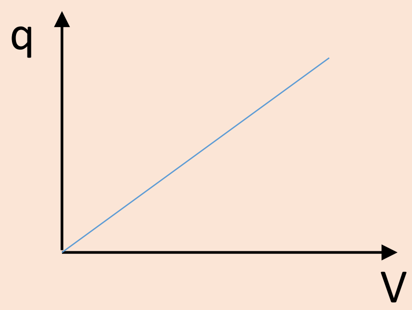
Energy stored in capacitor

$$dU = dq V(q)$$

$$U = \int dU = \int V(q) dq$$



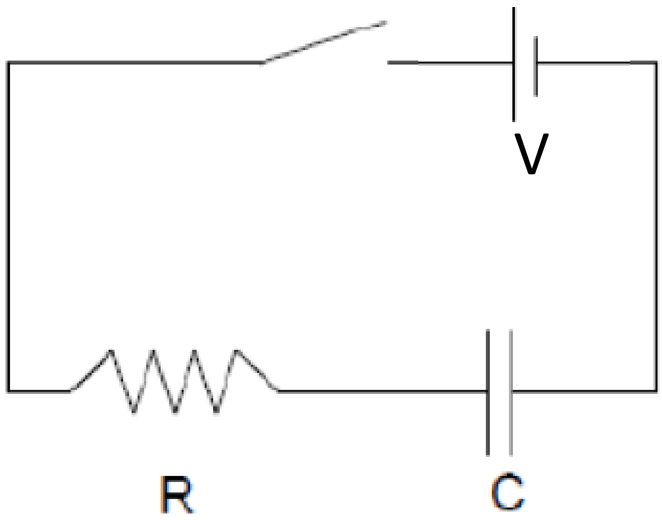
$$C = \frac{q}{V}$$



$$U = \int_0^Q \frac{q}{C} dq = \frac{Q^2}{2C}$$

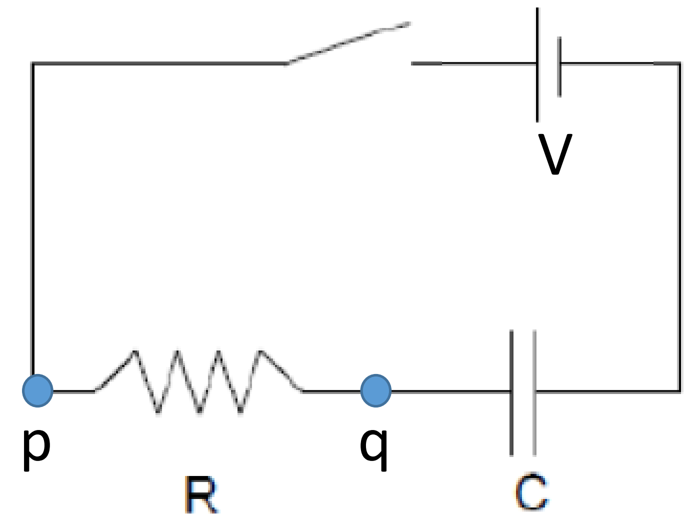
$$U = \frac{Q^2}{2C} = \frac{CV^2}{2} = \frac{QV}{2}$$

Time dependence behavior



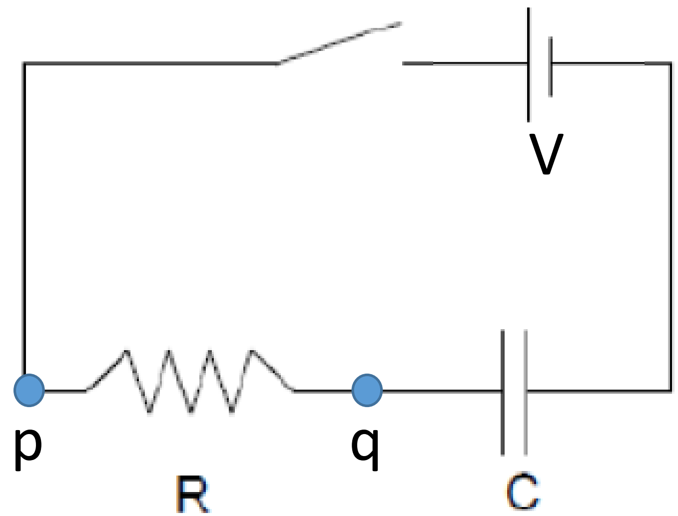
When the switch is closed, count as t = 0, the capacitor has charge 0 and increases to it's maximum Q. ➔ **the charge on the capacitor is changing over time!!!**

The capacitor was initially uncharged. When the switch is just closed, what is the potential difference across the resistor?



A. 0
B. V
C. Smaller than V
D. Larger than V

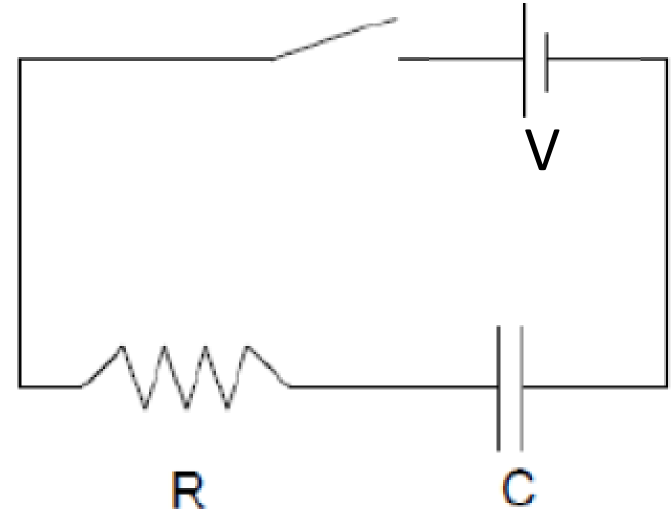
The capacitor was initially uncharged. When the switch has been closed for very long time, what is the potential difference across the resistor?



A. 0
B. V
C. Smaller than V
D. Larger than V

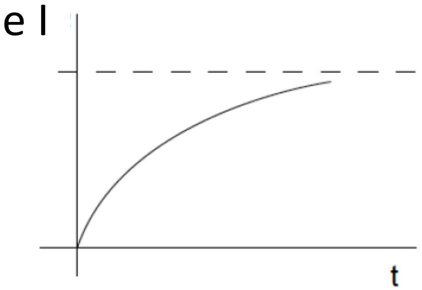
Quiz:

When the switch is closed, which types of the diagrams best describe the (1) current in the loop; (2) potential drop across the resistance; (3) potential drop across the capacitor; and (4) the amount of charge on the capacitor as a function of time? Assuming the capacitor was initially uncharged.

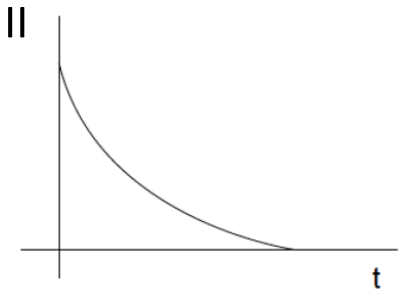


A. Types I, II, I, II
B. Types I, I, I, I
C. Types I, II, II, II
D. Types II, II, I, I
E. Types I, II, I, I

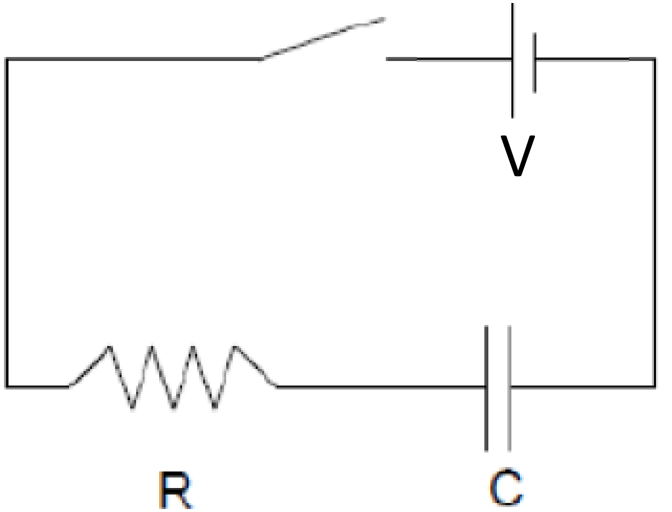
Type I



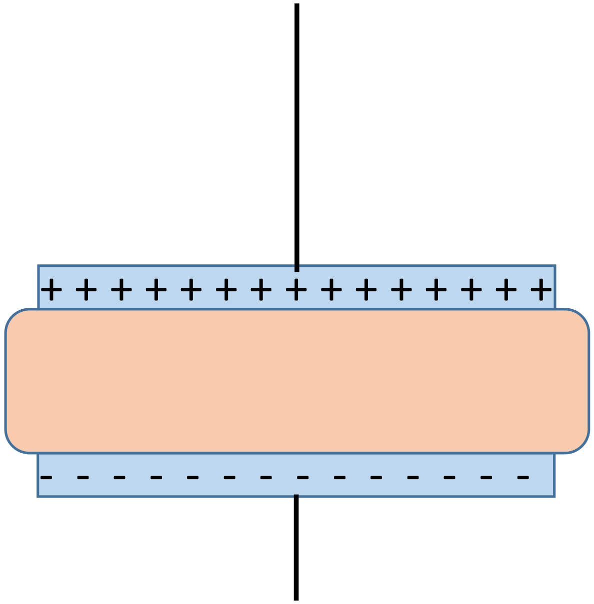
Type II



How to calculate

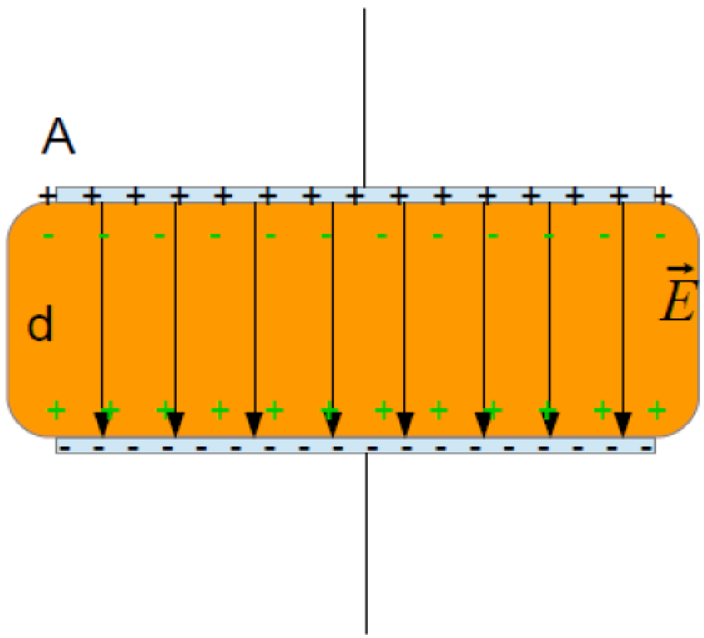


When an insulator (dielectric material) is placed in between the two plates of the capacitor, what will happen to the insulator?

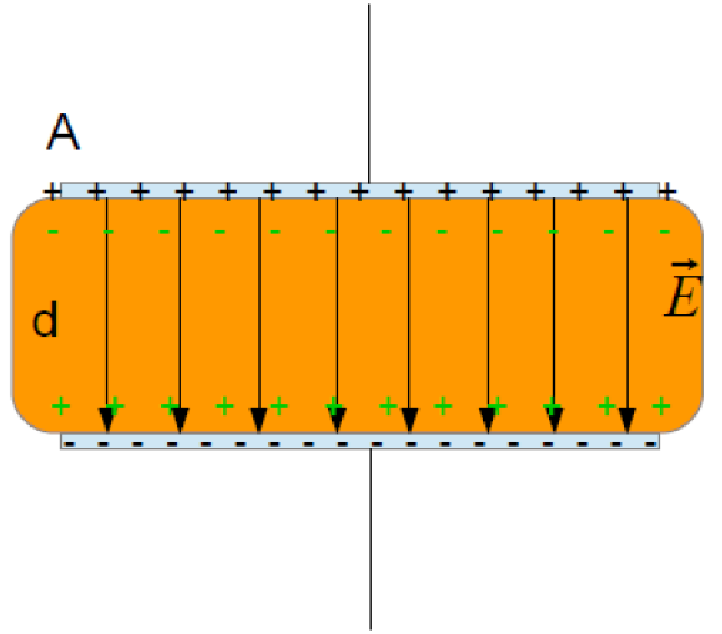


A. Nothing will happen
B. It will be polarized with the top/bottom surfaces (near the "+"/"-" metal plate) more negative/positive.
C. It will be polarized with the top/bottom surfaces (near the "+"/"-" metal plate) more positive/negative.
D. It will be polarized with the right/left of the material more positive/negative.
E. I am not sure.

There will be polarized to as shown. The polarized charges are less since these charges could not move.



Compare to "without" the insulator, what would be expected regarding the electric field and the capacitance?



A. The electric field will become zero in the materials. The capacitance will become larger.
B. The electric field will become larger in the materials. The capacitance will become smaller.
C. The electric field will become smaller in the materials. The capacitance will become larger.
D. The electric field will become smaller and reverse the direction in the materials. The capacitance will be the same.
E. The electric field will become smaller and reverse the direction in the materials. The capacitance will become larger.

The capacitance become larger due to the dielectric materials, and it depends on how easy the material could be polarized.

Dielectric constant: $K = \frac{C}{C_0}$

See Table 24.1 on page 801 for K values for different materials

$$\mathrm{C} = KC_0 = K\varepsilon_0 \frac{A}{d} = \varepsilon \frac{A}{d}$$

$K\varepsilon_0 = \varepsilon$ or $K = \frac{\varepsilon}{\varepsilon_0}$

Each material has a break down threshold electric field, named **dielectric strength** (just like atmosphere when lightning happens). This puts an upper limit of the possible potential you can apply to the capacitor.