PHY-112
Principles of Physics-II

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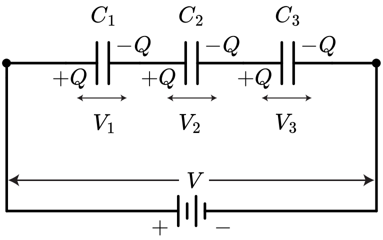
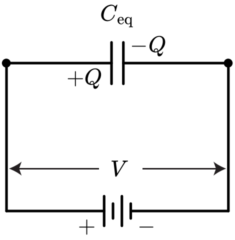
Spring-24 | Class-13

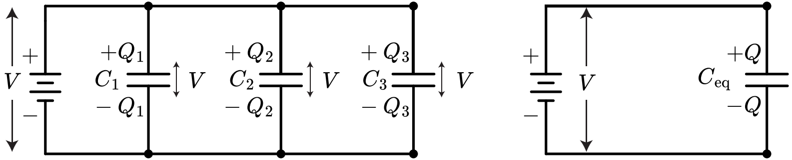
The voltage across each capacitor is not the same. The total voltage across the series combination equals the sum of the voltages across each capacitor.





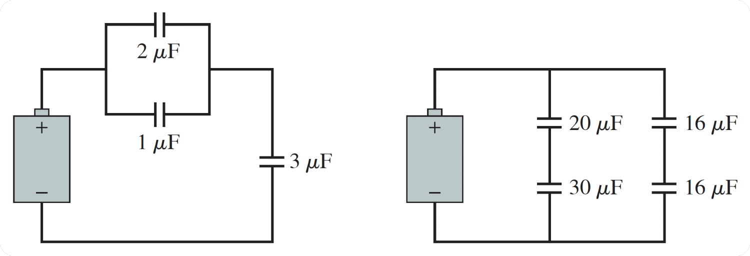
$$\frac{1}{C_{\text{eq}}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} = \sum_{i}^{n} \frac{1}{C_i}$$

The voltage across each capacitor is the same. The total charge stored in the combination is the sum of the charges stored in each individual capacitor.

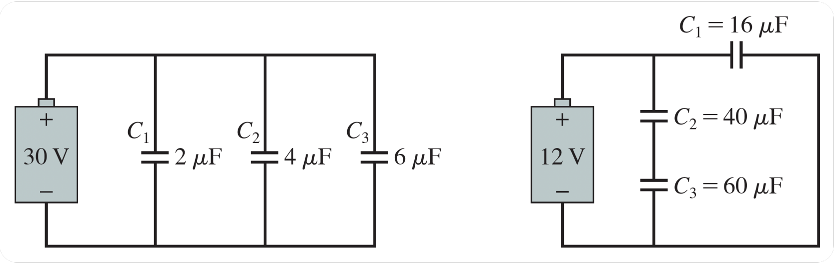


$$C_{\text{eq}} = C_1 + C_2 + C_3 = \sum_i^n C_i$$

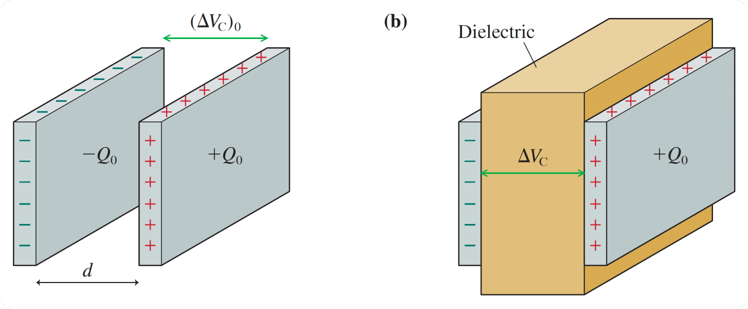
Q: What is the equivalent capacitance of the following two circuits?



Q: What are the charges and potential differences across each capacitor?



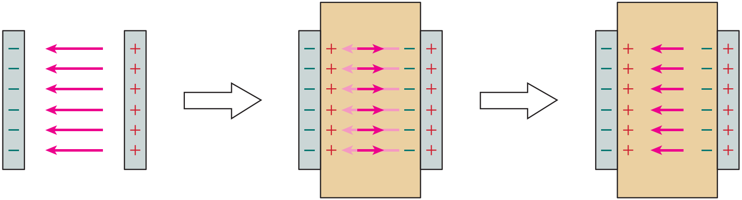
Vacuum-insulated and Dielectric filled Capacitors



$$E_0 = \frac{\sigma_0}{\epsilon_0}$$

$$E_{\text{ind}} = \frac{\sigma_{\text{ind}}}{\epsilon_0}$$

$$E_{\text{new}} = E_0 - E_{\text{ind}}$$



Define the Dielectric Constant

$$\kappa = \frac{E_0}{E_{\text{new}}}$$

What happens to the Potential Difference?

$$
\begin{aligned}
(\Delta V_C)_{\text{new}} &= E_{\text{new}} d \\
&= \frac{E_0 d}{\kappa} \\
(\Delta V_C)_{\text{new}} &= \frac{(\Delta V_C)_0}{\kappa}
\end{aligned}
$$

The presence of a dielectric reduces the capacitor voltage.

What happens to the Capacitance?

$$
\begin{aligned}
C_{\text{new}} &= \frac{Q}{(\Delta V_C)_{\text{new}}} \\
&= \frac{Q}{\left(\frac{(\Delta V_C)_0}{\kappa}\right)} \\
&= \kappa \frac{Q}{(\Delta V_C)_0} \\
&= \kappa C_0
\end{aligned}
$$

The presence of a dielectric increases the capacitance by a factor equal to the dielectric constant.

The Permittivity of Free Space

$$\kappa = \frac{C_{\text{new}}}{C_0} = \frac{\dfrac{\epsilon A}{d}}{\dfrac{\epsilon_0 A}{d}}$$

$$\kappa = \frac{\epsilon}{\epsilon_0} = \frac{E_0}{E_{\text{new}}}$$

$$\epsilon = \kappa \epsilon_0$$

A New Set of Capacitor Equations

$$\text{Capacitance,} \quad C = \frac{\epsilon A}{d} = \frac{(\kappa \epsilon_0) A}{d}.$$

$$\text{Energy Density,} \quad u_C = \frac{1}{2} \epsilon E^2 = \frac{1}{2} (\kappa \epsilon_0) E^2.$$

Q: A $5.0\,\mathsf{nF}$ parallel-plate capacitor is charged to $160\,\mathsf{V}$. It is then disconnected from the battery and immersed in distilled water ($\kappa = 78.57$). What are—

- the capacitance and voltage of the water-filled capacitor
- the energy stored in the capacitor before and after its immersion?

Q: A chest defibrillator unit contains a $150\,$mF capacitor that is charged to $2100\,$V. The capacitor plates are separated by a $0.050\,$mm-thick insulator with dielectric constant 120.

- What is the area of the capacitor plates?
- What are the stored energy and the energy density in the electric field when the capacitor is charged?