King Saud University
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111 PHYS (GENERAL PHYSICS 2)
CHAPTER 26: Capacitance and Dielectrics
LECTURE NO. 5

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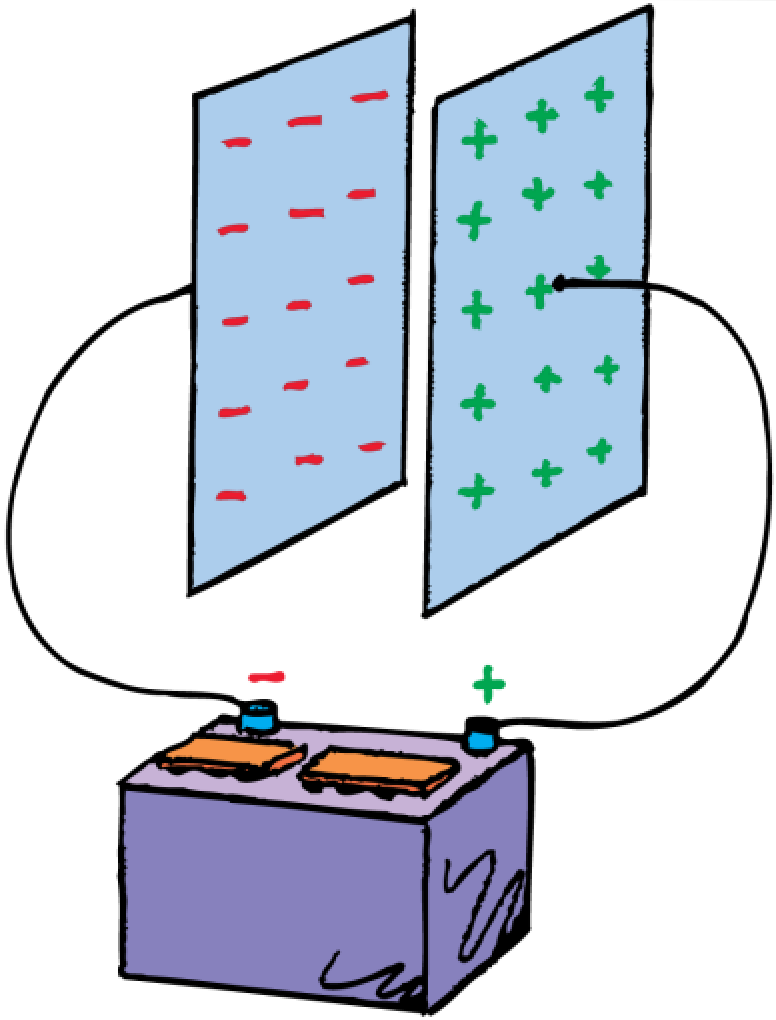
26.1 Definition of Capacitance

- Electrical energy can be stored in a device called a **capacitor**.
  - Computer memories use very tiny capacitors to store the 1's and 0's of the binary code.
  - Capacitors in photoflash units store larger amounts of energy slowly and release it rapidly during the flash.
- The charge storing capacity of a capacitor is called its **capacitance**.
- An electric field exists inside a charged capacitor, between the positive and negative charge separation.

26.1 Definition of Capacitance

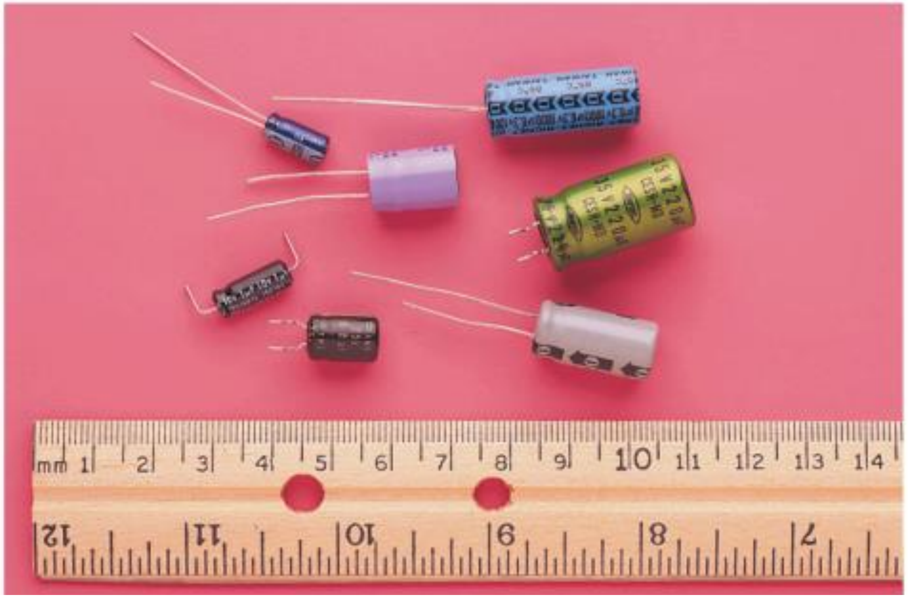
The simplest capacitor is a pair of conducting plates separated by a small distance, but not touching each other.

- Charge is transferred from one plate to the other.
- The capacitor plates then have equal and opposite charges.
- The charging process is complete when the potential difference between the plates equals the potential difference between the battery terminals—the battery voltage.
- The greater the battery voltage and the larger and closer the plates, the greater the charge that is stored.



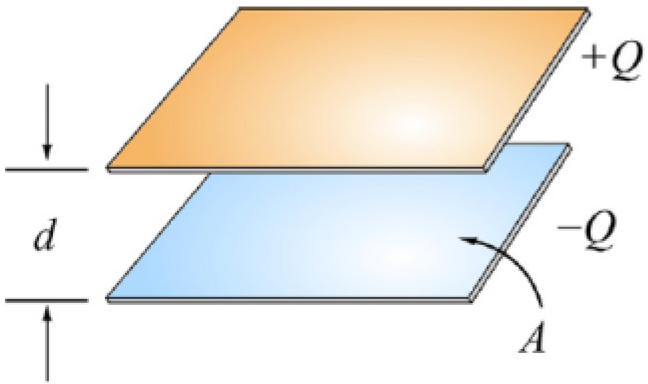
26.1 Definition of Capacitance

- In practice, the plates may be thin metallic foils separated by a thin sheet of paper.
- This “paper sandwich” is then rolled up to save space and may be inserted into a cylinder.



26.1 Definition of Capacitance

- During the charging process, a charge Q is moved from one conductor to the other one, giving one conductor a charge +Q, and the other one a charge -Q .
- A potential difference ΔV is created, with the positively charged conductor at a higher potential than the negatively charged conductor.
- The simplest example of a capacitor consists of two conducting plates of area, which are parallel to each other, and separated by a distance d.



A parallel-plate capacitor

26.1 Definition of Capacitance

- Experiments show that the amount of charge Q stored in a capacitor is linearly proportional to ΔV , the electric potential difference between the plates.

$$Q = C\,|\,\Delta V\,|$$

Where:

C :is a positive proportionality constant called ***capacitance***.

Capacitance is a measure of the capacity of storing electric charge for a given potential difference.

26.1 Definition of Capacitance

Unit of Capacitor

- The SI unit of capacitance is the *farad*

$$1\ \mathrm{F} = 1\ \text{farad} = 1\ \text{coulomb/volt} = 1\ \mathrm{C/V}$$

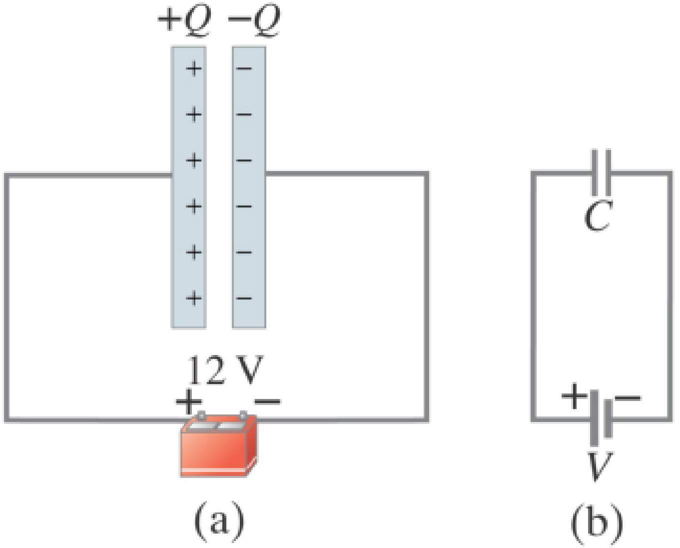
A typical capacitance is in the picofarad ($1\ \mathrm{pF} = 10^{-12}\ \mathrm{F}$) to millifarad range, ($1\ \mathrm{mF} = 10^{-3}\ \mathrm{F} = 1000\ \mu\mathrm{F}$; $1\ \mu\mathrm{F} = 10^{-6}\ \mathrm{F}$).

26.1 Definition of Capacitance

The Symbol of Capacitor

- Parallel-plate capacitor connected to battery.

(b) is a circuit diagram.



- The symbol of capacitors in circuits.

26.1 Definition of Capacitance

Type of capacitors

1. Parallel-Plate Capacitor
2. Cylindrical Capacitor
3. Spherical Capacitor

26.2 Calculating Capacitance

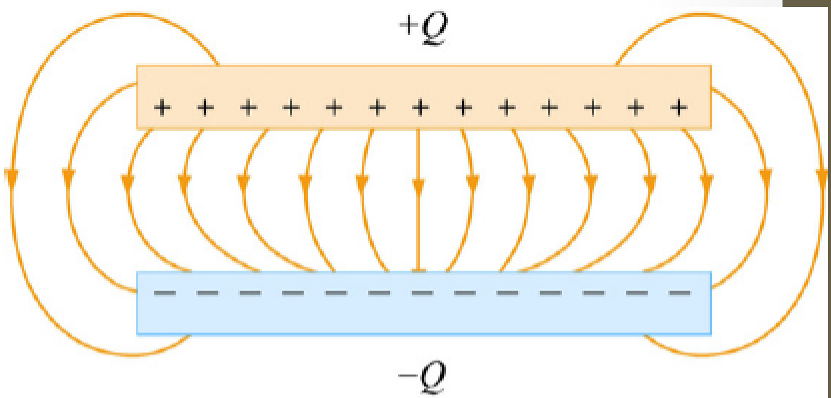
Parallel-Plate Capacitor

Two metallic plates of equal area A separated by a distance d.

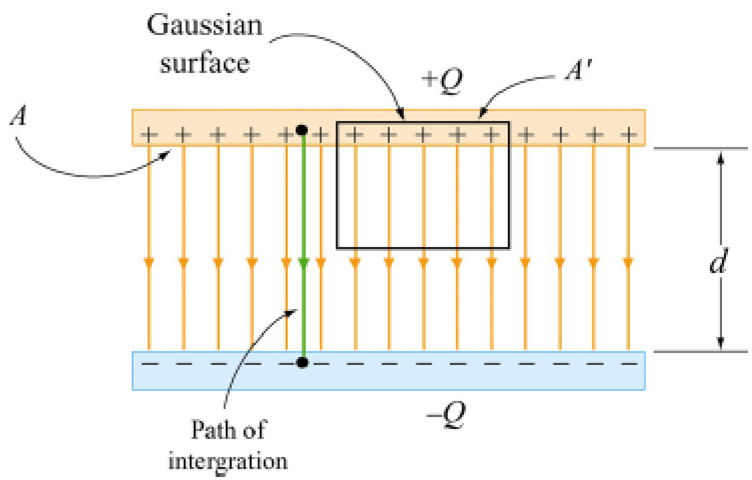
The top plate carries a charge +Q while the bottom plate carries a charge –Q.

The charging of the plates can be accomplished by means of a battery which produces a potential difference. Thus, the capacitance of the system.

$$\boxed{C = \frac{Q}{|\Delta V|} = \frac{\varepsilon_0 A}{d} \qquad \text{(parallel plate)}}$$



The electric field between the plates of a parallel-plate capacitor



26.2 Calculating Capacitance

$$\boxed{C = \frac{Q}{|\Delta V|} = \frac{\varepsilon_0 A}{d} \qquad \text{(parallel plate)}}$$

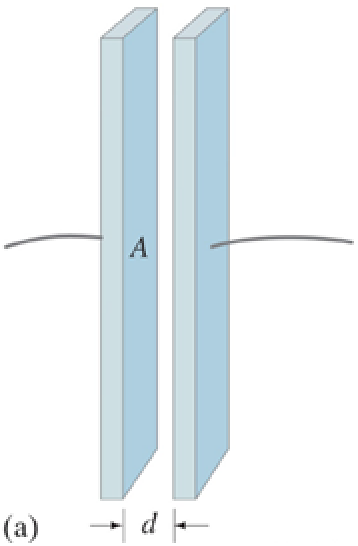
Where:

ε_0 (the ability of a substance to store electrical energy in an electric field) the value of the permittivity for air which is

8.84×10^{-12} F/m.

A area of plate

d distance between the plates



26.2 Calculating Capacitance

The value of the electric field between the plates is:

$$E = \frac{\sigma}{\epsilon_0} = \frac{Q}{\epsilon_0 A}$$

Because the field between the plates is uniform, the magnitude of the potential difference between the plates equals Ed

$$\Delta V = Ed = \frac{Qd}{\epsilon_0 A}$$

$$C = \frac{Q}{\Delta V} = \frac{Q}{Qd/\epsilon_0 A}$$

$$\boxed{C = \frac{\epsilon_0 A}{d}}$$

That is, the capacitance of a parallel-plate capacitor is proportional to the area of its plates and inversely proportional to the plate separation.

26.3 Combinations of Capacitors

Type of Connections

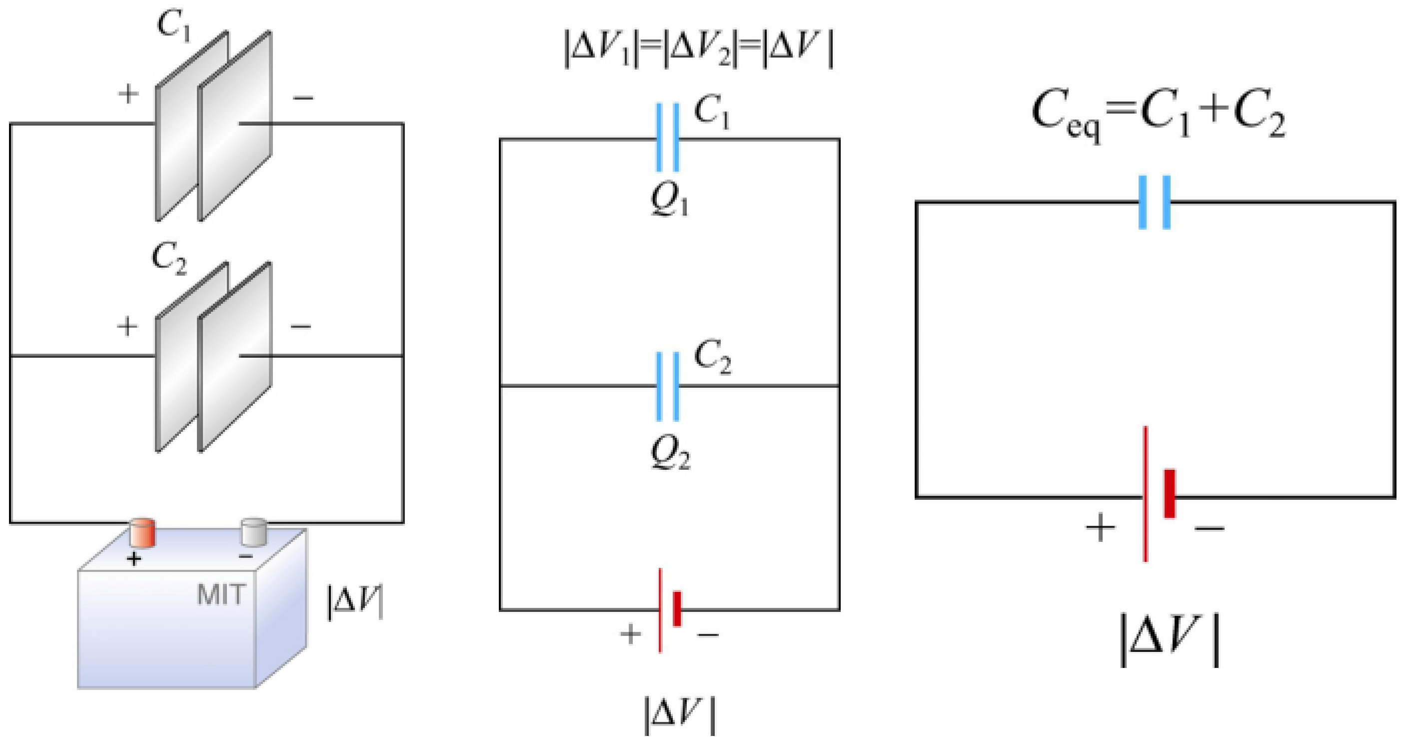
There are two types of connections of capacitors in an electric circuit.

1. Parallel Connection
2. Series Connection

26.3 Combinations of Capacitors

1. Parallel Connection

- Suppose we have two capacitors C1 with charge Q1 and C2 with charge Q2 that are connected in parallel:



Capacitors in parallel and an equivalent capacitor.

26.3 Combinations of Capacitors

1. Parallel Connection

- The left plates of both capacitors C1 and C2 are connected to the positive terminal of the battery and have the same electric potential as the positive terminal. Similarly, both right plates are negatively charged and have the same potential as the negative terminal. Thus, the potential difference $|\Delta V|$ is the same across each capacitor. This gives

$$C_1 = \frac{Q_1}{|\Delta V|}, \qquad C_2 = \frac{Q_2}{|\Delta V|}$$

26.3 Combinations of Capacitors

1. Parallel Connection

- These two capacitors can be replaced by a single equivalent capacitor C_{eq} with a total charge Q supplied by the battery. Q is shared by the two capacitors.

$$Q = Q_1 + Q_2 = C_1 |\Delta V| + C_2 |\Delta V| = (C_1 + C_2)|\Delta V|$$

- The equivalent capacitance.

$$C_{\text{eq}} = \frac{Q}{|\Delta V|} = C_1 + C_2$$

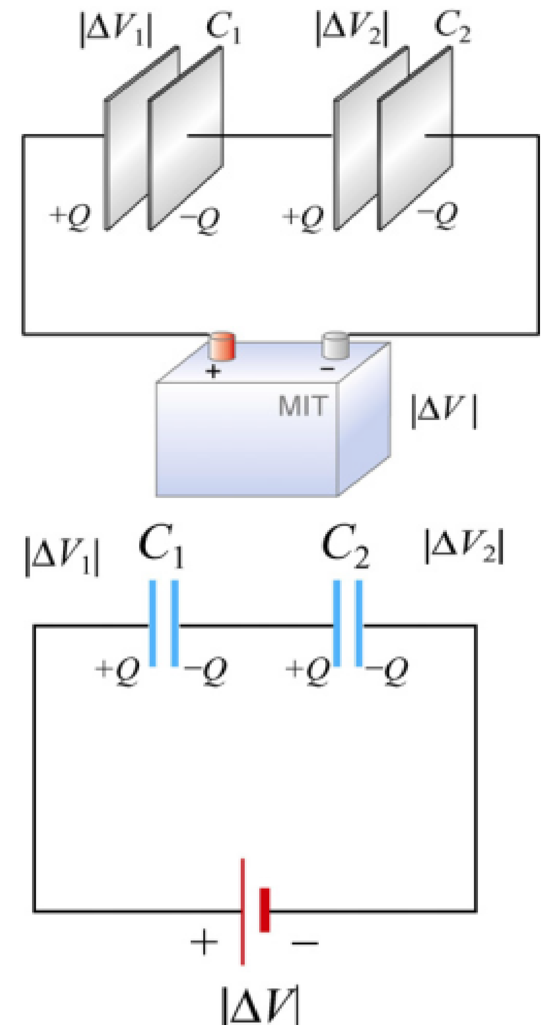
- The generalization to any number of capacitors

$$\boxed{C_{\text{eq}} = C_1 + C_2 + C_3 + \cdots + C_N = \sum_{i=1}^{N} C_i \qquad \text{(parallel)}}$$

26.3 Combinations of Capacitors

2. Series Connection

- Suppose two initially uncharged capacitors C1 and C2 are connected in series.
- A potential difference $|\Delta V|$ is then applied across both capacitors.
- The left plate of capacitor C1 is connected to the positive terminal of the battery and becomes positively charged with a charge +Q, while the right plate of capacitor C2 is connected to the negative terminal and becomes negatively charged with charge –Q as electrons flow in.
- What about the inner plates? They were initially uncharged; now the outside plates each attract an equal and opposite charge. So the right plate of capacitor C1 will acquire a charge –Q and the left plate of capacitor +Q.



Capacitors in series

26.3 Combinations of Capacitors

2. Series Connection

- The potential differences across capacitorsC1 and C2 are

$$|\Delta V_1| = \frac{Q}{C_1}, \quad |\Delta V_2| = \frac{Q}{C_2}$$

- the total potential difference is simply the sum of the two individual potential differences:

$$|\Delta V| = |\Delta V_1| + |\Delta V_2|$$

26.3 Combinations of Capacitors

2. Series Connection

- The total potential difference across any number of capacitors in series connection is equal to the sum of potential differences across the individual capacitors.
- These two capacitors can be replaced by a single equivalent capacitor Ceq= Q/ |ΔV|.

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

- The equivalent capacitance for two capacitors in series becomes

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

26.3 Combinations of Capacitors

2. Series Connection

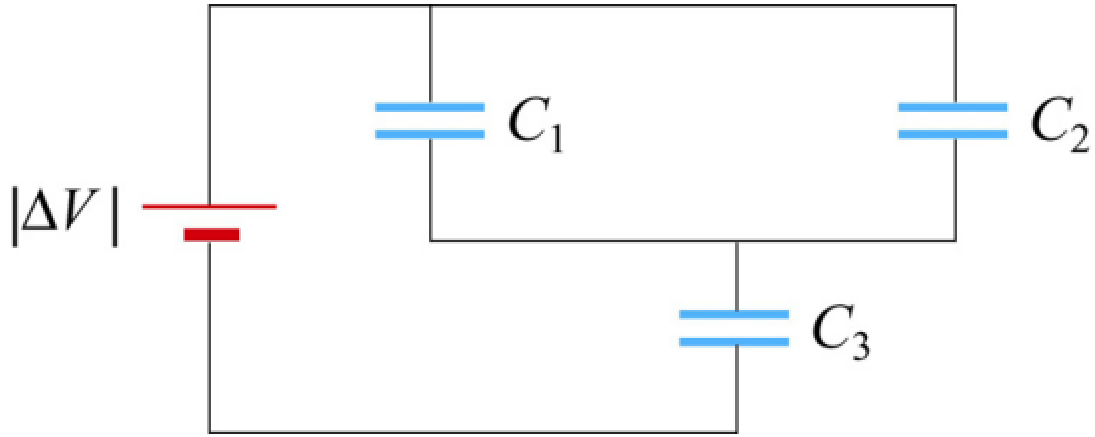
- The generalization to any number of capacitors connected in series is

$$\boxed{\frac{1}{C_{\text{eq}}} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots + \frac{1}{C_N} = \sum_{i=1}^{N} \frac{1}{C_i} \qquad (\text{series})}$$

26.3 Combinations of Capacitors

Example of Equivalent Capacitance (1)

Find the equivalent capacitance for the combination of capacitors shown in Figure below

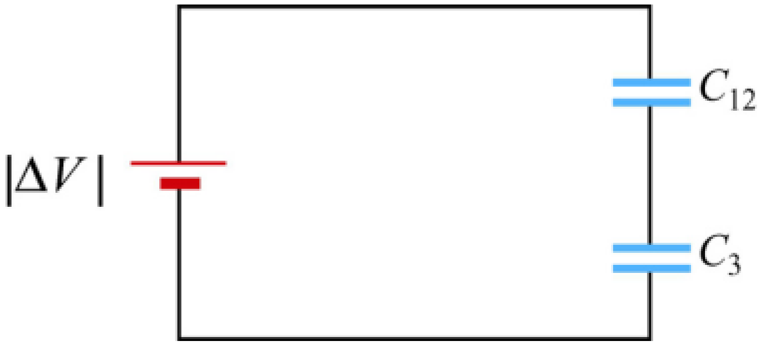


26.3 Combinations of Capacitors

Example of Equivalent Capacitance (1)

- Since C1 and C2 are connected in parallel, their equivalent capacitance C12 is given by

$$C_{12} = C_1 + C_2$$



26.3 Combinations of Capacitors

Example of Equivalent Capacitance (1)

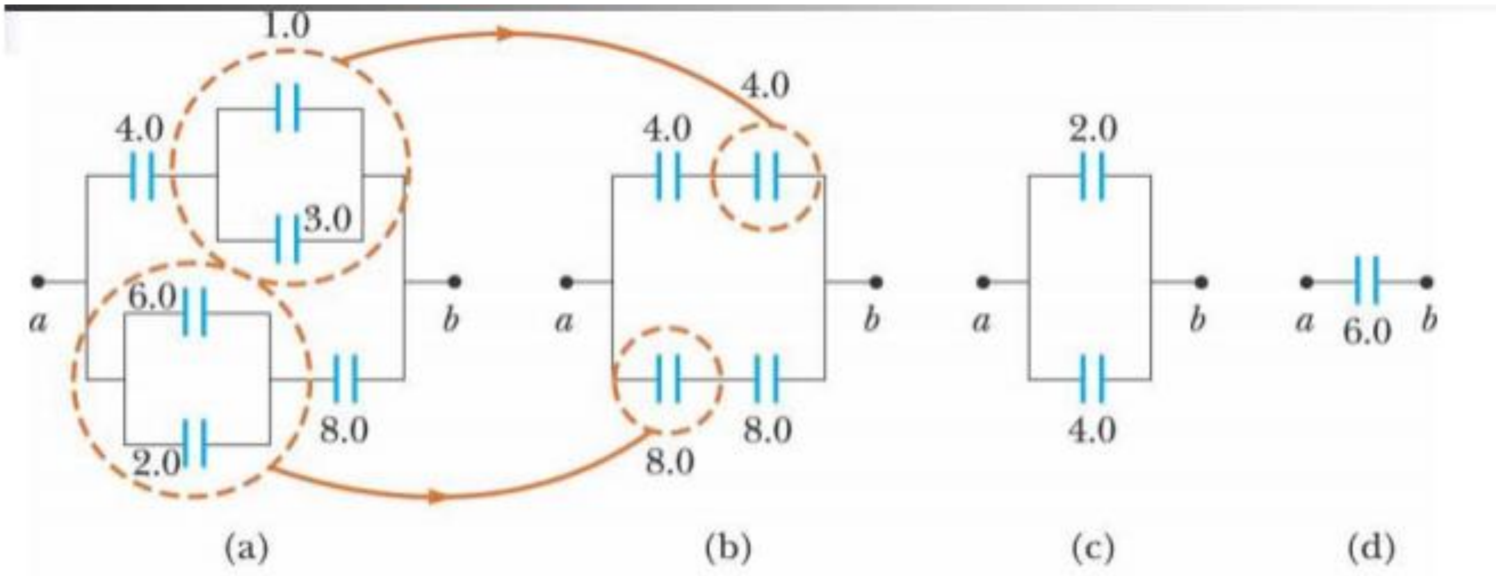
- Now capacitor C12 is in series with C3.the equivalent capacitance C123 is given by

$$\frac{1}{C_{123}} = \frac{1}{C_{12}} + \frac{1}{C_3}$$

$$\boxed{C_{123} = \frac{C_{12}C_3}{C_{12}+C_3} = \frac{(C_1+C_2)C_3}{C_1+C_2+C_3}}$$

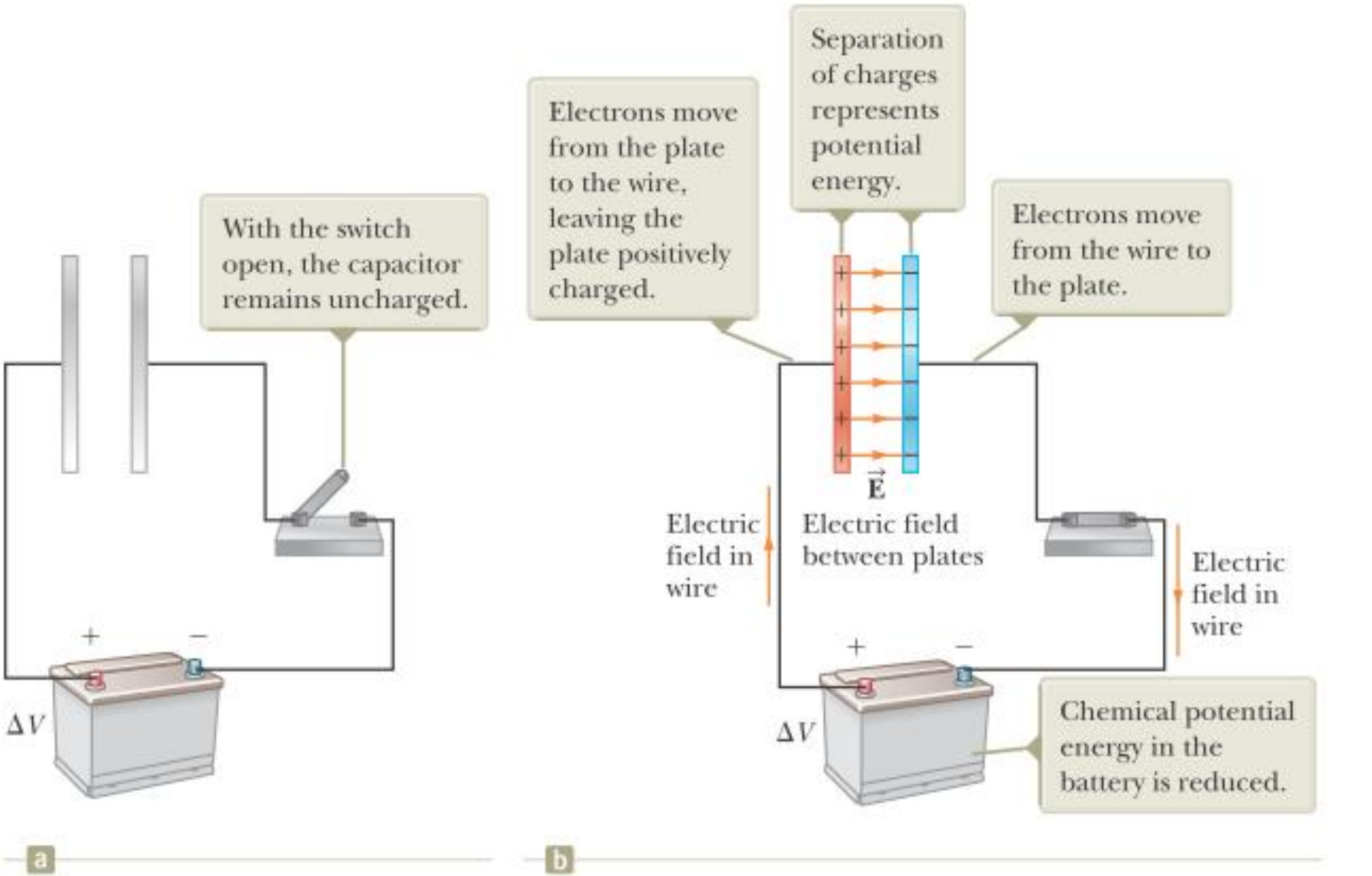
26.3 Combinations of Capacitors

Example of Equivalent Capacitance (2)



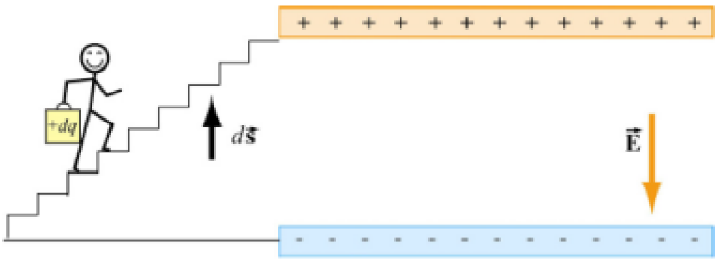
- The 1.0-μF and 3.0-μF capacitors are in parallel as are the 6.0-μF and 2.0-μF capacitors
- These parallel combinations are in series with the capacitors next to them
- The series combinations are in parallel and the final equivalent capacitance can be found

26.4 Energy Stored in a Charged Capacitor



26.4 Energy Stored in a Charged Capacitor

- A charged capacitor not only stores charge, but also energy.
- The amount of energy stored is equal to the work done to charge it. During the charging process, the battery does work to remove charges from one plate and deposit them onto the other.



Work is done by an external agent in bringing *+dq from the negative plate and depositing the charge on the positive plate.*

- Suppose the amount of charge on the top plate at some instant is +q, and the potential difference between the two plates is $|\Delta V|=q/C$.

26.4 Energy Stored in a Charged Capacitor

- the amount of work done to overcome electrical repulsion is $dW = |\Delta V|\, dq$. If at the end of the charging process, the charge on the top plate is $+Q$ then the total amount of work done in this process is

$$W = \int_0^Q dq\, |\Delta V| = \int_0^Q dq\, \frac{q}{C} = \frac{1}{2}\frac{Q^2}{C}$$

- This is equal to the electrical potential energy U_E of the system

$$\boxed{U_E = \frac{1}{2}\frac{Q^2}{C} = \frac{1}{2} Q |\Delta V| = \frac{1}{2} C |\Delta V|^2}$$

26.5 Capacitors with Dielectrics

- In many capacitors there is an insulating material such as paper or plastic between the plates. Such material, called a dielectric.
- used to maintain a physical separation of the plates. Since dielectrics break down less readily than air, charge leakage can be minimized, especially when high voltage is applied.

26.5 Capacitors with Dielectrics

- Experimentally it was found that capacitance C increases when the space between the conductors is filled with dielectrics.
- Dialectrics increase the amount of charge a capacitor can hold, at a given voltage. The molecules in a dielectric tend to become oriented in a way that reduces the external field.
- This means that the electric field within the dielectric is less than it would be in air, allowing more charge to be stored for the same potential.

26.5 Capacitors with Dielectrics

- When a dielectric material is inserted to completely fill the space between the plates, the capacitance increases to

$$C = \kappa_e C_0$$

Where:

- Ke is called the dielectric constant.
- C_0 is a capacitance when there is no material between the plates- (air).

26.5 Capacitors with Dielectrics

- Capacitance of a parallel-plate capacitor filled with dielectric K:

$$C = K\epsilon_0 \frac{A}{d}$$

where K_e called the dielectric constant.

26.5 Capacitors with Dielectrics

- some dielectric materials with their dielectric constant. Experiments indicate that all dielectric materials have $K_e > 1$.

Material	κ_e
Air	1.00059
Paper	3.7
Glass	4–6
Water	80

26.5 Capacitors with Dielectrics

The Advantages of Dielectrics

Dielectrics provide the following advantages:

- Increase in capacitance.
- Increase the maximum operating voltage.
- Possible mechanical support between the plates
    - Allows plates to be close together without touching.
    - This decreases d and increases C.

26.5 Capacitors with Dielectrics

The Factors of Capacitance

- The capacitance does not depend on the voltage; it is a function of the geometry and materials of the capacitor.
- **Capacitance depends on THREE factors**
  - Area
  - Separation (think coulomb force)
  - Material

Summary

- Definition of Capacitance
- Calculating Capacitance
- Combinations of Capacitors; parallel & series
- Energy Stored in a Charged Capacitor
- Capacitors with Dielectrics

The End