Definition of Capacitance

The **capacitance**, *C*, of a capacitor is defined The capacitance of a capacitor is the amount of charge the capacitor can store per unit of potential difference.

The SI unit of capacitance is the **farad** (F).

The farad is a large unit, typically you will see microfarads (mF) and picofarads (pF).

Capacitance will always be a positive quantity .The capacitance of a given capacitor is constant.

The capacitance is a measure of the capacitor's ability to store charge .

Makeup of a Capacitor

A capacitor consists of two conductors.

- These conductors are called plates.
- When the conductor is charged, the plates carry charges of equal magnitude and opposite directions.

A potential difference exists between the plates due to the charge.

Parallel Plate Capacitor

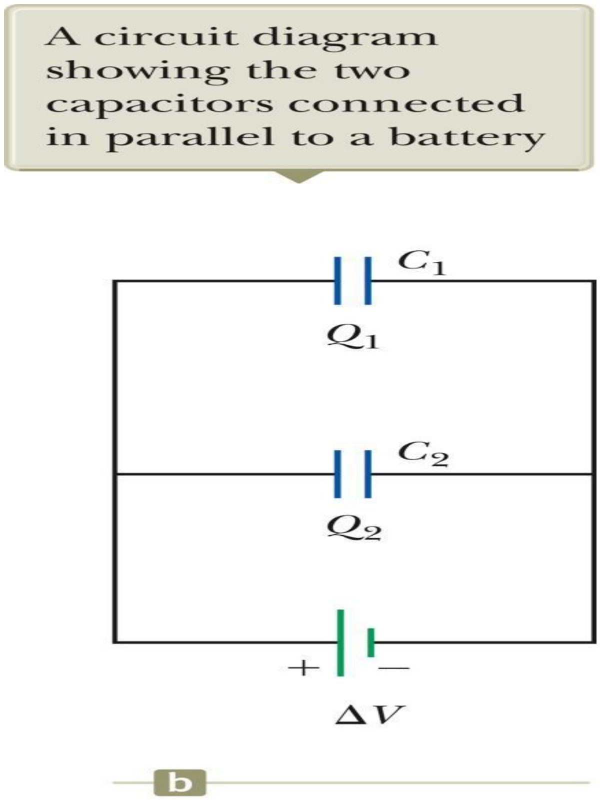
Each plate is connected to a terminal of the battery.

- The battery is a source of potential difference.

If the capacitor is initially uncharged, the battery establishes an electric field in the connecting wires.

The capacitors can be replaced with one capacitor with a capacitance of *equivalent capacitor* (C_{eq}.) .

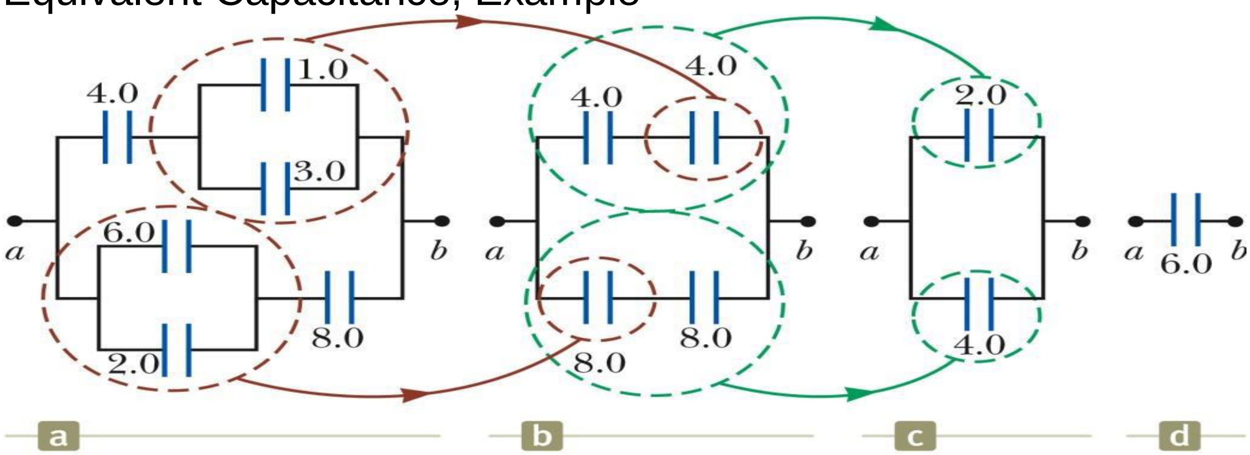
- The C_{eq}. must have exactly the same external effect on the circuit as the original capacitors



$C_{eq} = C_1 + C_2 + C_3 + \ldots$

The equivalent capacitance of a parallel combination of capacitors is greater than any of the individual capacitors.

Equivalent Capacitance, Example



The 1.0-mF and 3.0-mF capacitors are in parallel as are the 6.0-mF and 2.0-mF 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.

Capacitance –Parallel Plates

The charge density on the plates is $\sigma = Q/A$.
□A is the area of each plate, the area of each plate is equal

□Q is the charge on each plate, equal with opposite signs

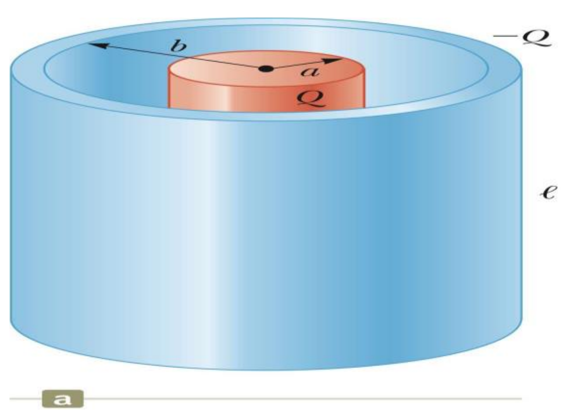
The electric field is uniform between the plates and zero elsewhere.
The capacitance is proportional to the area of its plates and inversely proportional to the distance between the plates./

$$C = Q/V = Q/Ed = Q/ \; Qd/\varepsilon_o A = \varepsilon_o A/d$$

Capacitance of a Cylindrical Capacitor

$$V = -2k_e□\lambda \ln (b/a)$$

Where □$\lambda = Q/\ell$
The capacitance is□ $C=Q/V=$ □ ℓ /2 k ln (b /a) □ □ □



Capacitance of a Spherical Capacitor

The potential difference will be kQ(1/b-1/a)

The capacitance will be C=Q/V = ab/k(b-a)

Capacitors in Parallel,

The capacitors can be replaced with one capacitor with a capacitance of *C*eq.

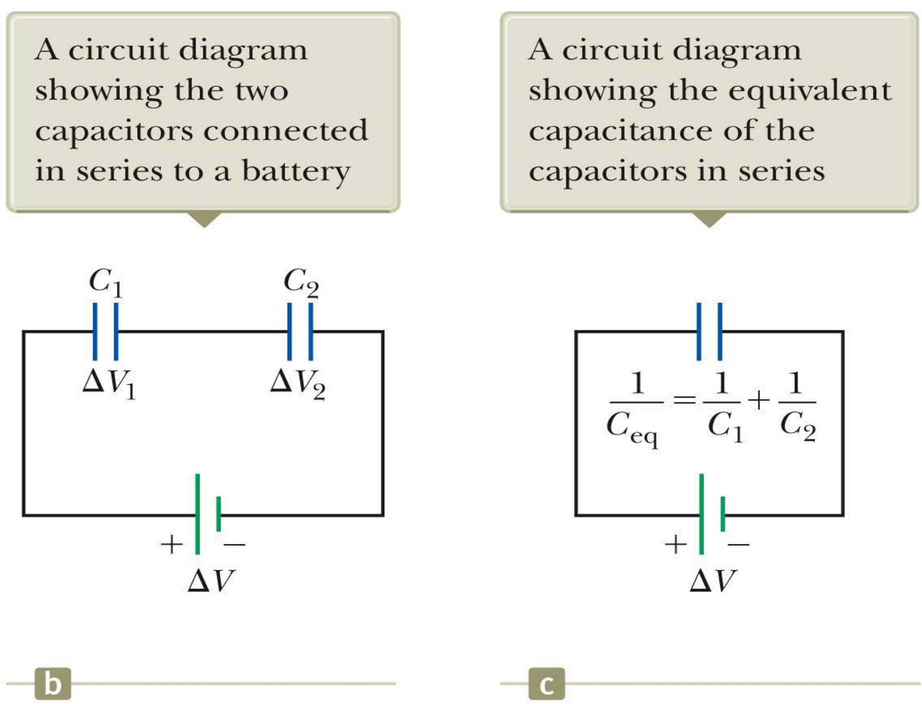
The *equivalent capacitor*must have exactly the same external effect on the circuit as the original capacitors.

Capacitors in Series

An equivalent capacitor can be found that performs the same function as the series combination.

The charges are all the same.

Q1 = Q2= Q



Energy Stored in a Capacitor

Assume the capacitor is being charged and, at some point, has a charge(*q)* on it.
The work needed to transfer a charge from one plate to the other is d W=V dq =q/c dq
The work required is the area of the tan rectangle.
The total work required is

$$W = \int (q/C)\, dq = Q /2\, C$$

The work done in charging the capacitor appears as electric potential energy

$$U=Q^2/2C = \tfrac{1}{2} QV = 1/2CV^2$$

This applies to a capacitor of any geometry.
The energy stored increases as the charge increases and as the potential difference increases.
In practice, there is a maximum voltage before discharge occurs between the plates.

The energy can be considered to be stored in the electric field . For a parallel-plate capacitor, the energy can be expressed in terms of the field as

$$U= \tfrac{1}{2} (\varepsilon_o A d)E^2.$$

It can also be expressed in terms of the energy density (energy per unit volume)

$$\text{The energy density} = \tfrac{1}{2}\, \varepsilon_o\, E^2.$$

Capacitors with Dielectrics

A dielectric is a nonconducting material that, when placed between the plates of a capacitor, increases the capacitance. Dielectrics include rubber, glass, and waxed paper

With a dielectric, the capacitance becomes $C = \kappa C_o$.

κ is the dielectric constant of the material.

The capacitance increases by the factor κwhen the dielectric completely fills the region between the plates.

If the capacitor remains connected to a battery, the voltage across the capacitor necessarily remains the same.
If the capacitor is disconnected from the battery, the capacitor is an isolated system and the charge remains the same.

For a parallel-plate capacitor,
$C = \kappa (\varepsilon_o A) / d$
*d*is limited by the electric discharge that could occur though the dielectric medium separating the plates.
In theory, *c*ould be made very small to create a very large capacitance.
In practice, there is a limit to *d*.

For a given *d*, the maximum voltage that can be applied to a capacitor without causing a discharge depends on the **dielectric strength** of the material.