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Welcome
to
PHYS 212: Physics

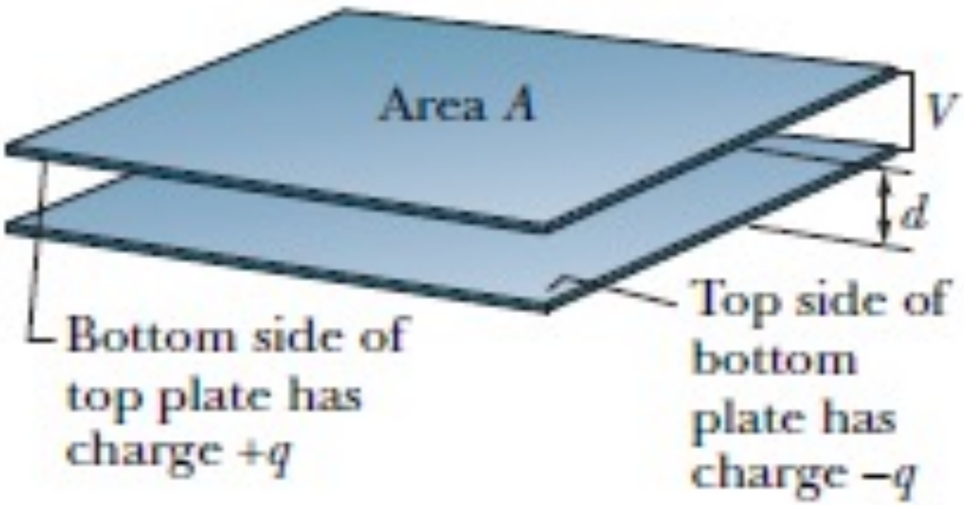
Chapter#25

Capacitance

Topics

- Capacitance.
- Calculating the Capacitance.
- Capacitors in Parallel & in Series.
- Energy Stored in a Electric Field.
- Capacitor with Dielectric.

25-1 Capacitance



(a)

A capacitor consists of two isolated conductors (the plates) with charges ***+q*** and ***-q***. Its capacitance ***C*** is defined from

$$q = CV.$$

where **V** is the potential difference between the plates.

Capacitance

The proportionality constant **C** is called **the capacitance of the capacitor**. **Its value depends only on the geometry of the plates and not on their charge or potential difference.**

The capacitance is a measure of how much charge must be put on the plates to produce a certain potential difference between them: **The greater the capacitance, the more charge is required**.

The **SI unit** of capacitance is the coulomb per volt, name the farad(F):

1 farad =1 F =1 coulomb per volt = 1 C/V.

the microfarad (1 μF $=10^{-6}$ F) and the picofarad (1 pF $=10^{-12}$ F).

Checkpoint 1

Does the capacitance C of a capacitor increase, decrease, or remain the same (a) when the charge q on it is doubled and (b) when the potential difference V across it is tripled?

25-2 Calculating the Capacitance

- The capacitance depends on geometrical factors like the plate area (**A**) and the separation between the plates (**d**).

$$C = \frac{\varepsilon_0 A}{d}$$

So, **C** increases as **A** increases or **d** decreases.
Here, permittivity constant ε_0 is given as

$$\varepsilon_0 = 8.85 \times 10^{-12} F/m$$

- If there is **a single isolated conducting sphere** of radius **R**, then its capacitance is

$$C = 4\pi\varepsilon_0 R$$

Quick Quiz 26.2 Many computer keyboard buttons are constructed of capacitors, as shown in Figure 26.5. When a key is pushed down, the soft insulator between the movable plate and the fixed plate is compressed. When the key is pressed, the capacitance (a) increases, (b) decreases, or (c) changes in a way that we cannot determine because the complicated electric circuit connected to the keyboard button may cause a change in ΔV.

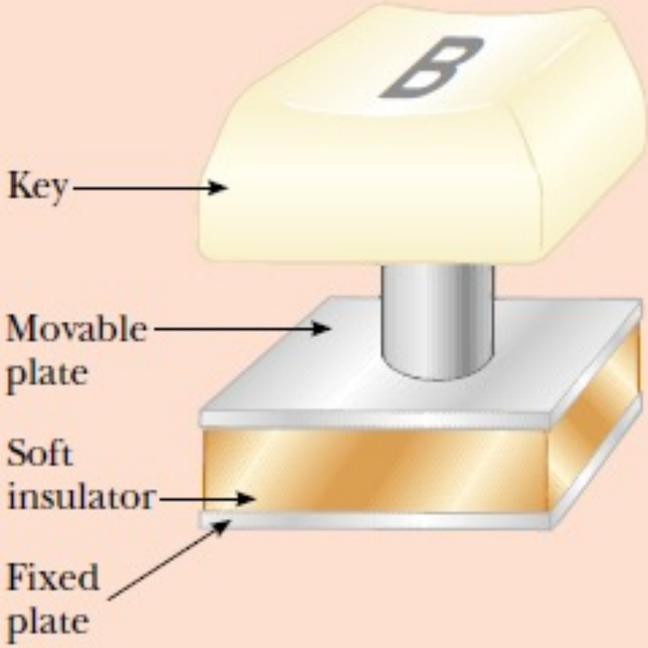


Figure 26.5 (Quick Quiz 26.2) One type of computer keyboard button.

Problem-1:

A parallel-plate capacitor with air between the plates has an area $A = 2.00 \times 10^{-4}\ \text{m}^2$ and a plate separation $d = 1.00$ mm. Find its capacitance.

Answer:

1.77 pF

Problem-2:

The two metal objects in Fig. 25-24 have net charges of $+70\ \text{pC}$ and $-70\ \text{pC}$, which result in a $20\ \text{V}$ potential difference between them. (a) What is the capacitance of the system? (b) If the charges are changed to $+200\ \text{pC}$ and $-200\ \text{pC}$, what does the capacitance become? (c) What does the potential difference become?

Figure 25-24

Answer:

(a) The capacitance of the system is $C = 3.5\text{pF}$.

(b) The capacitance is independent of q; it is still 3.5 pF.

(c) The potential difference becomes $\Delta V = 57\ \text{V}$.

Problem-3:

A parallel-plate capacitor has circular plates of 8.20 cm radius and 1.30 mm separation.

(a) Calculate the capacitance.

(b) Find the charge for a potential difference of 120 V.

Answer:

(a) $C = 1.44\times10^{-10}\,\mathrm{F} = 144\ \mathrm{pF}$.

(b) $q = 1.73 \times 10^{-8}\ \mathrm{C} = 17.3\ \mathrm{nC}$.

LEARN Capacitance depends only on geometric factors, namely, the plate area and plate separation.

Problem-4:

You have two flat metal plates, each of area 1.00 m^2, with which to construct a parallel-plate capacitor. (a) If the capacitance of the device is to be 1.00 F, what must be the separation between the plates? (b) Could this capacitor actually be constructed?

Answer:

(a) $d = 8.85 \times 10^{-12} \text{ m}$.

25-3 Capacitors in Parallel & in Series

Capacitors in Parallel

When a potential difference V is applied across several capacitors connected in parallel, that potential difference V is applied across each capacitor. The total charge q stored on the capacitors is the sum of the charges stored on all the capacitors.

$$q_1 = C_1V, \quad q_2 = C_2V, \quad \text{and} \quad q_3 = C_3V.$$

The total charge on the parallel combination of Fig. 25-8*a* is then

$$q = q_1 + q_2 + q_3 = (C_1 + C_2 + C_3)V.$$

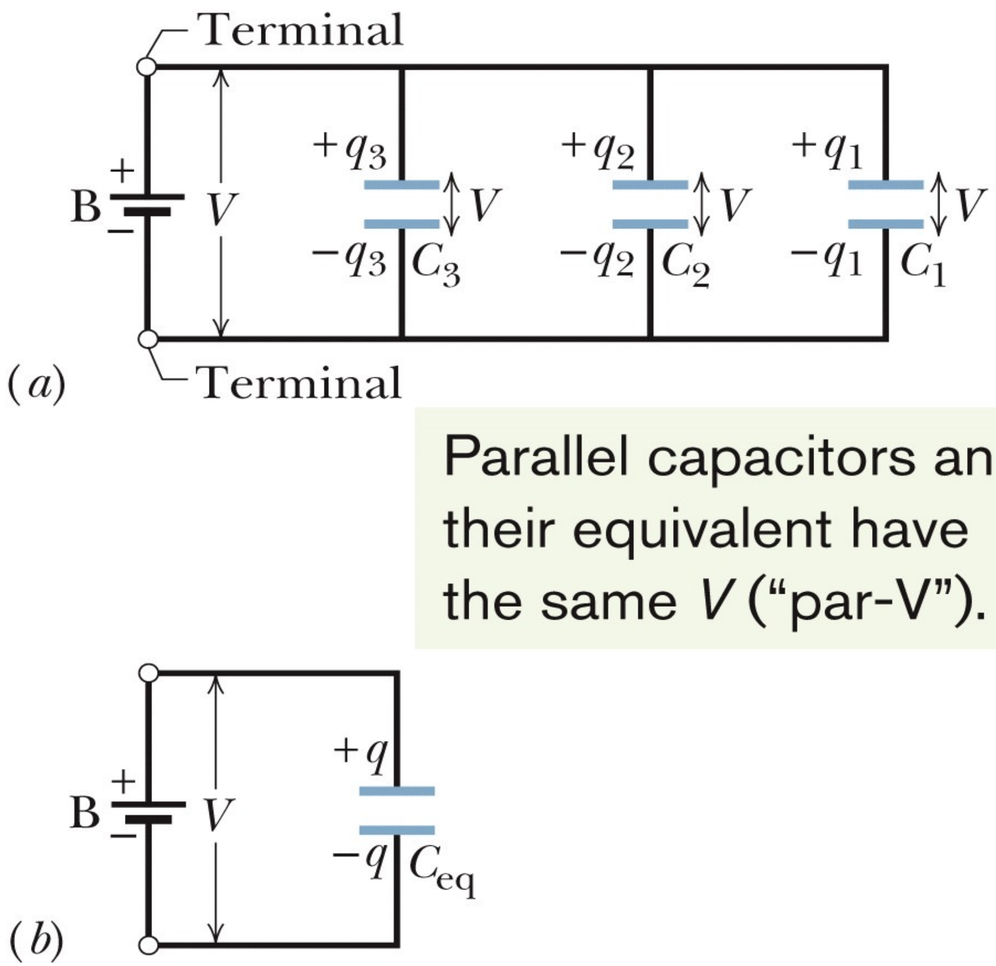
The equivalent capacitance, with the same total charge q and applied potential difference V as the combination, is then

$$C_{eq} = \frac{q}{V} = C_1 + C_2 + C_3,$$

a result that we can easily extend to any number n of capacitors, as

$$C_{eq} = \sum_{j=1}^{n} C_j \quad (n \text{ capacitors in parallel}).$$

Capacitors in Parallel



Parallel capacitors and their equivalent have the same *V* ("par-V").

Capacitors connected in parallel can be replaced with an equivalent capacitor that has the same *total* charge *q* and the same potential difference *V* as the actual capacitors.

Problem-5:

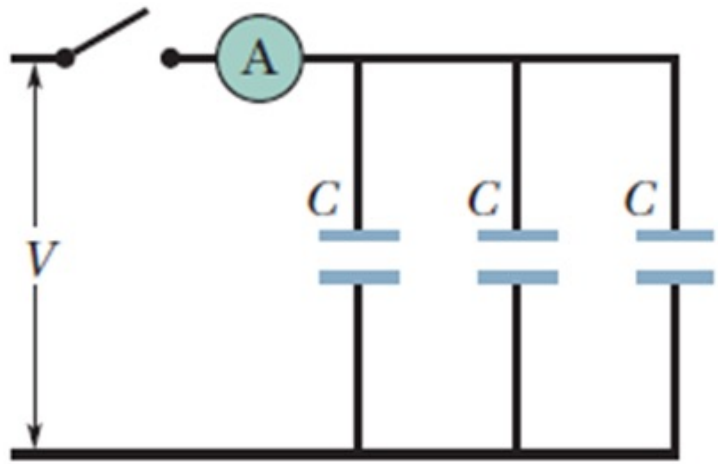
How many 1.00 μF capacitors must be connected in parallel to store a charge of 1.00 C with a potential of 110 V across the capacitors?

Answer:

$$N = 9.09 \times 10^3$$

Problem-6:

Each of the uncharged capacitors in Fig. 25-27 has a capacitance of 25.0 μF. A potential difference of $V = 4200$ V is established when the switch is closed. How many coulombs of charge then pass through meter A?



Answer:

$$q = 0.315\text{C}$$

Capacitors in Series

When a potential difference V is applied across several capacitors connected in series, the capacitors have identical charge q. The sum of the potential differences across all the capacitors is equal to the applied potential difference V.

$$V_1 = \frac{q}{C_1}, \quad V_2 = \frac{q}{C_2}, \quad \text{and} \quad V_3 = \frac{q}{C_3}.$$

The total potential difference V due to the battery is the sum

$$V = V_1 + V_2 + V_3 = q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right).$$

The equivalent capacitance is then

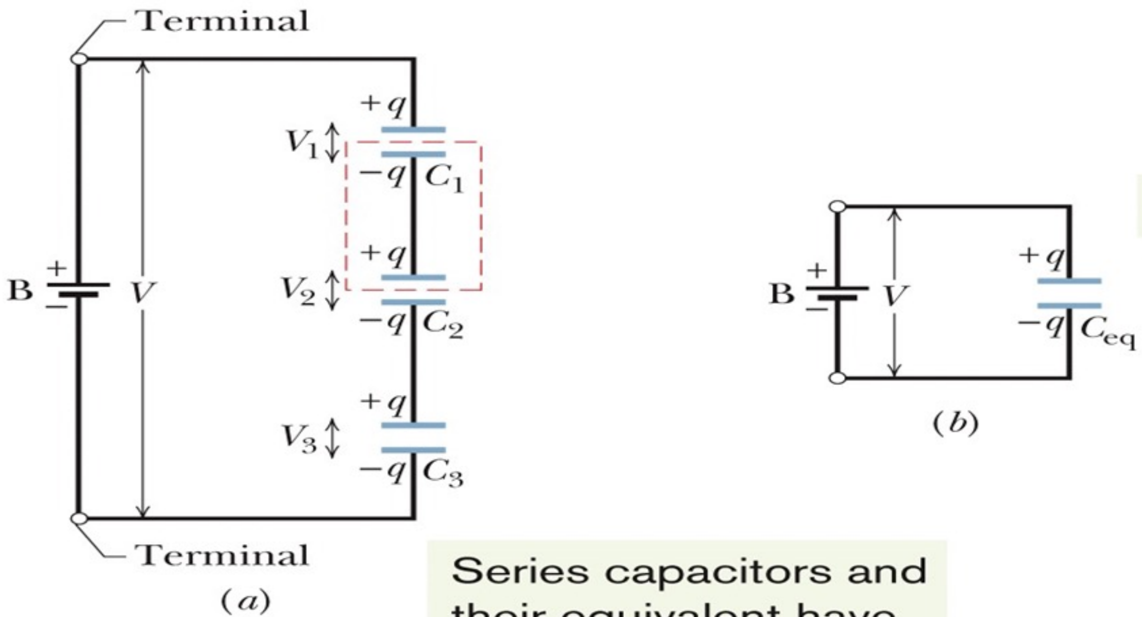
$$C_{eq} = \frac{q}{V} = \frac{1}{1/C_1 + 1/C_2 + 1/C_3},$$

or

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}.$$

$$\frac{1}{C_{eq}} = \sum_{j=1}^{n} \frac{1}{C_j} \quad (n \text{ capacitors in series}).$$

Capacitors in Series



Series capacitors and their equivalent have the same q (“seri-q”).

Capacitors that are connected in series can be replaced with an equivalent capacitor that has the same charge q and the same *total* potential difference V as the actual series capacitors.

Quick Quiz 26.3 Two capacitors are identical. They can be connected in series or in parallel. If you want the *smallest* equivalent capacitance for the combination, do you connect them in (a) series, in (b) parallel, or (c) do the combinations have the same capacitance?

Problem-7:

In Fig. 25-28, find the equivalent capacitance of the combination. Assume that C_1 is 10.0 μF, C_2 is 5.00 μF, and C_3 is 4.00 μF.

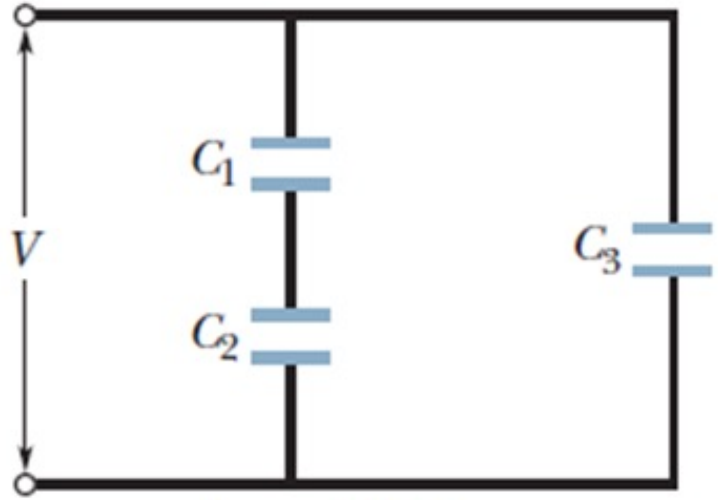


Figure 25-28

Answer:

$$C_{eq} = 7.33\ \mu\text{F}$$

Problem-8:

In Fig. 25-29, find the equivalent capacitance of the combination. Assume that $C_1 = 10.0\ \mu\text{F}$, $C_2 = 5.00\ \mu\text{F}$, and $C_3 = 4.00\ \mu\text{F}$.

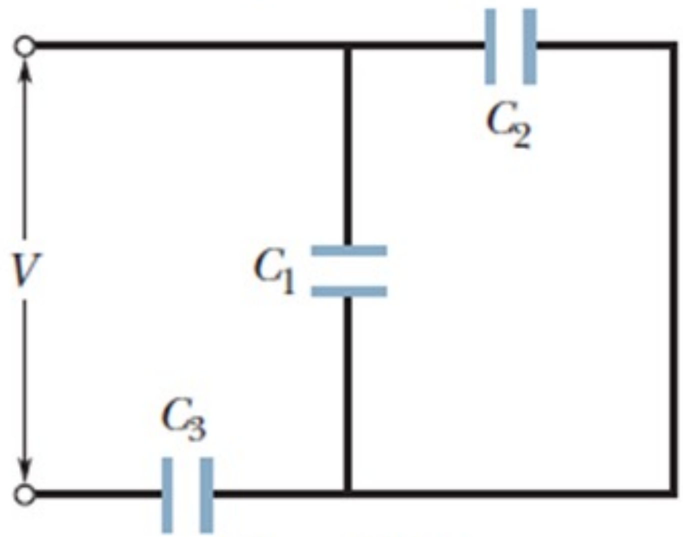


Figure 25-29

Answer:

$$C_{eq} = 3.16\,\mu\text{F}.$$

25-4 Energy stored in a Electric Field

❖The **electric potential energy *U*** of a charged capacitor,

$$U = \frac{q^2}{2C} \quad \text{(potential energy).}$$

and,

$$U = \tfrac{1}{2}CV^2 \quad \text{(potential energy).}$$

is equal to the work required to charge the capacitor.

❖This energy can be associated with the capacitor's electric field ***E***.

The potential energy of a charged capacitor may be viewed as being stored in the electric field between its plates.

Energy stored in a Electric Field

❖Every electric field, in a capacitor or from any other source, has an associated stored energy.

❖In vacuum, the **energy density *u*** (potential energy per unit volume) **in a field of magnitude** ***E*** is

$$u = \frac{1}{2}\varepsilon_0 E^2 \quad \text{(energy density).}$$

Problem-10:

What capacitance is required to store an energy of $10\ \mathrm{kW \cdot h}$ at a potential difference of $1000\ \mathrm{V}$?

U=1/2CV^2

Answer:

$C = 72\,\mathrm{F}.$

Problem-11:

A 2.0 μF capacitor and a 4.0 μF capacitor are connected in parallel across a 300 V potential difference. Calculate the total energy stored in the capacitors.

U= 1/2CV^2

Answer:

$U = 0.27\,\text{J}.$

25-5 Capacitor with Dielectric

❖If the space between the plates of a capacitor is completely filled with a **dielectric material**, the capacitance **C** in vacuum (or in air) is multiplied by the material's **dielectric constant** κ, (Greek kappa) which is a number greater than **1**.

$$C_{new} = \kappa C_{air}$$

In a region completely filled by a dielectric material of dielectric constant κ, all electrostatic equations containing the permittivity constant ε_0 are to be modified by replacing ε_0 with $\kappa\varepsilon_0$.

Problem-12:

A parallel-plate capacitor has plates of dimensions 2.0 cm by 3.0 cm separated by a 1.0-mm thickness of paper.
$\kappa = 3.7$ for paper

(A) Find its capacitance.

Answer:

$C = \boxed{20 \text{ pF}}$

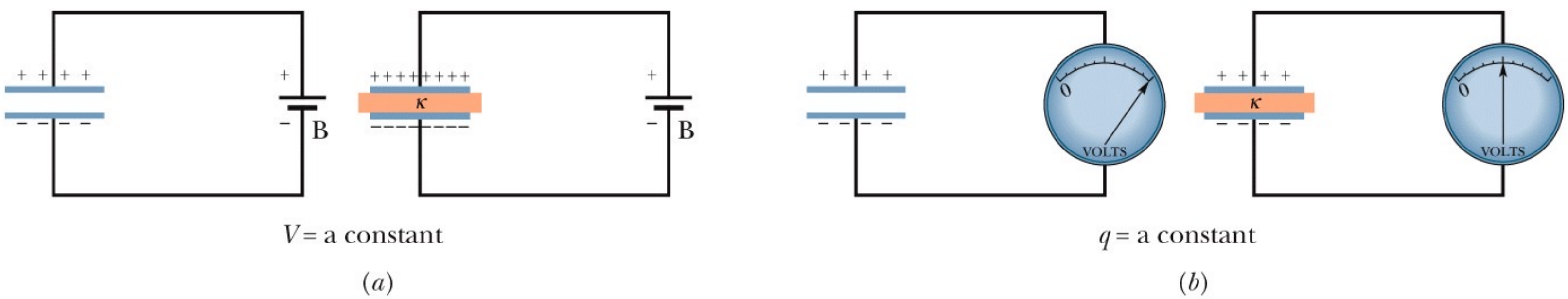
Problem-13:

An air-filled parallel-plate capacitor has a capacitance of 1.3 pF. The separation of the plates is doubled, and wax is inserted between them. The new capacitance is 2.6 pF. Find the dielectric constant of the wax.

Answer:

$\kappa = 4.0$.

Capacitor with Dielectric



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

❖If the **potential difference** between the plates of a capacitor is **maintained,** as by the presence of battery **B**,
the effect of a dielectric **is to increase the charge on the plates.**