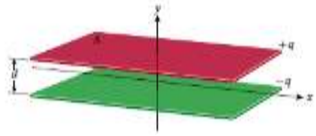
Unit Four . (Capacitors)



Electrical capacity: - The capacity of the capacitor to store the charge.
The capacitance is denoted (C) and measured in Farad (F).
Capacity is defined by:

$$C = \left|\frac{q}{\Delta V}\right|.$$

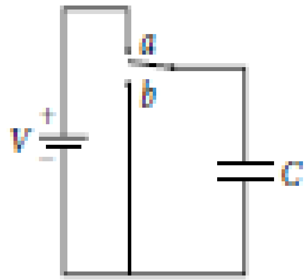
Forms of capacitors are a built-in capacitor, and a parallel plate capacitor.

Electric circuits for capacitors

The electrical circuit consists of simple wires or other conductive paths that connect the elements of the circuit.

Charge and discharge capacitor

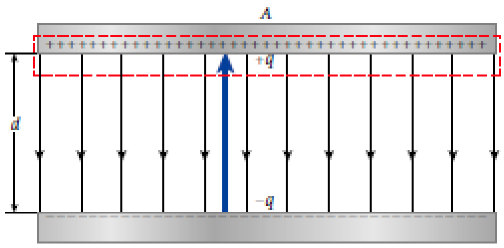
The capacitor is charged by connecting it to a battery or a constant electric potential power source.
The charge flows to the capacitor from the battery or power source until the electric potential difference in the capacitor is equal with electric potential Supplier.
If the capacitor is disconnected, it retains its charge and electric potential difference.
In the enclosed circuit: If the switch is in position (a), the circuit closes and the battery connects to the capacitor and the capacitor starts charging.
When the switch is in position (b), the capacitor plates are connected and the charge flows from one plate to another through the wire which It forms a physical connection between the plates .
when the charge on the plates dissipates, the electric potential difference between the plates decreases to zero.
The capacitor is said to have been discharged.



Parallel plates Capacitor

Its capacity is given by the following relationship: $C = \left|\frac{q}{\Delta V}\right| = \frac{\epsilon_0 A}{d}.$

From the relationship it is clear that the capacitance of this capacitor depends on: the area of the plates, the distance between the plates, and the nature of the Physical medium between the two plates.
Note: - The capacitor capacity is not affected by the amount of charge on it or the electric potential difference between its plates.



Example: - Calculate the area of the capacitor capacity (1μF)

Cylindrical Capacitor

Its capacity is given by the following relationship:

$$C=\left|\frac{q}{\Delta V}\right|=\frac{q}{\frac{q}{\epsilon_0 2\pi L}\ln\left(r_2/r_1\right)}=\frac{2\pi\epsilon_0 L}{\ln\left(r_2/r_1\right)}.$$

The capacity of this capacitor depends on its geometric shape only.

Spherical Capacitor

Its capacity is given by the following relationship: $C=4\pi\epsilon_0\frac{r_1 r_2}{r_2-r_1}.$

Its capacity also depends on the geometric shape only

If the conductor is single (i.e. its outer surface is infinite), then we have an insulated spherical conductor capacity, With the following relationship : $C=4\pi\epsilon_0 R.$

Q 1: What is the radius of an insulated spherical capacitor with a capacity of (1F)?

Q 2: - Spherical capacitor made of conductors and concentric, where the radius of the internal shield (r_1) and the radius of the outer shield (r_2). Another parallel plate capacitor made of the same material and two plates have the same surface area as the inner spherical capacitor.

Calculate the fractional ratio in the difference between the capacitors capacitance to the capacitance of the parallel plate capacitor that has the same separation between the diagonal halves of the spherical capacitor. ($d = r_2-r_1$).

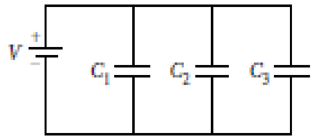
Q3: - Calculate the capacity of the planet (treated with Earth as an insulated spherical conductor with a radius of 6371km.

Capacitors in electrical circuits

First: Connect the capacitors in parallel:

• Equivalent capacity: -

$$C_{eq} = \sum_{i=1}^{n} C_i.$$



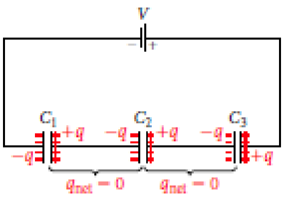
• Total charge and charge on each capacitor: -

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

$$q_1 = C_1\Delta V$$
$$q_2 = C_2\Delta V$$
$$q_3 = C_3\Delta V.$$

• The electric potential between the plates of each capacitor is equal to the total electric potential .

Second: Connect the capacitors in series:-



• Equivalent capacity: -

$$\frac{1}{C_{eq}} = \sum_{i=1}^{n} \frac{1}{C_i}.$$

• Electric charge: - fixed on each capacitor and equal to the total charge.

$$\Delta V = \frac{q}{C_{eq}}$$

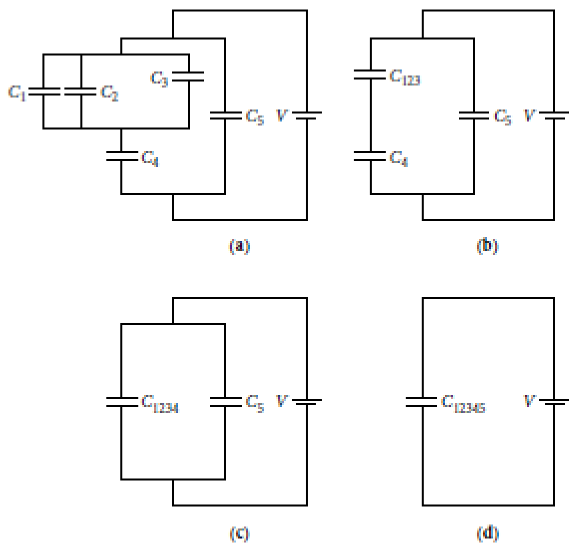
• electric potential difference: -

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

Question: - In the adjacent primary circuit (a) if the capacitance of each capacitor = 5µF.

Calculate: -

• Equivalent capacitance range of capacitors.



• Charge on each capacitor.

Energy stored in capacitors

$$U=\frac{1}{2}\frac{q^2}{C}=\frac{1}{2}C(\Delta V)^2=\frac{1}{2}q\Delta V.$$

A concept of electric energy density ($u=\frac{U}{\text{volume}}.$)

Compensation for volume and energy shall be:

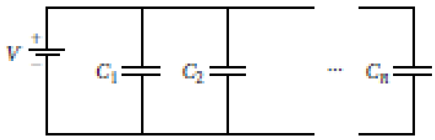
$$u=\frac{U}{Ad}=\frac{\frac{1}{2}C(\Delta V)^2}{Ad}=\frac{C(\Delta V)^2}{2Ad}.$$

Then

$$u=\frac{(\epsilon_0 A/d)(\Delta V)^2}{2Ad}=\frac{1}{2}\epsilon_0\left(\frac{\Delta V}{d}\right)^2.$$

The final compensation shall be as follows: $u=\frac{1}{2}\epsilon_0 E^2.$

Question: - How many capacitors are required to store energy (95.6J), the capacity of each capacitor (90 µF). All are connected in parallel via battery electric potential difference between its ends (160V).



Question: - A thunderstorm cloud width (2km) and length (3km) moving at an altitude (0.5km) over a flat area of the earth. What is the electric potential difference between the cloud and the ground if the cloud carries a charge of 160C and the ground is neutral?

Question: - A national ignition facility consisting of (192) power conditioning units, each of which contains (20) capacitors each (300µF) connected together in parallel and charged with a power source (24KV). The capacitors are charged over a period of time (90 s), then the laser is released by discharging all the energy stored in the capacitors within (40µs).

• How much energy is stored in the facility's capacitors?

• What is the average power released by the power modules during the laser pulse?

Cardiac Ventricular Defibrillator (AED)

Ventricular fibrillation is a condition in which the heart does not have a regular pattern, which prevents the heart from performing its function of maintaining regular blood circulation throughout the body.

The AED provides an electrical pulse to alert the heart to beat regularly.

The AED delivers 150J power through a pair of electrodes connected to the patient's chest .

This energy is stored by charging a capacitor through a special circuit of a low-voltage battery within (10 s) and the capacitor capacity is (100µF). Accordingly the charging capacity is: - $P = \frac{E}{t} = \frac{150\ \text{J}}{10\ \text{s}} = 15\ \text{W},$

This capacity is within a simple battery capacity.

This energy is discharged within (10ms) to be instantaneous capacity during the discharge of energy is: -

$$P = \frac{E}{t} = \frac{150\ \text{J}}{10\ \text{ms}} = 15\ \text{kW},$$

This capability falls within the capacity of a well-designed capacitor .

Capacitors and electrical insulators

When an insulator is placed between the flat capacitor plates, its capacity increases to equal: $C = \kappa C_{air}$

The value of the electric field becomes: $E = \frac{E_{air}}{\kappa} = \frac{q}{\kappa \varepsilon_o A} = \frac{q}{\varepsilon A}$

Note that ($\varepsilon = \kappa \varepsilon_o$)

The voltage difference becomes: $\Delta V = Ed = \frac{qd}{\kappa \varepsilon_o A}$

Thus the capacity with the insulator will be equal to the amount: $C = \frac{q}{\Delta V} = \frac{\kappa \varepsilon_o A}{d} = \kappa C_{air}$

Electrical Insulation Intensity: A characteristic of the ability of the insulating material to withstand the potential difference.

Note: - If the intensity of the electrical insulation exceeds the intensity of the electric field between the capacitor plates, the capacitor will be disrupted, where the capacitor then connects the charge between the plates via a spark. It is therefore useful to have a good capacitor designed without a specific capacity to withstand the required electric potential difference.

Question: - Parallel plate capacitor without dielectric capacity
($C = 2\mu F$) and connected to a differential battery (12V).
• Calculate the charge stored in the capacitor.

• Insert a dielectric ($\kappa = 2.5$) between the capacitor plates
To fill the space between them completely. Calculate the charge on the capacitor now

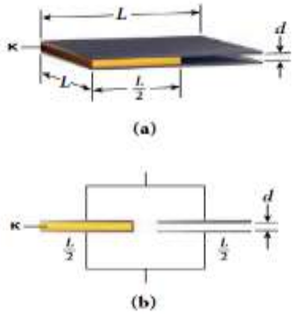
• If the insulation between the plates was removed. Calculate the charge and electric potential difference Between the plates when you keep the capacitor isolated. Justify your answer.

• Calculate the amount of change in electrical energy stored between the plates before and after insulation. Justify your answer.

Capacitor partially filled with dielectric

Question: - The parallel plate capacitor is connected to two squares with a side length (10cm) and the separation between them (0.25cm). Insert a dielectric between the two plates of constant electrical isolation (κ = 15) and a thickness equal to the distance between the plates. The width of the insulator is half the length of the plate (5cm). Calculate the capacity of this capacitor.

The solution :



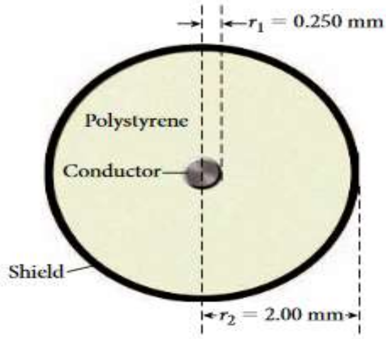
Coaxial cable capacity

A cable used to transmit television signals with minimal interference which transmits the signal very clearly. The coaxial cable is treated as a cylindrical capacitor since the charge resides on its surface.

Question: - A 20m coaxial cable consists of a conductor and a shield shielding a coaxial connector around the conductor. The space between the conductor and the shield is filled with material

Polystyrene has its own electrical insulation (2.6). See attached figure. Calculate: -

• Capacity of this capacitor

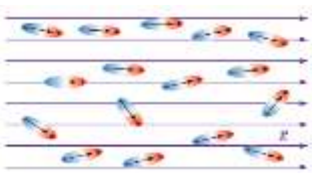


• Charge on the capacitor if connected to electric potential source (240V).

Electrical insulators

• Polarity: - It has a dipole torque because of its composition (eg water). When placed in the electric field, these molecules tend to align it.

(See Figure).



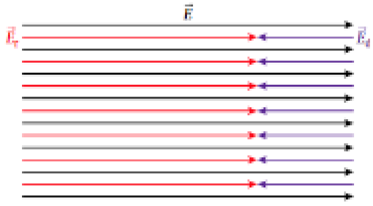
• Non-polar: - Atoms or molecules have no inherent dipole moment. Can be urged to be her

Bipolar torque via an external electric field because it may trigger opposite directions between forces

Electrical exertions on the positive and negative charges in the atom or molecule to offset these distributions

The two charges produce a bipolar induced torque.

In all polar and non-polar electrical insulators the resulting field within the capacitor is equal to the original field minus the induced field.



Electrolytic capacitors

$$E_T = E - E_d .$$

One of the capacitor plates is replaced by an electrolyte fluid, which is a fluid i
Its main disadvantage is that it is polarized and must always keep one of the p
potential.

Super capacitors

Are high capacity capacitors with very large capacity. This is done by increasing the common area between the plates and placing a large dielectric constant between them. Such capacitors can be charged and discharged millions of times and the time taken to charge them is short.

Capacities are used in Shanghai, China and at Abu Dhabi airports for passenger transport.

General exercises on capacitors

Q1: - Parallel plate capacitor capacity (4PF) and has a potential difference (10V). The two panels are 3mm apart and have air .

Calculate: -

• Charge on the capacitor .

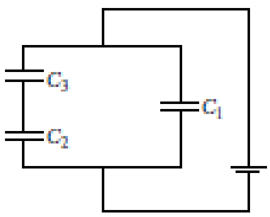
• Stored energy in the capacitor .

• The area of the plates .

• capacitor capacity if the space between the plates is filled with polystyrene (κ = 2.6)

Q 2: - The circuit attached three capacitors (C1 = 2nF, C2 = C3 = 4nF). Calculate: -

• Capacitor equivalent capacity.



• Charge on each capacitor.

Q3: - The parallel plate capacitor contains two square plates the length of their side (10cm) and the distance between them (1cm). 20% of the space between them is filled with dielectric constant ($\kappa_1 = 20$) and the rest of the space is filled with dielectric constant dielectric ($\kappa_2 = 5$). Find the capacitance of this capacitor.

Q4: - Parallel plate antenna capacitor connected to its battery (6V). Charging the capacitor With the energy stored between the two plates (720nJ), insert a dielectric between the two plates without disconnecting the battery for an additional 317nJ of energy flowing from the battery to the capacitor.

- What is the dielectric constant of the dielectric ?.

- If the area of each plate is ($50cm^2$), what is the charge on the positive capacitor plate after the introducing the dielectric?

- What is the amount of electric field between the plates before the insulator is inserted?

- What is the amount of electric field between the panels after the introducing the electrical insulation?

Q5: - Two capacitors parallel to the plates (C1, C2) are connected respectively to the battery (96V). Both capacitors have two plates with an area of ($1cm^2$) .

Separator (0.1mm), where the air occupies the space between the first capacitor and porcelain plates between the second capacitor ($\kappa = 7$) and the electrical insulation intensity (5.7Kv / mm).

• What is the charge on each capacitor after being charged?

• What is the total energy stored in the capacitors?

• What is the electric field between the capacitor tablet (C2)?

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