CAPACITORS :

Capacitors are simple passive device that can store electrical charges on their plates when connected to a voltage source.
The capacitor is a component which has the ability or "capacity" to store energy in the form of an electrical charge producing a potential difference (Static Voltage) across its plates, much like a small rechargeable battery.
In the basic form, a capacitor consists of two or more parallel conductive (metal) plates which are not connected or touching each other, but are electrically separated either by air or by some form of a good insulating material. The insulating material could be waxed paper, mica, ceramic, plastic or some form of a liquid gel as used in electrolytic capacitors. the insulating layer between a capacitors plates is commonly called the dielectric.
Due to this insulating layer, DC current can not flow through the capacitor as it blocks it allowing instead a voltage to be present across the plates in the form of an electrical charge.

The conductive metal plates of a capacitor can be either square, circular or rectangular, or they can be of a cylindrical or spherical shape with the general shape, size and construction of a parallel plate capacitor depending on its application and voltage rating.

When used in a direct current or DC circuit, a capacitor charges up to its supply voltage but blocks the flow of current through it because the dielectric of a capacitor is non-conductive and basically an insulator. However, when a capacitor is connected to an alternating current or AC circuit, the flow of the current appears to pass straight through the capacitor with little or no resistance.

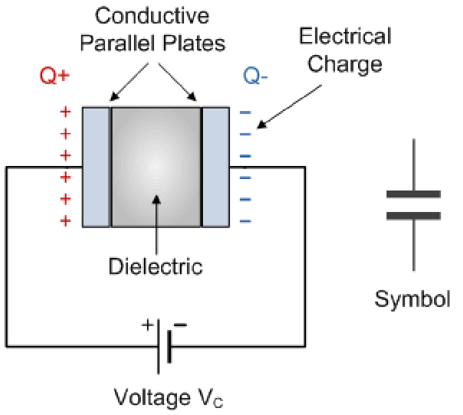
There are two types of electrical charge, a positive charge in the form of protons and a negative charge in the form of electrons. When a DC voltage is placed across a capacitor, the positive (+ve) charge quickly accumulates on one plate while a corresponding and opposite negative (-ve) charge accumulates on the other plate. For every particle of +ve charge that arrives at one plate a charge of the same sign will depart from the -ve plate.

Then the plates remain charge neutral and a potential difference due to this charge is established between the two plates. Once the capacitor reaches its steady state condition an electrical current is unable to flow through the capacitor itself and around the circuit due to the insulating properties of the dielectric used to separate the plates.

The flow of electrons onto the plates is known as the capacitors Charging Current which continues to flow until the voltage across both plates (and hence the capacitor) is equal to the applied voltage Vc. At this point the capacitor is said to be "fully charged" with electrons.

The strength or rate of this charging current is at its maximum value when the plates are fully discharged (initial condition) and slowly reduces in value to zero as the plates charge up to a potential difference across the capacitors plates equal to the source voltage.

The amount of potential difference present across the capacitor depends upon how much charge was deposited onto the plates by the work being done by the source voltage and also by how much capacitance the capacitor has.



The parallel plate capacitor is the simplest form of capacitor. It can be constructed using two metal or metalized foil plates at a distance parallel to each other, with its capacitance value in Farads, being fixed by the surface area of the conductive plates and the distance of separation between them.

By applying a voltage to a capacitor and measuring the charge on the plates, the ratio of the charge Q to the voltage V will give the capacitance value of the capacitor.

$C = \frac{Q}{V}$ ∴ The quantity of charge on the plates : $Q = C \cdot V$

The Capacitance of a Capacitor (C) :

Capacitance is the electrical property of a capacitor and is the measure of a capacitors ability to store an electrical charge onto its two plates with the unit of capacitance being the Farad (F) (named after the British physicist Michael Faraday).

Capacitance is defined as the quantity of charge (in Coulomb) is stored on the plates of a capacitor on applying unit electrical potential or voltage (1V).
C is always positive in value and has no negative units.

The dielectric and permittivity :

The overall capacitance of a capacitor depends on overall size of the conductive plates and their distance or spacing apart from each other, along with the type of dielectric material being used i.e. "Permittivity" (ε) of the dielectric.

The factor by which the dielectric material, or insulator, increases the capacitance of the capacitor compared to air is known as the Dielectric Constant, κ or ε_r. A dielectric material with a high dielectric constant is a better insulator than a dielectric material with a lower dielectric constant. Dielectric constant is a dimensionless quantity since it is relative to free space.
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Complex Permittivity : It is given by-

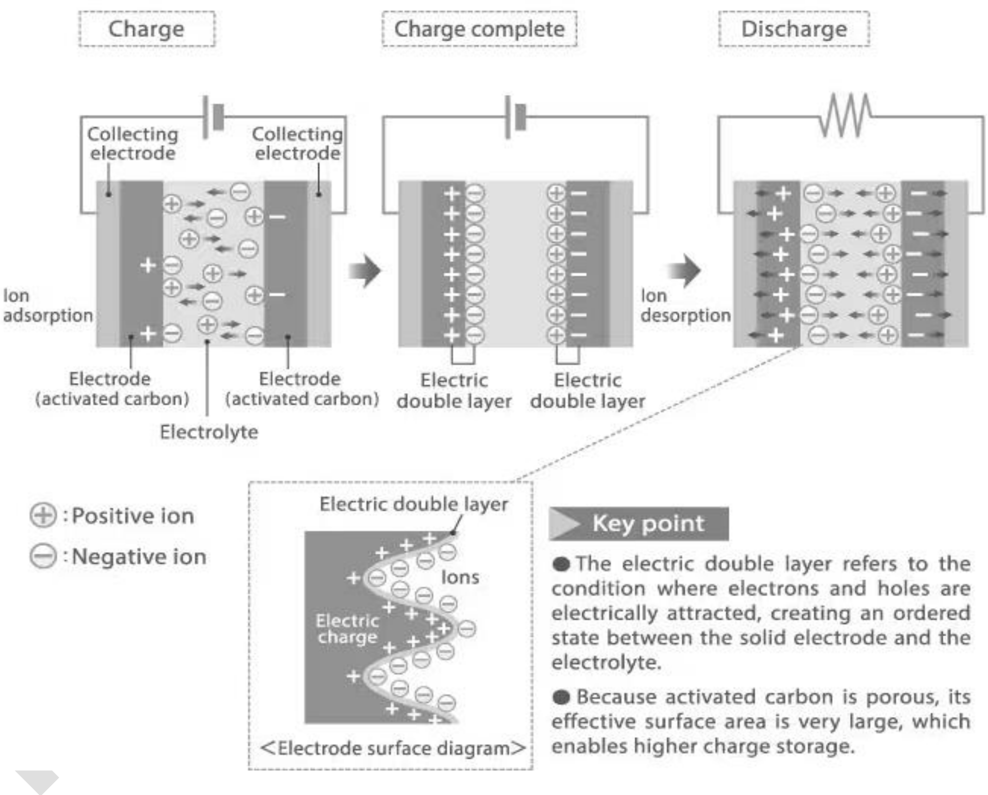
$$\varepsilon = \varepsilon_o \varepsilon_r$$

ε_o is the permittivity of vacuum and ε_r is the relative permittivity.

Principle and Construction of Electric Double Layer Capacitor (EDLC) :

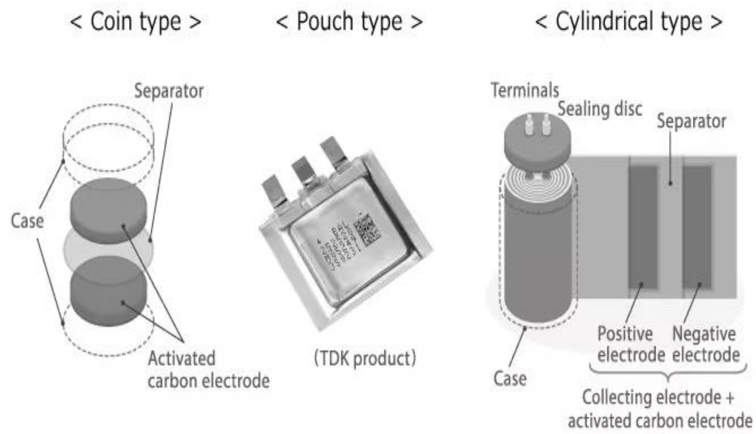
This special type of capacitor has properties that are about halfway between regular capacitors and rechargeable (secondary) batteries. While a battery stores an electrical charge through a chemical reaction, the EDLC stores charge by means of an electric double layer formed by ions adhering to the surface of an activated carbon electrode. Whereas charging a rechargeable battery requires several hours, an electric double layer capacitor can be charged in a matter of seconds. Furthermore, the number of charge cycles for a battery is limited, but the electric double layer capacitor in principle has no such limitation.

< Charging process for an electric double layer capacitor >



Types of electric double layer capacitors :

Electric double layer capacitors are divided into the following categories, according to their construction and shape. Sizes range from small chip and coin type products to large modules combining many interconnected cylindrical or rectangular cells.



Structures and shape	Capacitance	Main applications
Chip type	Ultra-low capacitance, 0.1 F and less	Clock and memory backup in various electronic devices
Coin type, molded type		
Pouch type, laminated type	Low capacitance, 0.1 to 1 F	Standby power for home appliances and A/V equipment
		Battery load leveling in mobile devices, high-brightness LED flash assist current, momentary power loss protection for SSDs, energy harvesting
Cylindrical type, rectangular type	Medium capacitance, 1 to 100 F	Road marking studs, LED signs, drive power for compact motors in toys
Modules (large number of interconnected cylindrical or rectangular cells)	High capacitance, 100 F and above	Energy regeneration in industrial equipment and automobiles, UPS (Uninterruptable Power Supply) equipment, emergency power supply for wind power generation control

Features and characteristics of electric double layer capacitors :

An electric double layer capacitor is a charge storage device which offers higher capacitance and higher energy density than an electrolytic capacitor. Electric double layer capacitors are suitable for a wide range of applications, including memory backup in electronic devices, battery load leveling in mobile devices, energy harvesting, energy regeneration in automobiles, and more. A further increase in energy density, improved charge/discharge characteristics and thermal characteristics, as well as electrode material improvements are some of the technical challenges that still need to be addressed. The main characteristics of electric double layer capacitors are described below.

● Capacitance :

The surface structure of the activated carbon (pore diameter and volume, specific surface area) has a large influence on capacitance.

● Internal resistance :

An electric double layer capacitor can be considered an equivalent circuit where a large number of miniature capacitors having internal resistance are connected in parallel. The resistance component of the electrolyte and electrodes etc. creates the internal resistance which causes a drop in effective voltage. For large current discharge applications, internal resistance should therefore be kept as low as possible.

● Leakage current :

When an electric double layer capacitor is charged for an extended period of time, the charge current decreases but it does not become zero. Rather it settles at a certain constant value, which is called the leakage current. The magnitude of this current is determined by factors such as electrode material, cell construction, usage temperature etc.

SUPER CAPACITORS :

A supercapacitor is a special type of energy storage device which has an extremely large capacitance by combining the capacitors & batteries properties into one device. Supercapacitors are high-capacity energy storage devices bridging the gap between conventional capacitors and batteries. They store energy electrostatically, enabling rapid charging/discharging, high power density, and millions of cycles, making them ideal for quick bursts of power, regenerative braking, and bridging power gaps, though they have lower energy density than batteries. These capacitors can store more energy as compared to other regular types of capacitors and provides high output power than batteries. Supercapacitors are also called an ultracapacitor which is easy to operate & very safe. Supercapacitors are available in three types based on requirements like EDLC or Electrostatic double-layer capacitors, Pseudo-capacitors, and Hybrid capacitors.

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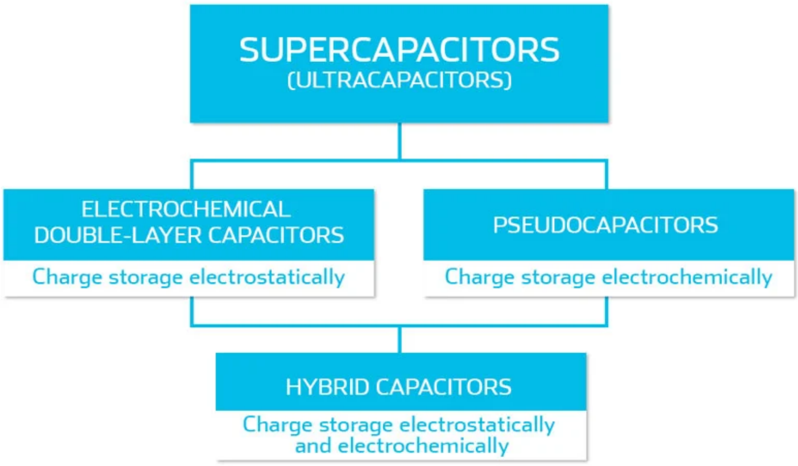


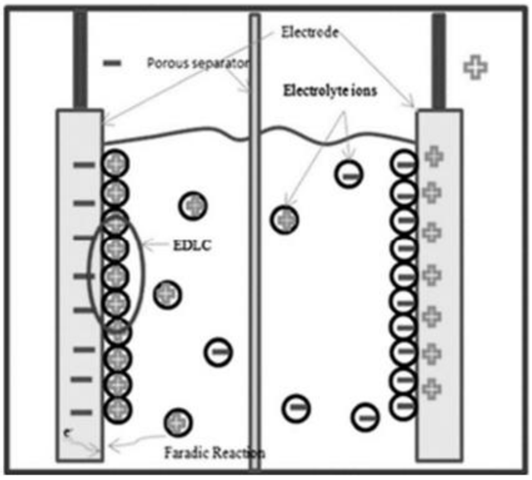
PSEUDO CAPACITORS :

Pseudocapacitors or faradaic supercapacitors are devices that are different from EDLCs. The electrodes of this capacitor include redox-active materials to store electrical energy using a different mechanism as compared to EDLCs.

Only a part of the charge is achieved because of the EDLC whereas a large amount of energy transfer & storage can be achieved through faradaic mechanisms like redox reactions electrosorption & intercalation. When an exterior potential is applied to this capacitor then quick and reversible redox reactions can occur on the electrode which includes the passage of charges between electrode & electrolyte. The charge & discharge mechanism of this capacitor is related to the one of the electric batteries.

A pseudocapacitor is a hybrid in between a battery & an EDLC (electric double layer capacitor). This capacitor includes two electrodes which are separated through an electrolyte. The storage of

charge mainly occurs through chemical & electrostatic processes.
The chemical process mainly involves transferring charge through Redox or reduction-oxidation reactions. When the charge transfer is comparable to that within a battery, then transfer rates are superior due to thinner redox material over the electrode otherwise fewer ions diffusion from the electrolyte into the structure. The values of capacitance are higher within pseudocapacitors due to several processes performing to store charge.



Pseudocapacitor Diagram

Working Principle :

The working principle of Pseudo-capacitor is to store electrical energy by transferring electron charge between electrode & electrolyte through reduction-oxidation reactions, electrosorption & intercalation processes called pseudo-capacitance. In an electrochemical capacitor, a pseudo-capacitor is an essential part that forms a super capacitor together with an EDLC or electric double-layer capacitor.

Pseudocapacitor materials are generally made up of metal oxides (RuO_2, NiO, MnO_2), metal sulfides, metal hydroxides, metal nitrides & conducting polymers like polyaniline & polypyrrole.

The energy storage in Pseudocapacitors can be done throughout the faradic reactions. So they store charge electrostatically where the transfer of charge can be done between electrode & electrolyte. Once the voltage is applied to a pseudocapacitor, then both reduction & oxidation occurs on the material of the electrode. The faradic process used in these capacitors will enhance the electrochemical reactions which provide greater specific capacitance & energy densities as compared to EDLCs.

Types of Pseudocapacitor :

Pseudocapacitors are classified into two types based on electrode materials used to store charge within pseudocapacitors as follows.
1. Metal oxide pseudocapacitor
2. Conducting Polymers pseudocapacitor.

Pseudo Capacitor vs Supercapacitor :

The difference between a pseudo capacitor and a supercapacitor includes the following.

Pseudocapacitor	Supercapacitor
Pseudocapacitor is also called faradaic supercapacitor.	A supercapacitor is also known as an ultracapacitor or electrochemical capacitor.
These capacitors are available in two types Metal oxide & conducting polymers.	These capacitors are available in three types Electrochemical double layer, Pseudocapacitor & Hybrid type.
Pseudocapacitors store parts within both physical & chemical energy.	EDLCs completely rely on the physical storage of energy.
Higher specific capacitance.	Lower specific capacitance.
High energy density.	Low energy density.
Low cycle life or low stability.	High cycle life or high stability.
It depends on redox reactions.	It does not depend on redox reactions.
Power density is high.	Very high power density.
The cost per energy unit is medium.	The cost per energy unit is high.

Advantages

The advantages of pseudocapacitors include the following -

- These capacitors have a higher power density.
- They have significantly longer lifetimes.
- As compared to lithium-ion batteries, they charge & discharge very quickly.
- The materials of pseudocapacitor materials will enhance the density of energy & allows the energy density storage within the bulk of electrode materials & at their surface.

Disadvantages

The disadvantages of pseudocapacitor include the following -

- These capacitors have less energy density, so they cannot be used in place of batteries in energy storage applications.
- They are not suitable for long-term energy storage devices.
- The output voltage of these capacitors refuses with their charge linearly.

Applications

The applications of pseudocapacitors include the following-

- Pseudocapacitors store electrical energy through a faradic reaction.
- It is part of an electrochemical capacitor that uses an electric double-layer capacitor to form a supercapacitor.
- These are used in consumer electronics.
- In wearable or flexible electronics
- Regenerative braking within automobile applications
- Kinetic energy (K.E) recovery systems like cranes, elevators, wind turbines, etc.