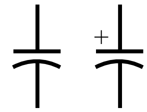
The Capacitor What is it?



Schematic Symbol

The capacitor is a device consisting essentially of two conducting surfaces separated by an insulating material.

This insulating material, called ***a dielectric.*** can be air, mica, glass, plastic film or oil.

In modern day capacitors, the dielectric is generally a type of thin plastic with a very high insulating value.

Electrically, the capacitor acts as a storage device. They store electrical energy that can be returned to the circuit as needed.

Basic Theory

In order to understand how the capacitor works, consider the simple capacitor shown in Fig. 1.

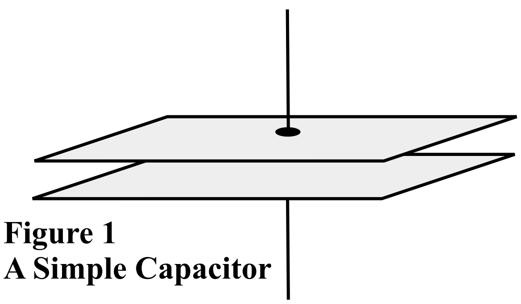


Figure 1
A Simple Capacitor

It consists of two conductive plates, separated by an air space. A wire is attached to each plate. There is no connection between the two plates.

This explanation uses electron flow

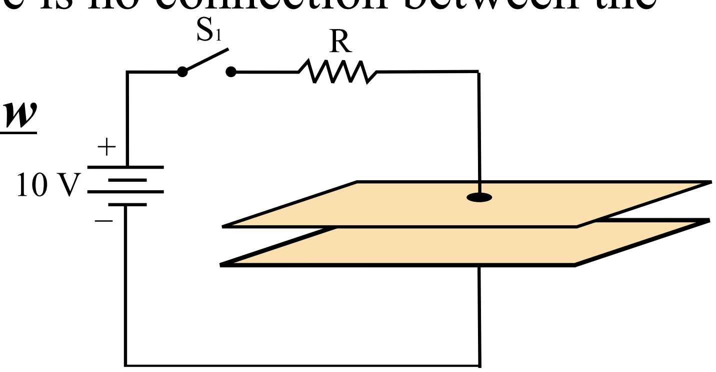


Figure 2

In Figure 2,we have connected our capacitor to a power supply and inserted a current limiting resistor. With the switch open and the capacitor discharged, the electrons in the conductive plates are evenly spread throughout the plates and there are the same number of electrons in each plate.
Electrons repel each other, and this is why they spread evenly.

Basic Theory

In figure 2, we close the switch. Suddenly, there is a voltage pressure across the two plates.

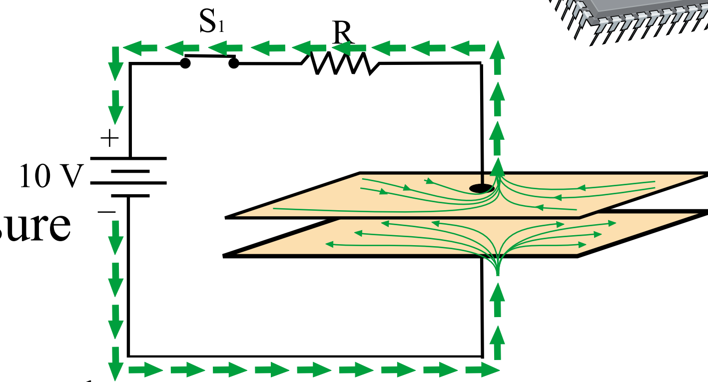


Fig. 3 The Switch is closed

Electrons rush off the upper plate and gather on the lower plate. This creates a sudden high current as the electrons rush through the power supply to change plates.

Remember that electrons repel each other. As more and more electrons collect on the lower plate, they are forced closer together. This causes a reverse pressure to build as more and more electrons are forced into the plate. As the reverse pressure builds, the current flow slows down. It stops when the reverse pressure is equal to the power supply voltage.

Now the upper plate is ***positive and is deficient in electrons*** and the ***lower plate is negative and has a n excess in electrons***.

In Fig. 4, the switch is now opened .Even though the power supply is disconnected from the capacitor, the voltage across the capacitor remains at 10 V.

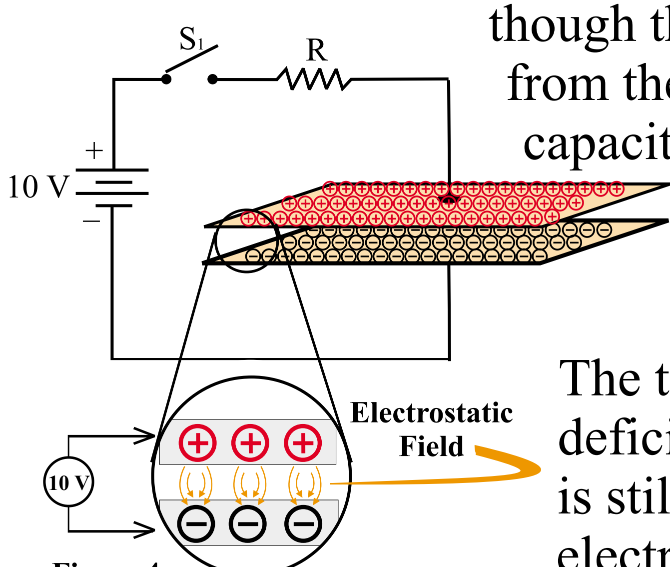


Figure 4
The switch is opened

The top plate is still positive and is deficient in electrons. The bottom plate is still negative and has an excess of electrons.

Basic Theory

The capacitor is in a charged state and will remain there as long as there is no leakage path for the electrons to escape from the bottom plate & return to the top plate.

Between the plates, there exists an electrostatic field of attraction , since one plate is positive and the other negative.

If we were to increase the supply voltage to 20 V and then closed the switch again, a current would flow again from the positive to the negative plate.

More electrons would be forced into the negative plate and the same number of electrons would be forcibly removed from the positive plate.

The process would continue and the reverse pressure would increase until it matched the supply pressure. As the pressures become equal, the current will trickle down and stop. The voltage pressure between the plates is now 20V, double what it was before we increased the supply voltage.

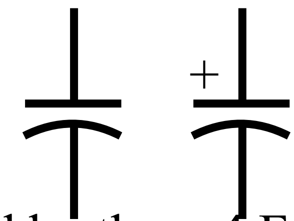
There is a limit to how high we can increase the supply voltage. If we increase it too high, the force of attraction between the plates becomes so strong that electrons on the negative plate jump across the gap and return to the positive plate.

Now our capacitor has suffered ***dielectric breakdown***. In most cases, this event is catastrophic and will destroy the capacitor.

Important Things to Know

- The capacity of the capacitor is measured in micro Farads (μF)

- The schematic symbol is
  the (+) denotes the positive lead



- The capacity to store energy is affected by these 4 Factors:

1) The ***area of the plates*** -larger area , larger capacity.
2) The ***distance between the plates*** -Less distance,larger capacity
3) The ***type of dielectric*** -(insulating material between the plates)
4) The ***applied voltage*** Increase voltage - Increase stored charge

- Capacitors have a maximum working voltage. This is a ***never exceed*** value. Be careful not to exceed this voltage or catastrophic breakdown of the capacitor is likely.
  Note: Some capacitors can explode in this condition.

- Some types of capacitors are polarity sensitive. Be careful not to install this type in your circuit the wrong way. It will often destroy the capacitor.
  Note: Some capacitors can explode in this condition.

The Definition of Capacitance

Capacitance is the measure of the capacitors ability to store charge. The unit for capacitance is the Farad (F).
The capacitance of a capacitor is one farad if its stores one coulomb of charge when the voltage across it's terminals is 1 Volt.

$$C = \frac{Q}{V}$$ (farads, F)

C = capacitance in farads
Q = charge in coulombs (C)
V = Volts (V)

How the Dielectric Increases Capacitance

We know that when our capacitor is charged, there is an electrostatic field of attraction that exists between the two plates. It is the effect that this force has on the plates that increases capacitance.

We need a material between the plates that will conduct the electrostatic field of attraction but will not conduct the electric charge.

The ability of the material to pass the electrostatic field is called ***permittivity***. ***Permittivity*** is defined as a measure of how easily it is to establish electric flux in a material.

Materials that have high permittivity have atoms that can be distorted to form dipoles. A dipole is an atom that has a negative and a positive side.

When the dipoles of the insulators lineup as shown Figure 5, it has the same effect as reducing the plate separation. When the dipoles of material are aligned, the material is polarized. Materials that are easily polarized are said to have a high permittivity.

The higher the dialectic permittivity the greater the capacitance.

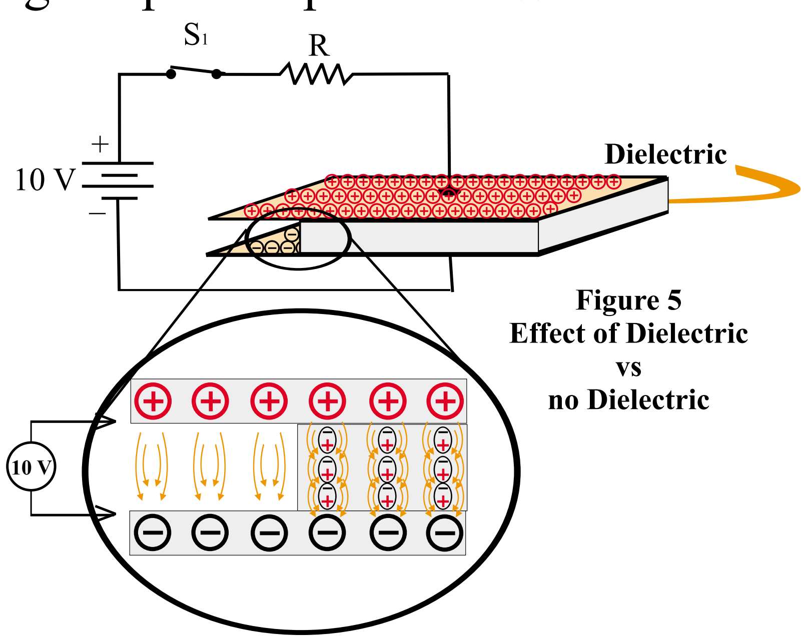


Figure 5
Effect of Dielectric
vs
no Dielectric

Capacitors In The Real World

Capacitors, like everything else, are not perfect. Capacitors have some non ideal characteristics that we need to look at.

Leakage Current

When a charged capacitor is disconnected from its source, it will eventually discharge. This is because no insulator is perfect and a small amount of charge leaks through the dielectric.

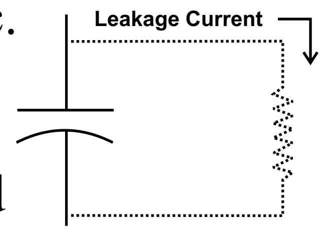


Figure 6 Leakage Current

Similarly, a small leakage current will pass through its dielectric when a capacitor is connected to source. The effect of leakage is modelled by the resistor shown in the Figure 6.

Since leakage is very small, R is very large, typically hundreds of Megohms.. The larger R is, the longer the capacitor will hold its charge. For most applications, leakage can be neglected.

Equivalent Series Resistance (ESR)

As a capacitor ages, resistance may develop in its leads as its internal connections begin to fail. This resistance is in series with the capacitor and may eventually cause problems.

Dielectric Absorption

When a capacitor is discharged by temporarily shorting its leads, it should have zero volts when the short is removed. However, atoms sometimes remain partially polarized, and when the short is removed, they can have residual voltage to appear across the capacitor. This effect is known as dielectric absorption. In electronic circuits, the voltage due to dielectric absorption can upset circuit voltage levels.

Capacitors In The Real World

Temperature Coefficient

Because dielectrics are affected by temperature, capacitance may change with temperature. If capacitance ***increases with increasing temperature,*** the capacitors said to have a ***positive temperature coefficient;*** if it ***decreases,*** the capacitor has a ***negative temperature coefficient***; if it ***remains essentially constant***, the capacitor has a ***0 temperature coefficient***.

The temperature coefficient is specified as a change in capacitance in parts per million (ppm) per degrees Celsius.

Types of Capacitors

Since no single capacitor type suits all applications, capacitors are made in a variety of types and sizes. Among these are fixed and variable types with different dielectrics and recommended areas of application.

Fixed Capacitors

Fixed capacitors are often identified by the dielectric. Common dielectric materials include ceramic, plastic, and mica, plus, for electrolytic capacitors, aluminum and tantalum oxide.
Two types of design variations include ***tubular*** and ***interleaved plates.***

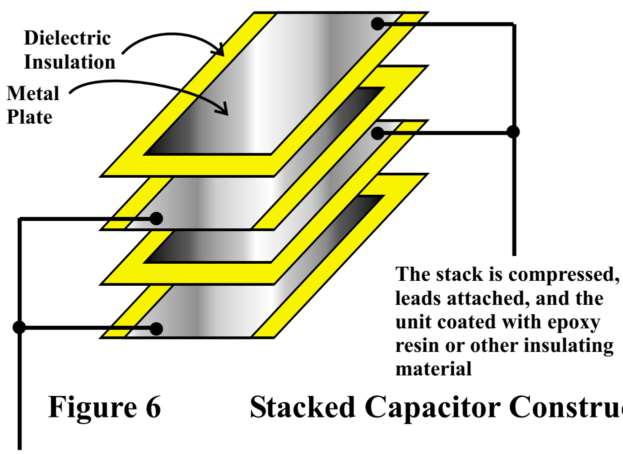
The interleaved design uses multiple plates to increase effective plate area. A layer of insulation separates the plates and alternate plates are connected together.

Fixed Capacitors

The tubular design uses sheets of metal foil separated by an insulator such as plastic film.

Fixed capacitors are encapsulated in plastic, epoxy resin, or other insulating material and identified with value, tolerance, and other appropriate data either via body markings or colour coding.

Electrical characteristics and physical size depend on the dielectric used.



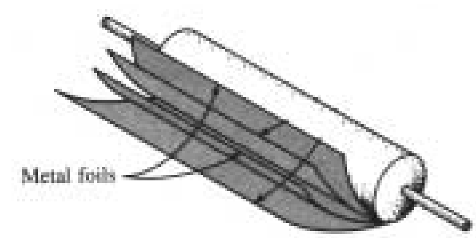


Figure 6 Stacked Capacitor Construction & Tubular Capacitor Construction

Ceramic Capacitors Two Types

Some ceramics, when used as a dielectric, have a very high permittivity. This type of ceramic can produce a great deal of capacitance in a small space, but the down side is that they yield capacitance characteristics that very widely with temperature and operating voltage.

There are other types of ceramics that, when used as a dialectic, produced capacitors that change little with temperature, voltage or aging. These capacitors are physically larger than those made using the high permittivity ceramic mentioned above.

Plastic Film Capacitors

Plastic film capacitors are of two basic types: ***film/foil*** or ***metallized film***.

Film/foil capacitors use metal foil separated by plastic film

Metallized film capacitors have their foil material vacuum deposited directly onto plastic film.

Film/foil capacitors are generally larger than metallized film units but have better capacitance stability and higher insulation resistance.

Metallized film capacitors are self-healing. If voltage stress around an imperfection exceeds breakdown, and arc occurs which evaporates the metallized area around the fault, isolating the defect. (Film\ foil capacitors are not self-healing)

Mica Capacitors

Mica capacitors are low in cost, with low leakage and good stability. Available values range from a few pF to about 0.1μF.

Electrolytic Capacitors

Electrolytic capacitors provide large capacitance (up to several hundred thousand μF) at relatively low-cost. Commonly used as filter capacitors, their leakage is relatively high and breakdown voltage relatively low. Electrolytics have either aluminum or tantalum as their plate material.

Tantalum devices are smaller than aluminum devices, have less leakage, and are more stable.

Capacitors

Electrolytic Capacitors

Electrolytic capacitor construction is similar to that shown in Figure 7. They are made by rolling strips of aluminum foil separated by gauze that is saturated with an electrolyte. During manufacture, chemical action creates a thin oxide layer that acts as the dialectic. This layer must be maintained during use.

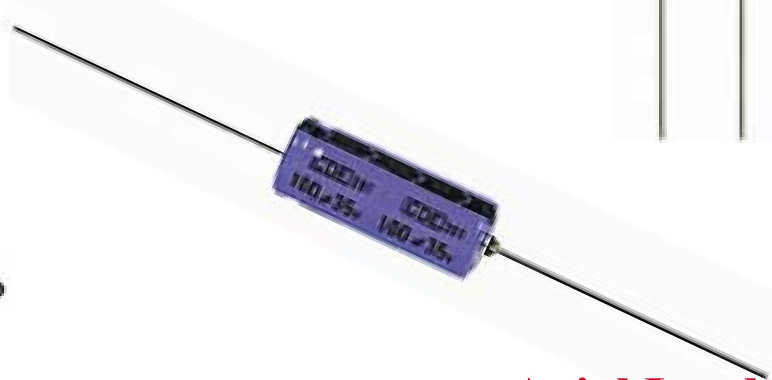
For this reason, ***electrolytic capacitors are polarized. The positive terminal must always be kept positive with respect to the negative terminal.***

Electrolytic capacitors also have a shelf life: that is, if they are not used for an extended period, they may fail when powered up.

Your parts kit has several electrolytic capacitors similar these.

Remember Most electrolytic capacitors are polarity sensitive and will breakdown if installed in the circuit with the wrong polarity.

Radial Leads



Axial Leads

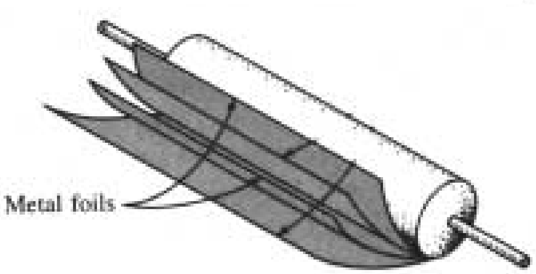


Figure 7 - Basic Construction of an Electrolytic Capacitor

Tantalum Capacitors

Tantalum capacitors come into basic types: ***wet slug*** and ***solid dielectric.***

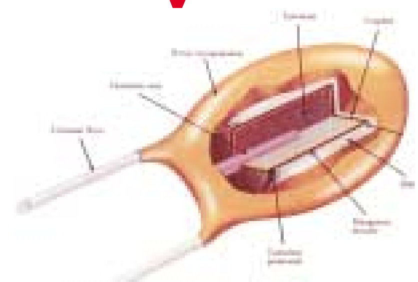


Fig. 9 Cutaway of a Tantalum capacitor

Figure 9 shows a cutaway view of the solid tantalum unit. The slug, made from powdered tantalum, is highly porous and provides a large internal surface area that is coated with an oxide to form the dialectic.

Tantalum capacitors are polarized and must be inserted into the circuit properly.

Surface Mount Capacitors

Many electronic products now use surface mount devices (SMDs).

Fig 10 - Surface Mount Ceramic Capacitor

Surface mount devices do not have connection leads, but are soldered directly onto the printed circuit board.

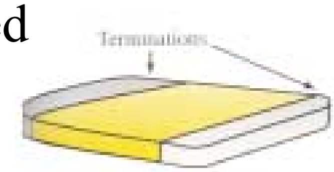


Figure 10 shows a ceramic chip capacitor. Such devices are extremely small and provide high packaging density.

Variable Capacitors

The most common variable capacitor is used in radio tuning circuits. It has a set of stationery plates and a set of movable plates which are ganged together and mounted on a shaft. As the shaft is rotated, the movable plates mesh with the stationery plates, changing the effective surface area and hence the capacitance.

Variable Capacitors

Another adjustable type is the ***trimmer or padder capacitor***, which is used for fine adjustments, over a very small range. In contrast to the variable capacitor, the trimmer is usually set to its required value and never touched again.

Capacitors in Parallel

For capacitors in parallel - add their individual capacitances

For capacitors in parallel - the total capacitance is always larger than the largest capacitance

$$C_T = C_1 + C_2 + \cdots + C_n$$

Example 10-6 Page 401

Capacitors in Series

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots + \frac{1}{C_n} \quad \text{or} \quad C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \cdots + \frac{1}{C_n}}$$

For capacitors in series - the total capacitance is always smaller than the smallest capacitance

Example 10-7, 10-8 Page 402

Worth Noting

- The formula for ***capacitors in series*** is similar to the formula for ***resistors in parallel***
- The formula for ***capacitors in parallel*** is similar to the formula for ***resistors in series.***

RC Circuits

Resistive/capacitive circuits are often simply referred to as RC circuits. The voltage and current levels in these types of circuits only change when some circuit condition is changed (e.g. A switch is moved).

A short period of time after the condition changes, the voltage and current levels will achieve new constant values called steady state values. The circuit action between the condition change and the steady state values being achieved is called the transient response. To aid in the analysis of direct current RC circuits an understanding of the basic operating characteristics of capacitors is essential.

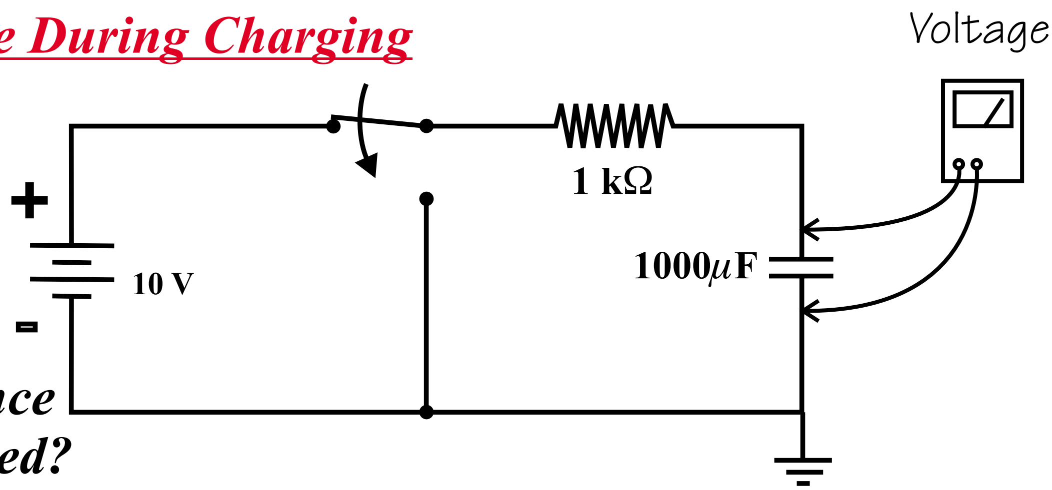
To change the voltage across a capacitor the charge on the capacitor must change. To change the charge current must flow for some period of time. This means the voltage across a capacitor cannot instantaneously change.

An uncharged capacitor will allow a circuit to pass current. Since a capacitor with no charge will have zero volts across its terminals, it initially looks like a short circuit.

No charge actually crosses the plates of an ideal capacitor. This means after a capacitor in a DC circuit has become completely charged it will have a voltage but no current will flow. Once this condition exists the capacitor looks like an open circuit. When the circuit reaches this condition it is said to be in steady state.

Capacitor Voltage During Charging

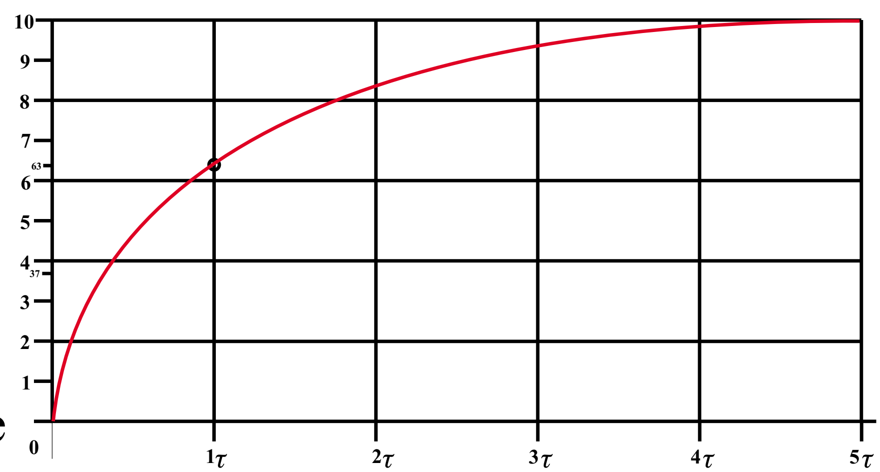
How long does it take for the capacitor in the circuit shown to charge up to the supply voltage once the switch is closed?



This circuit has a ***time constant*** that is determined by R times C. It is called Tau (τ) and for this circuit is 1 kΩ times 1000μF = 1 S

In 1 time constant, the voltage across the capacitor will rise from 0 to 63.2 % of maximum. (by definition)

In 5 time constants (5τ) , the capacitor has charged to 99.3 % of maximum. For our purposes we can consider the capacitor fully charged. In our example then, the capacitor will fully charge in 5 seconds.
(5 x 1 Sec. = 5 Sec.)



Capacitor Voltage During Charging

The time it takes a capacitor to charge is a function of R and C.

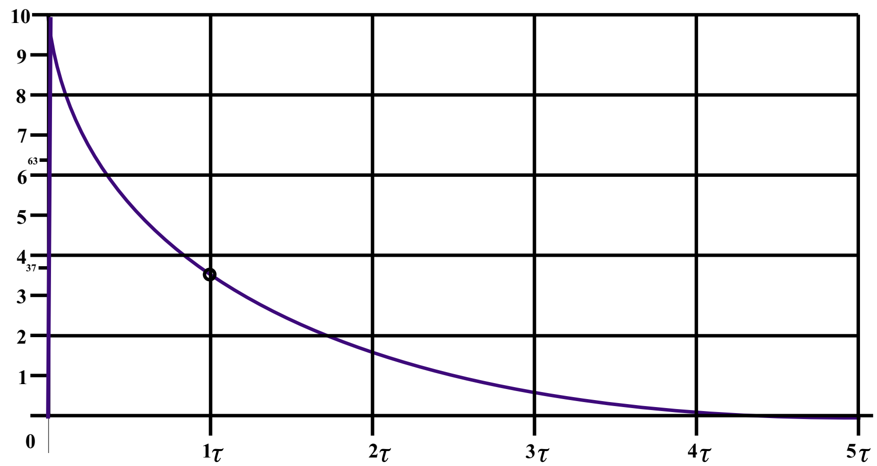
- If the capacitor is made larger, then the time constant increases
- If the resistance is made larger, then the time constant increases

It always takes 5 time constants to reach 99.3% of maximum charge.

Capacitor Current During Charging

What happens to the current in the circuit during the charge cycle.

At the moment the switch is thrown, the capacitor appears as a short circuit.



Capacitor Current During Charging

The current is only limited by the 1 kΩ resistor. the current instantly climbs to 10 mA (I = E/R).

The current then begins to fall. In one time constant (1τ), the current will have fallen to 36.8% of its start value or 3.68 mA. In 5 time constants (5τ), the current will have fallen to 0.67% of its start value or 0.67 mA.

At 5τ, the current is almost at zero. Since the dialectic between the capacitor plates is an insulator, no current can pass through it.

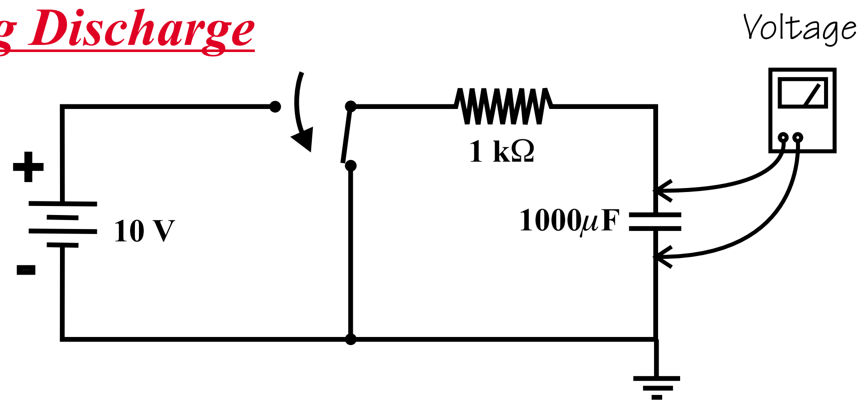
This means that the current in the circuit, which is due entirely to the movement of electrons from one plate to the other through the battery must decay to zero as the capacitor charges.

Steady State Conditions

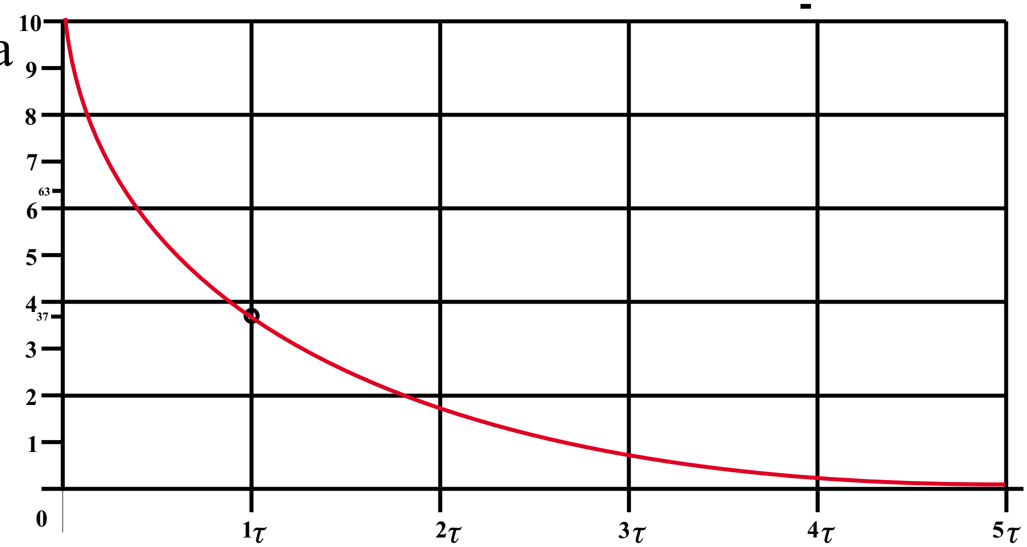
Once the capacitor voltage and current reach their final values and stop changing the circuit is said to be in ***steady-state.*** Since the capacitor has a voltage across it but no current through it, it looks like an open circuit.

Capacitor Voltage During Discharge

How long does it take the capacitor to completely discharge from the supply voltage to zero?



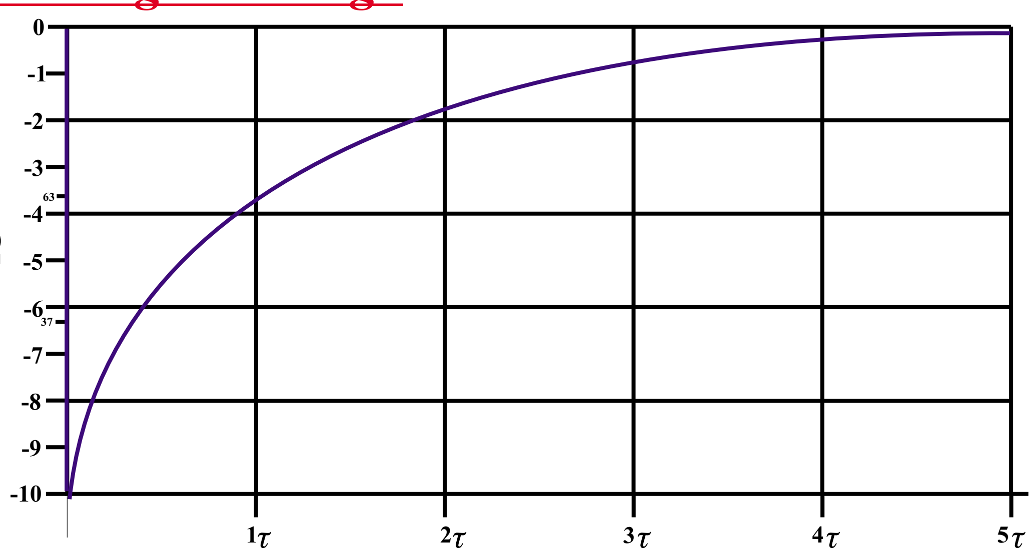
In 1 time constant, a fully charged capacitor will discharge to 36.8% of its full charge. In 5 time constants (5τ) it will contain only 0.67% of its full charge. For our purposes we can assume that the capacitor is discharged after 5 τ. In our example, this is again 5 seconds.



Capacitor Discharging Time Constant

Capacitor Current During Discharge

At the moment the switch is thrown, the current is only limited by the 1 kΩ resistor. the current instantly climbs to 10 mA (I = E/R). .



Capacitor Current During Discharge

The current then begins to fall. in one time constant (1τ), the current will have fallen to 36.8% of its start value or 3.68 mA.

In 5 time constants (5τ), the current will have fallen to 0.67% of its start value or 0.67 mA

Capacitor Charging Equations

We can find the instantaneous voltage on our capacitor using the following formula:

$$v_C = E\,(1 - e^{-t/RC})$$

We can find the instantaneous current in our capacitor using the following formula:

$$i_C = \frac{E}{R}\, e^{-t/RC}$$

We can find the instantaneous voltage across the resistor using the following formula:

$$v_R = E\,e^{-t/\tau}$$

Example 11-1 and 11-2 Page 420, 423