

# **Trade of Electrician**

**Standards Based Apprenticeship**

## **Capacitance**

**Phase 2**

**Module No. 2.1**

**Unit No. 2.1.8**

**COURSE NOTES**

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## Introduction

Welcome to this section of your course, which is designed to assist you the learner, understand what a capacitor is, how it is used in basic electrical circuits and complete basic circuit calculations.

### **Objectives**

By the end of this unit you will be able to:

- Understand the term capacitance
- Define the unit of capacitance
- Understand how a capacitor is charged
- List the factors affecting the charge on a capacitor
- List the factors affecting the capacitance of a capacitor
- Understand that energy can be stored in a capacitor
- List capacitor types
- Understand basic construction of capacitors
- Calculate total capacitance of capacitors in parallel
- Calculate total capacitance of capacitors in series
- Understand charge in a series circuit
- Calculate total stored charge in a series circuit
- Explain the term “working voltage of a capacitor”
- Calculate total capacitance of capacitors in series-parallel
- Test capacitors with a multimeter
- List potential dangers with capacitors

### **Reasons**

Capacitors are widely used in electrical equipment. Being able to identify, test and replace a faulty capacitor will be of great benefit to you in fault finding.

## Capacitance

The capacitor is a very common electrical component. It is used to store electrical energy. The term “capacitance” means, **the ability to store energy in the form of an electrical charge.**

The **capacitive effect** is of great benefit in electrical / electronic circuitry. For example, controlling AC current, tuning radio receivers, time-delay circuits, separating of AC currents from DC currents, power factor correction, fluorescent lamps and starting of single phase motors.

A capacitor consists of two conducting surfaces or plates, placed very close together but separated by an insulator called a dielectric. See Figure 1. The circuit schematic symbols for capacitors are also shown.

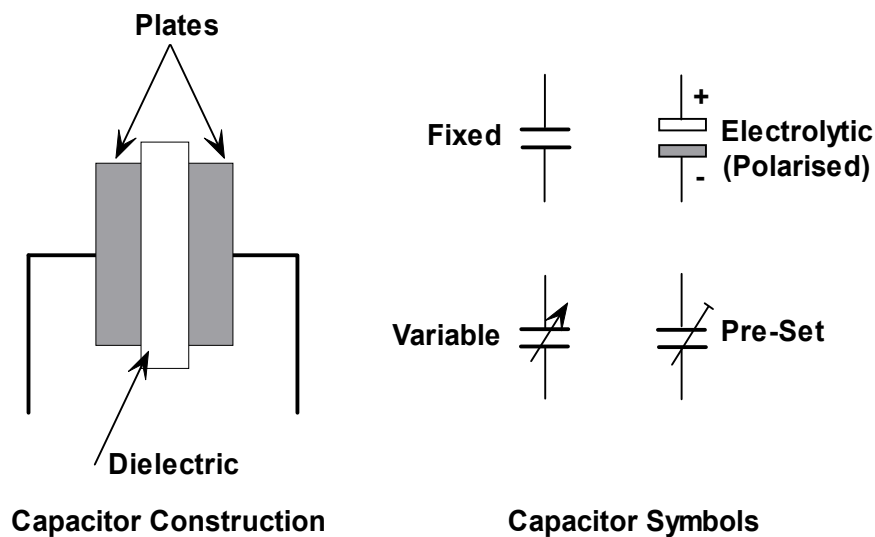


Figure 1

## The Unit of Capacitance

The unit of Capacitance is the Farad ( F ) and may be defined as:

One Farad is the amount of capacitance that will store a charge of one Coulomb when an EMF of one Volt is applied.

Hence:

$$\text{Charge} = \text{Capacitance} \times \text{Voltage}$$

$$Q = \text{Capacitance ( Farads )} \times \text{Voltage ( Volts )}$$

$$Q = C \times U$$

Q = The stored charge in the capacitor and is expressed in Coulombs. Earlier we learned that Coulombs are equal to current ( amperes ) multiplied by time ( seconds ) or  $Q = I \times t$ .

C = Capacitance is measured in Farads. It must be remembered that the unit of 1 Farad represents a very large charge. Actual capacitor values will be in Microfarads, Nanofarads or Picofarads where:

$$\text{One Microfarad} = \frac{1}{1,000,000} \quad \text{or} \quad \frac{1}{10^6} \quad \text{or} \quad 10^{-6} \text{ Farads}$$

$$\text{One Nanofarad} = \frac{1}{1,000,000,000} \quad \text{or} \quad \frac{1}{10^9} \quad \text{or} \quad 10^{-9} \text{ Farads}$$

$$\text{One Picofarad} = \frac{1}{1,000,000,000,000} \quad \text{or} \quad \frac{1}{10^{12}} \quad \text{or} \quad 10^{-12} \text{ Farads}$$

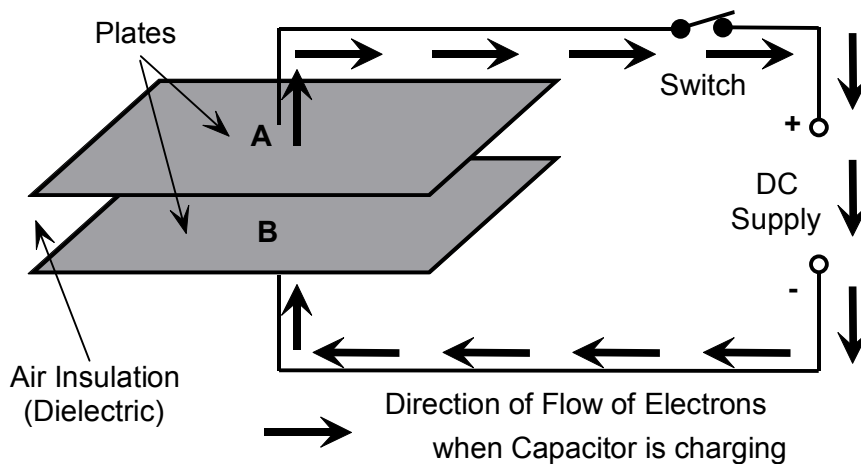
If a capacitor were marked with a value of 1000 pF, it could equally have been marked with a value of 1 nF. Similarly, a capacitor of 0.001  $\mu$ F could have been marked 1 NF. Therefore it can be seen that there are one thousand Picofarads in a Nanofarad, and also that there are 1 thousand Nanofarads in a Microfarad.

It is common practice to represent the prefix “micro” by the Greek letter  $\mu$ . For example, 10 microfarads may be written 10 $\mu$ F. The value of capacitance is usually clearly marked on the body of the capacitor.

## Charging of Capacitors

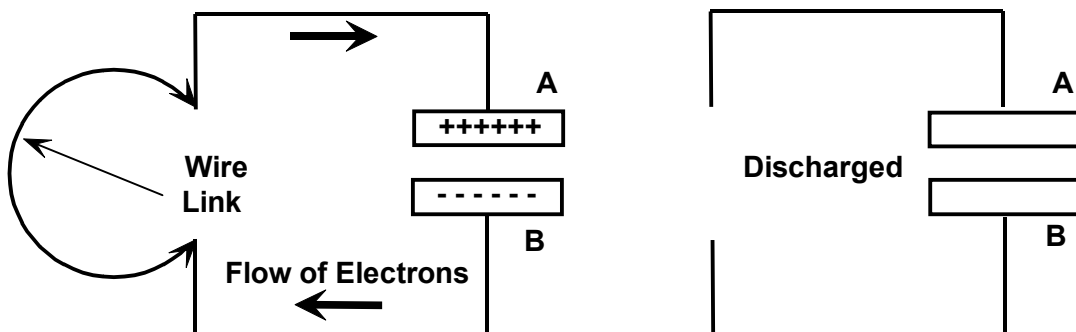
Refer to Figure 2. When the switch is closed, electrons on the upper plate A are attracted to the positive pole of the battery. This leaves a shortage of electrons on plate A, which, is therefore positively charged. At the same time, electrons gather on the lower plate, B, causing it to become negatively charged. Since plates A and B are now charged with opposite polarity, there is a difference of potential between them. When this difference of potential is equal to the battery voltage, no more charge can be placed on the capacitor. Notice that the capacitor voltage has an opposing polarity to that of the battery. When the capacitor cannot be charged any further, we consider it to be, **fully charged**.

If the switch is now opened the capacitor will remain charged, because there is no path for the excess electrons on plate B to flow to plate A.



**Figure 2**

Refer to Figure 3. If a wire link is placed across the plates of a charged capacitor, electrons will flow from B to A. This action discharges the capacitor and returns it to the uncharged state.



**Figure 3**

**Example 1**

Calculate the charge on a 10 $\mu$ F capacitor when it is connected across a 200V DC supply.

$$\begin{aligned} C &= 10\mu\text{F} = 10 \times 10^{-6} \text{ Farads} \\ U &= 200 \text{ Volts} \end{aligned}$$

$$Q = C \times U$$

$$Q = 10 \times 10^{-6} \times 200$$

$$Q = \underline{\underline{0.002 \text{ Coulombs}}}$$

**Example 2**

A steady current of 10 Amps flows into a previously discharged capacitor for 20 seconds, when the potential difference between the plates is 600 Volts. What is the capacitance of the capacitor?

$$\begin{aligned} I &= 10 \text{ Amps} \\ t &= 20 \text{ Seconds} \end{aligned}$$

$$Q = I \times t$$

$$Q = 10 \times 20$$

$$Q = \underline{\underline{200 \text{ Coulombs}}}$$

$$Q = C \times U$$

To get C on its own we transform the formula:

$$C = \frac{Q}{U}$$

$$C = \frac{200}{600}$$

$$C = \underline{\underline{0.33 \text{ Farads}}}$$



## Factors affecting the Value of the Charge on a Capacitor

From the previous exercises it can be seen that the factors affecting the value of the charge on a capacitor depends upon the capacitance and the voltage:

$$Q = C \times U$$

The greater the capacitance of a capacitor, the greater the charge for the same applied voltage. If 10 Volts is applied to a capacitor, it will charge to 10 Volts, after which no more charging occurs. The charge remains on the capacitor with or without the applied voltage connected.

When the voltage across the capacitor equals the supply voltage, no further current will flow. The capacitor is now fully charged and will remain charged even if disconnected from the supply. See Figure 4.

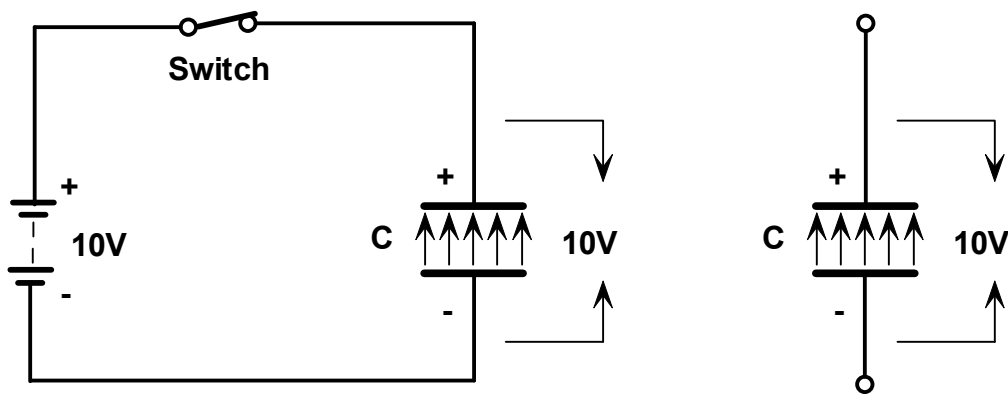


Figure 4

## Factors affecting the Capacitance of a Capacitor

The greater the capacitance of a capacitor the greater the charge for the same applied voltage. The factors affecting capacitance are:

1. Plate Area
2. Plate Spacing ( distance between the plates )
3. Dielectric Material.

### (1) Plate Area

If the plate area of a capacitor is increased there is a corresponding increase in capacitance, provided there is no change in the distance between the plates or in the dielectric material. See Figure 5.

Capacitance is directly proportional to plate area;

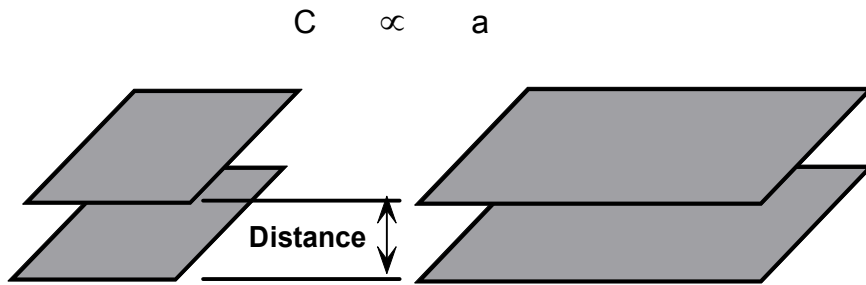


Figure 5

When two capacitors are placed in parallel, the plate area is increased and so the capacitance is increased. See Figure 6.

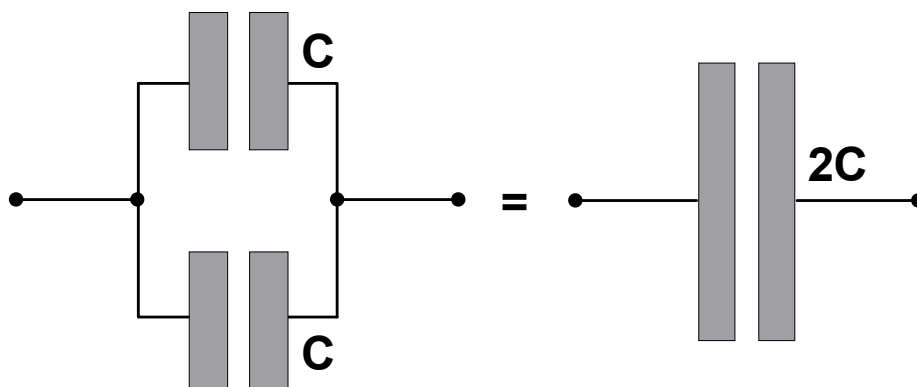


Figure 6

**(2) Plate Spacing**

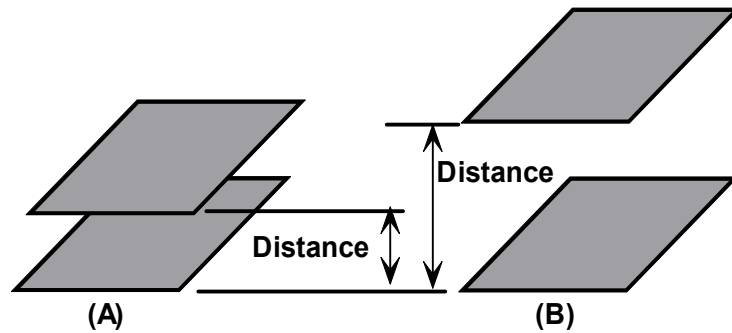
The capacitance of a capacitor changes when the distance between the plates changes. It increases when the plates are brought closer together and decreases when they are moved further apart.

Refer to Figure 7. Plates ( a ) have more capacitance than plates ( b ).

Capacitance is inversely proportional to the distance between the plates;

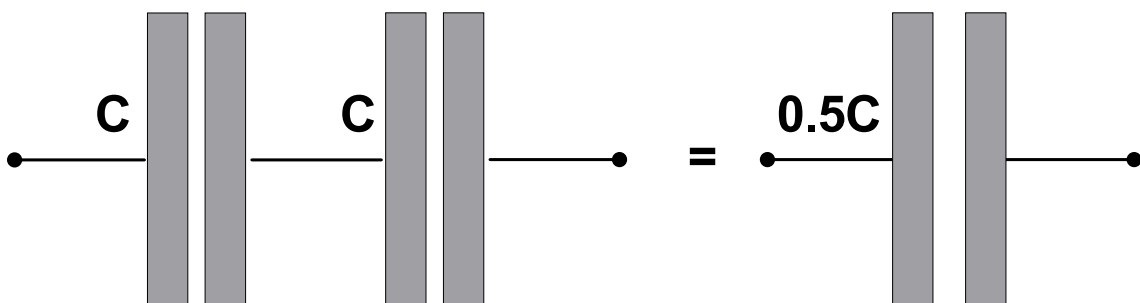
$$C \propto \frac{1}{d}$$

Where d = distance between plates



**Figure 7**

Refer to Figure 8. When two capacitors are connected in series, the distance between the plates has increased so the capacitance has decreased.



**Figure 8**

### (3) Dielectric Material

Using the same plates fixed a certain distance apart, the capacitance will change if different insulating materials are used for the dielectric. The effect of different materials is compared to that of air - that is, if the capacitor has a given capacitance when air is used as the dielectric, other materials used instead of air will multiply the capacitance by a certain amount called the “**dielectric constant**”.

Changing the Dielectric Material changes the capacitance. See Figure 9.

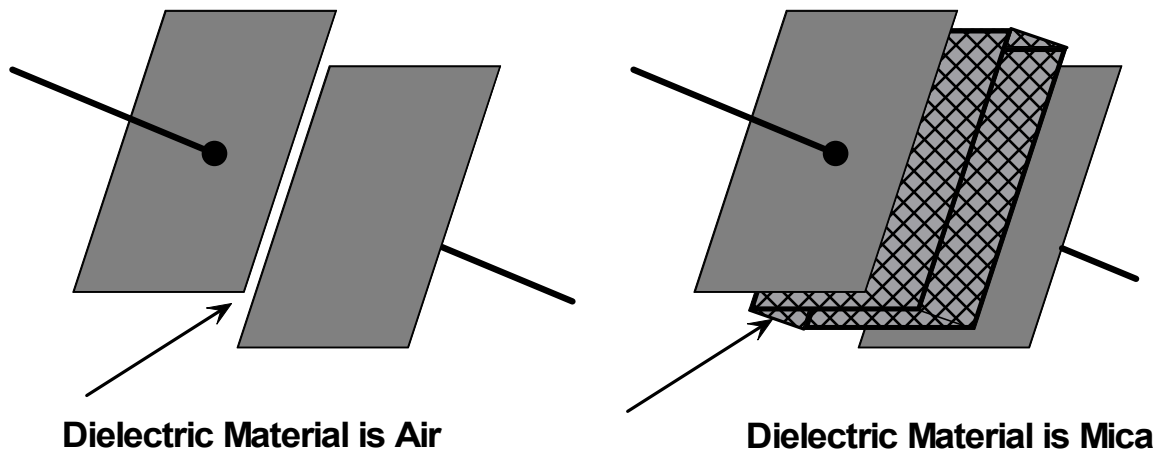


Figure 9

For example, some types of oiled paper have a dielectric constant of 3; and if such oiled or waxed paper is placed between the plates, the capacitance will be 3 times greater than it would be if the dielectric was air.

Different materials have different dielectric constants and so will alter the capacitance when they are placed between the plates to act as the dielectric. Listed below are the **Dielectric Constants** for typical materials

Air	1.0		
Quartz	3.4	to	4.2
Glass	5.1	to	8.0
Mica	7.0	to	8.0

## Energy stored in a Capacitor

When a capacitor is fully charged and immediately disconnected from the supply, the capacitor will remain charged.

If the capacitor is now shorted out by a piece of conductor the energy stored in the capacitor will be dissipated in the form of a spark / crack of the discharging current.

The energy stored in the capacitor is measured in joules ( symbol  $W$  ). The larger the capacitance value, the greater the energy stored by the capacitor, for a given voltage.

## Capacitor Types

Capacitors can be divided into two types, **polarised**, and **non-polarised**.

Polarised types include the standard aluminium electrolytic and tantalum electrolytic capacitors. They are widely used in power supplies. Both types have positive and negative terminals and **must** be correctly connected in order to maintain the dielectric action.

See Figure 10.

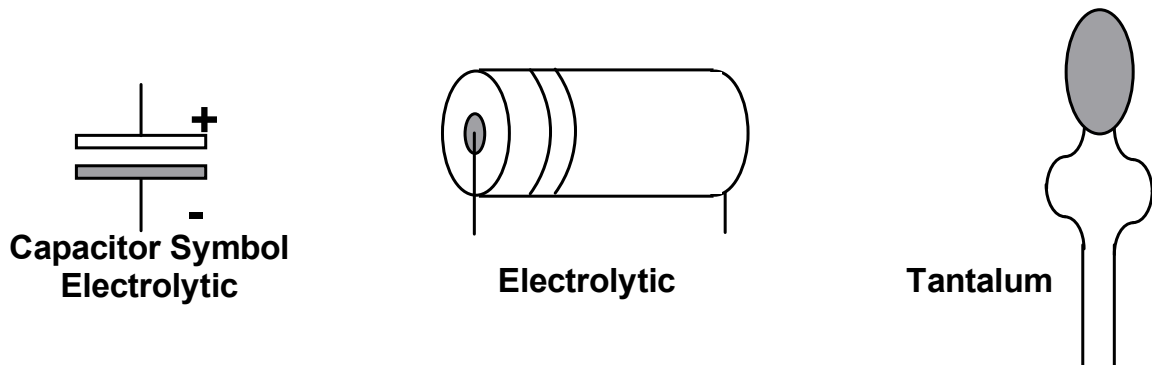


Figure 10

Non-polarised capacitors such as the polypropylene, polycarbonate, polyester, polystyrene, mica and ceramic types can be connected either way round. They all have extremely good dielectric properties. See Figure 11.

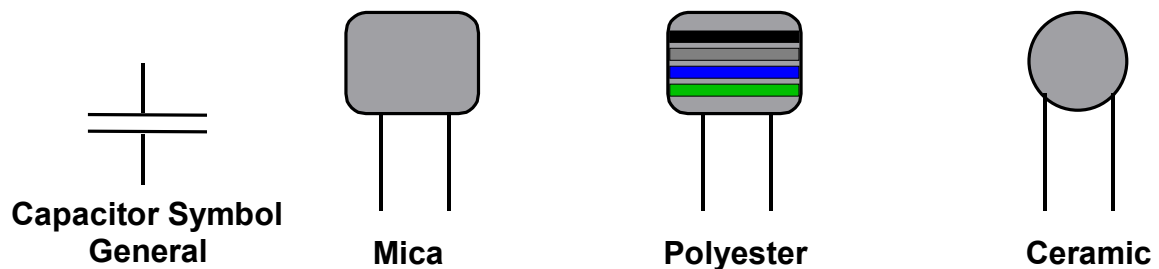


Figure 11

## Construction of Capacitors

General-purpose capacitors use wax or oil impregnated paper as the dielectric. Two long rectangular aluminium foils, separated by two slightly larger strips of the impregnated paper, are rolled up. They are then inserted into an insulated cylinder and sealed at the ends. A lead is brought out from each plate to enable the device to be connected to a circuit. Refer to Figure 12.

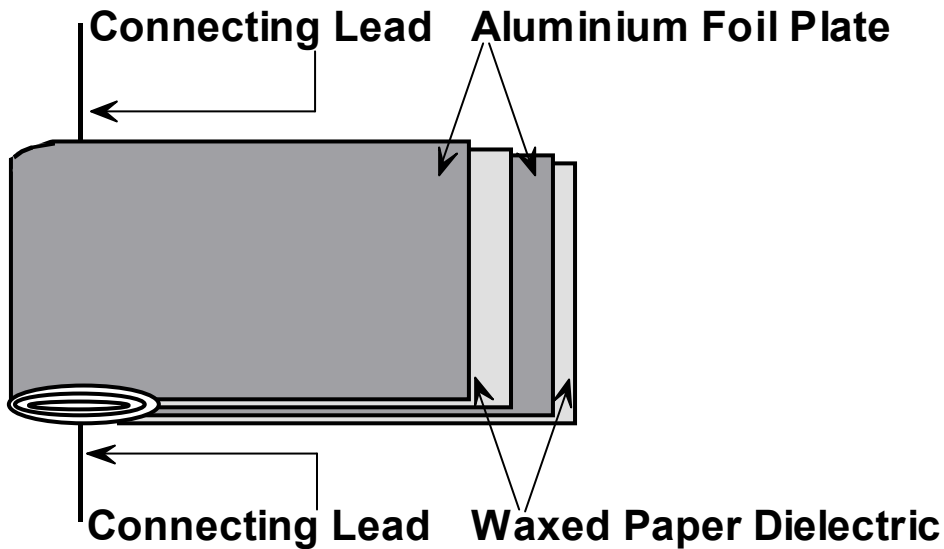


Figure 12

## Mica, Ceramic and Mylar Capacitors

Capacitors using mica dielectric have a capacitance range from a few pF to 0.02 $\mu$ F. These are usually precision capacitors, with high working voltages and excellent long-term stability. Ceramic and mylar type capacitors each exhibit certain advantages in particular circuit applications. Different capacitor types usually derive their names from the types of dielectric used. See Figure 13.

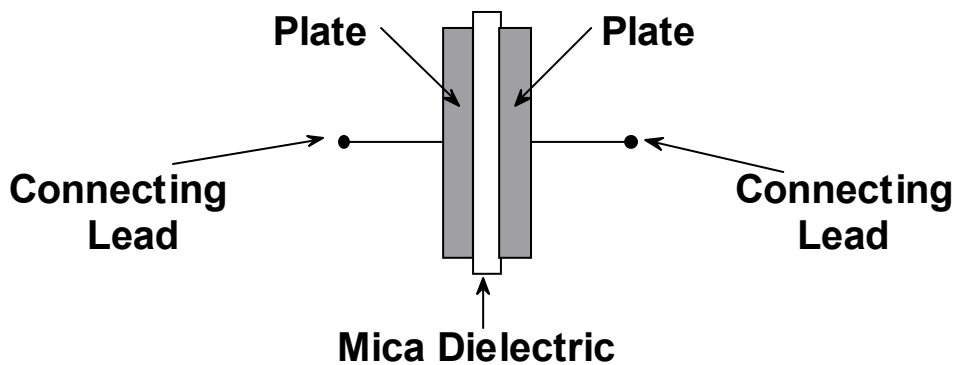


Figure 13

## Electrolytic Capacitors

Using normal construction, capacitors above  $2\mu\text{F}$  become very bulky and cumbersome. The electrolytic capacitor has a large capacitance within a package, which is much smaller than if normal construction were used.

The dielectric of electrolytic capacitors consists of a thin film of oxide formed by electrochemical action directly on a metal foil plate. The other plate consists of a paste electrolyte.

See Figure 14.

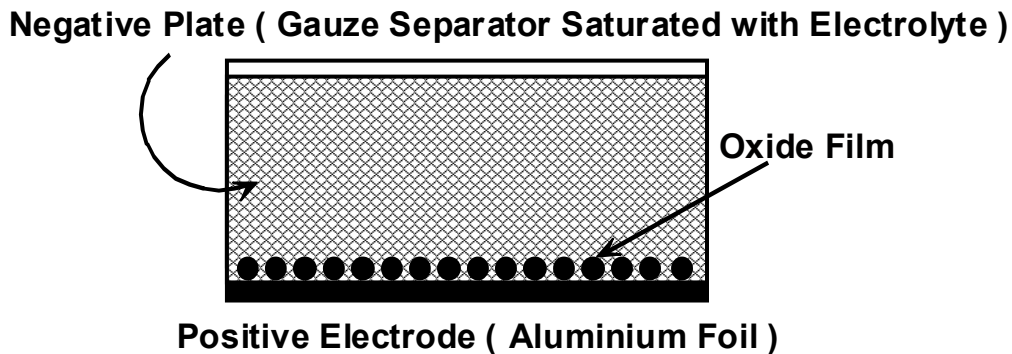


Figure 14

The large capacitance is a result of the **oxide dielectric layer** being extremely thin and the effective plate area being much increased by etching. An electrolytic capacitor is a **polarised component**, which means it must be connected into a circuit according to the plus and minus markings on its case. If it is connected wrong the capacitor is usually destroyed and may explode. They range in values from  $1\mu\text{F}$  to  $10,000\mu\text{F}$ .

## Capacitor Tolerances

Ceramic disk capacitors for general applications usually have a tolerance of  $\pm 20\%$ .

Paper capacitors usually have a tolerance of  $\pm 10\%$ .

For closer tolerances, Mica and Ceramic tubular capacitors are used. These have tolerance values of  $\pm 2$  to  $20\%$ .

Silver plated Mica capacitors are available with a tolerance of  $\pm 1\%$ .

The tolerances may be less on the minus side to make sure there is enough capacitance, particularly with electrolytic capacitors, which have a wide tolerance. For instance, a  $20\mu\text{F}$  electrolytic with a tolerance of  $-10\%$ ,  $+ 50\%$  may have a capacitance of 18 to  $30\mu\text{F}$ . However, the exact capacitance value is not critical in most applications of capacitors.

## Capacitors in Parallel

When two or more capacitors are connected in parallel the plate area is increased and so the capacitance is increased. See Figure 15.

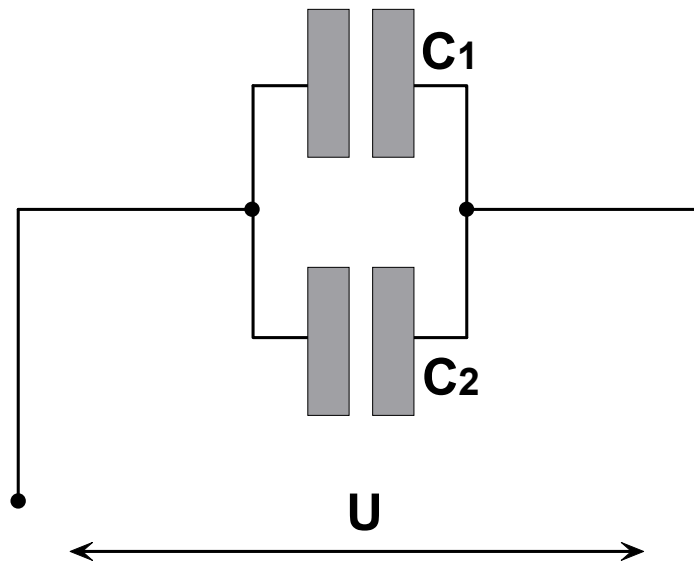


Figure 15

Therefore the total capacitance ( $C_T$ ) is the sum of the individual capacitances in a parallel.

$$C_T = C_1 + C_2 + \dots + C_N$$

When the group is connected to a supply  $U$ , the capacitors will each store a charge, and we will refer to these as  $Q_1$  and  $Q_2$  respectively. The total stored charge  $Q_T$  will be the sum of the individual charges:

$$Q_T = Q_1 + Q_2$$

As  $U$  is the same in a parallel circuit:

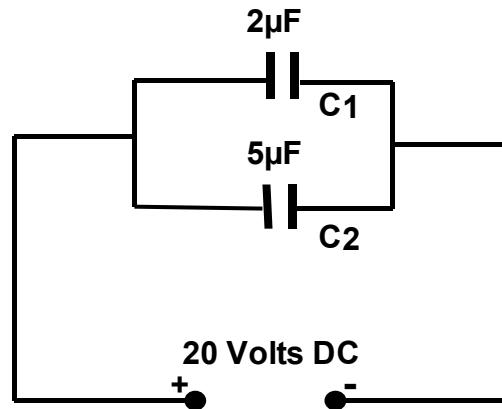
$$C_T = C_1 + C_2$$



**Example 1**

Two capacitors of capacitance  $2\mu\text{F}$  and  $5\mu\text{F}$  are connected in parallel to a 20V DC supply. Calculate:

- The equivalent capacitance of the group
- The total charge
- The charge on each capacitor.

**Solution 1**

$$\begin{aligned}
 \text{(a)} \quad C_T &= C_1 + C_2 \\
 C_T &= 2 + 5 \\
 C_T &= \underline{\underline{7\mu\text{F}}}
 \end{aligned}$$

$$\begin{aligned}
 \text{(b)} \quad \text{The total charge:} \\
 Q_T &= C_T \times U \\
 Q_T &= 7 \times 10^{-6} \times 20 \\
 Q_T &= \underline{\underline{140 \times 10^{-6} \text{ Coulombs}}}
 \end{aligned}$$

The charge on each capacitor is found by the formula:  $Q = C \times U$   
 As the capacitors are in parallel the voltage across them is the same.

$$\begin{aligned}
 \text{Charge on } 2\mu\text{F:} \\
 Q_1 &= 2 \times 10^{-6} \times 20 = \underline{\underline{40 \times 10^{-6} \text{ Coulombs}}}
 \end{aligned}$$

$$\begin{aligned}
 \text{Charge on } 5\mu\text{F:} \\
 Q_2 &= 5 \times 10^{-6} \times 20 = \underline{\underline{100 \times 10^{-6} \text{ Coulombs}}}
 \end{aligned}$$

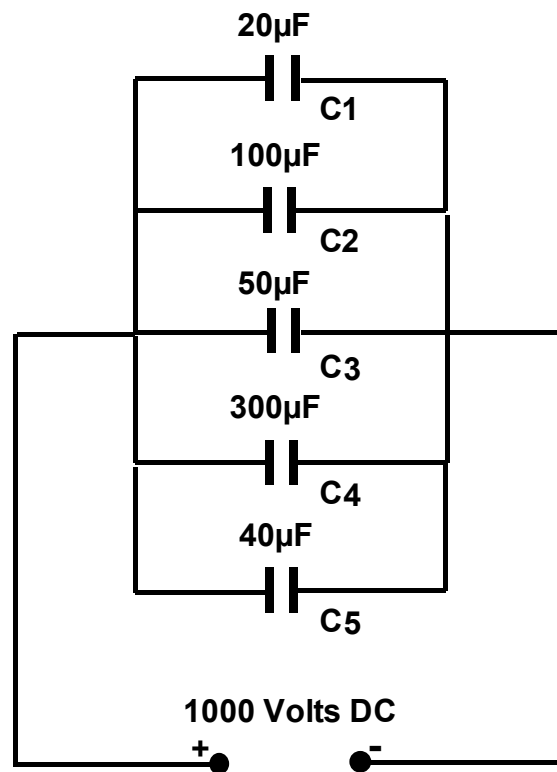
$$\begin{aligned}
 \underline{\underline{\text{Check:}}} \quad Q_T &= Q_1 + Q_2 \\
 140 \times 10^{-6} &= 40 \times 10^{-6} + 100 \times 10^{-6}
 \end{aligned}$$

**Example 2**

Five capacitors of capacitance  $20\mu\text{F}$ ,  $100\mu\text{F}$ ,  $50\mu\text{F}$ ,  $300\mu\text{F}$  and  $40\mu\text{F}$  respectively are connected in parallel to a  $1000\text{V}$  supply.

Calculate:

- The equivalent capacitance of the group
- The total charge
- The charge on each capacitor.

**Solution 2**

$$\begin{aligned} \text{(a)} \quad C_T &= C_1 + C_2 + C_3 + C_4 + C_5 \\ C_T &= 20 + 100 + 50 + 300 + 40 = \underline{\underline{510\mu\text{F}}} \end{aligned}$$

$$\begin{aligned} Q_T &= C_T \times U \\ Q_T &= 510 \times 10^{-6} \times 1000 = \underline{\underline{0.51 \text{ Coulombs}}} \end{aligned}$$

$$\begin{aligned} \text{(c)} \quad Q_1 &= C_1 \times U \\ Q_1 &= 20 \times 10^{-6} \times 1000 = \underline{\underline{0.02 \text{ Coulombs}}} \end{aligned}$$

$$\begin{aligned} Q_2 &= C_2 \times U \\ Q_2 &= 100 \times 10^{-6} \times 1000 = \underline{\underline{0.1 \text{ Coulombs}}} \end{aligned}$$

$$\begin{aligned} Q_3 &= C_3 \times U \\ Q_3 &= 50 \times 10^{-6} \times 1000 = \underline{\underline{0.05 \text{ Coulombs}}} \end{aligned}$$

$$\begin{aligned} Q_4 &= C_4 \times U \\ Q_4 &= 300 \times 10^{-6} \times 1000 = \underline{\underline{0.3 \text{ Coulombs}}} \end{aligned}$$

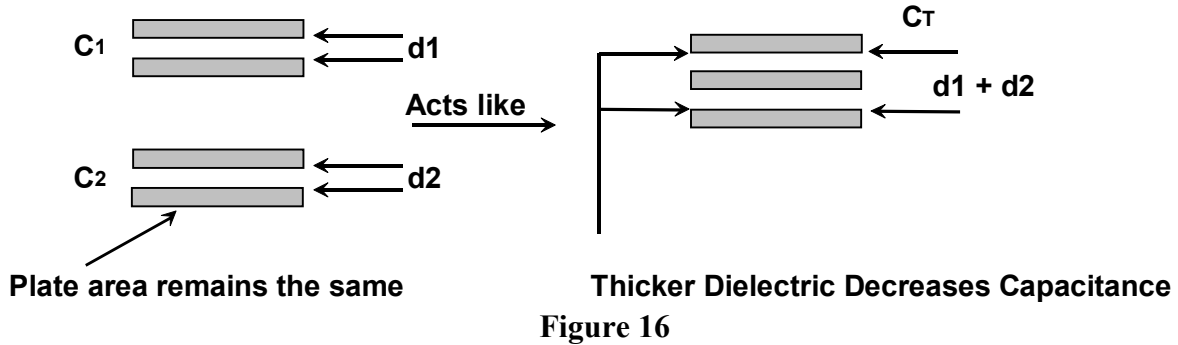
$$\begin{aligned} Q_5 &= C_5 \times U \\ Q_5 &= 40 \times 10^{-6} \times 1000 = \underline{\underline{0.04 \text{ Coulombs}}} \end{aligned}$$

**Check:**

$$\begin{aligned} Q_T &= Q_1 + Q_2 + Q_3 + Q_4 + Q_5 \\ Q_T &= 0.02 + 0.1 + 0.05 + 0.3 + 0.04 \\ Q_T &= \underline{\underline{0.51 \text{ Coulombs}}} \end{aligned}$$

## Capacitors in Series

Consider the effect of connecting two similar capacitors in series. The plate area remains the same, but the thickness of the dielectric increases. See Figure 16.



Capacitance  $\propto \frac{1}{\text{distance (d)}}$

Distance  $\propto \frac{1}{\text{Capacitance}}$

If all the distances between the plates of the capacitors are combined, there would be in effect, one capacitor of distance  $d_T$  ( $d_1 + d_2 = d_T$ ).

### Series Capacitance Formula

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \dots + \frac{1}{C_N}$$

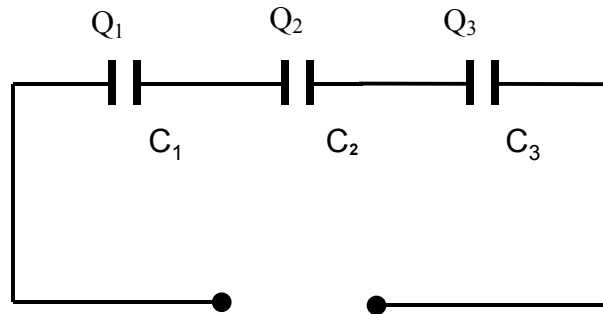
**Note:**

The total capacitance in a **series** circuit is calculated in the same manner as the total resistance in a **parallel** circuit.

The total capacitance in a **parallel** circuit is calculated in the same manner as the total resistance in a **series** circuit.

## Charge in a series circuit

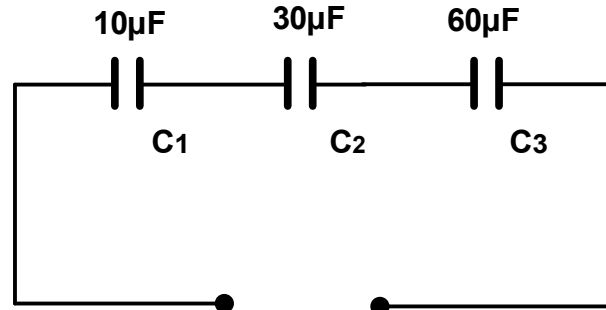
Just as current is the same in all resistors in a series circuit; charge is the same in all capacitors in a series circuit. This is because the same charging current must flow in all parts of a series circuit for the same time.



$$Q_T = Q_1 = Q_2 = Q_3 \text{ (Coulombs)}$$

**Example 1**

Calculate the total capacitance of three capacitors of values  $10\mu\text{F}$ ,  $30\mu\text{F}$  and  $60\mu\text{F}$  connected in series.

**Solution**

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$\frac{1}{C_T} = \frac{1}{10} + \frac{1}{30} + \frac{1}{60}$$

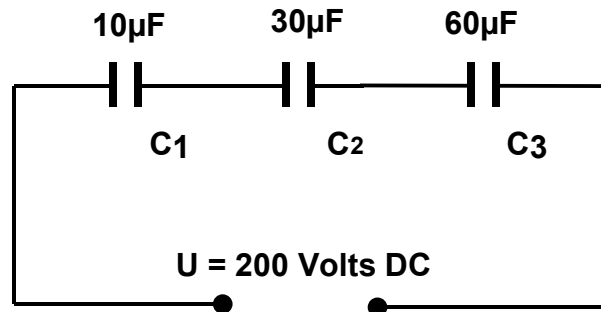
$$\frac{1}{C_T} = \frac{6 + 2 + 1}{60} = \frac{9}{60}$$

$$C_T = \frac{60}{9} = \underline{\underline{6.66\mu\text{F}}} \text{ ( to 2 decimal places )}$$

This example makes it clear that the total capacitance of a string of **series** connected capacitors is **less than** that of the **smallest** individual capacitor. This also applies to resistors in parallel.

## Total Stored Charge

The total charge can now be calculated for the previous example when connected to a 200 Volt supply.



$$Q_T = C_T \times U \text{ (Coulombs)}$$

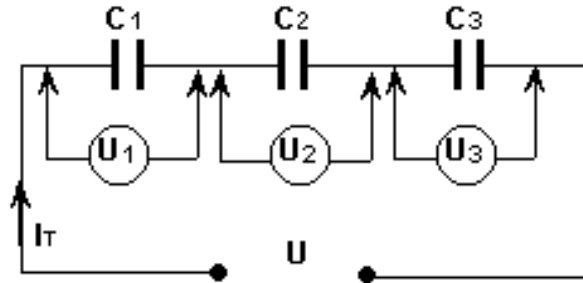
$$Q_T = 6.66 \times 10^{-6} \times 200$$

$$Q_T = \underline{\underline{1333 \times 10^{-6} \text{ Coulombs}}}$$

Since the capacitors are connected in **series**, the **charge** on each is the **same** as the total charge, i.e.  $1333 \times 10^{-6}$  Coulombs.

## Potential Difference

The supply voltage is  $U$  and the volt drops across the individual capacitors  $C_1$ ,  $C_2$  and  $C_3$  are  $U_1$ ,  $U_2$  and  $U_3$  respectively, since the capacitors are all in series:



$$U_T = U_1 + U_2 + U_3$$

$$Q = C \times U \quad U_1 = \frac{Q}{C_1}$$

$$U_1 = \frac{Q}{C_1} = \frac{1333 \times 10^{-6}}{10 \times 10^{-6}} = \frac{1333}{10} = \underline{\underline{133.30 \text{ Volts}}}$$

$$U_2 = \frac{Q}{C_2} = \frac{1333 \times 10^{-6}}{30 \times 10^{-6}} = \frac{1333}{30} = \underline{\underline{44.43 \text{ volts}}}$$

$$U_3 = \frac{Q}{C_3} = \frac{1333 \times 10^{-6}}{60 \times 10^{-6}} = \frac{1333}{60} = \underline{\underline{22.21 \text{ volts}}}$$

Note:

The sum of the three individual volt drops, across the three capacitors equals the supply voltage. The larger volt drop is across the smaller value capacitor and the smaller volt drop is across the larger value capacitor.



**Example**

Three capacitors of values  $6\mu\text{F}$ ,  $8\mu\text{F}$  and  $16\mu\text{F}$  respectively are connected in series to a 100 V DC supply. Calculate:

- (1) The total capacitance of the circuit
- (2) The total stored charge
- (3) The volt drop across each capacitor.

**Solution**

$$(1) \quad \frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$\frac{1}{C_T} = \frac{1}{6} + \frac{1}{8} + \frac{1}{16}$$

$$\frac{1}{C_T} = \frac{8 + 6 + 3}{48} = \frac{17}{48}$$

$$C_T = \frac{48}{17} = \underline{\underline{2.82\mu\text{F}}}$$

$$(2) \quad Q_T = C_T \times U$$

$$Q_T = 2.82 \times 10^{-6} \times 100$$

$$Q_T = \underline{\underline{282 \times 10^{-6} \text{ Coulombs}}}$$

$$(3) \quad U_1 = \frac{Q}{C_1} = \frac{282 \times 10^{-6}}{6 \times 10^{-6}} = \underline{\underline{47.05 \text{ Volts}}}$$

$$U_2 = \frac{Q}{C_2} = \frac{282 \times 10^{-6}}{8 \times 10^{-6}} = \underline{\underline{35.35 \text{ Volts}}}$$

$$U_3 = \frac{Q}{C_3} = \frac{282 \times 10^{-6}}{16 \times 10^{-6}} = \underline{\underline{17.63 \text{ Volts}}}$$

Check:

$$\begin{aligned} U_T &= U_1 + U_2 + U_3 \\ 100 &= 47.05 + 35.35 + 17.63 \\ 100 &= 100 \end{aligned}$$

## Working Voltage of a Capacitor

Manufacturers specify the safe working voltage on the body of capacitors and this value should not be exceeded. See Figure 17.

If this safe working voltage across a capacitor is exceeded, it is possible that the dielectric may break down causing a short circuit in the capacitor.

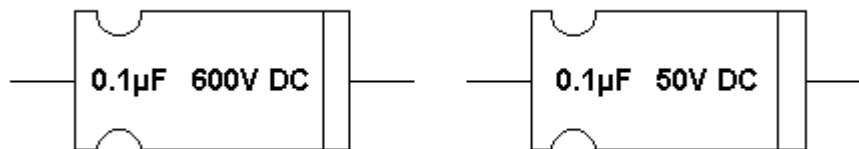


Figure 17

## Working Voltage of equal value Capacitors in Series

When two equal values of capacitors are connected in series, the working voltage is the sum of the two working voltages of the capacitors. For example, two equal value capacitors intended for 130 Volts maximum supply could be connected in series and placed across a supply of up to 260 Volts.

This is not done in practical circuits. It would be prudent to use two 260 Volt capacitors.

## Series / Parallel Capacitor Calculations

The following is the method used to find the total capacitance of the circuit shown in Figure 18.

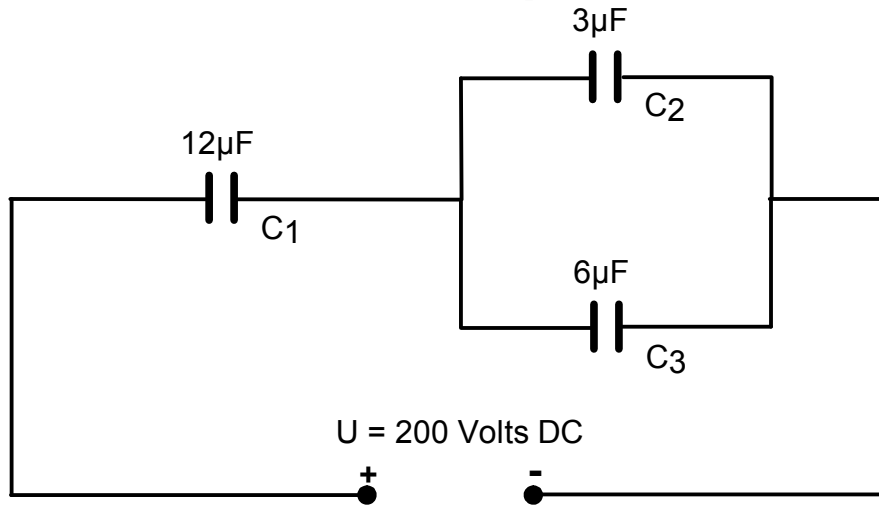
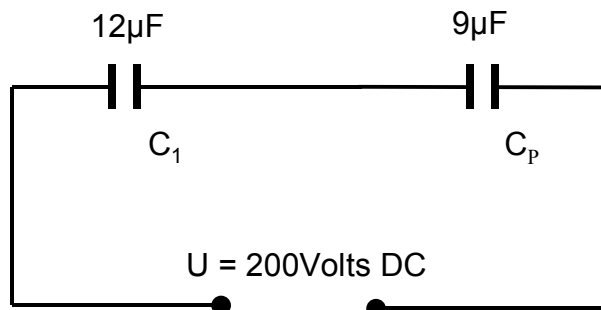


Figure 18

First find the total capacitance of the parallel branch ( $C_P$ ):

$$C_P = C_2 + C_3$$

$$C_P = 3 + 6 = \underline{9\mu\text{F}}$$



Equivalent Circuit

This  $9\mu\text{F}$  capacitor  $C_P$  is in series with the  $12\mu\text{F}$  capacitor.

To find the total capacitance of the circuit:

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_P}$$

$$\frac{1}{C_T} = \frac{1}{12} + \frac{1}{9}$$

$$\frac{1}{C_T} = \frac{3 + 4}{36} = \frac{7}{36}$$

$$C_T = \frac{36}{7} = \underline{\underline{5.14 \mu F}}$$

The total charge of the circuit:

$$Q_T = C_T \times U$$

$$Q_T = 5.14 \times 10^{-6} \times 200 = \underline{\underline{1028 \times 10^{-6} \text{ Coulombs}}}$$

Now we can find the volt drop across the 12 $\mu$ F capacitor:

$$U_1 = \frac{Q_T}{C_1} = \frac{1028 \times 10^{-6}}{12 \times 10^{-6}} = \frac{1028}{12} = \underline{\underline{85.66 \text{ Volts}}}$$

The volt drop across both capacitors in the parallel circuit will be the same ( $U_2$ ):

$$U_2 = \frac{Q_T}{C_P} = \frac{1028 \times 10^{-6}}{9 \times 10^{-6}} = \frac{1028}{9} = \underline{\underline{114.2 \text{ Volts}}}$$

As the 12 $\mu$ F capacitor is in series in the circuit, the total current flows through it and therefore the charge stored on it will equal the total charge  $Q_T$ .

$$Q_1 = U_1 \times C_1$$

$$Q_1 = 85.66 \times 12 \times 10^{-6} = \underline{\underline{1028 \times 10^{-6} \text{ Coulombs}}}$$

The stored charge on 3 $\mu$ F capacitor:

$$Q_2 = U_2 \times C_2$$

$$Q_2 = 114.2 \times 3 \times 10^{-6} = \underline{\underline{343 \times 10^{-6} \text{ Coulombs}}}$$

The stored charge on 6 $\mu$ F capacitor:

$$Q_3 = U_2 \times C_3$$

$$Q_3 = 114.2 \times 6 \times 10^{-6} = \underline{\underline{685 \times 10^{-6} \text{ Coulombs}}}$$

The charge stored by the two capacitors in parallel is equal to the total charge.

$$Q_T = Q_2 + Q_3$$

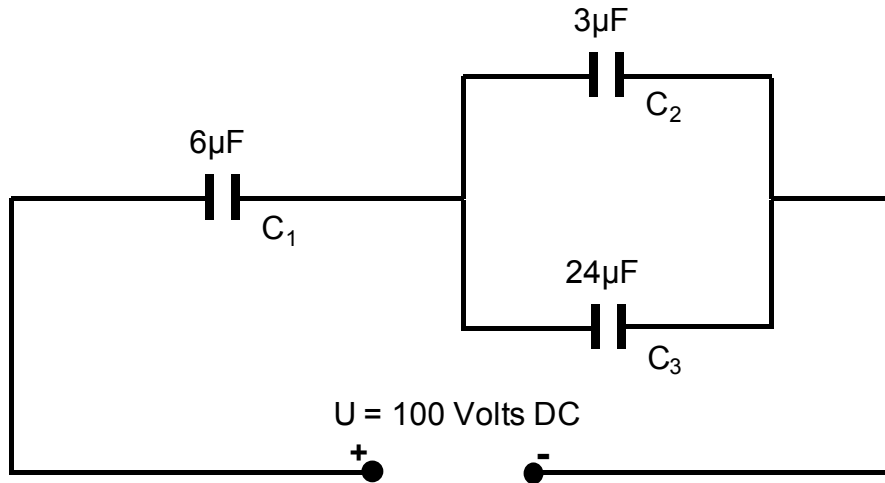
$$Q_T = 343 \times 10^{-6} + 685 \times 10^{-6}$$

$$\underline{1028 \times 10^{-6}} = \underline{1028 \times 10^{-6}}$$

### Question 1

Calculate for the circuit below:

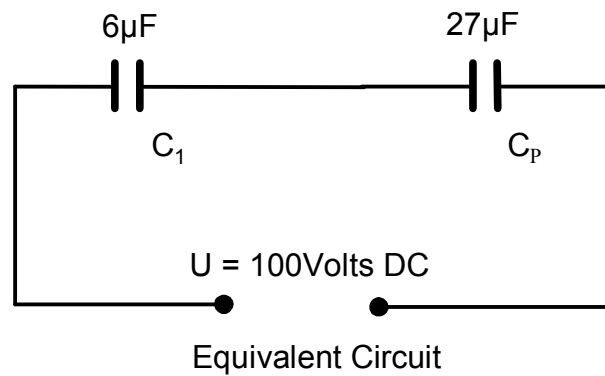
1. The total capacitance of the circuit
2. The total charge stored
3. The potential difference across each capacitor
4. The stored charge on the  $3\mu\text{F}$  capacitor
5. The stored charge on the  $24\mu\text{F}$  capacitor



### Solution to Question 1

$$(1) \quad C_p = C_2 + C_3$$

$$C_p = 3 + 24 = \underline{27\mu\text{F}}$$



$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_P}$$

$$\frac{1}{C_T} = \frac{1}{6} + \frac{1}{27}$$

$$\frac{1}{C_T} = \frac{9 + 2}{54} = \frac{11}{54}$$

$$C_T = \frac{54}{11} = \underline{\underline{4.91\mu\text{F}}}$$

$$(2) \quad Q_T = U \times C_T$$

$$Q_T = 100 \times 4.91 \times 10^{-6} = \underline{\underline{491 \times 10^{-6} \text{ Coulombs}}}$$

$$(3) \quad U_1 \text{ across } 6\mu\text{F capacitor} = \frac{Q_1}{C_1}$$

$$U_1 = \frac{491 \times 10^{-6}}{6 \times 10^{-6}} = \frac{491}{6} = \underline{\underline{81.83 \text{ Volts}}}$$

$$U_P \text{ across parallel capacitors} = \frac{Q}{C_P}$$

$$U_P = \frac{491 \times 10^{-6}}{17 \times 10^{-6}} = \frac{491}{17} = \underline{\underline{28.88 \text{ Volts}}}$$

(4) The stored charge on the 3 $\mu$ F capacitor:

$$\begin{aligned} Q_2 &= U_P \times C_2 \\ Q_2 &= 18.18 \times 3 \times 10^{-6} \\ Q_2 &= \underline{\underline{54.54 \times 10^{-6} \text{ Coulombs}}} \end{aligned}$$

(5) The stored charge on the 24 $\mu$ F capacitor:

$$\begin{aligned} Q_3 &= U_P \times C_3 \\ Q_3 &= 18.18 \times 24 \times 10^{-6} \\ Q_3 &= \underline{\underline{436.32 \times 10^{-6} \text{ Coulombs}}} \end{aligned}$$

The charge stored on the two capacitors in parallel is equal to the total charge.

$$\begin{aligned} Q_T &= Q_2 + Q_3 \\ 491 \times 10^{-6} &= 54.54 \times 10^{-6} + 436.32 \times 10^{-6} \\ \underline{491 \times 10^{-6}} &= \underline{491 \times 10^{-6}} \end{aligned}$$



## Capacitor Faults

Capacitors can become open or short-circuited. In either case, the capacitor is useless because it cannot store a charge. A leaky capacitor is equivalent to a partial short circuit where the dielectric gradually loses its insulating qualities under the stress of the applied voltage thus lowering its resistance.

A good capacitor has very high resistance of the order of megohms; a short-circuited capacitor has zero ohms resistance, and a leaky capacitor has a resistance lower than normal.

### ***Checking a Capacitor with an Analogue Multimeter***

The above faults in a capacitor can be checked using an analogue multimeter, set on the resistance range. The highest ohms range, such as R x 100K is preferable. This will also depend on the value of the capacitor.

Ensure that the capacitor to be checked is isolated from the supply. Some capacitors may have a discharge resistor otherwise the capacitor should be discharged manually. The capacitor must be disconnected from the circuit. The discharge resistor must be disconnected from the capacitor. It is only necessary to disconnect one side of the capacitor to isolate it from the discharge resistor and circuit. The meter leads are connected across the capacitor, keeping the fingers away from the connections, since the body resistance will affect the reading.

For a good capacitor, the meter pointer moves quickly toward the low-resistance side of the scale and then slowly recedes towards infinity. This charging effect shows that the capacitor can store a charge, indicating a good capacitor. It should be noted, that the internal battery of the meter, charges the capacitor, causing the fall of the meter reading.

### ***Ohmmeter Readings on Faulty Capacitors***

While the analogue multimeter method is only a rough indication of functionality, it will not indicate the value of a capacitor. The following will indicate the common capacitor faults:

- (1) If an ohmmeter reading immediately goes practically to zero and stays there, the capacitor is short-circuited.
- (2) If the capacitor shows no charging action but just reads a very high resistance, it may be open circuited. Some precautions must be remembered, however, since very high resistance is a normal condition for capacitors. Reverse the ohmmeter leads to discharge the capacitor, and check again. In addition, remember that capacitance values of 100pF, or less, normally take very little charging current for the low battery voltage of the ohmmeter.

## Potential Dangers with Capacitors

- (1) Capacitors charged to a high voltage may remain charged for hours after the equipment is turned off.

Warning:

Always discharge capacitors prior to handling or testing.

- (2) Electrolytic capacitors are polarised and must be connected according to the plus and minus markings on its case.

Warning:

If it is connected with the wrong polarity, the capacitor is usually destroyed and may EXPLODE with a danger to health and safety.

- (3) The manufacturers specify the safe working voltage on the body of a capacitor and this value should not be exceeded.

Warning:

Exceeding this value of voltage may cause the capacitor to EXPLODE with a danger to health and safety.

## Summary

1. A capacitor consists of two conductors separated by a dielectric.
2. The term “capacitance” means the ability to store energy.
3. The unit of capacitance is the Farad. Practical capacitors have much smaller capacitance values from:
  - Microfarads (  $1\mu\text{F}$  is  $1 \times 10^{-6}$  Farads ),
  - Nanofarads (  $1\text{nF}$  is  $1 \times 10^{-9}$  Farads ) and
  - Picofarads (  $1\text{pF}$  is  $1 \times 10^{-12}$  Farads ).
4. Q is the charge in Coulombs
  - $Q = I \times t$  ( Current x time )
  - $Q = C \times U$  ( Capacitance x Voltage )
5. Electrolytic capacitors are polarised.
6. The factors effecting capacitance are:
  - a. Plate Area
  - b. Plate Spacing ( distance between plates )
  - c. The Dielectric Material.
7. The total capacitance for a parallel circuit:
 
$$C_T = C_1 + C_2 + \dots + C_N$$
8. The total capacitance for a series circuit:
 
$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \dots + \frac{1}{C_N}$$
9. When checked with an analogue multimeter a good capacitor shows or indicates a charging effect.