Cambridge

A2 Level

Physics

CODE: (9702)

Chapter 24

Chapter 24: Capacitance

Figure 24.2 A variety of capacitors.

Capacitors in use

Capacitors are used to store energy in electrical and electronic circuits. This means that they have many valuable applications.

The two ammeters will give identical readings. The current stops when the potential difference (p.d.) across the capacitor is equal to the electromotive force (e.m.f.) of the supply. We then say that the capacitor is 'fully charged'.

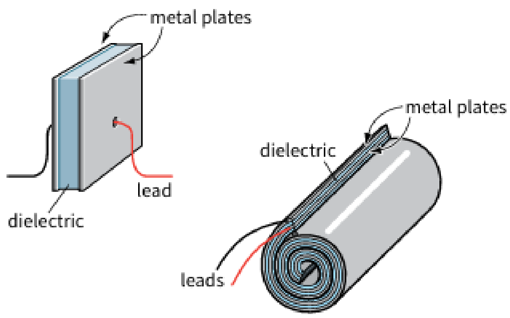


Figure 24.3 The construction of two types of capacitor.

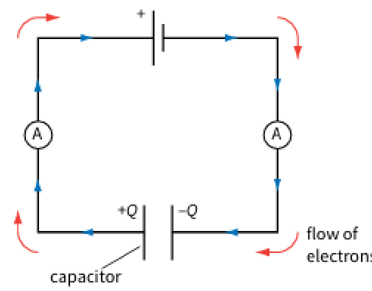


Figure 24.4 The flow of charge when a capacitor is charged up.

Note: The convention is that current is the flow of positive charge. Here, it is free electrons that flow. Electrons are negatively charged; conventional current flows in the opposite direction to the electrons (Figure 24.5).

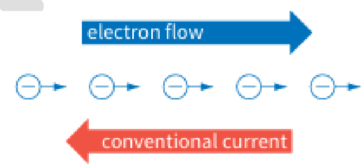


Figure 24.5 A flow of electrons to the right constitutes a conventional current to the left.

Charge on the plates

A capacitor with uncharged plates stores equal amounts of positive and negative charges. When connected to a supply, the charge +Q is transferred to the other plate, leaving behind charge –Q. The total charge on the capacitor is zero. To increase charge storage, a higher e.m.f supply is needed. When connected together, electrons flow back around the circuit, causing the capacitor to discharge. The magnitude of the charge on the plates is determined by the area under the current-time graph.

The meaning of capacitance

If you look at some capacitors, you will see that they are marked with the value of their **capacitance**

The capacitance C of a capacitor is defined by:

$$\text{capacitance} = \frac{\text{charge}}{\text{potential difference}}$$

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

where Q is the magnitude of the charge on each of the capacitor's plates and V is the potential difference across it the capacitor.

> The capacitance of a capacitor is the charge stored on one plate per unit of potential difference between the plates.

The charge on the capacitor may be calculated using the equation:

$$Q = VC$$

Units of capacitance

The unit of capacitance is the farad, F. From the equation that defines capacitance, you can see that this must be the same as the units of charge (coulombs, C) divided by voltage (V):

$$1\,\mathrm{F} = 1\,\mathrm{C\,V^{-1}}$$

Other markings on capacitors

Many capacitors are marked with their highest safe working voltage. If you exceed this value, charge may leak across between the plates, and the dielectric will cease to be an insulator. Some capacitors (electrolytic ones) must be connected correctly in a circuit.

Energy stored in a capacitor When you charge a capacitor, you use a power supp

Charge a capacitor by using a power supply to push electrons onto and off plates, increasing their potential energy. This energy is recovered when discharged. Large capacitors, like 1000 µF or more, do not store much energy when charged. The process involves pushing electrons onto and off plates, with increasing charge requiring more work due to increased repulsion between electrons and new ones.

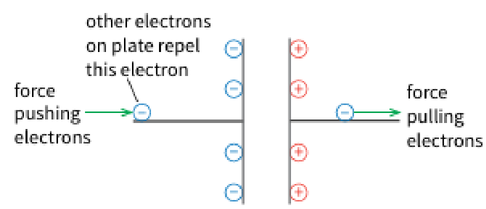


Figure 24.6 When a capacitor is charged, work must be done to push additional electrons against the repulsion of the electrons that are already present.

This graph shows how the p.d. V increases as the amount of charge Q increases. It is a straight line because Q and V are related by:

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

The area under a graph of p.d. against charge is equal to work done.

Capacitors in parallel

Capacitors are used in electric circuits to store energy. Situations often arise where two or more capacitors are connected together in a circuit. In this section, we will look at capacitors connected in parallel. The next section deals with capacitors in series.

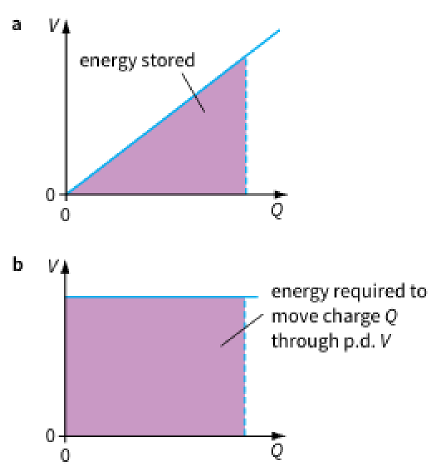


Figure 24.7 The area under a graph of voltage against charge gives a quantity of energy. The area in **a** shows the energy stored in a capacitor; the area in **b** shows the energy required to drive a charge through a resistor.

When two capacitors are connected in parallel (Figure 24.10), their combined or total capacitance Ctotal is simply the sum of their individual capacitances C1 and C2:

$$C_{\text{total}} = C_1 + C_2$$

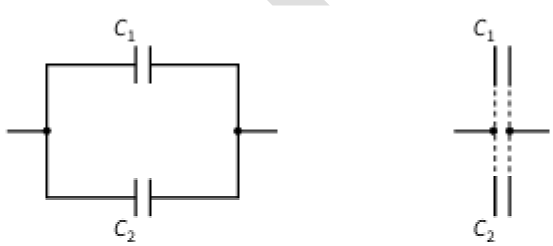


Figure 24.10 Two capacitors connected in parallel are equivalent to a single, larger capacitor.

Capacitors in parallel: deriving the formula

We can derive the equation for capacitors in parallel by thinking about the charge on the two capacitors. As shown in Figure 24.11, C1 stores charge Q1 and C2 stores charge Q2. Since the p.d. across each capacitor is V, we can write

$Q_1 = C_1V$ and $Q_2 = C_2V$

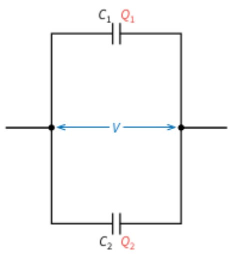


Figure 24.11 Two capacitors connected in parallel have the same p.d. across them, but different amounts of charge.

The total charge is given by the sum of these:

$$Q = Q_1 + Q_2 = C_1V + C_2V$$

Since V is a common factor:

$$Q = (C_1 + C_2)V$$

Comparing this with $Q = C_{total}V$ gives the required $C_{total} = C_1 + C_2$. It follows that for three or more capacitors connected in parallel, we have:

$$C_{total} = C_1 + C_2 + C_3 + \cdots$$

Capacitors in parallel: summary

For capacitors in parallel, the following rules apply:

- ■ ■ The p.d. across each capacitor is the same.
- ■ ■ The total charge on the capacitors is equal to the sum of the charges: $Q_{total} = Q1 + Q2 + Q3 + ...$
- ■ ■ The total capacitance C_{total} is given by: $C_{total} = C1 + C2 + C3 + ...$

Capacitors in series

In a similar way to the case of capacitors connected in parallel, we can consider two or more capacitors connected in series (Figure 24.12).

The total capacitance C_{total} of two capacitors of capacitances C1 and C2 is given by:

$$\frac{1}{C_{total}} = \frac{1}{C_1} + \frac{1}{C_2}$$

Here, it is the reciprocals of the capacitances that must be added to give the reciprocal of the total capacitance. For three or more capacitors connected in series, the equation for their total capacitance is:

$$\frac{1}{C_{total}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots$$

Figure 24.12 Two capacitors connected in series.

Capacitors in series: deriving the formula

The same principles apply here as for the case of capacitors in parallel. Figure 24.13 shows the situation. C_1 and C_2 are connected in series, and there is a p.d. V across them. This p.d. is divided (it is shared between the two capacitors), so that the p.d. across C_1 is V_1 and the p.d. across C_2 is V_2. It follows that:

$$V = V_1 + V_2$$

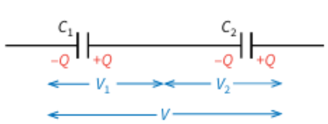


Figure 24.13 Capacitors connected in series store the same charge, but they have different p.d.s across them.

Comparing capacitors and resistors

It is helpful to compare the formulae for capacitors in series and parallel with the corresponding formulae for resistors (Table 24.3).

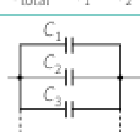
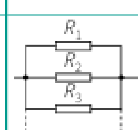
	Capacitors	Resistors
In series		
	store same charge	have same current
	$\frac{1}{C_{total}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots$	$R_{total} = R_1 + R_2 + R_3 + \cdots$
In parallel		
	have same p.d.	have same p.d.
	$C_{total} = C_1 + C_2 + C_3 + \cdots$	$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$

Table 24.3 Capacitors and resistors compared.

Capacitor networks

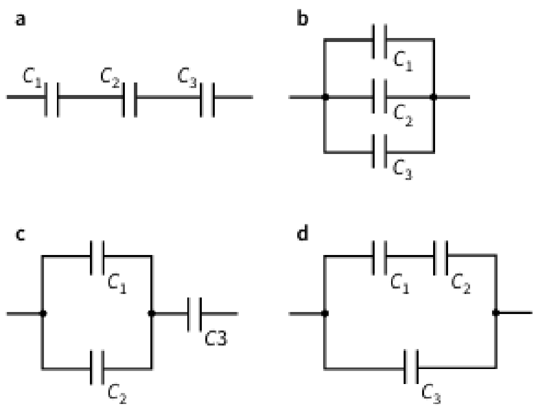


Figure 24.14 Four ways to connect three capacitors.

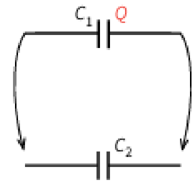


Figure 24.16 Capacitor of capacitance C_1 is charged and then connected across C_2.

Sharing charge, sharing energy

If a capacitor is charged and then connected to a second capacitor (Figure 24.16), what happens to the charge and the energy that it stores? Note that, when the capacitors are connected together, they are in parallel, because they have the same p.d. across them. Their combined capacitance C total is equal to the sum of their individual capacitances.