A2 Level Physics

Chapter 10 – Capacitors

10.1.1 Capacitors

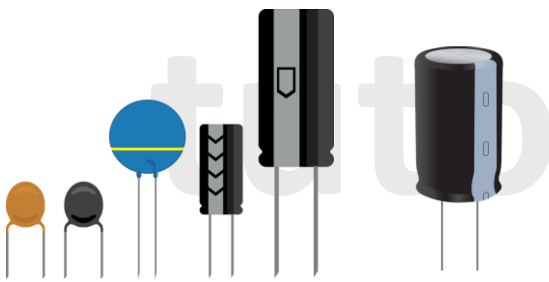
Notes

Capacitor

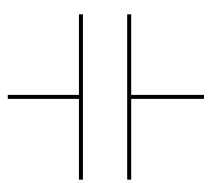
A capacitor is an arrangement of conductors and insulators designed to store electrical charge.

Capacitors come in various types, shapes, and sizes, but they all have two metal plates separated by an insulting material known as the dielectric (such as air or paper). The dielectric keeps the two metal plates from touching. If the metal plates are touching, no charge will be stored because the circuit will be completed.

If capacitors were made in their basic form of two flat conducting plates separated by an insulator, they would be excessively large and expensive. This is why the metal plates and dielectric are rolled into a cylindrical shape to make capacitors that can be connected in a circuit.



The circuit symbol for a capacitor is two parallel lines:



Charging of a Parallel-Plate Capacitor

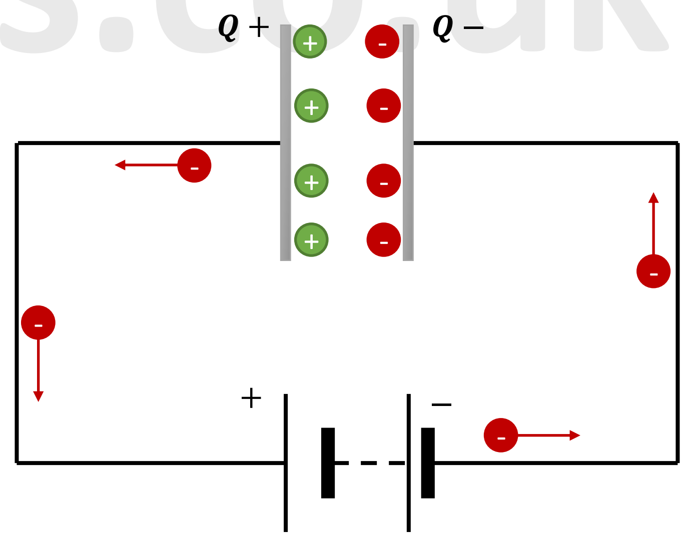
A capacitor is formed when two parallel metal plates are placed close together. When a direct current (D.C.) power source (such as a battery) is connected to such a capacitor, one of the plates gains electrons and becomes negatively charged.

This causes an equal number of electrons to be repelled from the other plate, which becomes positively charged as a result. The electrons arrive at one plate and are repelled from the other plate at the same time.

The plates are separated by an electrical insulator, preventing any charge moving between them. As a result, a potential difference builds up between the plates of the capacitor.

If one plate stores charge $-Q$, the other stores charge $+Q$ and we say charge Q is stored.

The potential difference (Voltage) of the source to which the plates are connected to determines the amount of charge stored.

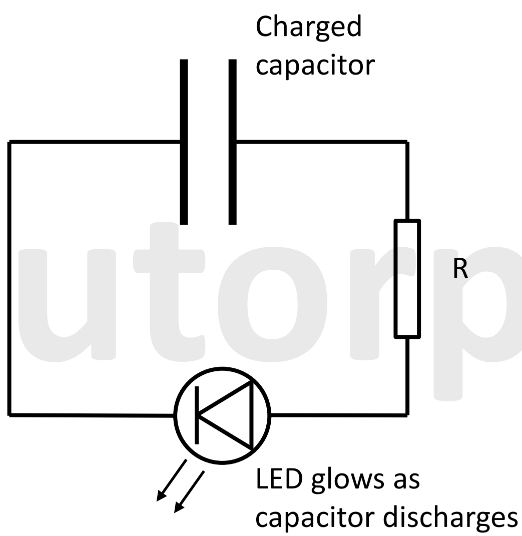


Discharging of a Parallel-Plate Capacitor

After a capacitor has been charged, it can be discharged by disconnecting it from the power supply and connecting the leads to an electrical component.

A discharge can be observed by connecting a charged capacitor to an LED through a protective resistor.

As the capacitor discharges, the LED glows.



Consider capacitors as buckets that hold electrical charge. You can fill up the bucket and empty it when you feel like it. The capacitance of a capacitor tells you how much charge it can store.

Capacitance

The amount of charge stored per unit potential difference across a capacitor is known as its capacitance (C).

Capacitance is measured in farads.

$$1\ farad\ (F) = 1\ coulomb\ per\ volt\ (CV^{-1})$$

$$Capacitance = \frac{charge}{potential\ difference}$$

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

Where:

C = capacitance in farads, F

Q = charge in coulomb, C

V = potential difference in volts, V.

Note:

The charge (Q) stored in a capacitor is proportional to the capacitors capacitance (C) and potential difference (V) across it.

$$Q = CV$$

1 farad is an extremely large capacitance value, and most practical capacitors are far smaller. So smaller sub-multiples are used:

$$1\ millifarad\ (mF) = 10^{-3}F$$
$$1\ microfarad\ (\mu F) = 10^{-6}F$$
$$1\ nanofarad\ (nF) = 10^{-9}F$$
$$1\ picofarad\ (pF) = 10^{-12}F$$

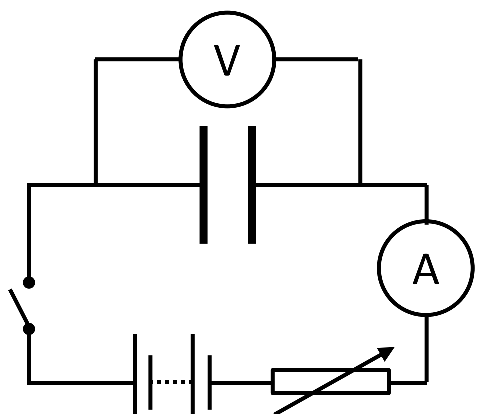
Investigating V and Q

Equipment:

- Capacitor
- Voltmeter
- Ammeter
- Battery
- Variable resistor
- Switch
- Stop watch

Method and Graphs:

- $C = \frac{Q}{V}$ rearranged gives $Q = CV$, and since the capacitance of a capacitor is fixed, this means Q is directly proportional to V. By charging a capacitor with a continuous current, you can investigate the relationship between the potential difference across and the charge stored on the capacitor.
- To begin, set up a test circuit to measure current and potential difference:



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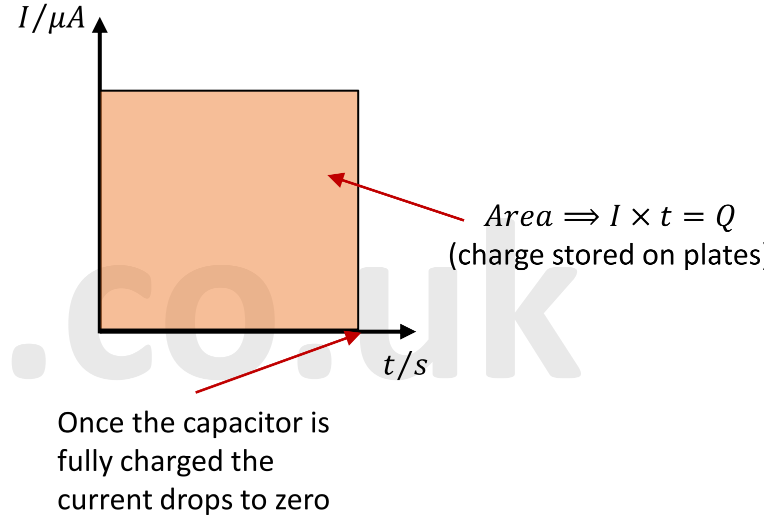
Investigating V and Q

- After closing the switch, adjust the variable resistor as needed to maintain a constant charging current for as long as possible (this becomes difficult when the capacitor is nearly full).
- At regular intervals, record the p.d. until it equals the battery p.d. The following graph can be plotted using a fixed charging current and the time it takes to charge the capacitor:



- The charge stored on the capacitor is represented by the area under the graph. You can also calculate the charge stored on the capacitor at a given time by using $Q = It$.
- Then plot the charge stored is against the potential difference across the capacitor at each recorded time interval, and the following graph is produced:

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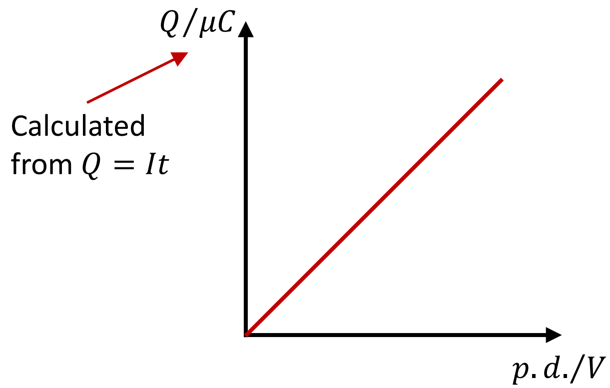
Investigating V and Q

- Then plot the charge stored is against the potential difference across the capacitor at each recorded time interval, and the following graph is produced:



- The graph is a straight line through the origin therefore Q and V are directly proportional. The gradient of the graph is the capacitance, C, and so you can carry out the same experiment to calculate the unknown capacitance of a capacitor.

Keep in mind that the axes may be swapped in the exam.

Safety:

To avoid the capacitor from exploding and releasing toxic chemicals, make sure it is connected with the right polarity and that its voltage rating exceeds the voltage of the battery.

Uses of Capacitors

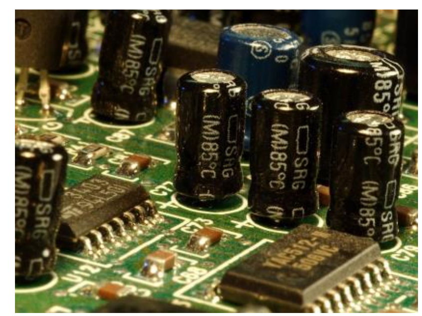
As capacitors can only store a small amount of charge and so they aren't commonly used as a substitute to batteries. You'd need roughly 6000 farads to store the same amount of energy as an AA battery. The capacitor would have to be huge to provide that many farads.

Capacitors are often only used to produce power for a short period of time since increasing the discharge time is difficult, and also as the capacitor discharges, the voltage in the circuit lowers.

But capacitors are still useful since they can hold charge until it is needed, then discharge it all in a fraction of a second, whereas a battery could take several minutes. But because of this instant discharge, charged capacitors can be quite dangerous if used incorrectly.

In a camera flash, for example, the camera battery charges the capacitor for a few seconds before dumping the whole charge into the flash almost instantly. This enables the camera flash to be extremely bright for a brief period of time.

Capacitors can also be used within a computer to provide temporary backup power in the event of a power outage, preventing data loss.



Capacitors in series and parallel

Capacitors in parallel

The diagram opposite shows two capacitors C_1 and C_2 connected in parallel to one another and have a supply of potential difference V connected to them.

Components connected in parallel have the same potential difference, so the charge stored by each capacitor is:

$Q_1 = C_1V$ and $Q_2 = C_2V$

So total charge stored (Q) is:

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

Therefore the total capacitance (C) is:

$$C = \frac{Q}{V} = \frac{C_1V + C_2V}{V} = C_1 + C_2$$

So, the total capacitance (C) of any number (n) of capacitors connected in parallel is given by:

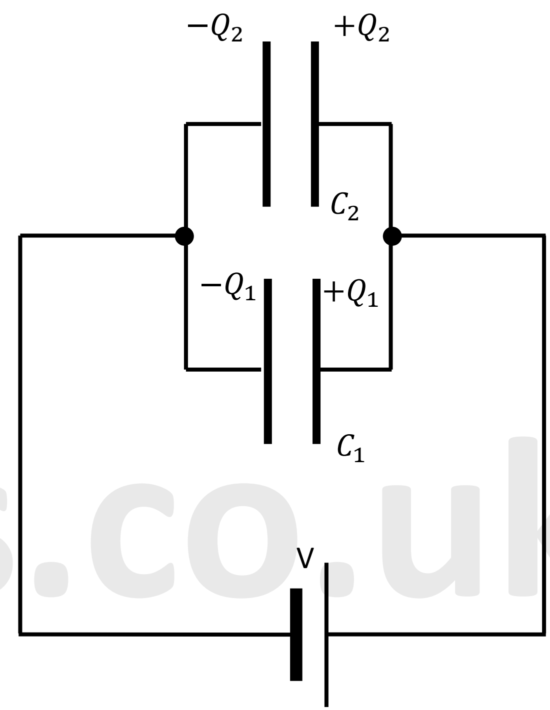
$$C = C_1 + C_2 + \ldots\ldots + C_n$$

For two capacitors in parallel, the ratio of the charge stored by each capacitor is:

$$\frac{Q_1}{Q_2} = \frac{C_1V}{C_2V} = \frac{C_1}{C_2}$$

So the ratio of the charge stored by each capacitor is equal to the ratio of the capacitance $\frac{C_1}{C_2}$.

Capacitors in series and parallel



Capacitors in series and parallel

Capacitors in series

Consider two capacitors C_1 and C_2 that are connected in series and have a supply of potential difference V connected to them, as indicated in the diagram.

Components in series store the same charge, so the charge on each capacitor is the same $(= Q)$.

The p.d. across each capacitor is:

$V_1 = \frac{Q}{C_1}$ and $V_2 = \frac{Q}{C_2}$

The total p.d. (V) across the capacitor is:

$$V = V_1 + V_2$$

The total capacitance, $C = \frac{Q}{V}$ so $V = \frac{Q}{C}$

Therefore:

$$\frac{Q}{C} = \frac{Q}{C_1} + \frac{Q}{C_2}$$

Dividing throughout by Q gives us: $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$

So, the total capacitance (C) of any number (n) of capacitors connected in series is given by:

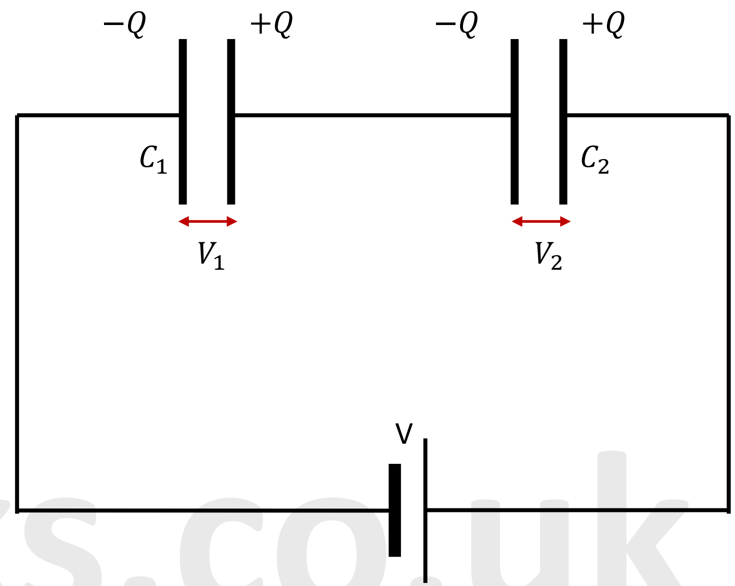
$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \dots \dots \frac{1}{C_n}$$

For two capacitors in series, the ratio of the p.ds,

$$\frac{V_1}{V_2} = \frac{Q}{C_1} + \frac{Q}{C_2} = \frac{C_2}{C_1}$$

So the ratio of the p.ds across the two capacitors is equal to the inverse ratio of the capacitances.

Capacitors in series and parallel



Investigating Capacitors in Series and Parallel

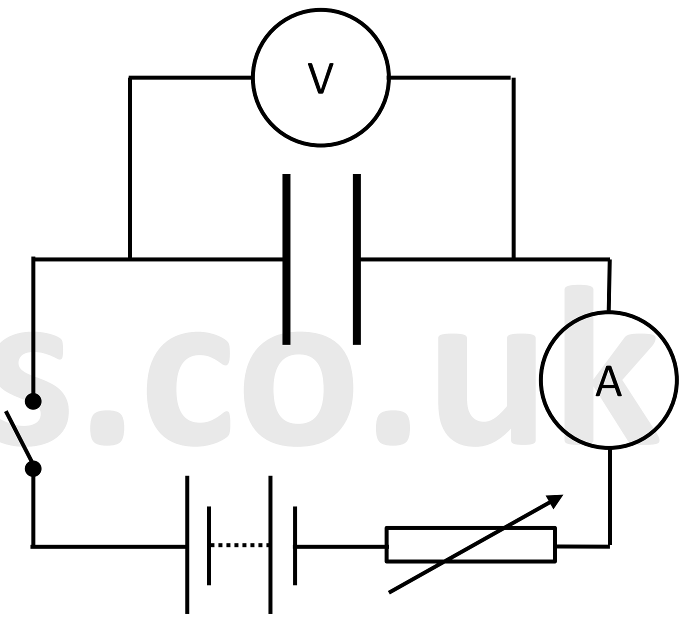
Equipment:

- Capacitors x 2
- Cell
- Voltmeter
- Ammeter
- Switch
- Variable resistor
- Stopwatch

Single Capacitor

- To charge the capacitor, set up the circuit as opposite
- Then, adjust the variable resistor to keep the current constant for as long as feasible after closing the switch.
- In a table, record the constant current value (I), the potential difference (V), and the time (t) since the switch was closed at regular intervals.
- Multiply the fixed charging current (I) value by the time in seconds since the switch was closed using $Q = It$ in order to get the charge across the capacitor (C).
- Plot a graph of charge (Q) against voltage (V) and draw a line of best fit.
- The capacitance of the capacitor in farads is determined by the gradient of the line of best fit.

Investigating Capacitors in Series and Parallel

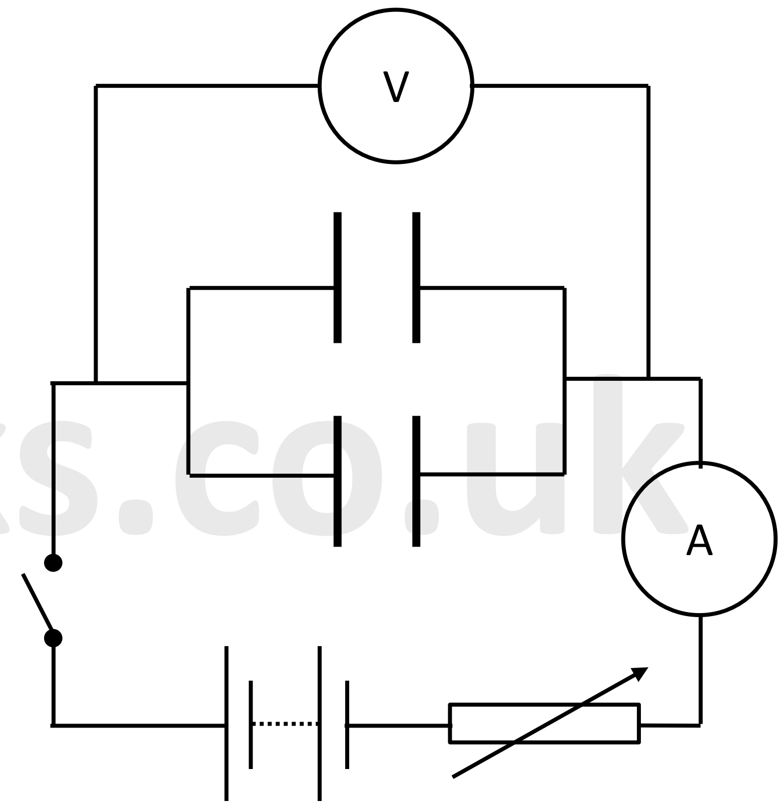


Investigating Capacitors in Series and Parallel

Parallel

- Set up the circuit as shown opposite to charge the capacitors.
- Then, adjust the variable resistor to keep the current constant for as long as feasible after closing the switch.
- In a table, record the constant current value (I), the potential difference (V), and the time (t) since the switch was closed at regular intervals.
- Multiply the fixed charging current (I) value by the time in seconds since the switch was closed using $Q = It$ in order to get the charge across the capacitor (C).
- Plot a graph of charge (C) against voltage (V) and draw a line of best fit.
- Find the gradient of the line of best fit. The gradient will give you the combined capacitance of the 2 capacitors.
- The total capacitance of the two capacitors in parallel should equal the sum of their individual capacitances.

Investigating Capacitors in Series and Parallel



Investigating Capacitors in Series and Parallel

Equipment:

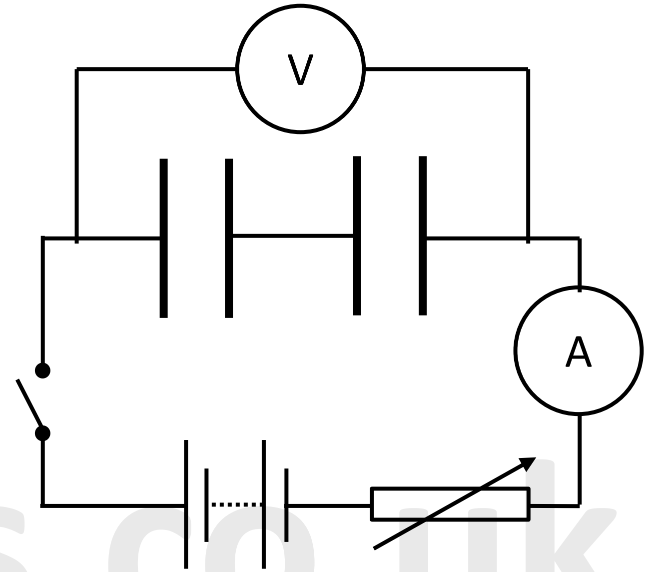
- Capacitors x 2
- Cell
- Voltmeter
- Ammeter
- Switch
- Variable resistor
- Stopwatch

Series

- Set up the circuit as shown to charge the capacitors.
- Then, adjust the variable resistor to keep the current constant for as long as feasible after closing the switch.
- In a table, record the constant current value (I), the potential difference (V), and the time (t) since the switch was closed at regular intervals.
- Multiply the fixed charging current (I) value by the time in seconds since the switch was closed using $Q = It$ in order to get the charge across the capacitor (C).
- Plot a graph of charge (C) against voltage (V) and draw a line of best fit.
- Calculate the gradient to find the combined capacitance of the two capacitors.
- If the capacitors have the same capacitance, the total capacitance should be half that of a single capacitor.
- This is because for capacitors in series, the overall capacitance (C) is given by:

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \dots \frac{1}{C_n}$$

Investigating Capacitors in Series and Parallel



Improvements:

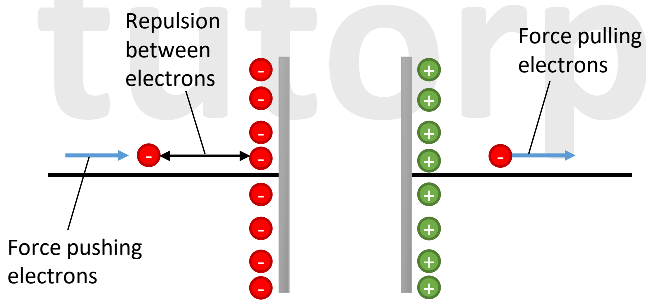
- Before closing the switch, double-check the voltmeter and ammeter for any systematic errors.
- Once the capacitor is fully charged, it will be impossible to maintain the current constant; therefore, while making your graph, only use the values for which the current is approximately constant.
- It is more efficient and convenient to use a data logger to record voltage and current since the data logger can calculate the charge $(Q = It)$ in real time and generate a real-time graph of charge against voltage.

Energy Stored in a Charged Capacitor

Work is done to push electrons onto one plate and off the other plate when a capacitor is charged.

At first there is a small amount of negative charge on the left hand plate and so the force repelling additional electrons is small. The repulsion force grows as the amount of charge stored increases, requiring more work having to be done to increase the amount of charge stored.

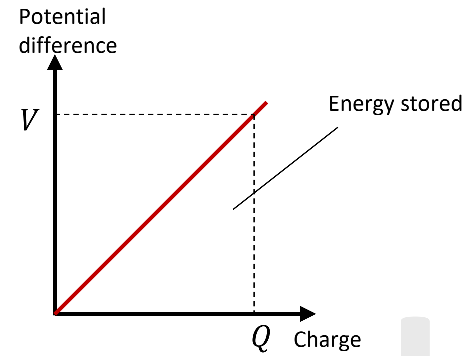
This requires energy, which comes from the power source and is stored as electrical potential energy as long as the charges are held. The electric potential energy is released when the charges are released.



Energy Stored in a Charged Capacitor

V is proportionate to Q because $V = \frac{Q}{C}$, hence the graph of V against Q is a straight line.

Consider a capacitor with capacitance (C) that receives a charge (Q) when the potential difference across it is (V).



Energy stored in the capacitor (E) = Work done in charging

$$E = Area\ enclosed\ by\ the\ \frac{V}{Q}\ graph$$

$$E = \frac{1}{2}QV$$

The gradient of the V/Q graph = 1/CAPACITANCE (C)

If the p.d. across a capacitor of capacitance (C) changes by an amount (V) when a quantity of charge (Q) flows into (or out of) it, the energy stored (or given out) by the capacitor (E) is given by:

$$E = \frac{1}{2}QV$$

Where:

E = Energy stored in J

Q = charge on capacitor in C

V = potential difference across capacitor in V

Energy Stored in a Charged Capacitor

$$E = \frac{1}{2}QV$$

And since $Q = CV$, $\text{E} = \frac{1}{2}CV \times V = \frac{1}{2}CV^2$

$$E = \frac{1}{2}CV^2$$

Where:

C = capacitance in F

And since $V = \frac{Q}{C}$, $\text{E} = \frac{1}{2}Q \times \frac{Q}{C} = \frac{1}{2}\frac{Q^2}{C}$

$$E = \frac{1}{2}\frac{Q^2}{C}$$

The electric field between the plates stores the energy of a charged capacitor.

The charge (Q) flows at a constant p.d. (V) if the capacitor is charged from a battery (or equivalent source). But the amount of energy drawn from the battery is equal to QV (i.e. twice the energy stored in the capacitor). The 'missing' energy is dissipated as heat in the connecting wires.

Dielectrics (AQA Only)

Dielectrics are just insulators. They are an important component of how capacitors work and one of the factors that influence overall capacitance.

Permittivity

A capacitor's properties affect how much charge it can store at a given voltage (its capacitance). The dielectric material that separates the two conducting plates is one of the things you can adjust. This changes the capacitance because different materials have different relative permittivities.

Permittivity is a measure of how difficult it is to generate an electric field in a given medium. The higher a material's permittivity, the more charge is required to generate an electric field of a given size.

Relative permittivity is the ratio of the permittivity of material to the permittivity of free space:

$$\varepsilon_r = \frac{\varepsilon_1}{\varepsilon_0}$$

Where:

ε_r = relative permittivity of material 1

ε_1 = permittivity of material 1 in Fm^{-1}

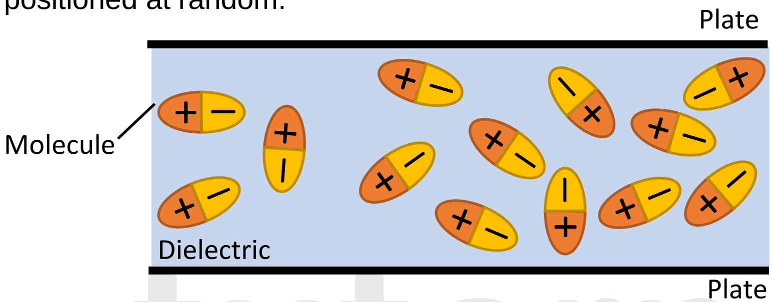
ε_0 = permittivity of free space = $8.85 \times 10^{-12}\ Fm^{-1}$

The dielectric constant is another name for relative permittivity.

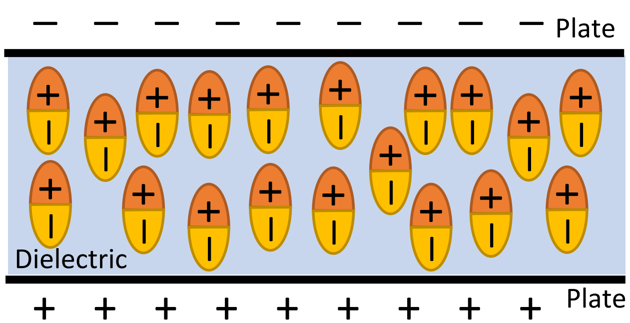
Dielectrics (AQA Only)

Polar Molecules

The motion (or action) of the molecules inside a dielectric helps to explain permittivity. Consider a dielectric made up of a large number of polar molecules, which have a positive and negative end. There is no electric field generated by a capacitor when no charge is being stored and so, as illustrated below, the molecules are positioned at random:



An electric field is created between the plates of a capacitor when a charge is supplied to it. The molecules' negative ends are attracted to the positively charged plate, and vice versa. As a result, the molecules rotate and position themselves anti-parallel to the electric field created between the plates. Since the material is non-conducting, the molecules do not move towards the plates and are thus stretched.

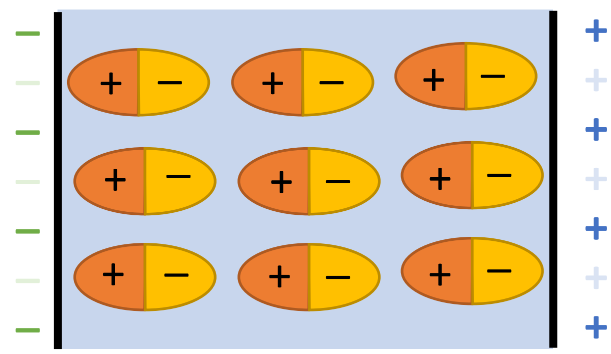


Dielectrics (AQA Only)

Anti-parallel just means that the molecules are aligned with the electric field lines, but are orientated in the opposite direction. As a result, the positive poles point to the negative plate, and the negative poles point to the positive plate.

The capacitance of a capacitor is increased by the presence of a dielectric, which lowers the voltage between the capacitor plates. Because the capacitor plates can still contain the same number of charges, their contribution to the voltage across the plate is partially cancelled. In other words some of the positive charges on the capacitor plate are having their contribution to the voltage negated by the fact that there is now a negative charge right next to them because of the charged molecules.

On the negative side of the capacitor plate, the same thing is happening. As a result, the overall charge on the capacitor remains the same, but the voltage between the plates has reduced due to dielectric polarisation. As $C = \frac{Q}{V}$, a decrease in the p.d. increases the capacitance.



Dielectrics (AQA Only)

Calculating Capacitance

The capacitance of a capacitor is determined by the capacitor's dimensions as well as the dielectric inside it. Capacitance can be calculated using the following formula:

$$C = \frac{A\varepsilon_0\varepsilon_r}{d}$$

Where:

C = capacitance, in F

A = effective area of a plate, in m^2

ε_0 = permittivity of free space, in Fm^{-1}

ε_r = relative permittivity

d = distance between the capacitor plates, in m.

Therefore the capacity is increased by increasing the relative permittivity of the dielectric or the area of the plates. Capacitance will decrease if the distance between the plates is increased.

Dielectrics (AQA Only)

Investigating capacitance

- Setting up two parallel plates separated by a dielectric and connecting the plates to a capacitance metre allows you to explore how capacitance changes. You can then change how much the two plates overlap to change the capacitor's effective area, or use different dielectric materials to change the relative permittivity.
- You can investigate how plate separation affects capacitance by stacking many layers of the same material.
- The relative permittivity of a variety of dielectrics can be calculated if you know the capacitance of a capacitor, the area of its plates, and the distance between plates.

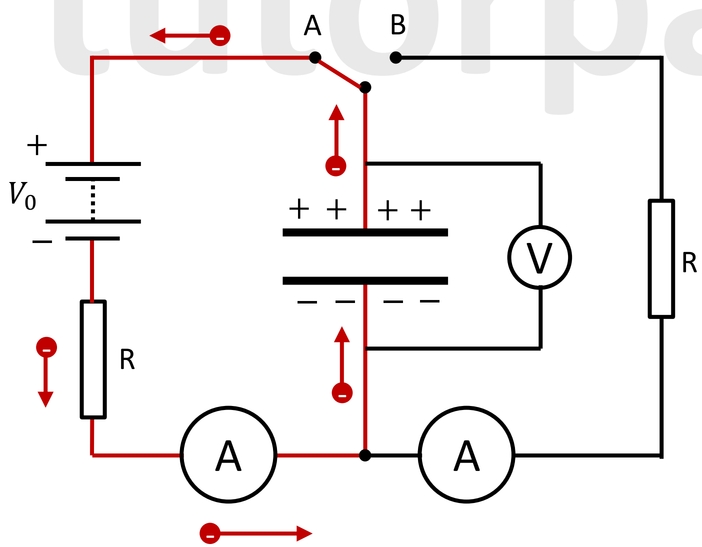
Charging and Discharging Capacitors

Remember on a capacitor the same number of electrons are repelled from the positive plate as are built up on the negative plate. This means that on each plate, an equal but opposing charge builds up, resulting in a potential difference between the plates. Because the plates are separated by an insulator (dielectric), no charge can flow directly between them.

The current through the circuit is initially very high. However, as charge accumulates on the plates, electrostatic repulsion makes depositing more electrons difficult. The current drops to zero when the p.d. across the capacitor equals the p.d. across the supply. This is when we say the capacitor is fully charged.

Charging through a fixed resistor

Consider the circuit shown below. The capacitor is charged up by the supply when the switch is in position (A).



Charging and Discharging Capacitors

At the beginning a current begins to flow however there is no potential difference across the capacitor, hence there is no p.d. opposing the current. The battery's potential difference causes a relatively high current of V/R to flow (where V is the power supply's voltage and R is the resistance of the resistor).

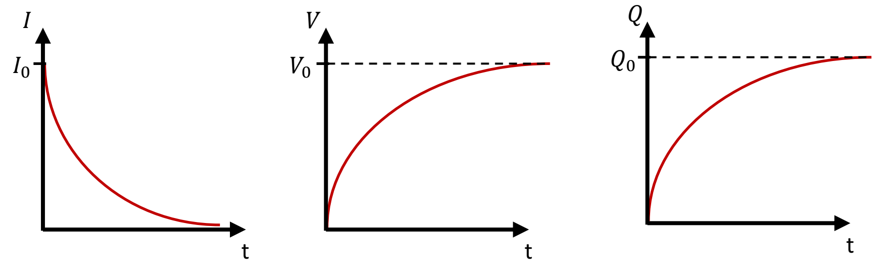
Slowly the p.d. across the capacitor increases as the capacitor charges, and the current slowly decreases.

Also, when you charge a capacitor through a fixed resistor, the resistance of the resistor has an impact on the charging time. The resistor reduces the charge (or discharge) rate by restricting the amount of current that may flow into or out of the capacitor.

Charging and Discharging Capacitors

Since the charge (Q) on the capacitor is proportional to the potential difference across it, the $Q - t$ graph is the same shape as the $V - t$ graph. The following graphs show I, V and Q change over time when charging a capacitor through a resistor.

As the capacitor charges, V and Q both increase and level off, but I decreases exponentially.



The Q/t, V/t and I/t may be represented by the following discharge equations:

$$Q = Q_0\left(1 - e^{-\frac{t}{RC}}\right)$$
$$V = V_0\left(1 - e^{-\frac{t}{RC}}\right)$$
$$I = I_0 e^{-\frac{t}{RC}}$$

Where:

Q, V, I = value of charge, p.d. and current at any time t

Q_0, V_0 = Values of charge, voltage across the capacitor when fully charged

I_0 = Initial current at time, t = 0

C = Capacitance of the capacitor

R = Resistance of the fixed resistor

t = time since charging began

e = exponential function

Charging and Discharging Capacitors

The charged capacitor discharges through the resistor when the switch is in position (B). The p.d. is what makes the current flow through the circuit. However, this current flows in the opposite direction from the charging current. When the p.d. across the plates and the current in the circuit are both zero, the capacitor is fully discharged.

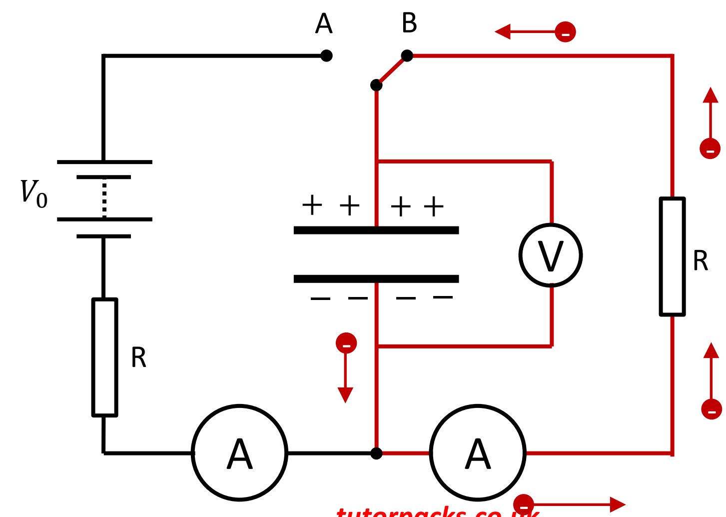
To investigate the behaviour of the discharging capacitor, use the setup shown below.

First move the switch to position A to start charging the capacitor. Then move the switch to position B to allow the capacitor to discharge after it has been fully charged.

The ammeter and voltage sensor can be connected to a datalogger, which can then be connected to a computer.

Use the computer to determine the charge on the capacitor over time as the ammeter value approaches zero.

The computer can then generate a number of graphs that show how the current, p.d., and charge change over time.

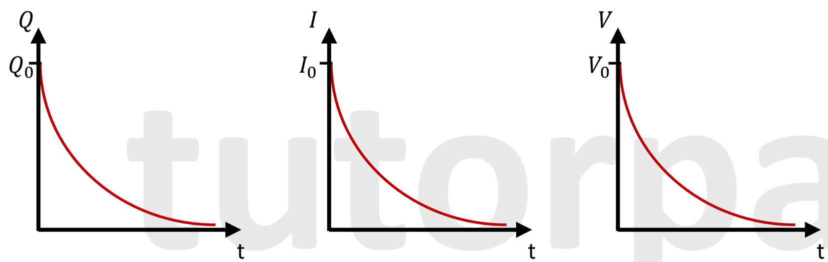


Charging and Discharging Capacitors

As the capacitor discharges, the following quantities decrease exponentially:

- The charge stored, Q
- The current flowing, I
- The p.d. or voltage across the capacitor, V

The three graphs below demonstrate this:



The $I - t$ graph is identical to the charging graph (although the current is now flowing in the opposite direction). The current begins at a relatively high level and gradually decreases until it reaches zero. This is because the p.d. across the capacitor (and hence across the resistor) decreases as the charge on the capacitor decreases.

Charging and Discharging Capacitors

Analysis of capacitor discharge graphs

Electrons begin to flow around the circuit once the charged capacitor is connected to the resistor (R).

If the Q stored is high, the V across the capacitor will be high and so the initial discharge I is also high.

As Q decreases so too does V and I, but the rate of decay decreases with time.

Mathematically:

$Q = CV$ and $V = IR$

So $V \propto Q$ and $I \propto V$

Therefore, if Q is high, V is high and so I is high.

Gradient of the $\frac{Q}{t}$ graph = current (I)

Initially the gradient is steep, so the current is high.

After some time, the gradient has decreased and so the current is less.

Area enclosed by the $\frac{I}{t}$ graph = charge (Q) that flowed from the capacitor.

Current, I is initially high, therefore the area under the graph is large, which indicates that a large amount of charge has flowed from the capacitor.

After some time, I has decreased, so the area under the graph is smaller, which means that less charge has flowed out of the capacitor.

Charging and Discharging Capacitors

The Q/t, I/t and V/t graphs may be represented by the following discharge equations:

$$Q = Q_0 e^{-\frac{t}{CR}}$$
$$I = I_0 e^{-\frac{t}{CR}}$$
$$V = V_0 e^{-\frac{t}{CR}}$$

These are all examples of the general equation:

$$x = x_0 e^{-\frac{t}{CR}}$$

Where:

Q, V, I = value of charge, p.d. and current at any time t

Q_0, V_0, I_0 = Values of charge, voltage across the capacitor when fully charged

C = Capacitance of the capacitor

R = Resistance of the fixed resistor

t = time since discharging began

e = exponential function

Time Constant (τ)

The quantity CR is called the **time constant** (τ) of the circuit.

$$\tau = CR$$

Where:

τ = time constant in s

C = capacitance of the capacitor in F

R = resistance of the resistor in Ω

Time constant (τ) is the time taken for the charge on a discharging capacitor (Q) to decrease to 1/e ($\approx 37\%$) of its initial value (Q_0).

Mathematically: If we consider the charge at time, τ.

$$t = \tau = CR$$

So: $-\frac{t}{CR} = -\frac{CR}{CR} = -1$

$$Q = Q_0 e^{-\frac{CR}{CR}}$$

$Q = Q_0 e^{-1}$ and $e^{-1} = 0.37$

$$Q = 0.37 Q_0$$

The charge is 37% of its original value.

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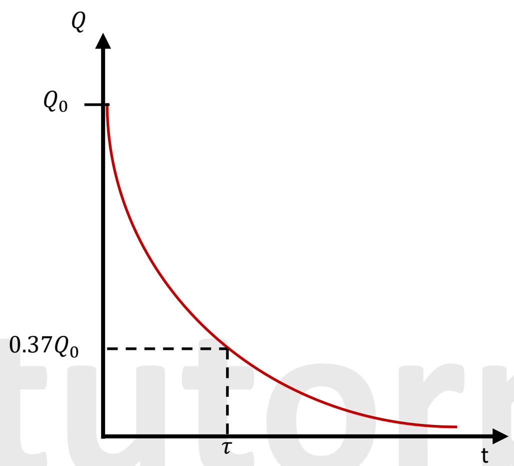
Time Constant (τ)

The larger the resistance in series with the capacitor, the longer it takes to charge or discharge. In practise, it is assumed that it takes roughly $5CR$ or $5\tau$to fully charge or discharge a capacitor.



You can find the time constant by using the formula $\tau = CR$ or by using the graph like the one shown above.

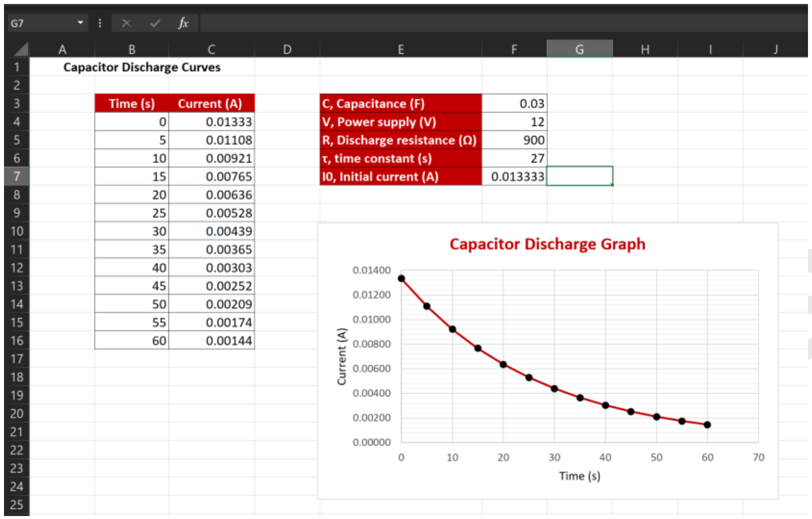
Capacitors

Continue to the next page.

Using a spreadsheet to investigate the time constant

We can use a spreadsheet to model a timing circuit that meets the needs of a certain situation (for example, a car courtesy light being on for a given amount of time).

This will allow us to type in many possible values for the circuit components and see what the result will be before building it. You may see an example of such a spreadsheet below.


Capacitor Discharge Curves

Time (s)	Current (A)
0	0.01333
5	0.01108
10	0.00921
15	0.00765
20	0.00636
25	0.00528
30	0.00439
35	0.00365
40	0.00303
45	0.00252
50	0.00209
55	0.00174
60	0.00144

C, Capacitance (F)	0.03
V, Power supply (V)	12
R, Discharge resistance (Ω)	900
τ, time constant (s)	27
I0, Initial current (A)	0.013333

You can make the spreadsheet without any observation and experimentation. Using the mathematics we learnt about in this pack, provide the various cells formulae to calculate what capacitor theory tells us will happen,. The time constant cell (F6), for example, does not require user input because it is set to display the multiplication of the capacitance (F3) and discharge resistance (F5). This value is then used in the formula below for calculating the values in the "Current" column (C3),

$$I = I_0 e^{-\frac{t}{CR}} \text{ or } I = I_0 e^{-\frac{t}{\tau}}$$

Using a spreadsheet to investigate the time constant

To create the capacitor discharge graph, I entered the following formula into the cells on Excel:

C, Capacitance (F)	0.03
V, Power supply (V)	12
R, Discharge resistance (Ω)	900
τ, time constant (s)	=F3*F5
I0, Initial current (A)	=F4/F5

Time (s)	Current (A)
0	=(F7)*EXP(-(B4)/(F6))
5	=(F7)*EXP(-(B5)/(F6))
10	=(F7)*EXP(-(B6)/(F6))
15	=(F7)*EXP(-(B7)/(F6))
20	=(F7)*EXP(-(B8)/(F6))
25	=(F7)*EXP(-(B9)/(F6))
30	=(F7)*EXP(-(B10)/(F6))
35	=(F7)*EXP(-(B11)/(F6))
40	=(F7)*EXP(-(B12)/(F6))
45	=(F7)*EXP(-(B13)/(F6))
50	=(F7)*EXP(-(B14)/(F6))
55	=(F7)*EXP(-(B15)/(F6))
60	=(F7)*EXP(-(B16)/(F6))

Log-linear Graphs

Log-linear graphs are graphs with a logarithmic axis on one of the axes. Log-linear and log-log plots (with both axes being logarithmic) are useful because they can often be used to make a straight-line graph when linear axes would show a curve. As a result, they're another good way to show graphically how charge, potential difference, and current change over time for a discharging capacitor.

Starting from the equation for charge on a discharging capacitor, the natural logarithm is taken of both sides:

$$Q = Q_0 e^{-\frac{t}{CR}}$$

$$In(Q) = In\left(Q_0 e^{-\frac{t}{CR}}\right)$$

By laws of logarithms $In(A \times B) = In(A) + In(B)$, so this can be written as:

$$In(Q) = In(Q_0) + In\left(e^{-\frac{t}{CR}}\right)$$

Another log rule is $In(e^A) = A$, so:

$$In(Q) = \left(-\frac{1}{CR}\right)t + In(Q_0)$$

This equation has the same form as the straight-line equation:

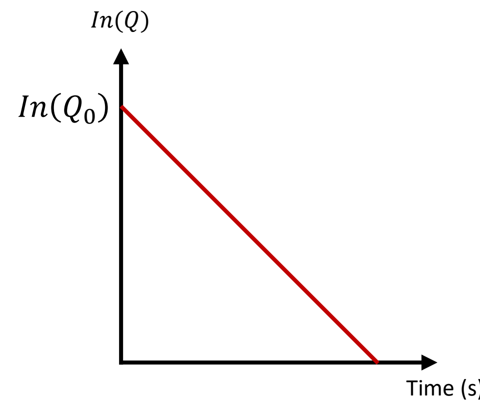
$$y = mx + c$$

When you plot $In(Q)$ against t, you'll notice that it's a straight line. The gradient is equal to $-\frac{1}{CR}$ when the equation for $In(Q)$ is compared to the equation for a straight line.

Therefore, the value for the time constant, CR can be calculated from the log-linear graph by dividing -1 by the gradient of the line. For example:

$$time\ constant = CR = -\frac{1}{gradient}$$

Log-linear Graphs



Because V and I have the same dependence on R and C, you could plot $In(V)$ or $In(I)$ against time and find the time constant in the same way.

Please see '10.1.2 Capacitors worked examples' pack for exam style questions.

For more revision notes, tutorials and worked examples please visit www.tutorpacks.co.uk.

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