THE DUBLIN ACADEMY OF EDUCATION

Leaving Certificate

PHYSICS

Higher Level

ELECTRICITY 1

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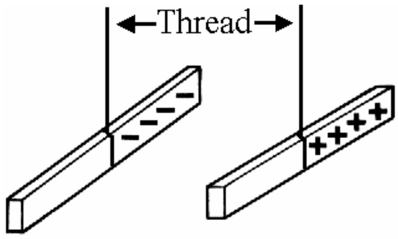
1: STATIC ELECTRICITY

Charge

If an object has more electrons than protons, it is negatively charged. If the object has more protons than electrons, then it is positively charged.

Opposite charges attract; similar charges repel each other.



You can demonstrate this by hanging two oppositely charged rods as shown and note that they both move towards each other. If were to hang two similarly charged rods near each other they would repel each other.

Question
Explain why a balloon that has been rubbed vigorously on a woolly jumper can stick to a wall.
Solution
The balloon becomes charged by friction. Like charges in the wall are repelled and so the balloon sticks to unlike charges left closest to the surface of the wall.

The symbol for charge is *Q* (from *quantity* of charge)
The *unit* of charge is the coulomb – the symbol for the coulomb is C.

An electron has a charge of 1.6×10^{-19} coulombs.

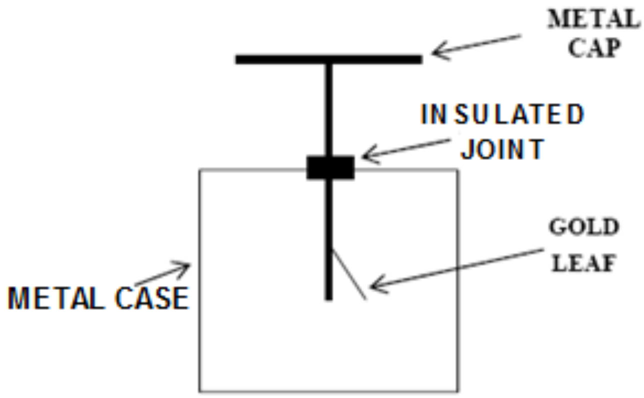
The coulomb is the amount of charge that passes when a current of one amp flows for one second.

Earthing

If an object becomes charged (due to a build-up of electrons say), and the object is then 'earthed' (connected to earth), the electrons will separate as much as possible, resulting in most of them quite literally 'going to earth'. The object then becomes neutral. Your home probably has a pole connecting the earth wire in your house directly to the ground.

The gold leaf electroscope (GLE)

You must know the structure of an electroscope and list some of its functions.



- If the GLE is uncharged, the leaves will fall together.
- If the leaves become charged – either positively or negatively – the leaves will stand apart.
- The earth connection on the right-hand side ensures that there is no excess charge on the wall of the electroscope (which could attract or repel the gold leaf, reducing the leaf's ability to rise if the GLE is charged).

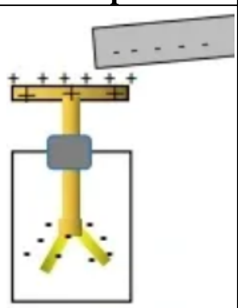
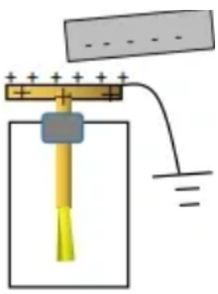
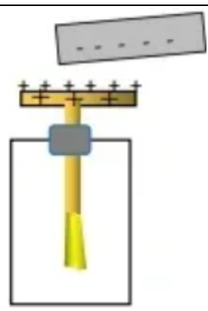
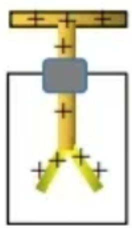
Functions of the gold leaf electroscope

1. To detect charge
2. To distinguish between positive and negative charge

Charging a conducting object by induction

To charge an insulated conductor positively

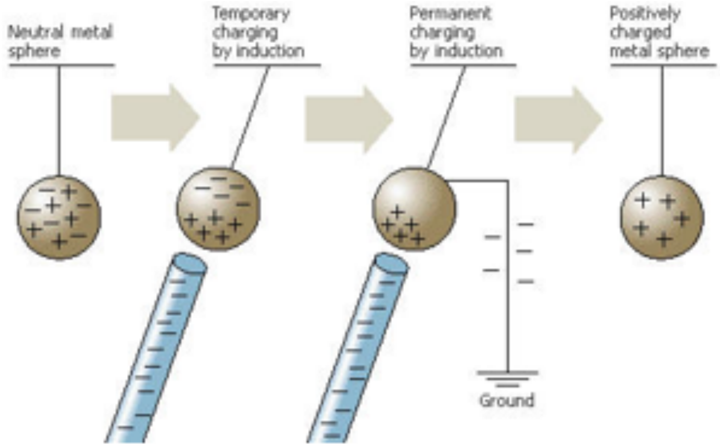
For illustration purposes we will choose a gold leaf electroscope as our object

Negatively charged rod is brought near the cap	Electroscope is earthed	Remove the earth connection	Remove the rod
			

1. Bring a negatively charge rod close to ***but not touching*** the conductor (the positive and negative charges become separated on the conductor).
2. Keeping the charged object in place, earth the conductor by connecting an earth wire or simply touching it with your finger {*some of the negative charge on the metal flows through you to earth}*.
3. Remove your finger, ***then*** (and only then) . . .
4. Remove the rod

The conductor is now positively charged.

You should now also be able to list the procedure necessary to charge an object *negatively* by induction and note also that the same process applies to charging any isolated conductor – see image on the right.



Summary – 4 points which you must include in your answer

- Bring ***charged*** rod close to (but not touching) insulated conductor.
- Earth electroscope
- Remove earth (while rod is close)
- Remove rod

Coulomb's Law

Coulomb's Law states that the force between two point charges is proportional to the product of the charges and inversely proportional to the square of the distance between them.

Mathematically: $F \propto (Q_1 Q_2)$

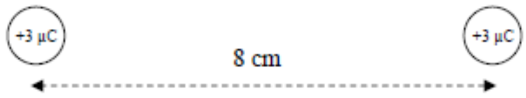
And $F \propto 1 / d^2$

Putting this together $\boxed{F = \frac{1}{4\pi\varepsilon}\frac{Q_1Q_2}{d^2}}$ where the proportional constant is $\frac{1}{4\pi\varepsilon}$

ε (epsilon) is known as "the permittivity" of the medium. {*it represents the extent to which one charge will be affected by another, e.g. glass has a different permittivity value than air}*
($\varepsilon_0 = 8.9 \times 10^{-12}$ F m^{-1})

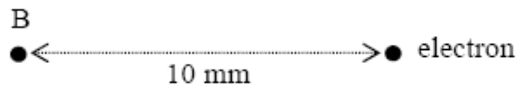
Example 1:

Calculate the force of repulsion between two small spheres when they are held 8 cm apart in a vacuum (each sphere has a positive charge of 3 μC).



Example 2:

A charge of 5 μC is placed at point B, which is 10 mm from an electron. Calculate the electrostatic force exerted on this charge.



Example 3:
Calculate the force of repulsion between a deuterium and a tritium nucleus when they are 2 nm apart in free space.

Example 4:

Calculate the electrostatic force of repulsion between two protons separated by 10^{-10} m (a typical inter-atomic distance). Calculate the gravitational force of attraction between them.

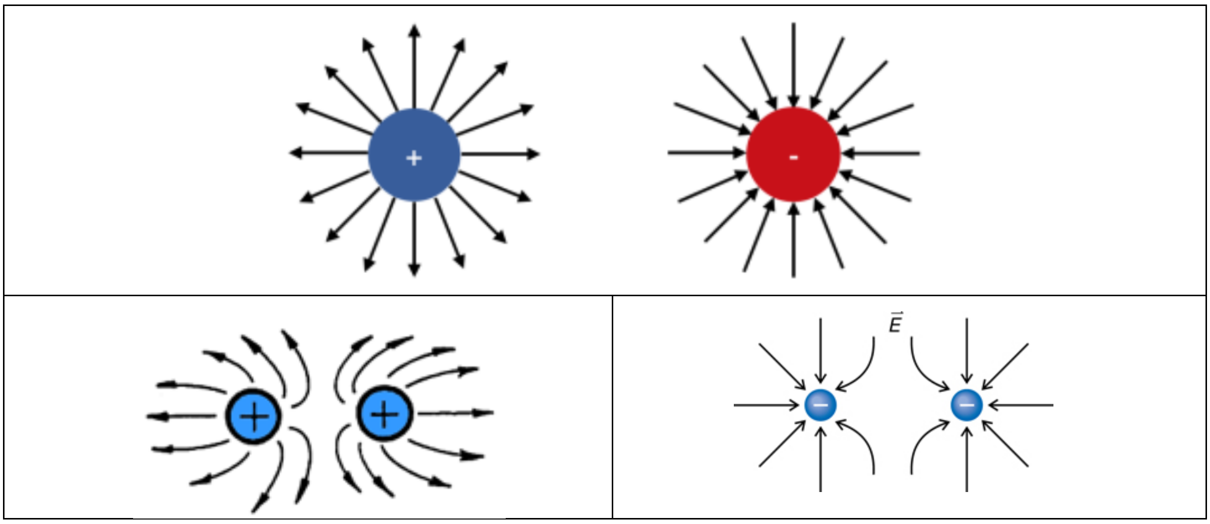
Electric fields

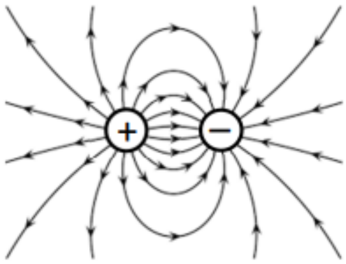
An electric field is a region of space where an electric charge experiences an electrostatic force.

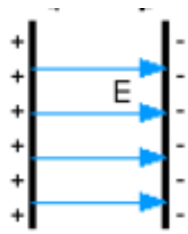
All charged objects create an electric field that extends outward into the space that surrounds it. This electric field will have an effect on any other charged object that enters the field.

Electric field patterns

The convention is that electric field lines come **out of a positive charge and into a negative charge**.





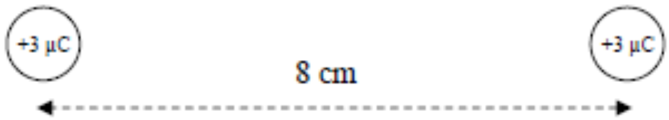


Example 5:

Draw the electric field around a positively charged sphere.

Example 6:

Copy the diagram and show on it the electric field generated by the charges.

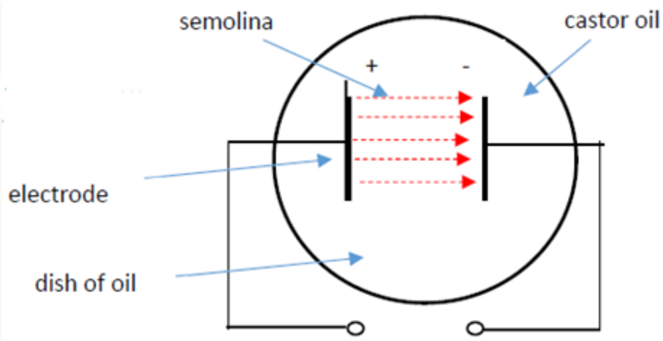


To demonstrate electric field patterns

Describe, with the aid of a labelled diagram, an experiment to show an electric field pattern. On your diagram, show the electric field, including its direction.

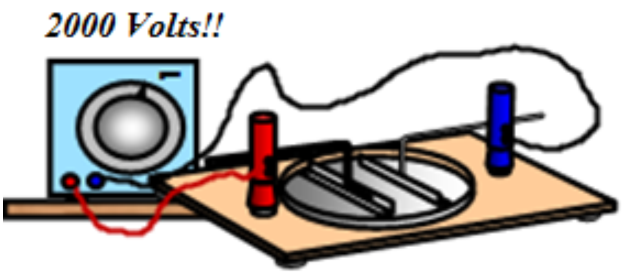
Procedure
Set up as shown. Diagram must include dish of castor oil, high voltage d.c. source, two electrodes

1. Turn on the power supply.
2. Sprinkle semolina powder over the electrodes.
3. Observation: Semolina forms electric field pattern.



Exam tips:

1. *You will lose marks in an exam if you do not stress the high voltage.*
2. *You will need to draw the circuit diagram to show how the apparatus is connected together.*
3. *You must specify semolina or a similar powder; metal filings are for demonstrating magnetic field lines and are not acceptable for this demonstration.*



Electric field strength

Sometimes it's useful to get a sense of how strong an electric field is. We do this mathematically by calculating the effect the field would have on an imaginary test charge of one coulomb.

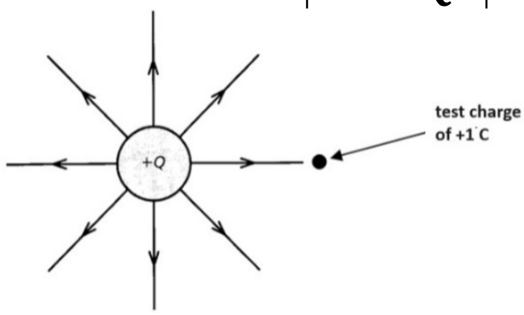
Electric field strength (E) at a point is the force *per unit charge* at that point.
{This is one of the most asked definitions on the syllabus}

$$\mathbf{E = \frac{F}{Q}}$$

The unit of electric field strength is the newton per coulomb (N C^{-1}).

Also note that because: $F = \dfrac{1}{4\pi\varepsilon}\dfrac{Q_1Q_2}{d^2}$

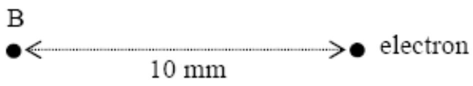
$$\boxed{E = \frac{1}{4\pi\varepsilon}\frac{Q}{d^2}}$$



We now have two equations for electric field strength; if a *distance* is given in the question, it means that you need to use the second equation.

Example 7:

Calculate the electric field strength at the point B, which is 10 mm from an electron.



Example 8:

What is the electric field strength 53 pm from a proton?

Example 9:

Point A is a 5 μC point charge while point B is a 10 μC point charge. If the charge at point B increases to 20 μC, does the electric field at B:
(i) increase
(ii) decrease
(iii) remain unchanged

Electric field strength a distance ‘*d*’ from the surface of a charged sphere

If question asks us to calculate the electric field strength at a point which is a distance d from the surface of a sphere, then the distance used in the calculation must be the distance that point and *the centre of the sphere* (so $d + r$, where r is the radius of the sphere). This is because we the charge is spread equally around all parts of the surface so mathematically; we can treat the question as though all the charge was located at the centre of the sphere (similar to the centre of gravity of a sphere).

Example 10:

A metal sphere of diameter 5 cm holds a charge of –6 μC. Calculate the electric field strength at a distance of 3 cm from the surface of the sphere.

Example 11:

The spherical dome of a Van de Graaff generator has a diameter of 40 cm and a charge of 3.8 μC. What is the electric field strength at a point 4 cm from the surface of the dome?

Example 12:

A spherical conductor has a diameter of 12 cm. There is an electric field strength of 2.3 N C^{-1} at a distance of 5 cm from the surface of this spherical conductor. Calculate the charge on the conductor.

Example 13:

The dome of a Van de Graff generator is charged. The dome has a diameter of 30 cm and its charge is 4 C. A 5 μC point charge is placed 7 cm from the surface of the dome.
(i) Calculate the electric field strength at a point 7 cm from the dome.
(ii) Calculate the electrostatic force exerted on the 5 μC point charge.

Direction of electric field strength at a point

The convention is that the direction of the electric field lines at a point indicate the direction of force experienced by a test unit positive charge at that point. This means that if the source of the electric field is a positive charge then the field lines at the test charge will point *away from* the source charge, and if the source of the electric field is a negative charge then the field lines at the test charge will point *towards* from the source chare.

Question

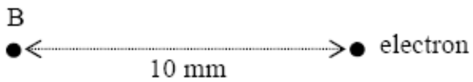
The diagram shows a negative charge – Q at a point X.
Copy the diagram and show on it the direction of the electric field strength at Y.

Solution

*"The electric field strength at Y" means "the force that would be exerted on a **unit positive** charge if it were at position Y" so to answer this question imagine that **you are that positive charge** at Y; what direction would you be pushed or pulled towards?}*
In this case there is a negative charge at point *X* so if I was a positive charge at position *Y* I would be attracted to *X*.
Answer: Draw an arrow from *Y* pointing towards *X*.

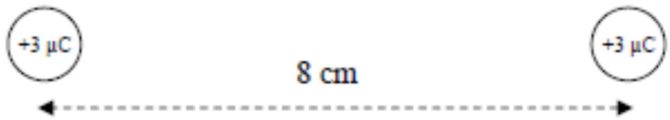
Example 14:

What is the direction of the electric field strength at B?



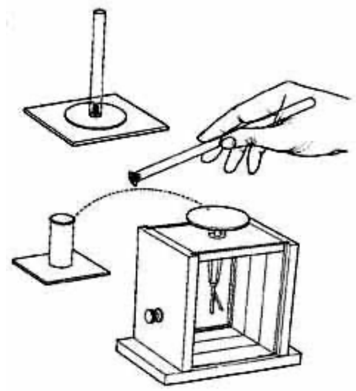
Example 15:

Copy the diagram and mark a place where the electric field strength is zero.



Distribution of charge on an insulated conductor

1. All static charge resides on the outside of a conductor



Demonstration

1. Charge the conductor (a metal can will do fine).
2. Using ***a proof plane***, touch the inside of the can and bring it up to the GLE. Notice that there is no deflection.
3. Touch the proof plane off the outside of the can and bring it up to the GLE. Notice that there is a deflection.
4. Conclusion: charge resides on outside only

Question

All the charge resides on the surface of a Van de Graff generator's dome. Explain why.

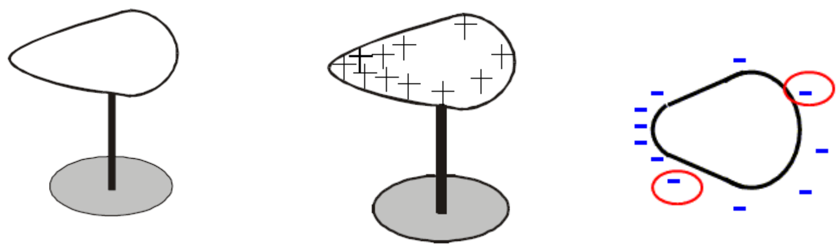
Solution

Like charges repel and the charges are a maximum distance apart on the outside surface of dome.

Application:

- A Van der Graff generator is used to generate a large build-up of charge which resides on the outside surface of the dome.
- A full-body metal-foil suit protects an operator when working on high voltage power lines (strictly speaking it doesn't even have to be solid – a wire mesh would also work).

2. Charge density on a conductor is greatest where the conductor is most pointed

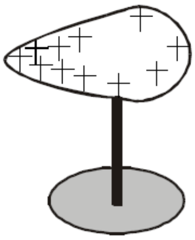


Demonstration

1. Charge a pear-shaped conductor .
2. Use a proof plane to bring charge from the curved end to the GLE and note that there is a minimal deflection.
3. Use a proof plane to bring charge from the pointed end to the GLE and note that the deflection is much greater.
4. Conclusion: Most of the charge is at the pointed end.

Point discharge

1. On a pear-shaped conductor, most charge accumulates on the pointed end.
2. If the build-up of charge is sufficiently large the repulsion between charges becomes so great that some 'jump off' the surface, colliding with and ionising atoms in the surrounding air.
3. Ions with opposite charge are attracted towards the point and neutralise the charge on it.



Demonstrating point discharge

1. Attach a nail to the surface of a working Van der Graff generator.
2. Bring up a candle and notice that the flame moves away from the Van der Graff.
   This is because of the 'wind' generated by point discharge.

Applications of electric fields

1. Precipitators (used to extract smoke particles from the air).
2. Photocopier machines

Industrial hazards

1. Explosion in flour-mills or when fuelling aircraft
2. Damage to integrated circuits.
3. Electric shock

Static Electricity: Higher Level Exam Questions

2024 HL Q6h

A lightning conductor can be placed on top of a tall building. Explain how a lightning conductor works.

2024 HL Q6j

Calculate the electrostatic force between two protons that are 5.6×10^{-15}m apart in a vacuum.

2023 HL Deferred Paper Q6j

Explain why a balloon that has been rubbed vigorously on a woolly jumper can stick to a wall.

2023 HL Q10

The Van de Graaff generator is named after the American physicist Robert J. Van de Graaff, pictured. It is an electrostatic generator that accumulates charge on a hollow metal dome and produces high voltages which can be used in the production of X-rays.

In a Van de Graaff generator, point discharge is used to move charge on to a belt at the lower comb in the generator.

(*i*) Describe how point discharge occurs.

(*ii*) Describe a laboratory experiment to demonstrate point discharge. (18)

The dome of a Van de Graaff generator has a diameter of 32 cm. A large electric field exists around the dome when it is given a charge of +200 nC.

(*iii*) Draw the electric field around the dome.

(*iv*) Calculate the electric field strength at the surface of the dome.

(*v*) Calculate the force experienced by an electron placed at the surface of the dome. (21)

2022 HL Q6g

Describe how an insulated metal sphere can be charged by induction using a nearby charged rod.

2022 HL Q9a

A metal sphere of diameter 5 cm holds a charge of –6 μC.

(*i*) Draw the electric field around the sphere.

(*ii*) Calculate the electric field strength at a distance of 3 cm from the surface of the sphere. (15)

2021 HL Q12

The Wimshurst machine is an electrostatic generator for generating high voltages. It uses the principles of charging by induction and point discharge to store energy in two large capacitors. Wimshurst machines provided a source of high voltage for early X-ray tubes.

(*i*) Describe a laboratory experiment to demonstrate charging by induction.

(*ii*) Explain how point discharge occurs. (18)

2020 HL Q5g

Draw a labelled diagram showing how an electric field pattern can be demonstrated in the laboratory.

2020 HL Q7

All insulated metal bodies can store charge.

(*i*) Describe how a pear-shaped metal body can be charged by induction.

(*ii*) Draw a diagram to show the distribution of charge on the body after charging. (12)

2019 HL Q7

In a thunderstorm different parts of a cloud become positively and negatively charged. There is a large electric field and a large potential difference between different parts of the cloud and between the cloud and the ground.

What is meant by potential difference? State its unit.

Define electric field strength. (15)

Describe how an insulated spherical conductor can be charged positively by induction.

A spherical conductor has a diameter of 12 cm. It is charged positively by induction.

Draw the electric field around the charged conductor.

There is an electric field strength of 2.3 N C^{-1} at a distance of 5 cm from the surface of this spherical conductor. Calculate the charge on the conductor. (21)

Explain how point discharge occurs.

Describe how point discharge can be demonstrated in the laboratory. (20)

2018 HL Q5g

Write an expression for the electric field intensity *E* at a distance *d* from a charge *Q*.

2017 HL Q5e

Explain how point discharge occurs.

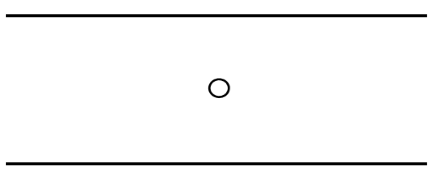
2017 HL Q5f

What is the electric field strength 53 pm from a proton?

2016 HL Q12b

In 1909 Robert Millikan determined the charge on an electron by experiment.

A tiny drop of oil was placed between two horizontal plates, one directly above the other as shown. The oil drop was ionised by X-rays so that it became negatively charged. An electric field was applied between the plates until the drop no longer moved up or down.



Define electric field strength.

In your answer book, sketch the electric field pattern between two oppositely charged parallel plates.

Draw a diagram to show the forces acting on the drop of oil when it is stationary. (16)

The electric field strength between the plates was 3.6×10^4 V m^{-1} when the drop of oil was stationary, and the mass of the drop was 2.4×10^{-15} kg.

Calculate the charge of the drop.

How many excess electrons are on this drop? (12)

(acceleration due to gravity = 9.8 m s^{-2})

2015 HL Q8

Define electric field strength. (6)

Both Van de Graaff generators and gold leaf electroscopes are used to investigate static electricity in the laboratory.

Draw a labelled diagram of a gold leaf electroscope.
Describe how it can be given a negative charge by induction. (20)

A Van de Graaff generator can be used to demonstrate point discharge.

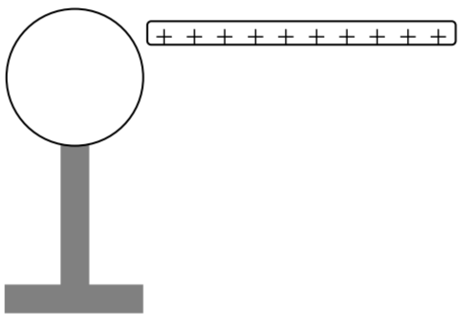
Explain, with the aid of a labelled diagram, how point discharge occurs.
Describe an experiment to demonstrate point discharge. (18)

The polished spherical dome of a Van de Graaff generator has a diameter of 40 cm and a charge of +3.8 μC.

What is the electric field strength at a point 4 cm from the surface of the dome? (12)

2013 HL Q5g

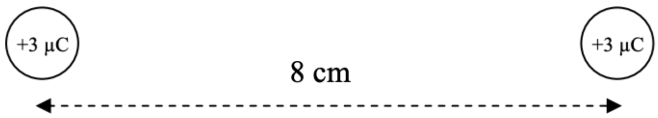
A positively-charged rod is brought near to a neutral, conducting sphere that is on top of an insulating stand, as shown in the diagram. How would a student charge the sphere negatively by induction?



2013 HL Q12c

Define the unit of charge, the coulomb. State Coulomb's law. (9)

Calculate the force of repulsion between two small spheres when they are held 8 cm apart in a vacuum. Each sphere has a positive charge of +3 μC. (9)

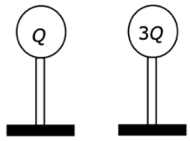


Copy the diagram above and show on it the electric field generated by the charges. Mark on your diagram a place where the electric field strength is zero. (10)

2011 HL Q9

(*a*) State Coulomb's law. (6)

Two identical spherical conductors on insulated stands are placed a certain distance apart. One conductor is given a charge Q while the other conductor is given a charge $3Q$ and they experience a force of repulsion F. The two conductors are then touched off each other and returned to their original positions. What is the new force, in terms of F, between the spherical conductors? (18)



(*b*) Draw a labelled diagram of an electroscope.

Why should the frame of an electroscope be earthed?

Describe how to charge an electroscope by induction. (15)

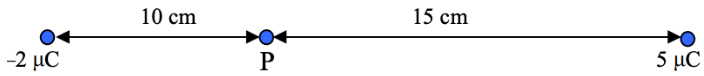
(*c*) How does a full-body metal-foil suit protect an operator when working on high voltage power lines?

Describe an experiment to investigate the principle by which the operator is protected. (17)

2010 HL Q12d

Define electric field strength and give its unit of measurement. (9)

The diagram shows a negative charge of 2 μC, positioned 25 cm away from a positive charge of 5 μC.



Copy the diagram into your answerbook and show on it the direction of the electric field at point P.

Calculate the electric field strength at P. (15)

Under what circumstances will point discharge occur? (4)

(permittivity of free space = 8.9×10^{-12} F m^{-1})

2008 HL Q5f

What is the force exerted on an electron when it is an electric field of strength 5 N C^{-1}?

2007 HL Q8

Define electric field strength and give its unit of measurement. (9)

Describe how an electric field pattern may be demonstrated in the laboratory. (12)

The dome of a Van de Graff generator is charged. The dome has a diameter of 30 cm and its charge is 4 C. A 5 μC point charge is placed 7 cm from the surface of the dome.

Calculate:

(i) the electric field strength at a point 7 cm from the dome

(ii) the electrostatic force exerted on the 5 μC point charge. (15)

All the charge resides on the surface of a Van de Graff generator's dome. Explain why.
Describe an experiment to demonstrate that total charge resides on the outside of a conductor.
Give an application of this effect. (20)

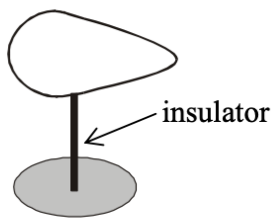
(permittivity of free space = 8.9×10^{-12} F m^{-1})

2006 HL Q5g

Why is Coulomb’s law an example of the inverse square law?

2005 HL Q5g

A pear-shaped conductor is placed on an insulated stand is shown. Copy the diagram and show how the charge is distributed over the conductor when it is positively charged. (7)



2005 HL Q10

Define electric field strength.

State Coulomb's law of force between electric charges. (12)

Why is Coulomb's law an example of an inverse square law? (6)

Give two differences between the gravitational force and the electrostatic force between two electrons. (6)

Describe an experiment to show an electric field pattern. (12)

Calculate the electric field strength at the point B, which is 10 mm from an electron.

What is the direction of the electric field strength at B?

A charge of 5 μC is placed at B. Calculate the electrostatic force exerted on this charge. (20)

(permittivity of free space = 8.9×10^{-12} F m^{-1}; charge on the electron = 1.6×10^{-19} C)

2004 HL Q5g

Identify two hazards caused by static electricity.

2003 HL Q12c

State Coulomb's law of force between electric charges. (6)

Define electric field strength and give its unit. (9)

How would you demonstrate an electric field pattern? (9)

The diagram shows a negative charge – Q at a point X. Copy the diagram and show on it the direction of the electric field strength at Y. (4)

2002 HL Q11

Read the following passage and answer the accompanying questions.

Benjamin Franklin designed the lightning conductor. This is a thick copper strip running up the outside of a tall building. The upper end of the strip terminates in one or more sharp spikes above the highest point of the building. The lower end is connected to a metal plate buried in moist earth. The lightning conductor protects a building from being damaged by lightning in a number of ways.

During a thunderstorm, the value of the electric field strength in the air can be very high near a pointed lightning conductor. If the value is high enough, ions, which are drawn towards the conductor, will receive such large accelerations that, by collision with air molecules, they will produce vast additional numbers of ions. Therefore the air is made much more conducting and this facilitates a flow of current between the air and the ground. Thus, charged clouds become neutralised and lightning strikes are prevented. Alternatively, in the event of the cloud suddenly discharging, the lightning strike will be conducted through the copper strip, thus protecting the building from possible catastrophic consequences.

Raised umbrellas and golf clubs are not to be recommended during thunderstorms for obvious reasons.

On high voltage electrical equipment, pointed or roughly-cut surfaces should be avoided.

(Adapted from "Physics – a teacher's handbook", Dept. of Education and Science.)

(a) Why is a lightning conductor made of copper? (7)

(b) What is meant by electric field strength? (7)

(c) Why do the ions near the lightning conductor accelerate? (7)

(d) How does the presence of ions in the air cause the air to be more conducting? (7)

(e) How do the charged clouds become neutralised? (7)

(f) What are the two ways in which a lightning conductor prevents a building from being damaged by lightning? (7)

(g) Why are raised umbrellas and golf clubs not recommended during thunderstorms? (7)

(h) Explain why pointed surfaces should be avoided when using high voltage electrical equipment. (7)

2: POTENTIAL DIFFERENCE

Potential difference

The potential difference (p.d.) between two points is the work done when a charge of 1 coulomb moves from one point to the other.

The unit of potential difference is **the volt (symbol V).**

The volt

The potential difference between two points is one volt if one joule of work is done when bringing a charge of one coulomb from one point to another.

An everyday word for the term 'potential difference' is 'voltage'.

Relationship between work, charge and potential difference

work = potential difference × charge

$$\boxed{\mathbf{W = V \times Q}}$$

Potential at a point

The potential at a point refers to the work done in bringing a positive charge from that point to earth.

3: CAPACITANCE

Capacitors

A capacitor is a device used to store separated charge.

The symbol for capacitance is *C*
Don't confuse 'capacitance' (symbol C) with 'charge' (symbol Q).
The unit of capacitance is the farad; symbol is F.

Circuit symbol for a capacitor:

The capacitance of a conductor is the ratio of the charge on the conductor to its potential.

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

Example 1:

The charge on the capacitor is 0.025 C and the potential difference across it is 250 V. Calculate the capacitance.

Example 2:

A capacitor has a capacitance of 6×10^{-2} F. Calculate the charge stored on the capacitor when it is connected to a 12 V d.c. power supply.

Example 3:

The capacitor has a capacitance of 200 μF. Calculate its charge when connected to a 6 V battery.

Example 4:

What is the positive charge stored on a 5 μF capacitor when connected to 120 V d.c. supply?

The parallel plate capacitor

The relationship between capacitance, overlap area and distance between plates for a parallel plate capacitor is as follows:

$$\boxed{C = \varepsilon \frac{A}{d}}$$

Example 5:

The capacitance of a parallel plate air capacitor is 5 pF. If the plates of the capacitor are 2 cm apart, what is the common area of the plates? Take $\varepsilon_{air} = \varepsilon_0 = 8.854 \times 10^{-12}$ F m^{-1}

Example 6:

The plates of an air-filled parallel plate capacitor have a common area of 40 cm^2 and are 1 cm apart. Calculate the capacitance of the capacitor. Take $\varepsilon_{air} = \varepsilon_0 = 8.85 \times 10^{-12}$ F m^{-1}

Example 7:

The capacitance of a parallel plate capacitor is 12 µF. While the battery is connected the distance *d* is increased by a factor of three. Calculate the new capacitance.

Relative permittivity ε_r

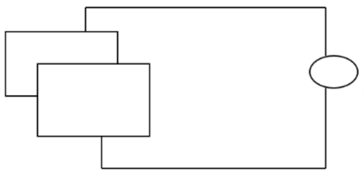
Relative permittivity or a medium is defined as the ratio of the permittivity of that medium to the permittivity of a vacuum. As it is the ratio of permittivities it has no unit.

$$\boxed{\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}}$$

Example 8:

The plates of a parallel plate capacitor of capacitance 3.2 pF have a common area of 20 cm^2 a nd are 15 mm apart. Calculate the relative permittivity of the capacitor's dielectric.

To demonstrate the factors affecting the capacitance of a parallel plate capacitor



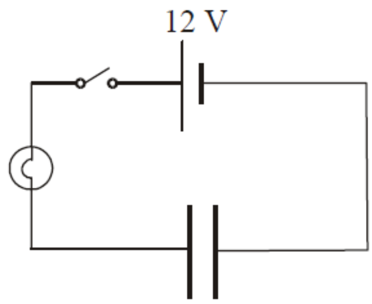
1. Connect the two parallel plates to a multimeter set to read capacitance. Note the capacitance.
2. Increase the distance between them – note that the capacitance decreases.
3. Move one plate slightly to the side (decreasing the overlap area) – note that the capacitance decreases.
4. Place different slabs of insulating material between the plates such as plastic and glass – note that the capacitance is lowest when nothing (air) is between the plates.

The three factors that affect the capacitance of a parallel plate capacitor are

1. Overlap area
2. Distance between the plates
3. Permittivity of the medium

Exam tip: "medium" is not an acceptable answer.

To show that a charged capacitor stores energy



- Set up as shown.
- Close the switch to charge the capacitor.
- Remove the battery and connect the terminals together to ‘short’ the circuit.
- The bulb will flash as the capacitor discharges, showing that it stores energy.

The energy stored in a capacitor

$$\boxed{W = \frac{1}{2}CV^2}$$

Example 9:

How much energy is stored in a 100 μF capacitor when it is charged to a potential difference of 12 V?

Example 10:

Calculate the energy stored in a 5 μF capacitor when a potential difference of 20 V is applied to it.

Example 11:

A capacitor of capacitance 100 μF is charged to a potential difference of 20 V. What is the energy stored in the capacitor?

Example 12:

Two parallel metal plates are placed a distance *d* apart in air. The plates form a parallel plate capacitor with a capacitance of 12 μF. A 6 V battery is connected across the plates.
(i) Calculate the charge on each plate.
(ii) Calculate the energy stored in the capacitor.

Example 13:

A 64 μF capacitor in a defibrillator is charged to a potential difference of 2500 V. The capacitor is discharged through electrodes attached to the chest of a heart attack victim.
(i) Calculate the charge stored on each plate of the capacitor.
(ii) Calculate the energy stored in the capacitor.

Common applications of capacitors

1. The 'flash' on a camera (an internal capacitor stores charge and releases it very quickly).
2. Tuning into a radio station (turning the dial changes the overlap area of an internal capacitor which in turn changes the frequency that gets amplified).
3. Touchscreens (the user's finger acts as a plate of a capacitor). See 2014 Question 9 [HL]
4. Allows alternating current (a.c.) to pass through it but blocks direct current (d.c.).
5. Smoothing out variations in direct current.
6. Used in circuits to only allow alternating current of a specific frequency to flow.

Example 14:

Diagram A shows a capacitor connected to a bulb and a 12 V a.c. supply. Diagram B shows the same capacitor connected to the bulb, but connected to a 12 V d.c. supply. What happens in each case when the switch is closed? Explain your answer.

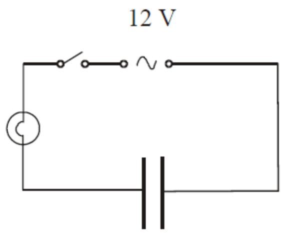


diagram A

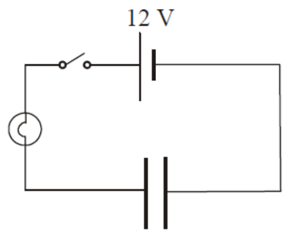


diagram B

Review of some electrical symbols and units

Quantity	Symbol	Unit	Symbol of unit
Charge	Q	*coulombs*	C
Current	I	*amps*	A
Capacitance	C	*farads*	F
Electric Field Strength	E	*newton per coulomb*	N/C

Capacitors are also used in defibrillators (see 2009 Question 9, HL).

2024 HL Q11

A device that is designed to store energy when it holds a charge is called a capacitor.

(*i*) Define capacitance.

(*ii*) Describe an experiment to demonstrate that capacitance depends on the common area of the plates of a parallel plate capacitor.

(*iii*) Sketch a suitable graph to show the relationship between capacitance *C* and the common area *A* between the plates of a parallel plate capacitor. (21)

A parallel-plate capacitor with metal plates of area 0.0225 m^2 are placed 8 mm apart in a vacuum.

(*iv*) A voltage of 3 kV is applied across the plates. Calculate the maximum potential energy stored in the capacitor.

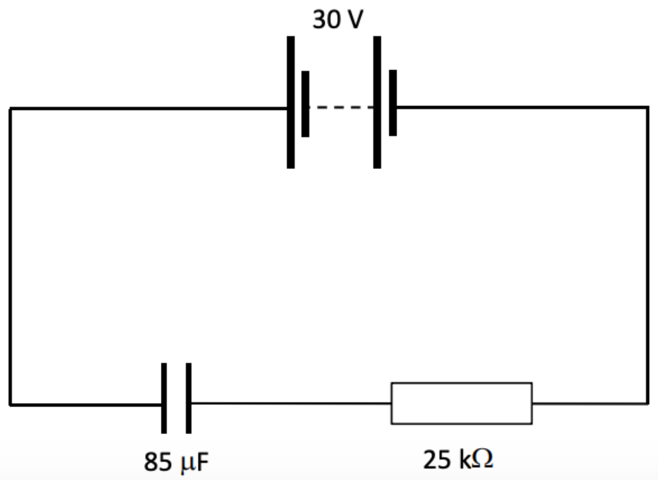
(*v*) A material with a relative permittivity of 2 is then inserted to completely fill the space between the capacitor plates. What is the effect on the maximum potential energy stored by the capacitor? (15)

Capacitors and resistors can be combined to create timing circuits such as those used to create the flash on a camera. The circuit diagram below shows a resistor and a capacitator connected in series with a 30 V power supply. The current flowing in the circuit at a given instant is 0.3 mA.

(*vi*) Calculate the potential difference across the resistor at this instant.

(*vii*) Calculate the charge held by the capacitor at this instant.

(*viii*) Draw a diagram to show the electric field between the plates of the charged capacitor. (20)



2023 HL Deferred Paper Q14d

(*i*) What is meant by capacitance?

(*ii*) Describe a laboratory experiment to demonstrate how the capacitance of a parallel-plate capacitor varies with the distance between the plates. (15)

(*iii*) Draw a diagram of the electric field between the plates of a charged parallel-plate capacitor.

The keys on some modern keyboards act as parallel-plate capacitors. When the key is pressed, the distance between the plates is changed.

(*iv*) A parallel-plate capacitor has a capacitance of 0.12 pF when the distance between its plates is 5 mm. Calculate its capacitance when the distance between its plates changes to 0.3 mm. (13)

2023 HL Q6g

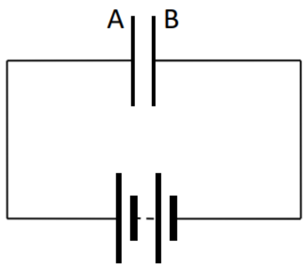
What is meant by potential difference?

2022 HL Deferred Paper Q14c

(*i*) What is a capacitor?

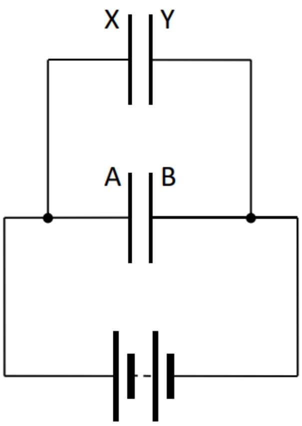
(*ii*) Define the unit of capacitance, i.e. the farad. (9)

A parallel plate capacitor of capacitance 3 μF has plates A and B connected across a 6 V battery, as shown in the diagram on the right.



Calculate the charge on (*iii*) plate A, (*iv*) plate B.

(*v*) Calculate the energy stored in the capacitor. (9)



A 2 μF capacitor, with plates X and Y, is now connected in parallel with the first capacitor across the 6 V battery, as shown in the diagram on the left.

Calculate the charge that is now on (*vi*) plate A, (*vii*) plate B, (*viii*) plate X, (*ix*) plate Y. (6)

(*x*) Calculate the capacitance of a single capacitor which could store as much energy as is stored in the two capacitors connected in parallel across the 6 V battery. (4)

2022 HL Q9b

A device that is designed to store energy when it holds a specific charge is called a capacitor.

(*i*) Describe an experiment to demonstrate that a charged capacitor stores energy.

A parallel-plate capacitor has a dielectric of permittivity ε and its plates have an area of overlap A. Voltage V is applied across the plates such that the capacitor stores energy W.

(*ii*) In terms of some or all of the symbols given, write an expression for (*a*) the charge on each plate of the capacitor, (*b*) the distance between the plates. (20)

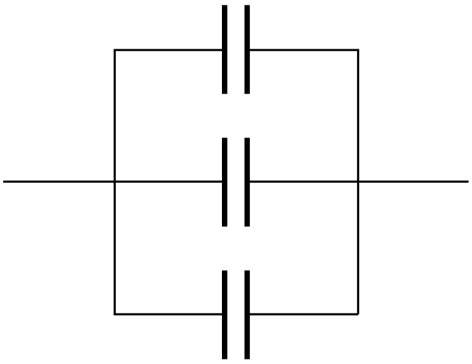
2021 HL Q12

The plates of a parallel plate capacitor of capacitance 3.2 pF have a common area of 20 cm^2 and are 15 mm apart.

(*iii*) Calculate the relative permittivity of the capacitor's dielectric.

(*iv*) What would be the effect on the capacitance if the distance between the plates was doubled?

(*v*) Three such capacitors are connected in parallel as shown below. Explain why the effective capacitance of this combination is 9.6 pF.



(*vi*) Draw the electric field pattern in a charged parallel plate capacitor. (21)

2020 HL Q7

All insulated metal bodies can store charge.

(*i*) Describe how a pear-shaped metal body can be charged by induction.

(*ii*) Draw a diagram to show the distribution of charge on the body after charging. (12)

A charged capacitor stores energy.

(*iii*) Define capacitance.

(*iv*) Draw the circuit symbol for a capacitor.

A 4000 μF capacitor is connected across 500 V. The stored energy is converted to heat when the capacitor is discharged through a heating element placed in 40 g of water in an insulated container.

(*v*) Calculate the maximum rise in temperature of the water. (18)

(*vi*) Describe an experiment to demonstrate how the capacitance of a parallel-plate capacitor changes with the distance between the plates.

A Leyden jar acts as a parallel-plate capacitor.

A student makes a Leyden jar in the laboratory. It consists of a cylindrical glass container of internal radius 6 cm. The glass in the jar is the capacitor's dielectric and has a relative permittivity of 2.1 and a thickness of 5 mm. Aluminium foil of height 17 cm coats the inside and outside vertical walls of the jar.

(*vii*) Calculate the surface area of the inner cylinder of aluminium foil.

(*viii*) Calculate the capacitance of the Leyden jar.

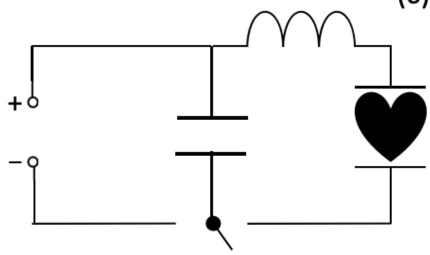
(*ix*) What property of glass allows it to be used as a dielectric? (26)

(*specific heat capacity of water = 4180 J kg^{-1} K^{-1}*)

2018 HL Q12c

Define capacitance and state its unit. (6)

A capacitor is an important component of a defibrillator. A simple defibrillator circuit is shown.



Each plate of a parallel plate capacitor in a defibrillator stores a charge of 0.11 C when a potential difference of 4.0 kV is applied across it.

Calculate the energy stored in the capacitor.

What is the net charge of the capacitor when it stores this energy?

The capacitor discharges in a time of 15 ms. Calculate the average current flowing as the capacitor discharges.

Draw a diagram of the electric field between the charged plates of a parallel plate capacitor. (22)

2016 HL Q5f

State and define the SI unit of capacitance.

2015 HL Q5f

Write an expression for the charge stored on one plate of a parallel plate capacitor in terms of the potential difference between the plates, their common area, the distance between them and the permittivity of the dielectric.

2014 HL Q9

Most modern electronic devices contain a touchscreen. One type of touchscreen is a capacitive touchscreen, in which the user's finger acts as a plate of a capacitor. Placing your finger on the screen will alter the <u>capacitance</u> and the <u>electric field</u> at that point.

Explain the underlined terms. (12)

Describe an experiment to demonstrate an electric field pattern. (12)

Two parallel metal plates are placed a distance *d* apart in air. The plates form a parallel plate capacitor with a capacitance of 12 μF. A 6 V battery is connected across the plates.

Calculate (*i*) the charge on each plate and (*ii*) the energy stored in the capacitor. (12)

While the battery is connected the distance *d* is increased by a factor of three. Calculate the new capacitance. (4)

A capacitor and a battery are both sources of electrical energy. State two differences between a capacitor and a battery. (6)

Touchscreens also contain two polarising filters. What is meant by polarisation of light? (6)

Give one application of capacitors, other than in touchscreens. (4)

2011 HL Q5e

The capacitance of a parallel plate air capacitor is 5 pF. If the plates of the capacitor are 2 cm apart, what is the common area of the plates? Take $\varepsilon_{air} = \varepsilon_0$.

2010 HL Q5e,f

(*e*) What is the positive charge stored on a 5 μF capacitor when it is connected to a 120 V d.c. supply? (7)

(*f*) Which one of the following devices is adjusted when tuning a radio: transformer, diode, capacitor, rheostat? (7)

2009 HL Q9

Define (i) potential difference, (ii) capacitance. (12)

A capacitor stores energy.
Describe an experiment to demonstrate that a capacitor stores energy. (14)

The ability of a capacitor to store energy is the basis of a defibrillator. During a heart attack the chambers of the heart fail to pump blood because their muscle fibres contract and relax randomly. To save the victim, the heart muscle must be shocked to re-establish its normal rhythm. A defibrillator is used to shock the heart muscle.

A 64 μF capacitor in a defibrillator is charged to a potential difference of 2500 V.
The capacitor is discharged through electrodes attached to the chest of a heart attack victim.

Calculate

(i) the charge stored on each plate of the capacitor;

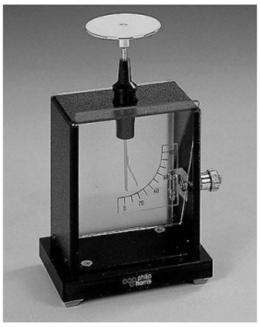
(ii) the energy stored in the capacitor;

(iii) the average current that flows through the victim when the capacitor discharges in a time of 10 ms;

(iv) the average power generated as the capacitor discharges. (30)

2008 HL Q12d

Define capacitance. (6)



Describe how an electroscope can be charged by induction. (10)

How would you demonstrate that the capacitance of a parallel plate capacitor depends on the distance between its plates? (12)

2007 HL Q5f

(f) Calculate the energy stored in a 5 μF capacitor when a potential difference of 20 V is applied to it. (7)

2006 HL Q12b

List the factors that affect the capacitance of a parallel plate capacitor. (6)

The plates of an air filled parallel plate capacitor have a common area of 40 cm^2 and are 1 cm apart. The capacitor is connected to a 12 V d.c. supply.

Calculate
(i) the capacitance of the capacitor;
(ii) the magnitude of the charge on each plate. (15)

What is the net charge on the capacitor?

Give a use for a capacitor. (7)

(permittivity of free space = 8.85×10^{-12} F m^{-1})

2005 HL Q5e

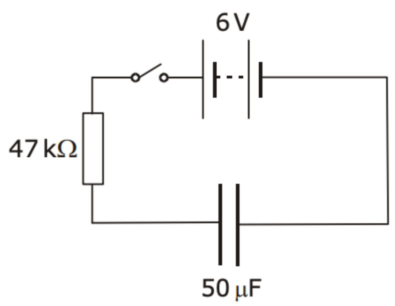
(e) A capacitor of capacitance 100 μF is charged to a potential difference of 20 V. What is the energy stored in the capacitor? (7)

2004 HL Q8

Define (i) potential difference, (ii) capacitance. (12)

Describe an experiment to demonstrate that a capacitor can store energy. (12)

The circuit diagram shows a 50 μF capacitor connected in series with a 47 kΩ resistor, a 6 V battery and a switch. When the switch is closed the capacitor starts to charge and the current flowing at a particular instant in the circuit is 80 μA.



Calculate

(i) the potential difference across the resistor and hence the potential difference across the capacitor when the current is 80 μA;

(ii) the charge on the capacitor at this instant;

(iii) the energy stored in the capacitor when it is fully charged. (27)

Describe what happens in the circuit when the 6 V d.c. supply is replaced with a 6 V a.c. supply. (5)

2002 HL Q5g

(g) How much energy is stored in a 100 μF capacitor when it is charged to a potential difference of 12 V? (7)

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