OCR A Level Physics

Your notes

Electric Fields

Contents

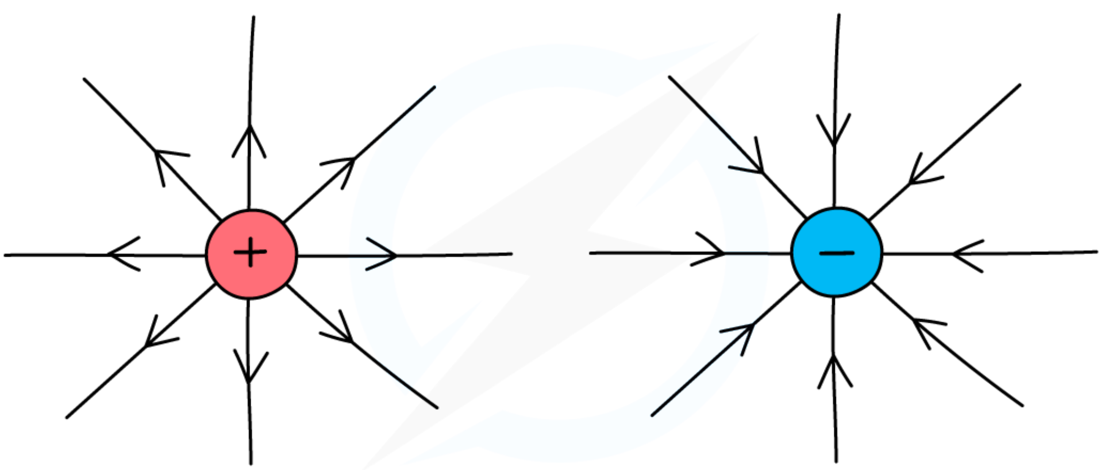
Your notes

Electric Fields

Defining Electric Fields

- A charged object creates an **electric field** around itself
  - This is similar to the way in which magnets create magnetic fields
- An electric field can be defined as:

  A region where an electric charge experiences a force
- If other charges enter the field then they will experience an electric force, attracting or repelling them from the object
  - Since force is a vector, the direction of this force depends on whether the charges are the same or opposite
- The force is either **attractive** or **repulsive**
  - Recall that **opposite charges** (positive and negative) charges **attract** each other
  - Conversely, **like charges** (positive and positive or negative and negative) **repel** each other

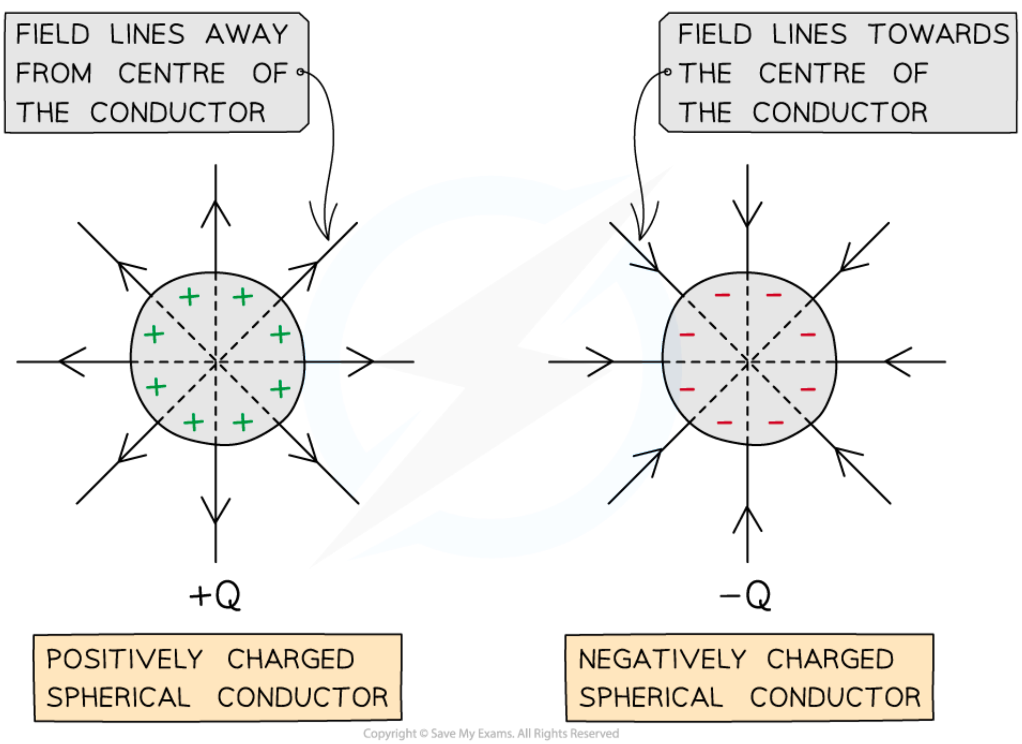


Electric fields are due to charges. The field around a charge gives rise to an electric force

Point Charge Approximation

Your notes

- For a point outside a spherical conductor, the charge of the sphere may be considered to be a **point charge** at its centre
  - A **uniform** spherical conductor is one where its charge is **distributed evenly**
- The electric field lines around a spherical conductor are therefore **identical to those around a point charge**
- An example of a spherical conductor is a **charged sphere**
- The field lines are **radial** and their direction depends on the charge of the sphere
  - If the spherical conductor is **positively** charged, the field lines are directed **away** from the centre of the sphere
  - If the spherical conductor is **negatively** charged, the field lines are directed **towards** the centre of the sphere



Electric field lines around a uniform spherical conductor are identical to those on a point charge

Your notes

Examiner Tips and Tricks

You might have noticed that the electric fields share many similarities to the gravitational fields. The main difference being the gravitational force is always attractive, whilst electrostatic forces can be attractive or repulsive.

You should make a list of all the similarities and differences you can find, as this could come up in an exam question.

Electric Field Lines

Your notes

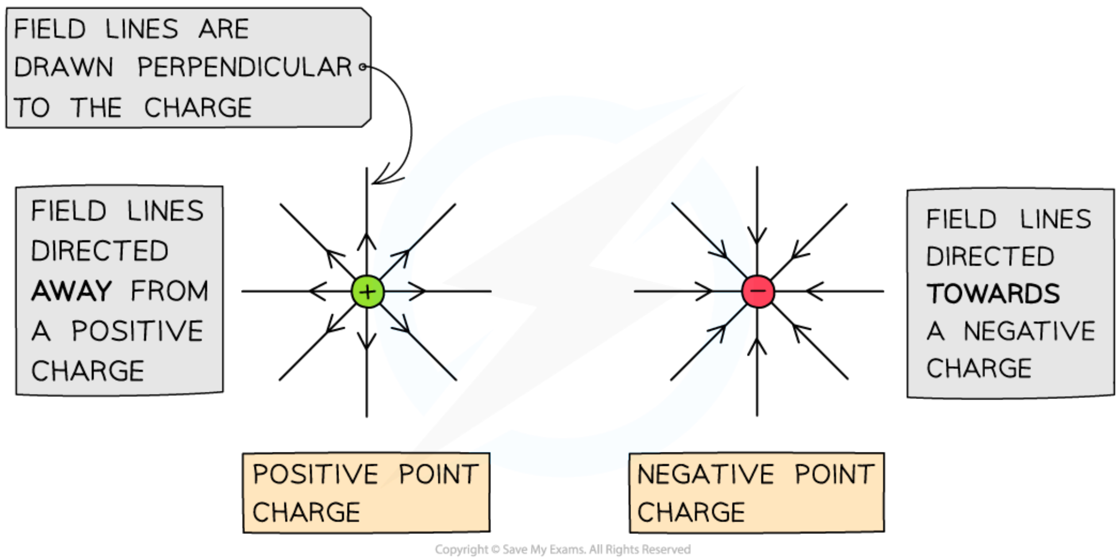
Electric Field Lines

- Field lines are used to represent the **direction** and **magnitude** of an electric field
  - In an electric field, field lines are always directed from the positive charge to the negative charge
- In a **uniform** electric field:
  - the field lines are **equally spaced** at **all** points
  - electric field strength is **constant** at all points in the field
  - the force acting on a test charge has the **same** magnitude and direction at all points in the field
- In a **radial** electric field:
  - the field lines are equally spaced as they exit the surface of the charge but the distance between them **increases** with distance
  - the electric field strength **decreases** with distance from the charge producing the field
  - the magnitude of the force acting on a test charge **decreases** with distance

Electric field around a point charge

- Around a point charge, the electric field is **radial** and the lines are directly radially inwards or outwards
  - If the charge is **positive** (+), the field lines are radially **outwards**
  - If the charge is **negative** (–), the field lines are radially **inwards**

Your notes



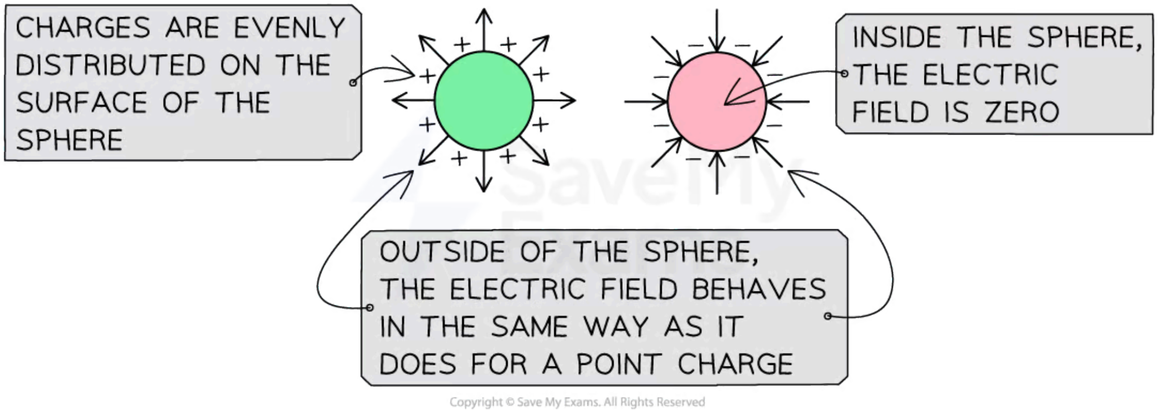
Electric field lines around a point charge are directed away from a positive charge and towards a negative charge

- A radial field spreads uniformly to (or from) the charge in all directions, and the strength of the field is indicated by the spacing of the field lines
  - The electric field is **stronger** where the lines are **closer** together
  - The electric field is **weaker** where the lines are **further** apart
- This shares many similarities to radial gravitational field lines around a point mass
  - Since gravity is only an attractive force, the field lines will look similar to the negative point charge, whilst electric field lines can be in either direction

Electric field around a conducting sphere

- When a conducting sphere becomes charged, the electric field around it is the **same** as it would be if all the charge was concentrated at the **centre**
  - This means that a charged sphere can be treated in the same way as a **point charge** in calculations

Your notes

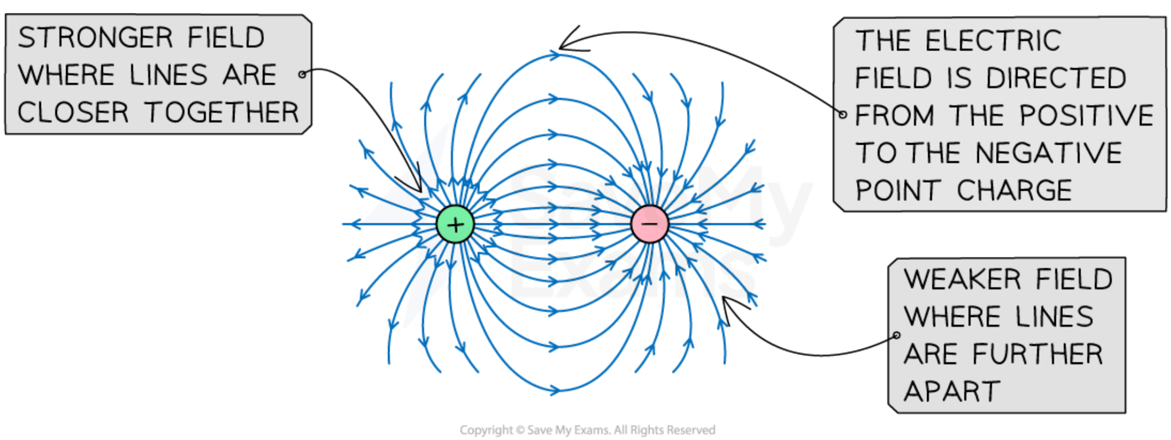


Electric field lines around a charged conducting sphere are similar to the field lines around a point charge

- **Note:** field lines are **always perpendicular** to the surface of a conducting sphere

Electric field between two point charges

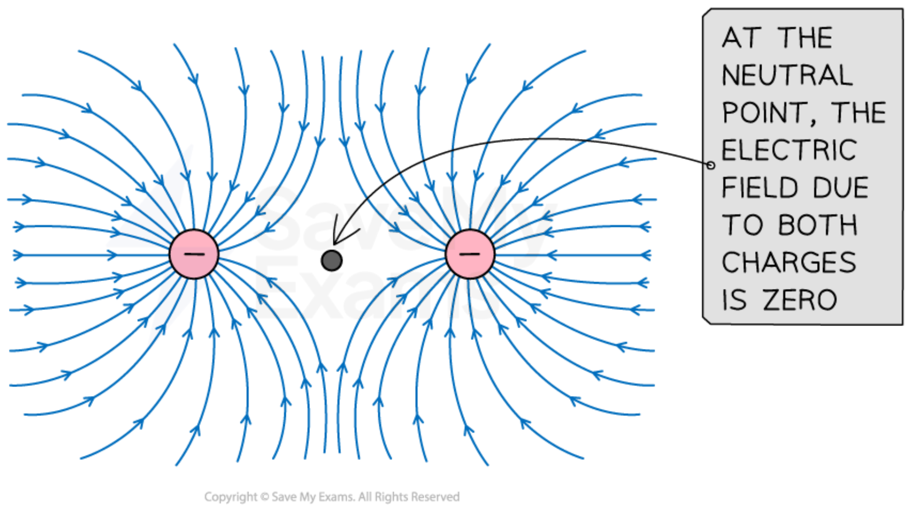
- For two **opposite** charges:
  - the field lines are directed from the positive charge to the negative charge
  - the **closer** the charges are brought together, the stronger the **attractive** electric force between them becomes



The electric field lines between two opposite charges are directed from the positive to the negative charge. The field lines connect the surfaces of the charges to represent attraction

Your notes

- For two charges of the **same** type:
  - the field lines are directed **away** from two positive charges or **towards** two negative charges
  - the **closer** the charges are brought together, the stronger the **repulsive** electric force between them becomes
  - there is a **neutral point** at the midpoint between the charges where the resultant electric force is zero

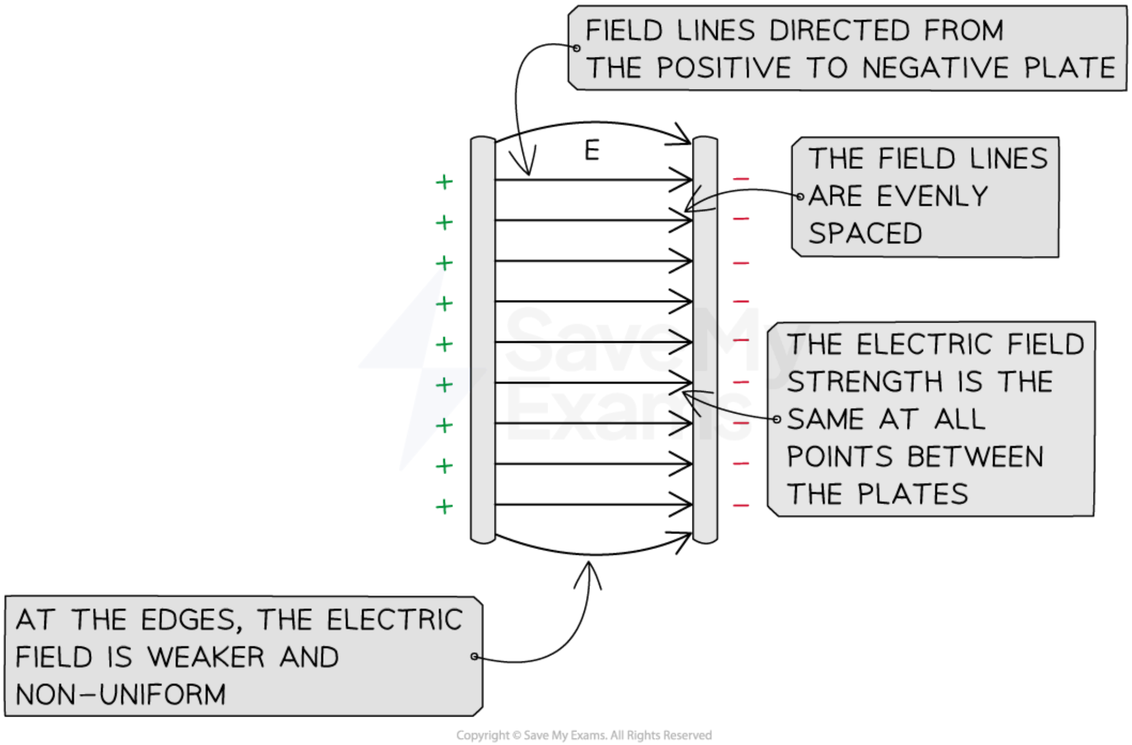


The electric field lines between two like charges are directed away from positive charges or towards negative charges. The field lines do not connect the surfaces of the charges to represent repulsion

Electric field between two parallel plates

- When a potential difference is applied between two parallel plates, they become charged
  - The electric field between the plates is **uniform**
  - The electric field beyond the edges of the plates is **non-uniform**

Your notes

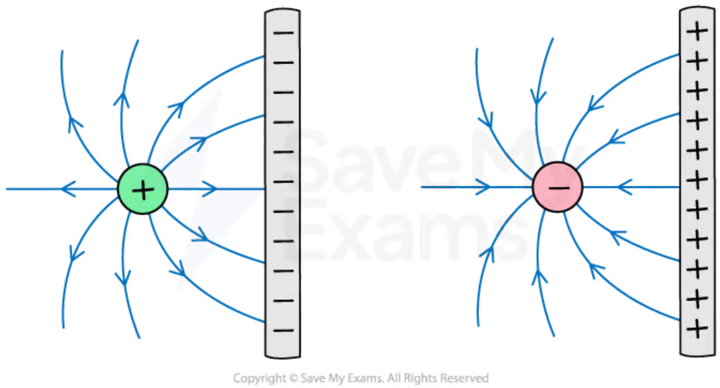


Electric field lines between two parallel plates are directed from the positive to the negative plate. A uniform electric field has equally spaced field lines

Electric field between a point charge and parallel plate

- The field around a point charge travelling between two parallel plates combines
  - the field around a point charge
  - the field between two parallel plates

Your notes



The electric field lines between a point charge and a parallel plate are similar to the field between two opposite charges. The field lines become parallel when they touch the plate

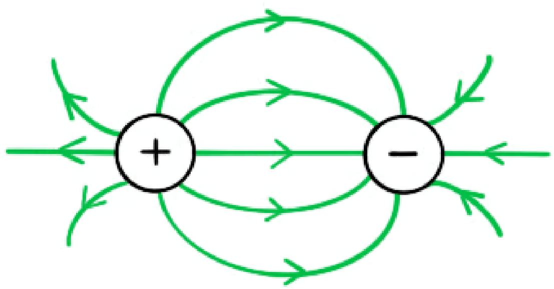
Worked Example

Sketch the electric field lines between the two point charges in the diagram below.

Answer:

- Electric field lines around point charges have arrows which point radially outwards for positive charges and radially inwards for negative charges
- Arrows (representing force on a positive test charge) point **from the positive charge to the negative charge**

Your notes



Examiner Tips and Tricks

Always label the arrows on the field lines! The lines must also touch the surface of the source charge or plates and they must **never** cross.

Electric Field Strength

Your notes

Electric Field Strength

- An electric field is a region of space in which an electric charge "feels" a force
- The **electric field strength** at a point is defined as:

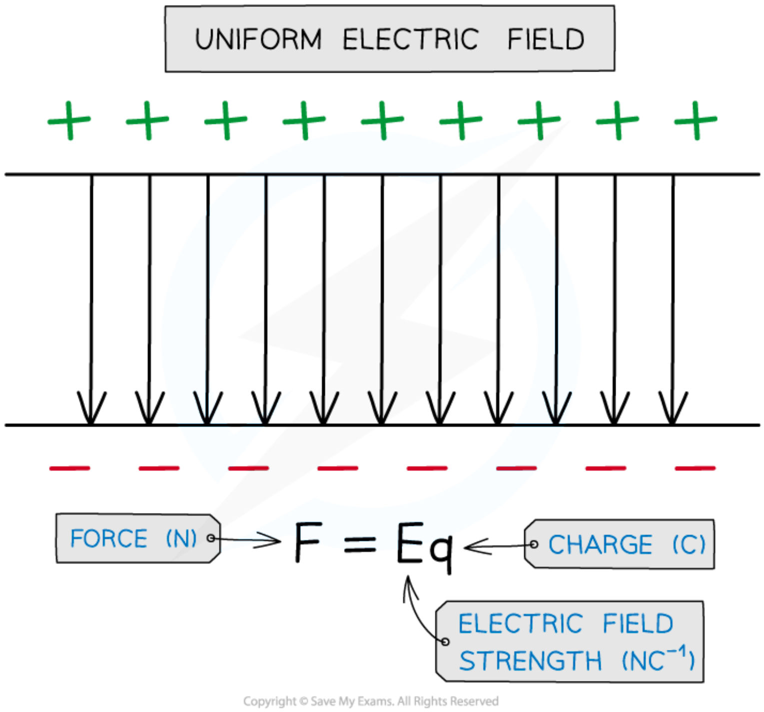
  The electrostatic force per unit positive charge acting on the charge at that point

- The electric field strength can be calculated using the equation:

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

- Where:
  - E = electric field strength (N C^{-1})
  - F = electrostatic force on the charge (N)
  - Q = charge (C)
- It is important to use a positive test charge in this definition, as this determines the direction of the electric field
- The electric field strength is a **vector** quantity, it is always directed:
  - **Away** from a positive charge
  - **Towards** a negative charge

Your notes



Worked Example

A charged particle is in an electric field with electric field strength 3.5×10^4 N C^{-1} where it experiences a force of 0.3 N.

Calculate the charge of the particle.

Answer:

Your notes

Step 1: Write down the equation for electric field strength

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

Step 2: Rearrange for charge Q

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

Step 3: Substitute in values and calculate

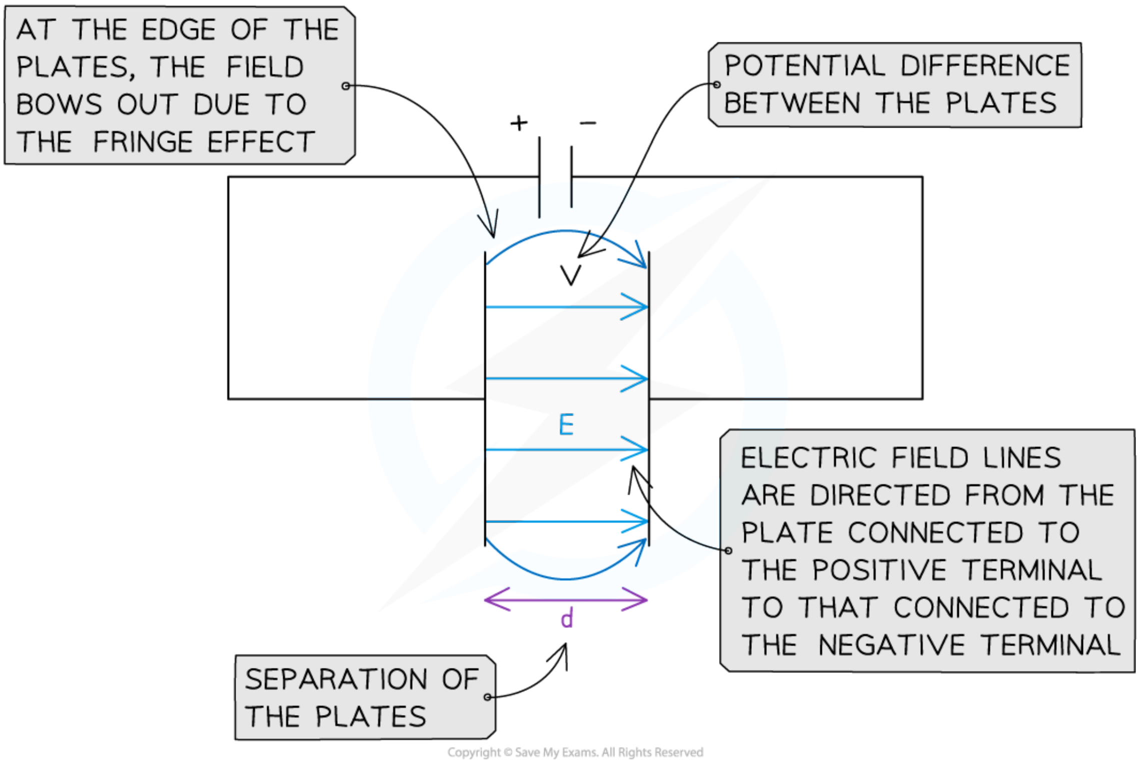
$$Q = \frac{0.3}{3.5 \times 10^4} = 8.571 \times 10^{-6} = \mathbf{8.6 \times 10^{-6}\ C\ (2\ s.f)}$$

Electric Field Strength in a Uniform Field

- The magnitude of the electric field strength in a **uniform** field between two charged parallel plates is defined as:

$$E = \frac{V}{d}$$

- Where:
  - E = electric field strength (V m^{-1})
  - V = potential difference between the plates (V)
  - d = separation between the plates (m)
- **Note:** the electric field strength is now also defined by the units **V m^{-1}**
- The equation shows:
  - The greater the **voltage** between the plates, the **stronger** the field
  - The greater the **separation** between the plates, the **weaker** the field
- This equation cannot be used to find the electric field strength around a point charge (since this would be a radial field)
- The direction of the electric field is from the plate connected to the **positive** terminal of the cell to the plate connected to the **negative** terminal

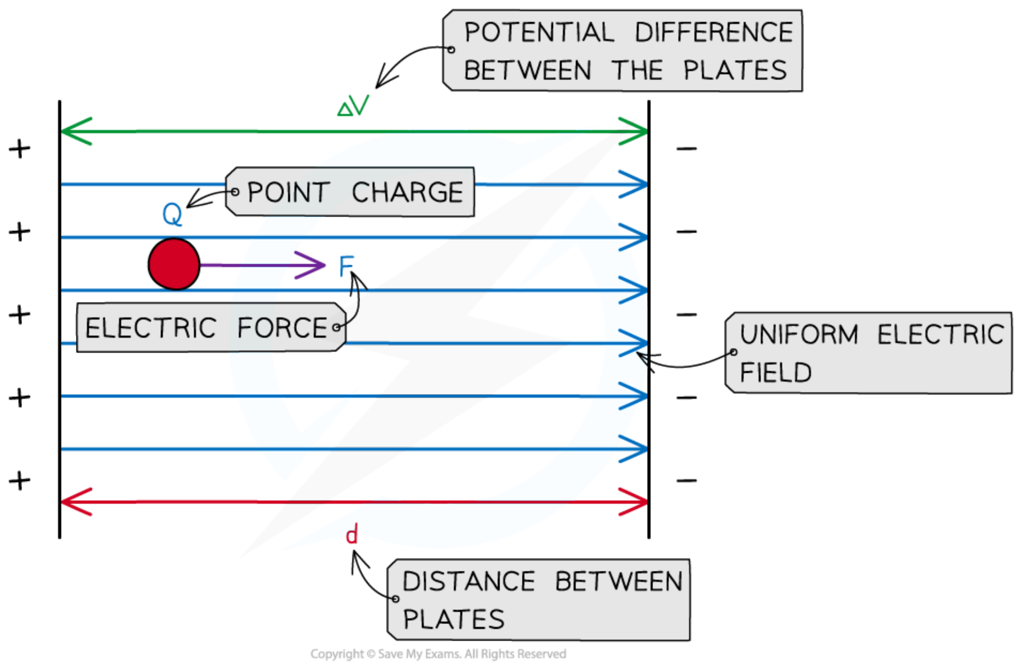


The E field strength between two charged parallel plates is the ratio of the potential difference and separation of the plates

- **Note:** if one of the parallel plates is **earthed**, it has a voltage of 0 V

Derivation of Electric Field Strength Between Plates

- When two points in an electric field have a different potential, there is a **potential difference** between them
  - To move a charge across that potential difference, **work** needs to be done
  - Two parallel plates with a potential difference ΔV across them create a uniform electric field



The work done on the charge depends on the electric force and the distance between the plates

- Potential difference is defined as the energy, *W*, transferred per unit charge, Q, this can also be written as:

$$\Delta V = \frac{W}{Q}$$

- Therefore, the work done in transferring the charge is equal to:

$$W = \Delta V \times Q$$

- When a charge Q moves from one plate to the other, its work done is:

$$W = F \times d$$

- Where:
  - *W* = work done (J)
  - *F* = force (N)
  - *d* = distance (m)
- Equate the expressions for work done:

$$F \times d = \Delta V \times Q$$

- Rearranging the fractions by dividing by Q and *d* on both sides gives:

$$\frac{F}{Q} = \frac{\Delta V}{d}$$

- Since $E = \frac{F}{Q}$ the electric field strength between the plates can be written as:

$$E = \frac{F}{Q} = \frac{\Delta V}{d}$$

Your notes

Worked Example

Two parallel metal plates are separated by 3.5 cm and have a potential difference of 7.9 kV.

Calculate the magnitude of the electric force acting on a stationary charged particle between the plates that has a charge of 2.6×10^{-15} C.

Answer:

Step 1: Write down the known values

- Potential difference, $V = 7.9$ kV $= 7.9 \times 10^3$ V
- Distance between plates, $d = 3.5$ cm $= 3.5 \times 10^{-2}$ m
- Charge, Q = 2.6×10^{-15} C

Step 2: Write down the equation for the electric field strength between the parallel plates

$$E = \frac{\Delta V}{d} = \frac{F}{Q}$$

Step 3: Rearrange for electric force, *F*

$$F = \frac{Q\Delta V}{d}$$

Step 4: Substitute the values into the electric force equation

$$F = \frac{(2.6 \times 10^{-15})(7.9 \times 10^3)}{(3.5 \times 10^{-2})} = 5.869 \times 10^{-10} \text{ N}$$

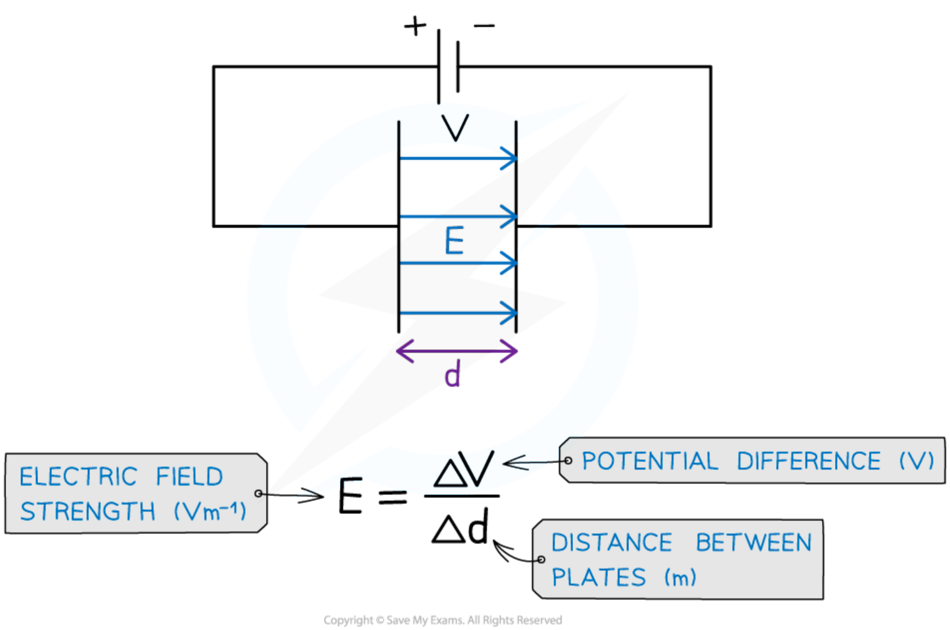
Step 5: State the final answer

- The magnitude of the electric force acting on this charged particle is 5.9×10^{-10} N

Your notes

Examiner Tips and Tricks

Remember the equation for electric field strength with V and d is only used for parallel plates, and not for point charges (where you would use $E = \frac{F}{Q}$)



Coulomb's Law

Your notes

Coulomb's Law

- All charged particles produce an electric field around it
  - This field exerts a force on any other charged particle within range
- The electrostatic force between two charges is defined by **Coulomb's Law**
  - Recall that the charge of a uniform spherical conductor can be considered as a point charge at its centre
- Coulomb's Law states that:

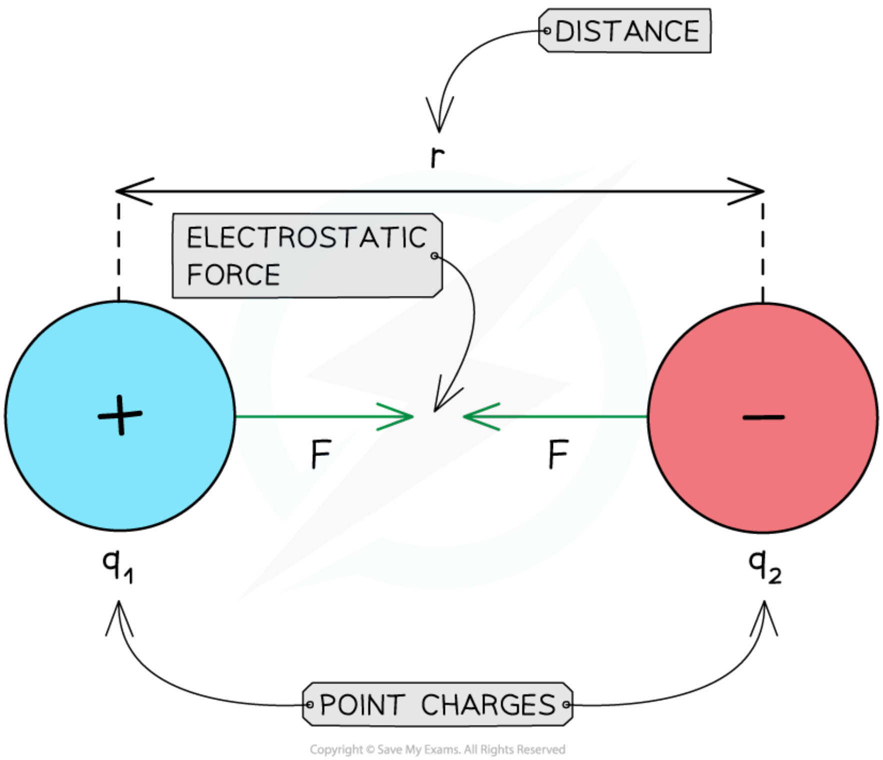
  The electrostatic force between two point charges is proportional to the product of the charges and inversely proportional to the square of their separation

- According to Coulomb's law, the electrostatic force between two point charges is calculated as follows:

$$F = \frac{Qq}{4\pi\varepsilon_0 r^2}$$

- Where:
  - F = electrostatic force (N)
  - Q, q = magnitudes of the charges (C)
  - r = distance between the centres of the two charges (m)
  - ε_0 = permittivity of free space = 8.85×10^{-12} $C^2 N^{-1} m^{-2}$

Your notes



Attractive electrostatic force between two opposite charges

- The $1/r^2$ relation is called the inverse square law
  - This means that when the separation of two charges doubles, the electrostatic force between them reduces by $(½)^2 = ¼$
- ε_0 is the **permittivity of free space**
  - $\varepsilon_0 = 8.85 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$ and refers to charges in a vacuum
  - The value of the permittivity of air is taken to be the same as ε_0
  - Any other material has a higher permittivity $\varepsilon > \varepsilon_0$
  - ε is a measure of the resistance offered by a material in creating an electric field within it

Repulsive & Attractive Forces

- For **like charges**:
  - The product Qq is positive
  - F is **positive**

- The charges **repel** each other
- For **opposite charges**:
  - The product Qq is negative
  - F is **negative**
  - The charges **attract** each other

Your notes

Worked Example

An alpha particle is situated 2.0 mm away from a gold nucleus in a vacuum.

Assuming them to be point charges, calculate the magnitude of the electrostatic force acting on each of the charges.

- Atomic number of helium = 2
- Atomic number of gold = 79

Answer:

Step 1: Write down the known quantities

- Distance, r = 2.0 mm = 2.0×10^{-3} m
- Atomic number of helium = 2
- Atomic number of gold = 79
- Elementary charge, e = 1.60×10^{-19} C (from the data booklet)
- Permettivity of free space, $\varepsilon_0 = 8.85 \times 10^{-12}$ $C^2\ N^{-1}\ m^{-2}$

Note: that you must convert the distance from millimetres (mm) into metres (m)

Step 2: Calculate the charges of the alpha particle and gold nucleus

- The elementary charge e (when taken to be positive) is the charge of a proton
  - An alpha particle (helium nucleus) has 2 protons
    - So its charge is:

$$q = 2 \times (1.60 \times 10^{-19}) = 3.2 \times 10^{-19} \text{ C}$$

- A gold nucleus has 79 protons
  - So its charge is:

$$Q = 79 \times (1.60 \times 10^{-19}) = 1.264 \times 10^{-17} \text{ C}$$

Step 3: Write down the equation to calculate the electrostatic force

$$F = \frac{Qq}{4\pi\varepsilon_0 r^2}$$

Step 4: Substitute the numbers into the equation

$$F = \frac{(3.2 \times 10^{-19})(1.264 \times 10^{-17})}{4\pi(8.85 \times 10^{-12})(2.0 \times 10^{-3})^2}$$

$$F = 9.1 \times 10^{-21}\ \text{N}$$

Examiner Tips and Tricks

You do not need to memorise the numerical value of the Coulomb's constant k or that of the permittivity of free space ε_0. They will both be given in the data booklet.

Unless specified in the question, you should assume that charges are located in a vacuum.

You should note that Coulomb's law can only be applied to charged spheres whose size is much smaller than their separation. Only in this case, the point charge approximation is valid. You must remember that the separation r must be taken from the centres of the spheres.

You cannot use Coulomb's law to calculate the electrostatic force between charges distributed on irregularly-shaped objects.

Your notes

Electric Field Strength of a Point Charge

Your notes

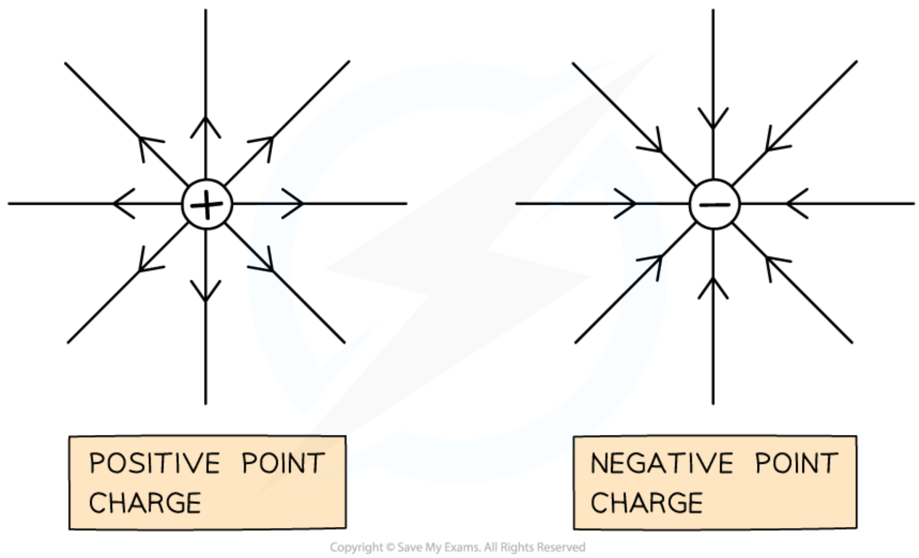
Electric Field of a Point Charge

- The electric field strength describes how strong or weak an electric field is at that point
- A point charge produces a **radial** field
  - A charge sphered also acts like a point charge
- The electric field strength *E* at a distance *r* due to a point charge Q in free space is defined by:

$$E = \frac{Q}{4\pi\varepsilon_0 r^2}$$

- Where:
  - Q = the point charge producing the radial electric field (C)
  - *r* = distance from the centre of the charge (m)
  - ε_0 = permittivity of free space (F m^{-1})
- This equation shows:
  - Electric field strength in a radial field is **not constant**
  - As the distance from the charge *r* increases, *E* decreases by a factor of $1/r^2$
- This is an inverse square law relationship with distance
  - This means the field strength *E* decreases by a factor of **four** when the distance *r* is **doubled**
- **Note:** this equation is only for the field strength around a **point charge** since it produces a radial field

Your notes



Direction of positive and negative point charges

- The electric field strength is a **vector** Its direction is the same as the electric field lines
  - If the charge is negative, the E field strength is negative and points **towards** the centre of the charge
  - If the charge is positive, the E field strength is positive and points **away** from the centre of the charge
- This equation is analogous to the gravitational field strength around a point mass

Worked Example

A metal sphere of diameter 15 cm is negatively charged. The electric field strength at the surface of the sphere is 1.5×10^5 V m^{-1}.

Determine the total surface charge of the sphere.

Answer:

Step 1: Write down the known values

- Electric field strength, $E = 1.5 \times 10^5$ V m^{-1}
- Radius of sphere, $r = 15 / 2 = 7.5$ cm $= 7.5 \times 10^{-2}$ m

Step 2: Write out the equation for electric field strength

$$E = \frac{Q}{4\pi \varepsilon_0 r^2}$$

Step 3: Rearrange for charge Q

$$Q = 4\pi\varepsilon_0 E r^2$$

Step 4: Substitute in values

$$Q = (4\pi \times 8.85 \times 10^{-12}) \times (1.5 \times 10^5) \times (7.5 \times 10^{-2})^2$$

$$Q = 9.38 \times 10^{-8} \text{ C} = 94 \text{ nC (2 s.f.)}$$

Examiner Tips and Tricks

Remember to always **square** the distance in the electric field strength equation!

Your notes

Electric vs Gravitational Fields

Your notes

Electric Fields vs Gravitational Fields

- A field can be defined as:

  A region in which an object will experience a force, such as gravitational or electrostatic, at a distance

- A gravitational field can be defined as:

  The gravitational force per unit mass exerted on a point mass

- An electrostatic field can be defined as:

  The electric force per unit charge exerted on a small positive test charge

- Fields can be described in terms of field strength, which is defined as:

$$\text{Field strength} = \frac{\text{force acting on a test object}}{\text{size of test object}}$$

- Electric field strength, *E*, and gravitational field strength, *g*, therefore, have very similar equations
  - Despite a few differences, they are analogous to one another in many ways
- In both cases, the nature of the test object is as follows:
  - **Gravitational fields:** small mass, *m*
  - **Electrostatic fields:** small positive charge, *q*

Uniform Fields

- A gravitational field is a region of space in which objects with mass will experience a force
- The gravitational field strength can be calculated using the equation:

$$g = \frac{F}{m}$$

- Where:
  - g = gravitational field strength (N kg^{-1})
  - F = gravitational force on the charge (N)
  - m = mass (kg)

Your notes

- The direction of the gravitational field is always directed **towards** the centre of the mass
  - Gravitational forces are **always attractive** and cannot be repulsive
- An electric field is a region of space in which an electric charge will experience a force
- The electric field strength can be calculated using the equation:

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

- Where:
  - E = electric field strength ($N\ C^{-1}$)
  - F = electrostatic force on the charge (N)
  - Q = charge (C)
- It is important to use a **positive** test charge in this definition, as this determines the **direction** of the electric field
- The electric field strength is a **vector** quantity, it is always directed:
  - **Away** from a positive charge
  - **Towards** a negative charge
- **Opposite charges** (positive and negative) **attract** each other
- Conversely, **like charges** (positive-positive or negative-negative) **repel** each other

Radial Fields

- A point charge or mass produces a **radial** field
  - A charged sphere also acts as a point charge
  - A spherical mass also acts as a point mass
- Radial fields always have an inverse square law relationship with distance
  - This means the field strength decreases by a factor of **four** when the distance r is **doubled**
- The gravitational force F_G between two masses is defined by:

$$F_G = \frac{Gm_1 m_2}{r^2}$$

- Where:

Your notes

- F_G = gravitational force between two masses (N)
- G = Newton's gravitational constant
- m_1, m_2 = two points masses (kg)
- r = distance between the centre of the two masses (m)

- The electric field strength E at a distance r due to a point charge Q in free space is defined by:

$$E = \frac{Q}{4\pi\varepsilon_0 r^2}$$

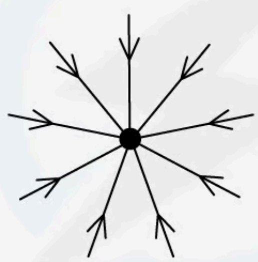
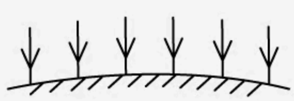
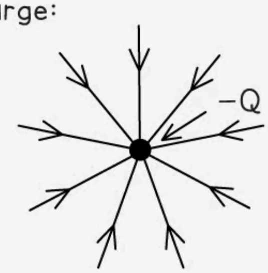
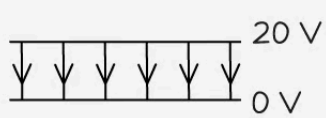
- Where:
  - Q = the point charge producing the radial electric field (C)
  - r = distance from the centre of the charge (m)
  - ε_0 = permittivity of free space ($F\ m^{-1}$) = ($\varepsilon_0 = 8.85 \times 10^{-12}\ F\ m^{-1}$)
- This equation shows:
  - The electric field strength in a radial field is **not constant**
  - As the distance, r, from the charge increases, E decreases by a factor of $1/r^2$

Gravitational vs Electrostatic Forces

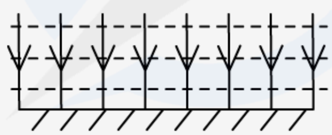
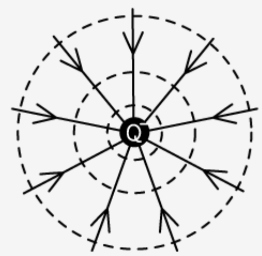
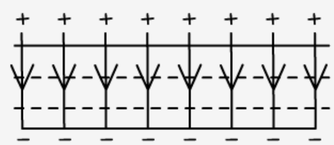
- The similarities and differences between gravitational and electrostatic forces are listed in the table below:

Comparing G and E Fields

Your notes

	Gravitational Fields	Electric Fields
Origin of the force	Mass	Charge
Force between two point masses/ charges	$F_G = \frac{GM_1M_2}{r^2}$	$F_E = \frac{Q_1Q_2}{4\pi\varepsilon_0 r^2}$
Type of Force	Attractive force	Attractive force (opposite charges) Repulsive force (like charges)
Field Strength	$g = \frac{F}{M}$	$E = \frac{F}{Q}$
Field strength due to a point mass/ charge	$g = \frac{GM}{r^2}$	$E = \frac{Q}{4\pi\varepsilon_0 r^2}$
Field Lines	Around a point mass:  In a uniform field (surface of a planet): 	Around a (negative) point charge:  In a uniform field (between charged) parallel plates: 

Your notes

Potential	$V = -\dfrac{GM}{r}$	$V = \dfrac{Q}{4\pi\varepsilon_0 r}$
Equipotential Surfaces	Around a point mass:  In a uniform field (surface of a planet): 	Around a point charge:  In a uniform field (between charged) parallel plates 
Work Done on a Mass or Charge	$\Delta W = M\Delta V$	$\Delta W = Q\Delta V$

- The key similarities are:
  - The magnitude of the gravitational and electrostatic force between two point masses or charges are **inverse square law** relationships
  - The field lines around a **point mass** and **negative point charge** are identical
  - The field lines in a **uniform** gravitational and electric field are identical
  - The **gravitational field strength** and **electric field strength** both have a 1 / r relationship in a **radial field**
  - The **gravitational potential** and **electric potential** both have a 1 / r relationship
  - **Equipotential surfaces** for both gravitational and electric fields are **spherical** around a point mass or charge and **equally spaced** parallel lines in uniform fields
  - The work done in each field is either the product of the **mass** and change in potential or **charge** and change in potential
- The key differences are:

- The gravitational force acts on particles with **mass** whilst the electrostatic force acts on particles with **charge**
- The gravitational force is **always** attractive whilst the electrostatic force can be attractive **or** repulsive
- The gravitational potential is **always** negative whilst the electric potential can be either negative **or** positive

Your notes

Motion of Charged Particles in an E Field

Your notes

Dielectric Action in a Parallel Plate Capacitor

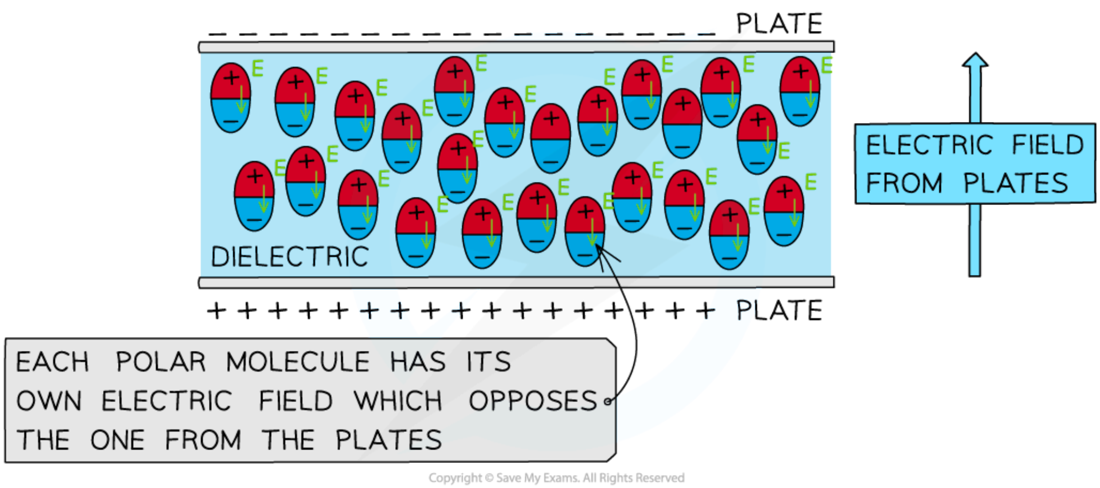
- Permittivity is the measure of how easy it is to generate an electric field in a certain material
- The relativity permittivity ε_r is sometimes known as the **dielectric constant**
- For a given material, it is defined as:

  The ratio of the permittivity of a material to the permittivity of free space

- This can be expressed as:

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

- Where:
  - ε_r = relative permittivity
  - ε = permittivity of a material (F m^{-1})
  - ε_0 = permittivity of free space (F m^{-1})
- The relative permittivity has **no** units because it is a ratio of two values with the same unit
- When the polar molecules in a **dielectric** align with the applied electric field from the plates, they each produce their own electric field
  - This electric field **opposes** the electric field from the plates



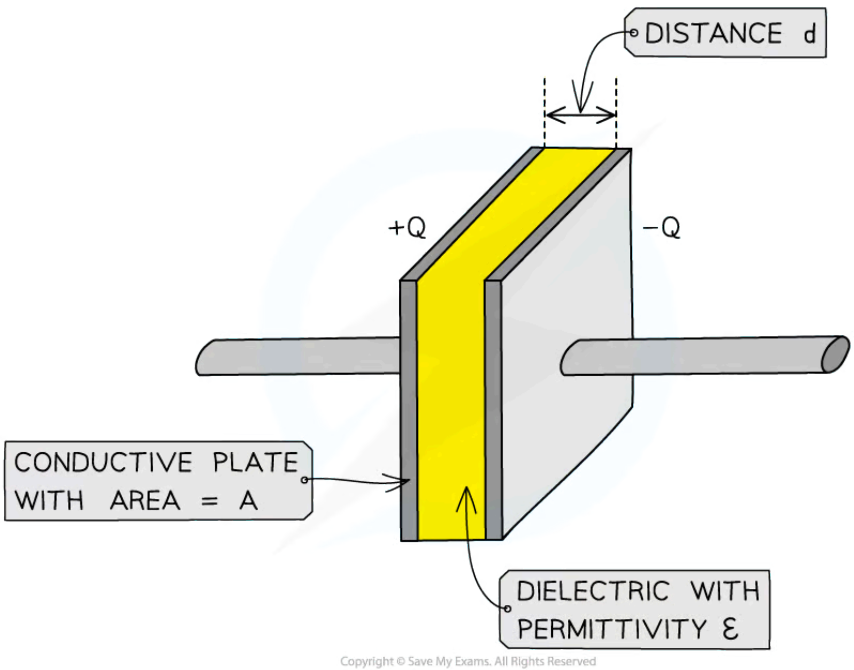
The electric field of the polar molecules opposes that of the electric field produced by the parallel plates

- The **larger** the opposing electric field from the polar molecules in the dielectric, the **larger** the permittivity
    - In other words, the permittivity is how well the polar molecules in a dielectric align with an applied electric field
- The opposing electric field **reduces** the **overall** electric field, which **decreases** the potential difference between the plates
    - Therefore, the capacitance of the plates **increases**
- The capacitance of a capacitor can also be written in terms of the relative permittivity:

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

- Where:
    - C = capacitance (F)
    - A = cross-sectional area of the plates (m^2)
    - d = separation of the plates (m)
    - ε_r = relative permittivity of the dielectric between the plates

- ε_0 = permittivity of free space (F m^{-1})
- Capacitor plates are generally square, therefore, if it has a length of L on all sides then the cross-sectional area will be $A = L^2$



A parallel plate capacitor consists of conductive plates each with area A, a distance d apart and a dielectric ε between them

Your notes

Worked Example

Calculate the permittivity of a material that has a relative permittivity of 4.5 × 10^{11}.

State an appropriate unit for your answer.

Answer:

Step 1: Write down the relative permittivity equation

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

Step 2: Rearrange for permittivity of the material ε

$$\varepsilon = \varepsilon_r \varepsilon_0$$

Step 3: Substitute in the values

$$\varepsilon = (4.5 \times 10^{11}) \times (8.85 \times 10^{-12}) = 3.9825 = 4 \text{ F m}^{-1}$$

Your notes

Worked Example

A parallel-plate capacitor has square plates of length *L* separated by distance *d* and is filled with a dielectric. A second capacitor has square plates of length *3L* separated by distance 3*d* and has air as its dielectric.

Both capacitors have the same capacitance.

Determine the relative permittivity of the dielectric in the first capacitor.

Answer:

Your notes

Step 1: Write down the capacitance equation with the relativity permittivity

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

Step 2: Write the known values for each capacitor

Capacitor 1:

$C = C$

$A = L^2$

$\varepsilon_r = \varepsilon_r$

$\varepsilon_0 = \varepsilon_0$

$d = d$

Capacitor 2:

$C = C$

$A = (3L)^2 = 9L^2$

$\varepsilon_r = 1$

$\varepsilon_0 = \varepsilon_0$

$d = 3d$

Since the dielectric for capacitor 2 is air, and air has a permittivity of ε_0

therefore using the equation:

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_0} = \frac{\varepsilon_0}{\varepsilon_0} = 1$$

for capacitor 2

Your notes

Step 3: Substitute them into the capacitance equation

$$C_1 = \frac{L^2 \varepsilon_0 \varepsilon_r}{d}$$

$$C_2 = \frac{9L^2 \varepsilon_0}{3d}$$

Step 4: Equate the capacitances

Both capacitors have the same capacitance

$$\frac{L^2 \varepsilon_0 \varepsilon_r}{d} = \frac{9L^2 \varepsilon_0}{3d}$$

Step 5: Cancel out d, L^2 and ε_0 from both sides to find the value of ε_r

$$\varepsilon_r = \frac{9}{3} = \mathbf{3}$$

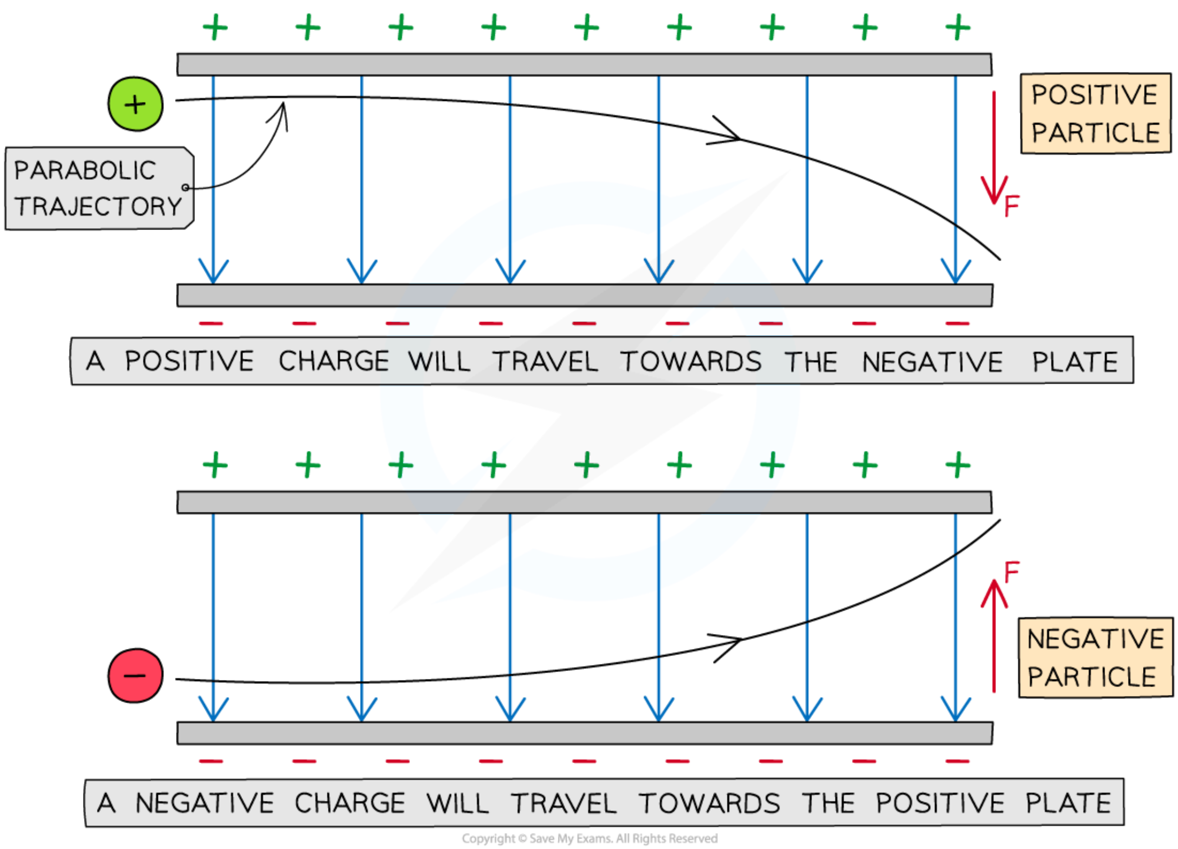
Examiner Tips and Tricks

Remember that *A*, the cross-sectional area, is only for **one** of the parallel plates. Don't multiply this by 2 for both the plates for the capacitance equation!

Motion of Charged Particles in an Electric Field

- A charged particle in an electric field will experience a **force** on it that will cause it to **move**
- If a charged particle remains still in a uniform electric field
  - It will move parallel to the electric field lines (along or against the field lines depending on its charge)
- If a charged particle in **motion** travels initially **perpendicular** through a uniform electric field (e.g. between two charged parallel plates)
  - It will experience a constant electric force and travel in a **parabolic trajectory**

Your notes



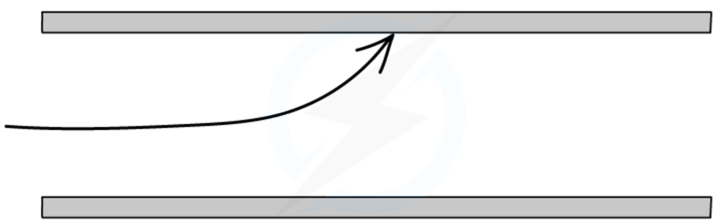
The parabolic path of charged particles in a uniform electric field

- The direction of the parabola will depend on the charge of the particle
  - A **positive** charge will be deflected towards the **negative** plate
  - A **negative** charge will be deflected towards the **positive** plate
- The force on the particle is the same at all points and is always in the same direction
- **Note:** an uncharged particle, such as a neutron experiences no force in an electric field and will therefore travel straight through the plates undeflected
- The amount of deflection depends on the following properties of the particles:
  - **Mass** – the greater the mass, the smaller the deflection and vice versa
  - **Charge** – the greater the magnitude of the charge of the particle, the greater the deflection and vice versa
  - **Speed** – the greater the speed of the particle, the smaller the deflection and vice versa

Your notes

Worked Example

A single proton travelling with a constant horizontal velocity enters a uniform electric field between two parallel charged plates. The diagram shows the path taken by the proton.



Draw the path taken by a boron nucleus that enters the electric field at the same point and with the same velocity as the proton.

Atomic number of boron = 5

Mass number of boron = 11

Answer:

Step 1: Compare the charge of the boron nucleus to the proton

- Boron has 5 protons, meaning it has a charge 5 × greater than the proton
- The force on boron will therefore be 5 × greater than on the proton

Step 2: Compare the mass of the boron nucleus to the proton

- The boron nucleus has a mass of 11 nucleons meaning its mass is 11 × greater than the proton
- The boron nucleus will therefore be less deflected than the proton

Step 3: Draw the trajectory of the boron nucleus

- Since the mass comparison is much greater than the charge comparison, the boron nucleus will be **much less deflected** than the proton
- The nucleus is positively charged since the neutrons in the nucleus have no charge
  - Therefore, the shape of the path will be the same as the proton

Your notes