

HIGHER PHYSICS

Charged Particles in Electric Fields

You must be able to:

State that, in an **electric field**, an **electric charge** experiences a **force**.

State that an **electric field** applied to a **conductor** causes the **free electric charges** in the conductor to **move**.

State that **work (W)** is done when a **charge (Q)** is **moved** in an **electric field**.

State that the **potential difference (V)** between **2 points** is a measure of the **work done** in moving **1 coulomb** of **charge** between the **2 points**.

State that if **1 joule of work** is done moving **1 coulomb of charge** between **2 points**, the **potential difference** between the **2 points** is **1 volt**.

State the relationship $V = W/Q$.

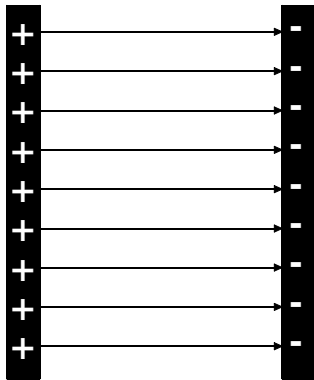
Carry out **calculations** using the above relationship.

Electric Fields

An **electric field** is a region where a **charged particle** (such as an **electron** or **proton**) experiences a **force** (an **electrical force**) without being touched.

If the charged particle is free to move, it will accelerate in the direction of the unbalanced force.

To represent an **electric field**, we draw **electric field lines**.



Electric field lines representing the uniform electric field between 2 oppositely charged electric plates.

The arrow heads show the direction in which a **positively charged particle** (such as a **proton**) would accelerate if it was placed in the electric field.

A **negatively charged particle** (such as an **electron**) would accelerate in the **opposite direction** to the arrow heads.

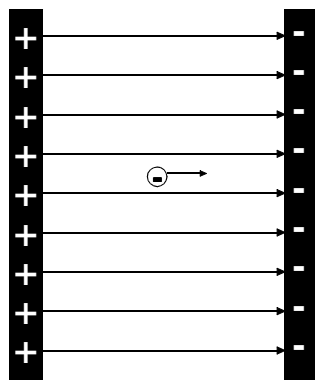
- In which direction would a **proton** (**positive charge**) accelerate in this electric field? _____
- In which direction would an **electron** (**negative charge**) accelerate in this electric field? _____

Work Done Moving a Charge in an Electric Field

Work is done when a **charge** is moved in an **electric field**.

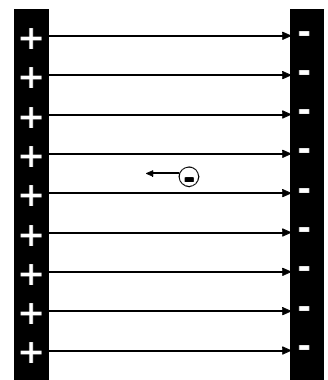
To move an **electron** (negative charge) towards the negatively charged plate, **work** must be done **against** the **electric field** in order to overcome the repulsion force between the electron and the negatively charged plate.

The **work done** is gained by the electron as **electrical potential energy**.



If the **electron** is free to move back towards the positively charged plate, the **electric field** does **work on** the electron.

The electron's **electrical potential energy** is changed to **kinetic energy** as the **electric field** moves the electron towards the positively charged plate.



- | | |
|--|--|
| <ul style="list-style-type: none"> ● Describe what happens when an electron is pushed towards the negative plate in an electric field: _____ _____ _____ _____ _____ | <ul style="list-style-type: none"> ● Describe what happens when an electron is free to move towards the positive plate in an electric field: _____ _____ _____ _____ _____ |
|--|--|

Work Done Moving a Charge and Potential Difference

The **potential difference** (V) between 2 points in an electric field is a measure of the **work done** (W) in moving **1 coulomb of charge** between the 2 points.

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

potential difference between 2 points in an electric field/
 joules per coulomb ($J\ C^{-1}$)
 OR volts (V)

work done in moving quantity of charge between 2 points in an electric field/
 joules (J)

quantity of charge/
 coulombs (C)

This formula defines the **volt**.

If **1 joule of work** is done by moving **1 coulomb of charge** between 2 points in an electric field, the **potential difference** between the 2 points is **1 volt**.

Explain what is meant by "1 volt": _____

Calculate the **potential difference** between 2 points in an electric field, if the field does:

- 25 J of work moving 5 C of charge between the 2 points.

- 100 J of work moving 2.5 C of charge between the 2 points.

- 16 J of work moving an electron (charge $-1.60 \times 10^{-19} C$) between the 2 points.

- $8 \times 10^{-18} J$ of work moving a beta particle (charge $-1.60 \times 10^{-19} C$) between the 2 points.

- $9.6 \times 10^{-19} J$ of work moving a proton (charge $+1.6 \times 10^{-19} C$) between the 2 points.

- $6.4 \times 10^{-20} J$ of work moving an alpha particle (charge $+3.2 \times 10^{-19} C$) between the 2 points.

Calculate the **work done** *by* an electric field, if the field moves:

- 3.5 C of charge through a potential difference of 140 V.

- An **electron** through a potential difference of 2.5 V.

- A **proton** through a potential difference of 12 V.

Calculate the **work done** *against* an electric field, if:

- 12.5 C of charge is moved through a potential difference of 250 V.

- An **electron** is moved through a potential difference of 160 V.

- A **proton** is moved through a potential difference of 3 200 V.

Calculate the quantity of **electric charge** moved by an electric field, if the field does:

- 120 J of work moving the charge through a potential difference of 240 V.

- 15 J of work moving the charge through a potential difference of 300 V.

- 3 200 J of work moving the charge through a potential difference of 1 000 V.

- 1.5×10^{-6} J of work moving the charge through a potential difference of 3 V.

- 3.6×10^{-18} J of work moving the charge through a potential difference of 12 V.

- 2.4×10^{-16} J of work moving the charge through a potential difference of 9.6 V.

Electrical Potential Energy to Kinetic Energy

- Describe and explain the motion of an **electron** in the **electric field** existing between a positively charged and a negatively charged metal plate: _____

- State the **energy change** the **electron** will experience: _____

When an **electron** is free to move in the **electric field** between two oppositely charged metal plates, the **work done** by the **electric field** on the **electron** is converted to **kinetic energy** of the **electron**.

work done on electron by electric field = gain in kinetic energy of electron

$$\begin{array}{ccc}
 & QV & = & \frac{1}{2}mv^2 \\
 \swarrow & & & \swarrow \quad \searrow \\
 \text{magnitude of charge} & & & \text{mass of electron} & & \text{speed of electron/} \\
 \text{on electron} & & & (9.11 \times 10^{-31} \text{ kg}) & & \text{m s}^{-1} \\
 (1.60 \times 10^{-19} \text{ C}) & & & & & \\
 & \text{potential difference} & & & & \\
 & \text{through which} & & & & \\
 & \text{electron is moved/} & & & & \\
 & \text{V} & & & &
 \end{array}$$

[This equation also applies to any other charged particle in an electric field].

Typical Problem

An electron is free to move in an electric field. The electron is accelerated by the field from rest through a potential difference of 500 V. Calculate the **speed** of the electron at the end of the acceleration.

$$\begin{array}{l}
 \text{work done on electron} & = & \text{gain in kinetic energy} \\
 \text{by electric field} & & \text{of electron} \\
 \therefore & QV & = & \frac{1}{2}mv^2 \\
 \therefore & (1.60 \times 10^{-19}) \times 500 & = & \frac{1}{2} \times (9.11 \times 10^{-31}) \times v^2 \\
 & & \therefore & v^2 = \frac{(1.60 \times 10^{-19}) \times 500}{\frac{1}{2} \times (9.11 \times 10^{-31})} \\
 & & \therefore & v = \sqrt{\frac{(1.60 \times 10^{-19}) \times 500}{\frac{1}{2} \times (9.11 \times 10^{-31})}} \\
 & & \therefore & v = \underline{\underline{1.33 \times 10^7 \text{ m s}^{-1}}}
 \end{array}$$

In each case below, an electron is accelerated from *rest* in an electric field through the stated potential difference. Calculate the **speed** of the electron in each case at the end of the acceleration.

● 100 V

● 250 V

● 750 V

● 1 200 V

● 1 500 V

● 10 000 V