# 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 $V = W/Q$.

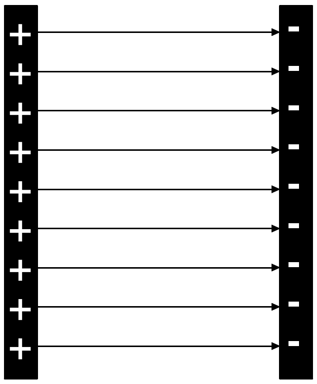
Carry out calculations using the above relationship.

# 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.

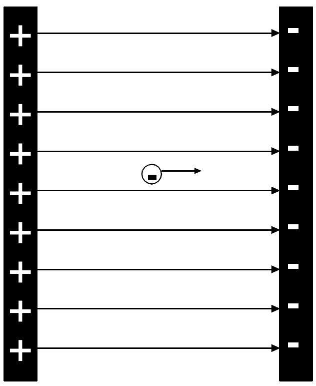
- In which direction would a **proton** (**positive** charge) accelerate in this electric field? _______________
  ________________________________________
- In which direction would an **electron** (**negative** charge) accelerate in this electric field? ________
  ________________________________________

# Work Done Moving a Charge in an Electric Field

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

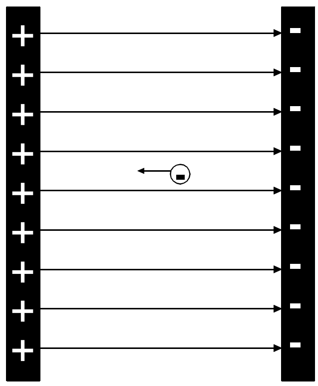
To move an **electron** (negative charge) towards the negatively charged plate, **work** must be done **against** the **electric field** in order to overcome the repulsion force between the electron and the negatively charged plate.

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.



- Describe what happens when an **electron** is pushed towards the **negative** plate in an **electric field**: _______________________
  ________________________________
  ________________________________
  ________________________________
  ________________________________
  ________________________________
  ________________________________
- Describe what happens when an **electron** is free to move towards the **positive** plate in an **electric field**: _______________________
  ________________________________
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# 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.

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

- V: potential difference between 2 points in an electric field/ joules per coulomb ($J\ C^{-1}$) OR volts (V)
- W: work done in moving quantity of charge between 2 points in an electric field/ joules (J)
- Q: 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. |
| • $1.5 \times 10^{-6}$ J of work moving the charge through a potential difference of 3 V. | • $3.6 \times 10^{-18}$ J of work moving the charge through a potential difference of 12 V. | • $2.4 \times 10^{-16}$ 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**

$$QV = 1/2\, m v^2$$

- $Q$: *magnitude of* charge on electron ($1.60 \times 10^{-19}$ *C*)
- $V$: potential difference through which electron is moved/ V
- $m$: mass of electron ($9.11 \times 10^{-31}$ kg)
- $v$: speed of electron/ $m\ s^{-1}$

**[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.

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

$$\therefore \quad QV = 1/2\, m v^2$$

$$\therefore \quad (1.60 \times 10^{-19}) \times 500 = 1/2 \times (9.11 \times 10^{-31}) \times v^2$$

$$\therefore \quad v^2 = \frac{(1.60 \times 10^{-19}) \times 500}{1/2 \times (9.11 \times 10^{-31})}$$

$$\therefore \quad v = \sqrt{\frac{(1.60 \times 10^{-19}) \times 500}{1/2 \times (9.11 \times 10^{-31})}}$$

$$\therefore \quad v = \underline{\underline{1.33 \times 10^{7}\ m\ s^{-1}}}$$

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 |