# Electric fields notes.

## Study Design

On completion of this unit the student should be able to analyse gravitational, electric and magnetic fields, and apply these to explain the operation of motors and particle accelerators, and the orbits of satellites.

**Key knowledge**

**Fields and interactions**

- describe magnetism and electricity using a field model
- investigate and compare theoretically and practically magnetic and electric fields, including directions and shapes of fields, attractive and repulsive effects, and the existence of dipoles and monopoles
- investigate and compare theoretically and practically electrical fields about a point mass or charge (positive or negative) with reference to:

- the direction of the field
- the shape of the field
- the use of the inverse square law to determine the magnitude of the field
- potential energy changes (qualitative) associated with a charge moving in the field

- investigate and apply theoretically and practically a field model to magnetic phenomena, including shapes and directions of fields produced by bar magnets, and by current-carrying wires, loops and solenoids
- identify fields as static or changing, and as uniform or non-uniform

**Effects of fields**

- analyse the use of an electric field to accelerate a charge, including:

- electric field and electric force concepts:  and
- potential energy changes in a uniform electric field: $W = qV$,
- the magnitude of the force on a charged particle due to a uniform electric field: $F = qE$

- analyse the use of a magnetic field to change the path of a charged particle, including:

- the magnitude and direction of the force applied to an electron beam by a magnetic field: $F = qvB$, in cases where the directions of $v$ and $B$ are perpendicular or parallel
- the radius of the path followed by an electron in a magnetic field: , where $v << c$

**Application of field concepts**

- describe the interaction of two fields, allowing that electric charges, magnetic poles and current carrying conductors can either attract or repel

- investigate and analyse theoretically and practically the force on a current carrying conductor due to an external magnetic field, $F = nIlB$, where the directions of $I$ and $B$ are either perpendicular or parallel to each other
- investigate and analyse theoretically and practically the operation of simple DC motors consisting of one coil, containing a number of loops of wire, which is free to rotate about an axis in a uniform magnetic field and including the use of a split ring commutator
- investigate, qualitatively, the effect of current, external magnetic field and the number of loops of wire on the torque of a simple motor
- model the acceleration of particles in a particle accelerator (including synchrotrons) as uniform circular motion (limited to linear acceleration by a uniform electric field and direction change by a uniform magnetic field).

## Conductors and insulators

A conductor allows the flow of electrons through the material. Metal is a good conductor of electricity, because the structure of metals is such that the outermost electrons are free to move around in the fixed crystal lattice made up of the atoms.

Insulators don't allow the free movement of electrons, materials such as plastic and glass are good insulators.

Semiconductors, used in electronics, can be doped to allow them to significantly improve their conduction qualities.

## Emf and electric potential

If charges are moving, they have energy, a battery or generator is the usual source of this energy. When electrons flow through a battery or other power supply, they gain electrical potential energy. As the electrons flow around a circuit, they lose this energy when passing through components that have resistance, eg. globes.

> The energy transferred to one coulomb of charge within the battery is called the **electromotive force** of the battery.

The unit of electromotive force (EMF) is the volt (V). EMF can be considered as a 'concentration of charge'. The work done in pushing the charges together is stored as electrical potential energy. A battery with an emf of 6 V transfers 6 J of energy to each coulomb of charge, when charge moves through the battery.

> The energy transferred to a circuit component per unit charge is called the potential difference between the two terminals of the component.

The unit for potential difference (P.D.) is also the volt. One volt equals one joule per coulomb.

$$1\ \text{V} = 1\ \text{J C}^{-1}$$

The term 'emf' and 'p.d.' are often simply referred to as **voltage**. The SI unit for (electrical) potential is *joules per coulomb*, this is given the name volt after Alessandro Volta, the inventor of the first chemical battery.

## Electrical energy

When a current passes through a resistor, the resistor gets hot. Electrical energy is being converted to thermal energy. Electrical energy can also be converted into mechanical energy.

If 'Q' of charge passes through a potential difference of 'V', the work done by the electrical force is

$$W = Q\,V.$$

So if it takes 'V' joules of energy to get '1' coulomb of charge from one place to another, then it takes 'VQ' joules to get 'Q' coulomb from one place to another

As the current is the rate at which charge is moving, the total charge Q = I t.

$$\Rightarrow \qquad W = V\,I\,t.$$

## COULOMBS LAW (for point charges)

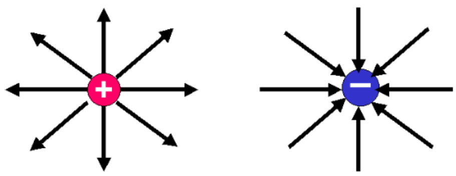
The force of attraction or repulsion between two charges $Q_1$ and $Q_2$ a distance 'r' metres apart is proportional to the product of the charges and inversely proportional to the square of the distance between the charges. $F = \dfrac{kQ_1Q_2}{r^2}$ where F is the force in newtons, $Q_1$ & $Q_2$ are measured in coulomb, and 'r' is measured in metres, then $k = \dfrac{1}{4\pi\varepsilon_0}$ where $\varepsilon_0$ is called the permittivity of free space, $k = 9 \times 10^9$ N m$^2$ C$^{-2}$. This is only used when the two charges are in air.

## Electric fields

An electric field is the space around a charge, or a group of charges. We know if a field is present at a particular space because if we place a point charge there, it will experience a force. (Much the same as a point mass experiences a force in a gravitational field). The stronger the force, the stronger the field.

The magnitude of the field is the size of the force it causes to act on a charge of one coulomb. The direction of the field is defined as the direction of the force it causes to act on a positive charge.
An electric field **E** is the region around a charged body where another charged body would experience electric forces of attraction or repulsion. The direction of the electric field is defined as the direction of the force on a positive charge placed in the field.

Electric field around positive point charge



Electric field around negative point charge

The strength of the field is indicated by the closeness of the field lines.

## ELECTRIC FIELDS around point charges

Combining $F = \dfrac{kQq}{r^2}$ and F = Eq, for a point charge Q, give $E = \dfrac{kQ}{r^2}$. The units are N C$^{-1}$.

## Electric forces

Electric forces are given by the product of the electric field and the quantity of charge.

$$F_E = q\mathbf{E}$$

Where $F_E$ = electric force (N)
q = charge (C)
**E** = electric field (N / C)

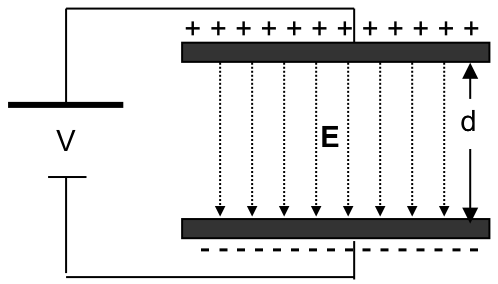
Therefore, the direction and magnitude of the electric forces represent the direction and magnitude of the electric field at that point.

## Electric fields between charged plates

In the region between parallel charged plates, the electric field **E** is uniform. The strength of the field depends on the potential difference between the plates and the distance between the plates.

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

Where E = electric field strength (V/m)
$\Delta V$ = potential difference (V)
d = distance between plates (m)




Another way of thinking of this is that the electric field is the gradient of the voltage vs distance graph.

## Electric potential energy

An object has gravitational potential energy due to its location in a gravitational field. Similarly, a charged object has potential energy due to its location in an electric field. Therefore work is required to push a charged particle against an electric field of a charged body. This work changes the electric potential of the charged particle. This work done moving the particle will either increase or decrease its energy. If the energy increases, then on release, this energy changes to kinetic energy.

$$\text{Electric potential} = \frac{\text{electric potential energy}}{\text{charge}}$$

$$\therefore\ 1\ \text{volt} = 1\frac{\text{joule}}{\text{coulomb}}$$

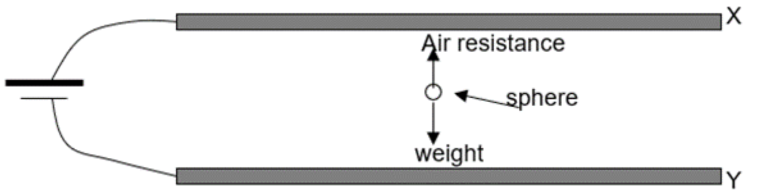
## Circuits

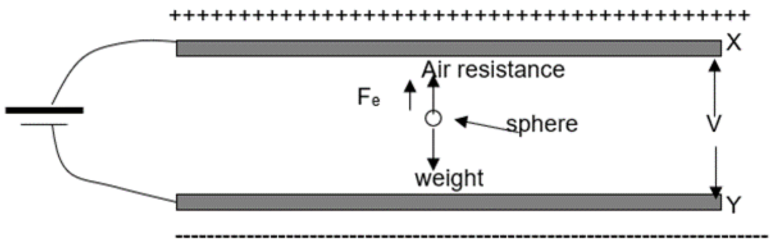
When the elements in a circuit are in series, they all have the same current. The potential drop across each element is proportional to the resistance. If the resistance is zero, then that part of the circuit is an equipotential, i.e. there is no voltage drop.

The electric field in a wire is given by $\frac{\Delta V}{d}$

## Millikans experiment

In 1907 Robert Millikan set out to show that electric charge came in fundamental units (called the elementary unit). He set up two plates X and Y, which were charged by battery (B) to 8000V. He used small identical oil drops and observed their motion under a microscope.
The small spheres fell due to the force of gravity. An opposing upward force due to air resistance increases as the velocity of the spheres increases. In a short time the two forces equalised, this allowed him to calculate the weight from the measurements of their speed. When the plates were charged by the battery, the speed changed as a result of the added electric force on the drops. Some drops fell even faster, others almost stopped or even rose. As the speed at which the drops fell was directly related to the total force on them, he was able to calculate the strength of the electric force. From this he was able to calculate the electric charge on the drop.




The direction of $F_e$ depends on the charge on the sphere. Millikan found that the charge on the oil drop was always a multiple of a particular value. I.e. the charge on the oil drop is given by: q = ne, where n is a whole number, and e was $1.6 \times 10^{-19}$C. Millikan suggested that 'e' is the charge on an electron. Millikan argued that an oil drop got its charge by gaining or losing electrons, hence the 'e' charge on the drop had to be a whole number times the charge on one electron.
In 1909 Millikan determined that

**Mass of electron = $9.1 \times 10^{-31}$ kg**

**Charge of electron e = $-1.6 \times 10^{-19}$ C**

This data has been on the formula sheet that is supplied for the exam, so you don't need to memorise it.

## Linear accelerators

Electrical potential energy is stored in an electric field. An electric field exerts a force on charged particles, this can be used to increase their speed and kinetic energy. The field will do work on the charged particles. An electron will experience a force in the opposite direction to the field, due to its negative charge.

The electric force is given by F = qE, and this results in an acceleration given by F = ma. Equating these two gives qE = ma.

The work done is given by $W = F \times d$, (if the force is constant, from a uniform field). The change in KE (typical to assume the particle starts from rest) is the work done.
$\therefore$ $W = \Delta KE = qEd$, where d is the distance between where the charges enter the field and exit the field.

The work done on a charge is also given by $W = qV$, and since $V = Ed$, we get $W = qEd$. The simplest device is an electron gun, which produces electrons and then accelerates them. The same process is used in Mass Spectrometers, Electron microscopes, Synchrotrons and the Large Hadron Collider.

**Some resources**

1. Electricity introduction.

https://www.youtube.com/watch?v=ZAFW4zdXpbY

2. How to measure electrical charge by Derek Muller

https://www.youtube.com/watch?v=DvlpAsDwXPY

3. Electricity (Hewitt drewit)

http://www.youtube.com/watch?v=0z9moyl8uZg&index=88&list=PL6Pw5RXSrjGNN6Kp1fq 7X_rgoGu6qKM8j

4. Electric Potential (Hewitt drewit)

http://www.youtube.com/watch?v=nnLf090OPNg&index=91&list=PL6Pw5RXSrjGNN6Kp1f q7X_rgoGu6qKM8j

5. Electric Fields (Hewitt drewit)

https://www.youtube.com/watch?v=9nlflkR8tvs&index=89&list=PL6Pw5RXSrjGNN6Kp1fq7 X_rgoGu6qKM8j