CAIE Physics A-level

Topic 18: Electric Fields

Notes

18 - Electric Fields

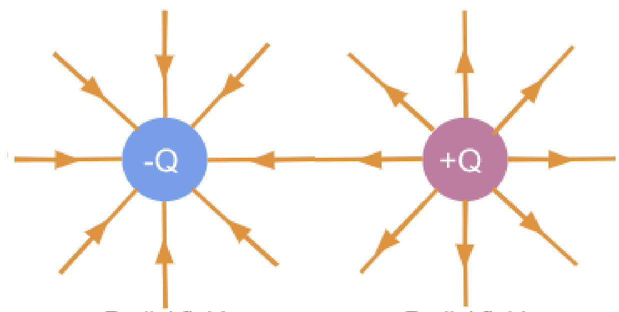
18.1 - Electric Fields and Field Lines

A **force field** is an area in which an object experiences a **non-contact force**. Force fields can be represented as **vectors**, which describe the direction of the force that would be exerted on the object, from this knowledge you can deduce the direction of the field. They can also be represented as diagrams containing **field lines**, the distance between field lines represents the strength of the force exerted by the field in that region- the closer the lines, the stronger the force that would be exerted.

An **electric field** is one formed during the interaction of **charges**. The force F on a charge in an electric field is dependent on the **electric field strength E** and the magnitude of the charge q:

$$F = Eq$$

An electric field can be represented by **field lines**. The arrows on the field lines show the direction in which the force is acting. Electric field lines show the direction that the force would act on a positive test charge in the field. Thus conventionally, electric field lines are shown as pointing **away** from a **positive** charge and **towards** a **negative** one, as shown below.

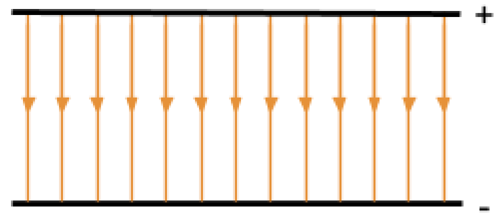


18.2 - Uniform Electric Fields

Electric field strength (E) is the force per unit charge experienced by an object in an electric field. This value is constant in a uniform field, but varies in a radial field. There are three formulas you can use to calculate this value; the first is general, the second is used to find the magnitude of E in a uniform field formed by two parallel plates, while the third is used only for radial fields. The first two are presented below, the third shall be covered later in 18.4:

$$E = \frac{F}{Q} \qquad E = \frac{\Delta V}{\Delta d}$$ (for uniform fields formed by parallel plates)

where V is the potential difference across the plates, and d is the distance between the plates. As mentioned before, electric field lines show the direction of the force acting on a **positive** test charge. A **uniform field** exerts that **same** electric force everywhere in the field, as shown by the parallel and equally spaced field lines.



Uniform Field

You can derive an equation to calculate the **work done** by **moving a charged particle between the parallel plates** of a uniform field using the equations for electric field strength defined previously:

Work done $= F \times d$

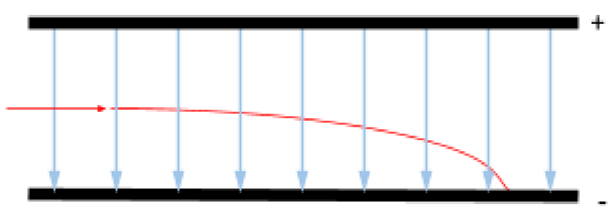
Rearrange $E = \frac{F}{Q}$ to get F as the subject. $F = EQ$

Rearrange $E = \frac{\Delta V}{d}$ to get d as the subject. $d = \frac{\Delta V}{E}$

Substitute the above values into the general formula for work done.

Work done = $EQ \times \frac{\Delta V}{E}$ Work done = $Q\Delta V$

Uniform electric fields made by two parallel plates can sometimes be used to find out whether a particle is charged, and whether its charge is negative or positive. This is done by firing the particle at right angles to the field and observing its path: a charged particle will experience a **constant electric force** either in or opposite to the direction of the field (depending on its charge), this causes the particle to **accelerate** towards one of the plates and so it follows a **parabolic shape**. If the charge on the particle is positive, it will follow the direction of the field, if the charge is negative it will move opposite to the direction of the field.



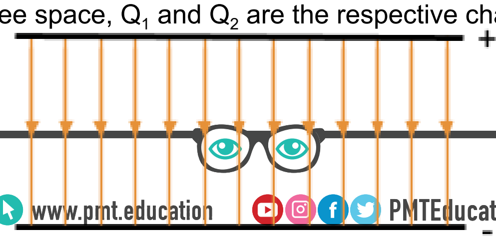
For example, in the diagram to the left, the particle must have a positive charge as it follows a parabolic shape in the direction of the field.

18.3 - Electric Force Between Point Charges

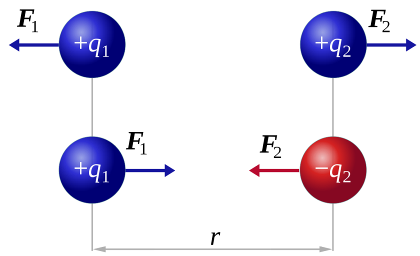
Coulomb's law states that the magnitude of the force between two point charges in a **vacuum** is **directly proportional to the product of their charges**, and **inversely proportional to the square of the distance** between them.

$$F = \frac{1}{4\pi\varepsilon_0} \frac{Q_1 Q_2}{r^2}$$

where ε_0 is the permittivity of free space, Q_1 and Q_2 are the respective charges, and r is the distance between charges.



Air can be treated as a vacuum when using the above formula, and for a charged sphere, **charge may be assumed to act at the centre of the sphere**.



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If charges have the **same** sign the force will be **repulsive**, and if the charges have **different** signs the force will be **attractive**.

18.4 - Electric Field of a Point Charge

For a specific point in the field, the electric field strength created by a point charge with a radial field in free space is given by

$$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$$ (for radial fields)

where ε_0 is the permittivity of free space, Q is the magnitude of charge, r is the distance away from the point charge.

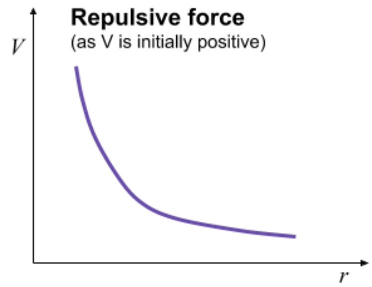
18.5 - Electric Potential

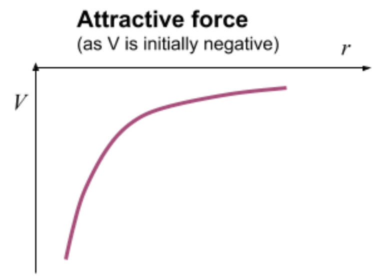
Absolute electric potential (V) at a point is the potential energy per unit charge of a positive point charge at that point in the field. The absolute magnitude of electric potential is **greatest at the surface of a charge**, and as the distance from the charge increases, the potential decreases, so **electric potential at infinity is zero**. To find the value of potential in a **radial field** you can use this formula:

$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$$

where ε_0 is the permittivity of free space, Q is the charge, and r is the distance from the charge.

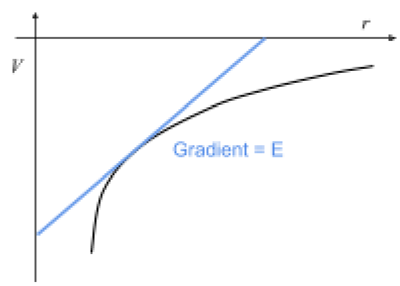
Whether the value of potential is negative or positive depends on the sign of the charge (Q). When the charge is positive, **potential is positive and the force (on a positive test charge) is repulsive**. When the charge is negative, **potential is negative and the force (on a positive test charge) is attractive**, here the graph is similar to the one for gravitational potential which is always an attractive force.





The **gradient of a tangent to a potential (V) against distance (r) graph**, gives the value of **electric field strength (E)** at that point:

$$E = \frac{\Delta V}{\Delta r}$$



The **electric potential of two point charges Q and q** follows from the definitions above and can be written as

$$E = \frac{Qq}{4\pi\varepsilon_0 r}$$

This is the potential between the two charges, rather than the potential experience by a third test charge due to the two.