Charge and Field

Electric Fields

Unlike gravitational fields, which can only exert attractive forces, electric fields can attract or repel objects that are charged. When drawing field lines that represent the forces due to a charged object, the arrows show the direction of the force on a positive charge.

The electric field between two parallel plates is uniform; it maintains a constant strength at all points between the plates.

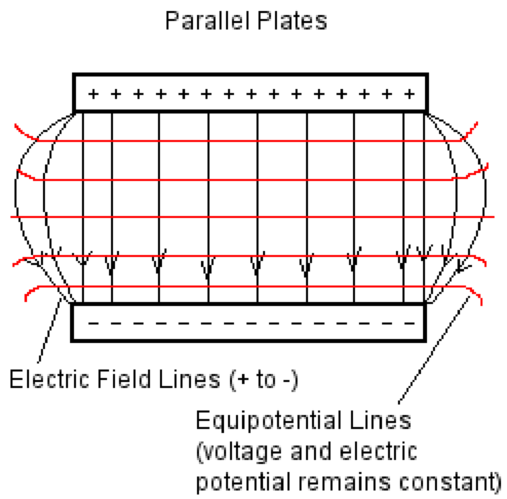

Figure 1 – Parallel Plates

Uniform Electric Fields

At each position in Figure 2, the test charge (positive) has a potential energy.

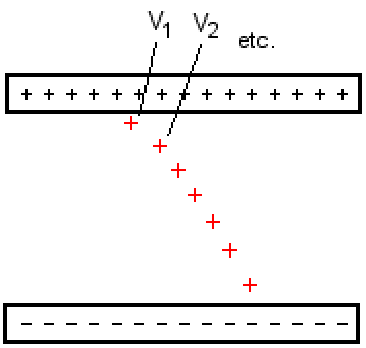

Figure 2 – Test Charge accelerating between parallel plates.

The potential energy in Joules:

$$V = \frac{J}{Q} \quad \text{so} \quad PE = qV_E$$

Where PE = potential energy (J), q = charge (Coulombs), V_E = electric potential (Volts).

The **Field Strength** between the plates is constant. It is defined as the Force per Coulomb:

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

Where E = Field Strength (NC^{-1}), F = force (N), q = charge (C).

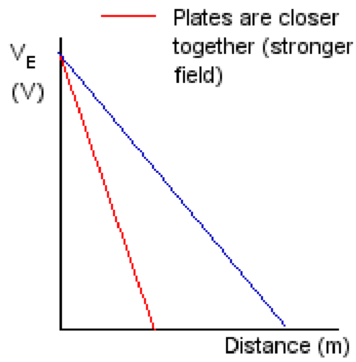

Figure 3 – Graph showing electric potential against distance between 2 parallel plates

The gradient of a potential/distance graph is the field strength.

$$E = \frac{V_E}{d} = \frac{F}{q}$$

where E = field strength (Vm^{-1} or NC^{-1}), V_E = electric potential (V), d = distance between plates (m), F = force (N), and q = charge (C).

Deflection Tubes

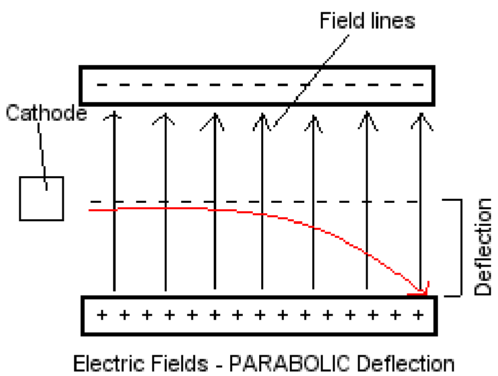

Figure 4 – Deflection Tube set-up

A deflection tube involves a cathode and a field. The cathode means electrons are accelerated through the field. In an electric field, this deflection is parabolic, and hence we can use the kinematic equations to work out different aspects of this. The deflection will be the distance, s.

$$s = ut + \tfrac{1}{2}at^2 \qquad v^2 = u^2 + 2as \qquad v = u + at \qquad a = \frac{(v-u)}{a} \qquad F = ma$$

Due to conservation of energy, KE = PE, hence: $qV_E = \tfrac{1}{2}mv^2$ This equation is very important!

The accelerating force experienced by the electron, F = Eq (rearranging above formulae).

Milikan's Oil Drop Experiment

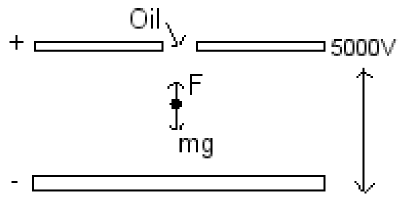

Figure 5 – Milikan's Oil Drop Experiment

Milikan's oil drop experiment was used to find the charge on one electron, which turned out to be -1.6×10^{-19}C.

The oil drops are squirted in at the top. These will vary in size, but will all have a negative charge. Milikan used a microscope to focus on a drop;et, and adjusted the voltage until it 'hovered', i.e. the gravity and voltage were balanced, F = mg.

He then measured the radius of each spherical droplet, and since $Density = \frac{mass}{volume}$:

$m = \rho \times (\frac{4}{3} \pi r^3)$. Since F = Eq, Eq = mg. (E is known because it is the voltage over the distance).

$$\text{So,} \quad q = \frac{mg}{E}$$

He found that the lowest factor of all of these measurements of q (he measured many many oil drops) was -1.6×10^{-19}C.

Magnetic Fields

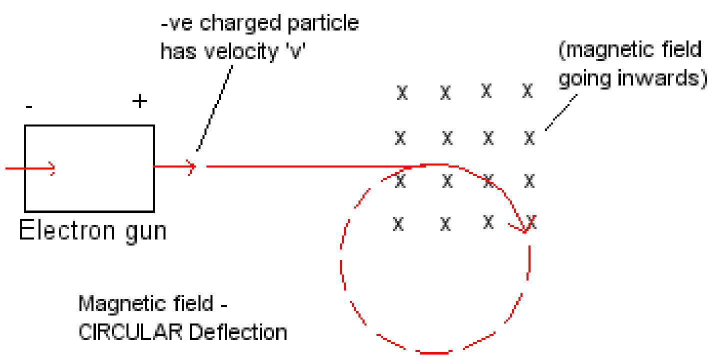

Figure 6 – Magnetic field deflection

The electron is deflected downwards to due Fleming's left hand rule (remember current goes in opposite direction to electron motion). If this was a proton, the deflection would be up (current changed). The deflection is part of **circular motion**.

Circular motion has centripetal force and acceleration where $F = \frac{mv^2}{r}$ and $a = \frac{v^2}{r}$.

Since F = BqV (where F = force, B = flux density, q = charge, V = velocity of particle), we can equate:

$$\frac{mv^2}{r} = BqV \text{ , hence } \frac{mv}{r} = Bq \quad .$$

This enables us to find the mass of the particle etc.

Uses – Mass Spectrometers

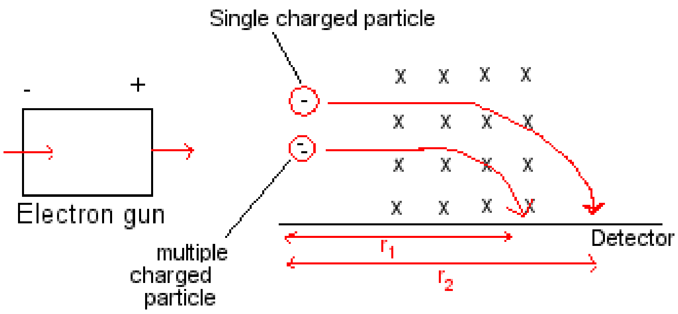

Figure 7 – Mass spectrometer

A sample is incinerated an ionised. The appropriately charged particles (in this case negative) enter a field of known size. The voltage is more, so the velocity can be worked out. The smaller charged particle will be deflected more, or the one with the greater charge (F = BqV). [This depends on the mass/charge ratio, deflecting more charged, faster moving and lighter ions more].

A detector is calibrated so it knows the radius – because it registers where it is hit.

$\frac{mv}{r} = Bq \text{ hence , } m = \frac{Bqr}{v}$. So the mass can be calculated, and the element identified.

This is used by forensic scientists (e.g. Soil on suspects shoes matches with soil at scene of crime) and by rovers investigating what other planets are made up of etc.

Particle Accelerators

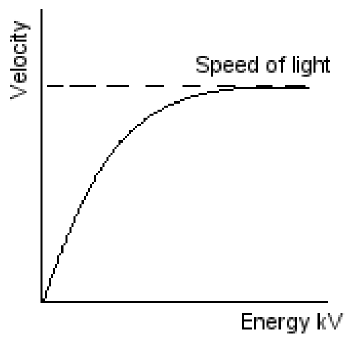

Figure 8 – Graph showing velocity against energy.

Energy and momentum can keep increasing due to relativity, i.e. mass increase ½ mv^2 and p =mv. (Even though the velocity cannot be increased so much, due to the speed of light limit).

(See folder for information on Particle accelerators)

Non-Uniform Electric Fields

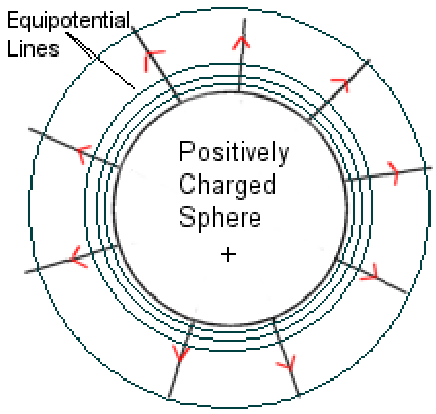

Figure 9 – A charged sphere and non-uniform electric field

There is a radial field here, the charge flows from positive to negative. Unlike gravity, the field direction can differ, depending on the charge of the sphere. The spacing between the equipotential lines differ. The potential near the surface is greater than further away.

These equipotential lines have a separation difference for the same voltage difference. e.g. 1V to 2V and 4V to 5V are differently spaced. Both the potential and field strength decrease as we distance ourselves from the sphere.

Coulomb's Law

In 1785, Coulomb realised that the force between 2 charges depends on the size of the charges and the distance between them.

$$F = \frac{k \cdot Q_1 \cdot Q_2}{r^2} \quad \text{(remember} \quad F = \frac{-GMm}{r^2} \quad)$$

Field Strength

The strength, E, of an electric field can be measured by considering the force on a second 'test' charge Q_2 at a distance 'r' from Q_1.

$$Field\ Strength = \frac{Force}{charge} = \frac{F}{q} = \frac{\frac{k \cdot Q_1 \cdot Q_2}{r^2}}{Q_2}$$

$$E = \frac{k \cdot Q_1}{r^2} \quad \text{(remember} \quad g = \frac{-Gm}{r^2} \quad)$$

Potential in a Radial Field

Potential varies as 1/r. Is we plot electric potential against distance, the field strength, E, is the gradient of the curve at the tangent.

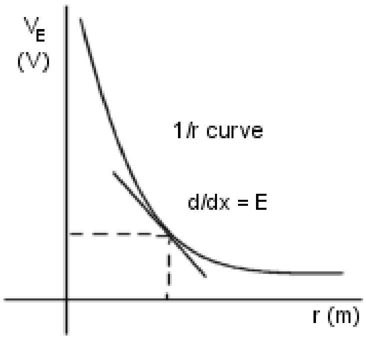

Figure 10 – potential in radial field

The potential depends on the charge,

$$V_E = \frac{k \cdot Q_1}{r} \quad \text{(remember} \quad V_G = \frac{GM}{r} \quad \text{)}$$

The equations used to govern non-uniform electric fields are very similar to those used in a non-uniform gravitational field. The only differences are charge takes place of mass, and k takes the place of G.

$k = \frac{1}{(4 \cdot \pi \cdot \epsilon_0)}$, where ϵ_0 is the permittivity of free space = 8.85×10^{-12} Fm^{-1}.

So, **k = 8.98×10^9 Nm^2C^{-2}.**