22 Electric Field

22.1 Field Patterns

Like charges repel, unlike charges attract.

- **Electrons** are responsible for charging in most situations.

  An **uncharged atom** contains equal numbers of protons and electrons, an **uncharged solid** contains equal numbers of electrons and protons.

- **Electrical conductors** contains lots of **free electrons** - they are not attached to any one atom.

  An isolated conductor can be charged by direct contact with any charged object.

- **Electrically insulating material** do not contain free electrons - all electrons in an insulator are attached to individual atoms.

  Some insulator are **easy to charge** because their surface atoms easily gain or lose electrons.

The **gold leaf electroscope** is used to detect charge.

1. If a charged object is in contact with the metal cap, some of the charge of the object **transfer to the electroscope**.
2. As a result, the **gold leaf** and the **metal stem** attached to the cap **gain the same type of charge** and the leaf rises because it is repelled by the stem.

Field Lines and Patterns

Any two charged object exerts equal and opposite forces on each other without being directly in contact.

- An electric field is said to surround each charge.
- The path a **free positive test charge** is called a **field line**.

  The direction of an electric field line is the direction a positive test charge would move along.

22.2 Electric Field Strength

The electric field strength E at a point in the field is defined as the **force per unit charge** on a positive test charge placed at that point.

The unit of E is the **newton per coulomb** $\mathrm{N\,C^{-1}}$.

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

Uniform Electric Field

The field lines between two oppositely charged flat plates are

- **Parallel** to each other.
- At **right angle** to the plates.
- From the positive plate to the negative plate.

The field between the plates in **uniform** because the electric field strength has the same magnitude and direction everywhere between the plates.

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

Field Factors

- An electric field exists near any charged body.
- The greater the charge on the body, the stronger the electric field is.
- For a **charged metal conductor**, the charge on it spread across the surface.
- The **more concentrated** the charge is on the surface, the greater the strength of the electric field strength is above the surface.

The electric field between two oppositely charged parallel plates depends on the **concentration of charge** on the surface of the plates. The charge on each plate is spread evenly across the surface of the plate.

$$E \propto \frac{Q}{A}$$

And introduce a constant of proportionality such that

$$\frac{Q}{A} = \varepsilon_0 E$$

where $\varepsilon_0 = 8.85 \times 10^{-12}\mathrm{F\,m^{-1}}$, also called the **permittivity of free space**. It represents that **charge per unit area** on a surface in a vacuum that produces an electric field strength of one volt per metre between the plates.

22.3 Electric Potential

The electric potential at a pertain position in any electric field is defined as the **work done per unit positive charge** on a positive test charge when it is moved from infinity to that point.

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

the unit of electric potential is the **volt**, equal to $1\mathrm{J\,C^{-1}}$.

Potential Gradients

The equipotentials for an electric field are like equipotential for a gravitational field.

- Both are lines of **constant potential energy** for the appropriate test object.
- In one case a test charge, the other case a test mass.

The **potential gradient** at any point in an electric field is the **change of potential per unit change of distance** in a given direction.

- The closer the equipotentials are, the greater the potential gradient is at right angles to the equipotentials.
- If the field is uniform (between two oppositely charged parallel plates), the potential gradient is
  - Constant.
  - The potential **increases in the opposite direction** to the electric field.
  - Equal to $\frac{V}{d}$

The electric field strength is equal to the **negative of the potential gradient**.

$$E = -\frac{dV}{dx}$$

22.4 Coulomb's Law

- Like charges repel, unlike charges attract.
- The force between two charged objects depends on **how close they are** to each other. $F \propto \frac{1}{r^2}$ and $F \propto Q_1 Q_2$

Coulomb law states for the force between two **point charges**.

$$F = \frac{kQ_1Q_2}{r^2}$$

The constant of proportionality $k = \frac{1}{4\pi\varepsilon_0}$

Coulomb's law is written as

$$F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r^2}$$

where $\frac{1}{4\pi\varepsilon_0} = 9.0 \times 10^9 \mathrm{m\,F^{-1}}$.

22.5 Point Charges

- A **point charge** is a convenient expression for a charged object in a situation where distances under consideration are **much greater than the size of the object**.
- A **test charge** in an electric field is a **point charge** that does not alter the electric field in which it is placed.

$$E = \frac{F}{q} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$$

If a test charge is in an electric field due to several point charges, each charge exerts a force on the test charge. The **resultant force per unit charge** $\frac{F}{q}$ on the test charge gives the **resultant electric field strength** at the position of the test charge.

Radial Electric Fields

- The **electric field lines** of force surrounding a point charge Q are radial.
- The **equipotentials** are therefore concentric circles on Q.

For a charged sphere, we can say the charge is at the centre of the sphere.

The **electric potential** at distance r from Q

$$V = \frac{1}{4\pi\epsilon_0}\frac{Q_1Q_2}{r}$$

1. Because the electric field strength is the **force per unit charge** on a small positive test charge.
2. The area under a graph of electric field strength against distance gives the **work done per unit charge**.
3. Which is the **change in potential** when a positive test charge is moved through the section represented.