Electrostatics (Chapter 12)

Electromagnetic interactions are responsible for:

- Holding subatomic particles together (quarks) as atoms
- Holding atoms together as molecules
- Holding molecules together as objects
- Ultimately for holding your nose on your face!

- **All biological processes** are governed by the interaction of **charges**, e.g.:

  - seeing - feeling - moving
  - thinking - smelling - living…

History:

- Greeks noticed that **amber** (fossilized pine tree resin) **attracts** lint and hair (like a comb does) when **rubbed**.
- Greek word for **amber** is "**elektron**" and by mid-17th century scientists thought of amber as containing an **invisible fluid** called **electricity**.

- Nowadays we demonstrate **electrostatic effects** by **rubbing plastic** or **glass** rods with different **furs** or **fabrics**.
- **Laws of mechanics** indicate that there must be a **force** present to cause **attractive motion** "**electrostatic force**".
- Origin of the force lies in the **transfer** of "**electric charge**" (or electromagnetic charge).

  (Note electric and magnetic phenomena are one and the same – both are manifestations of charge).
- "**Electrostatics**" is the study of **charge** at **rest**.

  Everyday examples:

  - Combed hair "standing on end"
  - Electric shocks during winter indoors
  - "Sticky" plastic wrappings
  - "Clinging" styrofoam packing
  - Photocopy machine paper

Basic Experiments

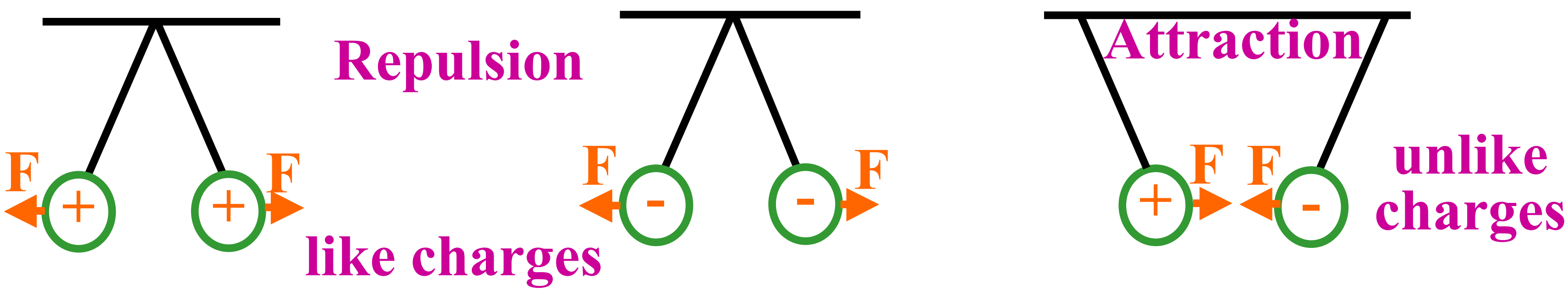
- **Charge** gives rise to an **electric force** (electromagnetic force).
- If vigorously rub **plastic** (rubber) rod with **fur** and then hold two objects just apart you can see the fur **straining** to reach the rod – **attraction**.
- Two pieces of **glass** rod rubbed with **silk** –they will **repel** each other but will **attract** the **silk** and the **charged plastic rod**.

Result - Two distinct types of electrostatic charge:

❖ **"Like charges repel; unlike charges attract".**

- **Benjamin Franklin, USA (18th cent.):** (Single fluid model)

He arbitrarily proposed that the charge on **glass rod** when rubbed with silk be called **positive** (and the other **negative**).



Current Knowledge

- We now know that **all substances** consist of **positively** and **negatively** charged particles.
- The **positive charges** are "**locked up**" inside the atom's "**nucleus**" (which are heavy and essentially **stationary**), and the charge is carried by **protons**.
- The **negative charges** are carried by **electrons** which are light and **highly mobile**.
- An object contains the **same amount** of **positive** and **negative charge** and externally behaves as if it has **no net charge**, i.e. it is **electrically neutral**.

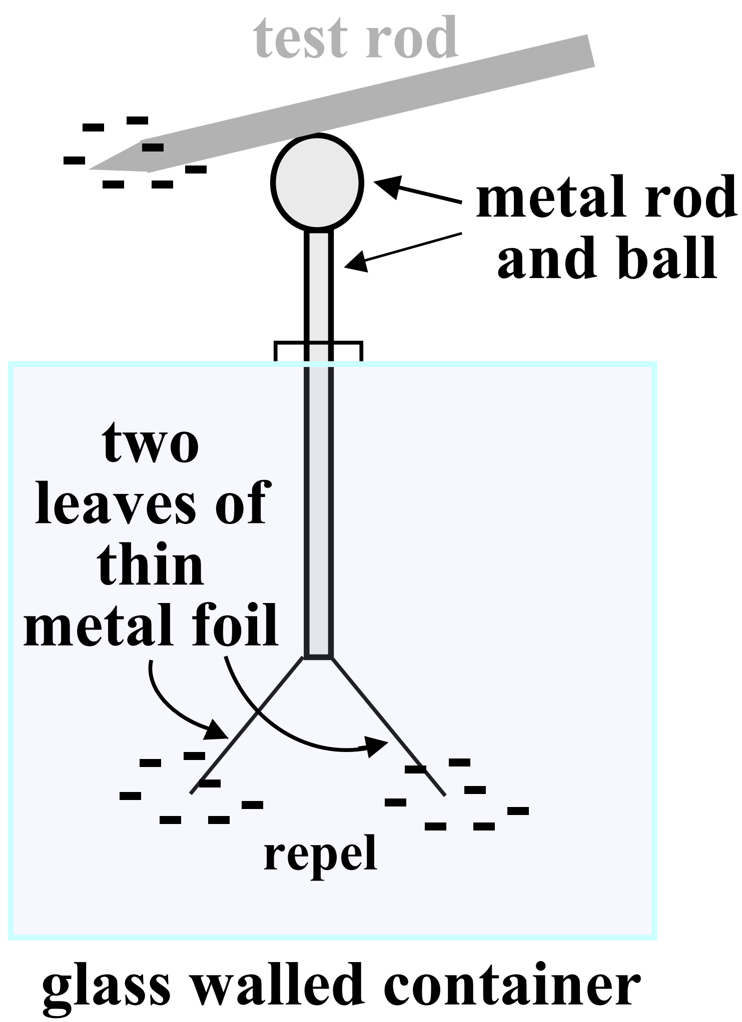
e.g. 20 units of +ve charge and 20 units of –ve charge add up to **zero net charge**… and no observable net electric force.

Charge is Quantized and Conserved

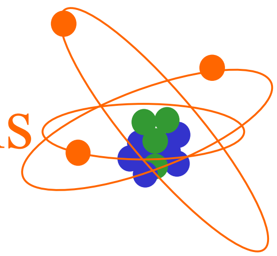
- The **charge** on the **electron** is **equal** and **opposite** to the **charge** on **proton** (to 1 part in 10^{20}!)
- The **electron** is a **fundamental particle** with a **fixed** amount of **charge** ($Q_e = 1.6 \times 10^{-19}$ C) regardless of the material.
- Charge is therefore **quantized** in multiples of **$\pm Q_e$.**
- An everyday neutral object becomes electrically **charged** either by **losing** or **gaining electrons**:
  - The glass rod looses electrons (to become +ve) and the silk gains them (and becomes –ve).
  - The plastic gains electrons from the fur to become –ve.
- Note: Franklin said the glass rod **gained fluid** to become **positive**, so he guessed wrong but had the right concept.
- The **total charge** within an isolated system is **always constant.** i.e. **charge is conserved.**

Electroscope

- A simple instrument for **detecting electrical charge** and **comparing** its **polarity**.
- If foil leaves **uncharged** they **hang straight down**.
- When ball touched by a **charged** rod the **leaves deflect** (i.e. repel each other).
- Amount of **deflection** is **proportional** to the amount of **charge**.
- Other charged objects can then be brought near to **compare polarity** and **magnitude** of charge.



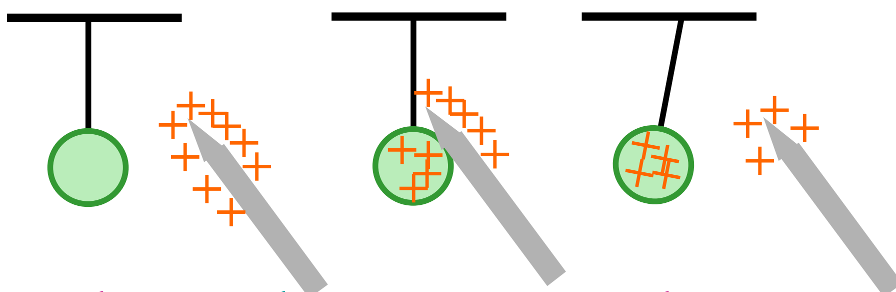
Charge Transfer



- Atoms are electrically neutral but the outer electrons are least strongly bound – most easily shed.
- When two different substances are put in contact – one may **give up** (i.e. donate) electrons while the **other gains** them.
- This results in **electrostatic attraction.**

E.g. Sheet of **plastic** on a **metal plate** – the metal gains **electrons** from the plastic and the **positive** plastic then **attracts** the **negative** metal – **sticky!**

- Rubbing helps strip electrons from donor material to grabber material.
- Positive glass rod has a deficiency of electrons.



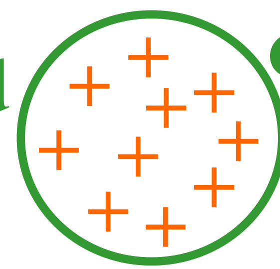
+ve charge transfer

- When rod **contacts** sphere electrons are drawn off sphere.
- Sphere becomes positive and repels away from rod.

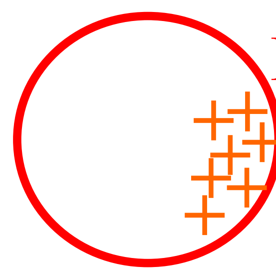
❖**Result: Only electrons are transferred**! (for +ve or –ve charging.)

Insulators and Conductors

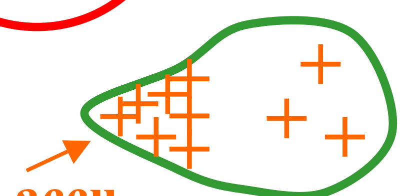
- The distinction between **conductors** and non-conductors (**insulators**) lies in the relative **mobility** of the **electrons** within the materials.
- Metals contain a vast number (~1 per atom) of **highly mobile** electrons.
- Insulators hold fast to their electrons and will latch on to excess ones introduced to them.
- A conductor **allows charge** introduced anywhere within it to **flow freely** and re-distribute **evenly**.



- When an **insulator** receives charge, it retains it in a **confined region** at place of introduction.



- Conductors: no matter what shape of conductor, **excess charge** always resides on its **outer surface**.

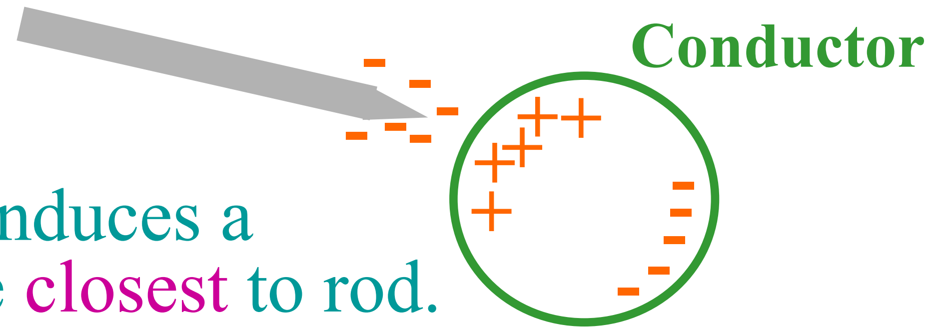


Electrostatic Induction

Conductors:

- It is not necessary for a charged object to physically touch a conductor (e.g. an electroscope) in order for it to respond to its presence.

Example:



- The negatively charged rod induces a positive charge on the sphere closest to rod.
- Electrons are repelled to farthest side but the overall charge on sphere is still **zero**.
- If rod is then **removed**, sphere will return to a **neutral charge** distribution.
- However, if the –ve charge on sphere is removed (by touching rear side) the sphere will remain charged positive.
- This process will **not** work for an insulator as electrons **not free** to move.

Electrostatic Induction

Insulators:

- When an **insulator** is exposed to an **electric charge** the individual **atoms** become **polarized**, i.e. the **distribution of charge** within the atom /molecule **changes.**
- The net effect of **atomic polarization** is that the **whole body** of the insulator becomes **polarized**.
- The overall charge of the insulator is **still zero.**
- Polarization of insulators is an important property and explains why:

  - dust sticks to your TV set.

  - a charged balloon sticks to ceiling.

  - electrostatic precipitators can be used to clean soot from industrial smoke.