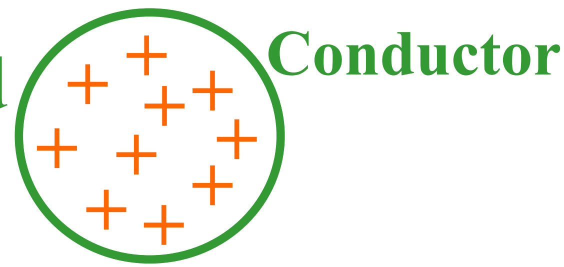
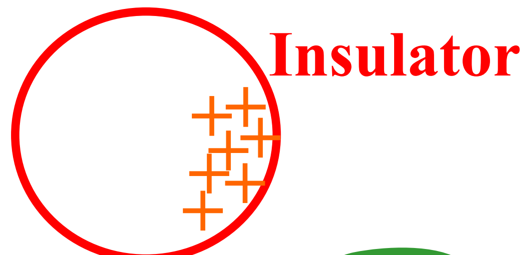
Recap: Insulators and Conductors

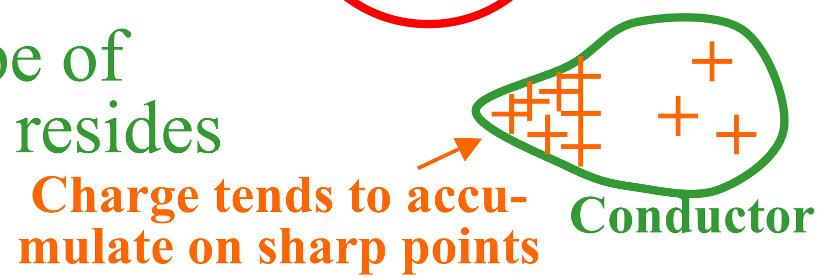
- The distinction between **conductors** and non-conductors (**insulators**) lies in the relative **mobility** of the **electrons** within the materials.
- Metals contain a vast number (~1 per atom) of **highly mobile** electrons.
- Insulators **hold fast** to their electrons and will latch on to excess 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.



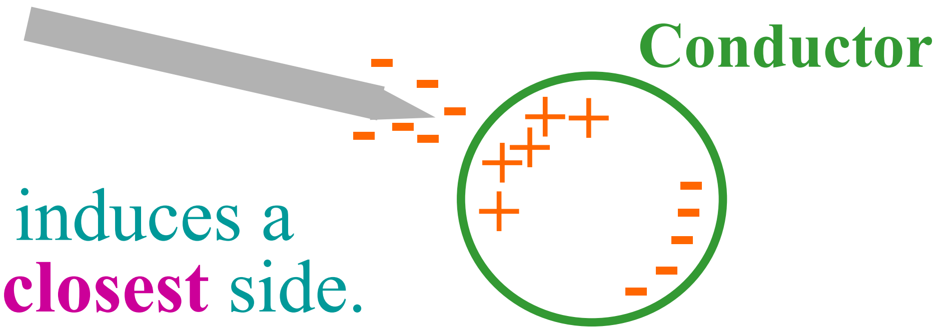
- Conductors: no matter what shape of conductor, **excess charge** always resides on its **outer surface**.



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.



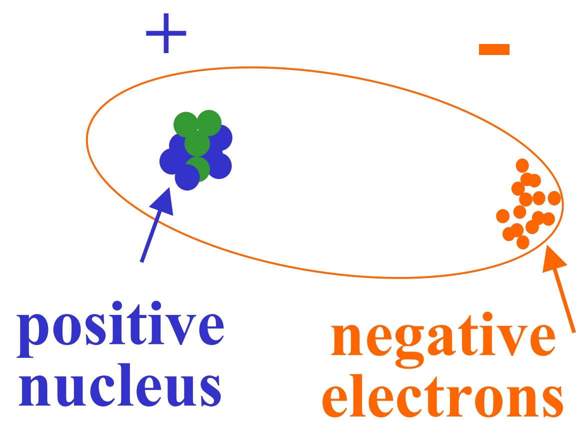
Example:

- The **negatively charged** rod induces a **positive charge** on sphere's **closest** side.
- **Electrons are repelled** to farthest side but the overall charge on sphere is still **<u>zero</u>**.
- 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

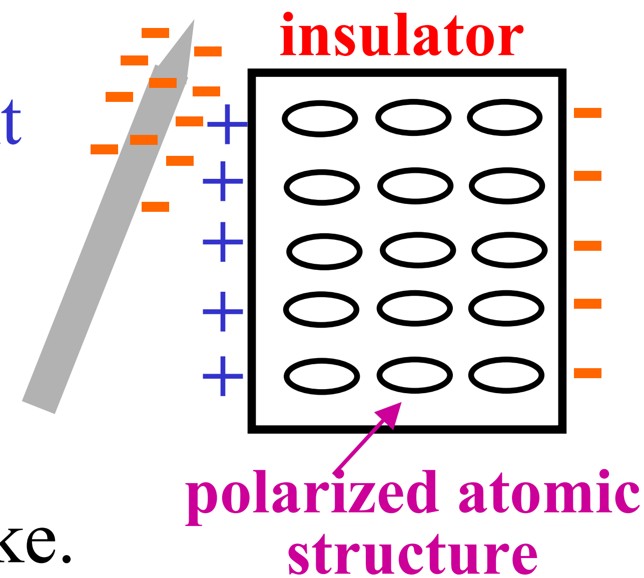
Insulators:

- 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 the ceiling.
  - electrostatic precipitators can be used to clean soot from room/ industrial smoke.



Electrostatics 2 (Chapter 12)

Summary:

- Different materials **vary widely** in their ability to allow electric charge to flow.
- Most metals are **good conductors**, but glass, plastic, rubber and other non-metallic materials are **poor conductors** – i.e. good insulators.
- Conductors and insulators can both be **charged by contact** with a charged body.
- Only **conductors** can be charged by **induction** without touching the charged body.
- Insulators become **polarized** in presence of charged objects: Explains why they are attracted to charged objects.
- **Force due to charges:**
- We cannot see electric charge but we can **see the effects** of the force acting between charged objects (e.g. electroscope).

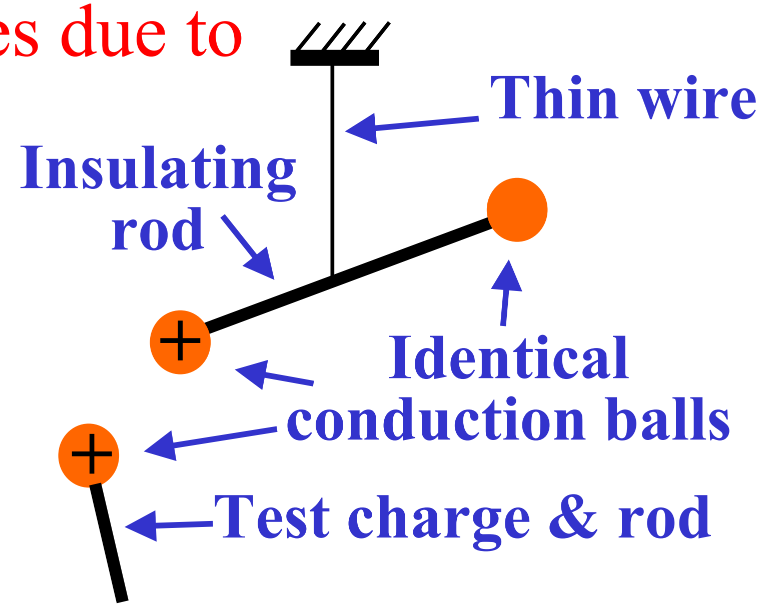
Question: We know force can be **repulsive** or **attractive**, but how does it vary with:

- charge quantity?   - separation of charges?

- We know that the "**electrostatic force**" acts at a distance – like gravity (i.e. objects do **not** need to be in contact).
- 18th century speculation that electrostatic force has **same form** as gravitational force.

Charles Coulomb (18th century) – experimentalist:

- He developed a very sensitive instrument, now called a '**Torsion Balance**' to measure forces due to different charges /separations.
- A **force** applied to either ball produces a **torque** that causes wire to **twist**.
- Magnitude of **force** is proportional to **angle** of deflection.



Problem: How to determine amount of charge on balls?

- **Ingenious solution** based on principle of "charge division", i.e. charge is **shared equally** when **identical balls** are used.
- Initial charge of test ball is **unknown**, but its value can be halved, quartered very accurately – and placed on other balls.
- Coulomb used these relative amounts to investigate how strength of force varied with charge quantity and separation.

Coulomb's Law:

❖ The **electrostatic force** between two charged objects is proportional to the **quantity of each charge** and inversely proportional to the **square of the distance** between charges.

$$\mathbf{F = \frac{k.q_1.q_2}{r^2}}$$

Units: **Newtons**

where: q = charge – measured in Coulombs (C).

k = Coulombs constant = 9×10^9 $N.m^2/C^2$.

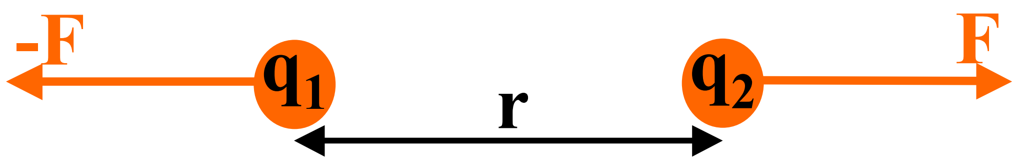
- The two interacting charges experience equal but oppositely directed forces (Newton's 3rd law).

Same charge:
Repulsion

Opposite charge:
Attraction

Example: What is the electrostatic force between two positive charges?

$q_1 = 4\ \mu C$
$q_2 = 8\ \mu C$
$(1\ \mu C = 10^{-6}\ C)$
$r\ = 10\ cm$



$$F = \frac{k.q_1.q_2}{r^2} = \frac{(9 \times 10^9)\,(4 \times 10^{-6})\,(8 \times 10^{-6})}{(0.1)^2}$$

Result: F = 28.8 N

- If 'r' is doubled, the force is reduced by a factor of 4, etc.

Comparison of Coulombs Law and Newton's Law of Gravitation

- Electrostatic force has identical form to gravitation equation:

Electrostatic

$$F_e = \frac{k.q_1.q_2}{r^2}$$

Gravitation

$$F_g = \frac{G.m_1.m_2}{r^2}$$

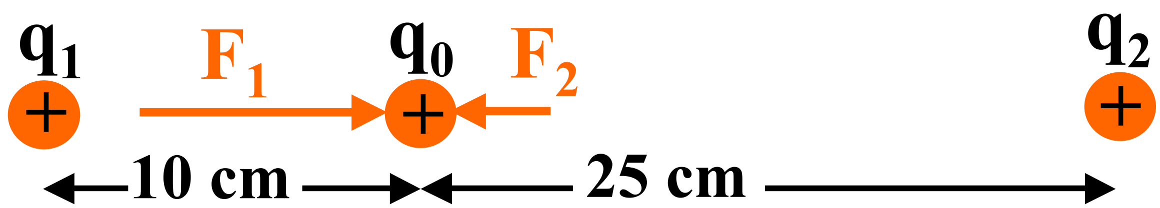
- F_g depends on products of two **masses**,
- F_e depends on products of two **charges**.
- **Direction is not the same:** F_g is always attractive but F_e can be attractive or repulsive.
- **Magnitude is not the same:** For normal sized objects and for sub-atomic particles, the value of F_g is much weaker than F_e.
- Thus, it is the **electrostatic forces** that hold a body together (**not the gravitational force**) for everyday solids, liquids and gases.

Force Due to Several Charges

- Force is a vector. For point-like" charges we can compute the net force on any one charge due to its neighbors.

$$F_{net} = F_1 + F_2 + F_3 \text{ etc.}$$

Example:



Forces F_1 and F_2 act independently on test charge (q_0).

$$F_1 = \frac{k.q_1.q_0}{0.1^2} = 7.2 \text{ N (to right)}$$

$$F_2 = \frac{k.q_2.q_0}{0.25^2} = 2.9 \text{ N (to left)}$$

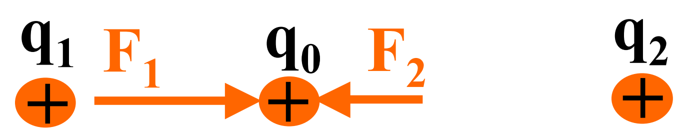
$q_1 = 2\ \mu C$
$q_2 = 5\ \mu C$
$q_0 = 4$ cm

$$F_{net} = F_1 - F_2 = 7.2 - 2.9 = 4.3 \text{ N (to right)}$$

Note, the larger effect of F_1 (even though the charge was smaller) is due to its **closer proximity** to q_0.

Electric Field

- Does the presence of an electric charge somehow modify the space around it?
- The concept of an electric field associated with charged objects is very a important **visual aid** in modern physics.
- Electric fields allow us to examine the effects of a complex distribution of charges at any point.



- Reconsider example –
  We calculate force due to q_1 on q_0 and q_2 on q_0 separately.
- If we knew the sum effects of q_1 and q_2 at any point could calculate force on q_0 directly. (I.e. we need to know the force per unit charge acting on q_0… wherever it is located.)

❖ The **electric field** at a point is the **force per unit positive charge** that would be exerted on charge placed at that point.

$$E = \frac{F}{q_0}$$

Units: **N/C**

Electric Fields

- The electric field 'E' is a vector acting in **same direction** as **force** on a **positive charge** placed at that point.
- Once 'E' is known then the force 'F' on any introduced charge 'q' is given directly by:

$$\mathbf{F = q \cdot E}$$ (Units: Newtons)

Note: If q is +ve E and F in same direction.
If q is –ve F is opposite in direction to E.

- Electric field and electrostatic force are **not** the same!

E.g. We can talk about an electric field at a point in space even if **no 'test' charge** at that point.

- The field tells us the magnitude and direction of force that would be exerted **if a charge 'q'** is placed at a given point.

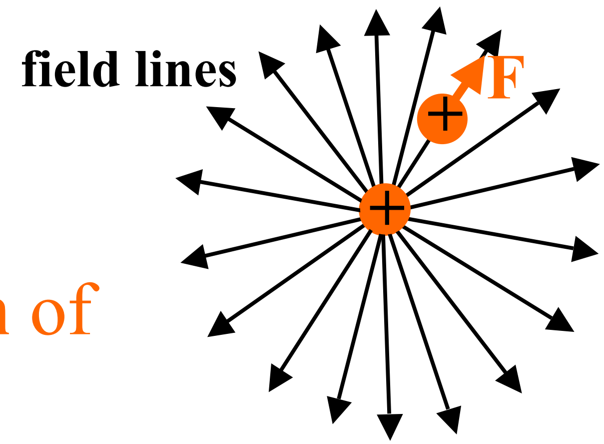
i.e. the **field exists** regardless of whether there is a test charge present or not!

- 'E' fields can exist in **vacuum** as well as **solids, liquids, gases**.

Electric Field Lines

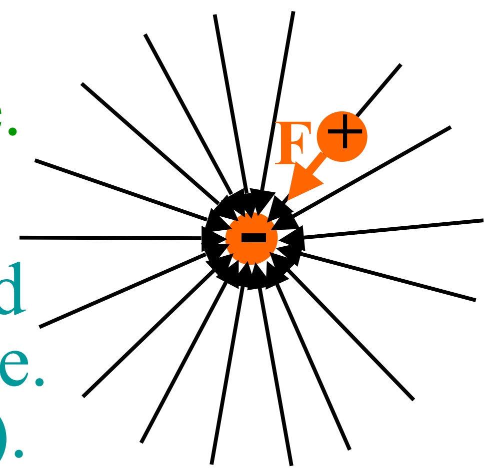
- Concept of electric field lines initially used by **Michael Faraday** (19th century) to **aid visualizing** electric (and magnetic) effects.
- **James Clerk Maxwell** (19th century), theoretician, formally developed concept of field lines.

Positive Charge:



- Field lines radiate **outwards** from a +ve charge.
- Force on +ve test charge gives **direction** of field.

Negative Charge:

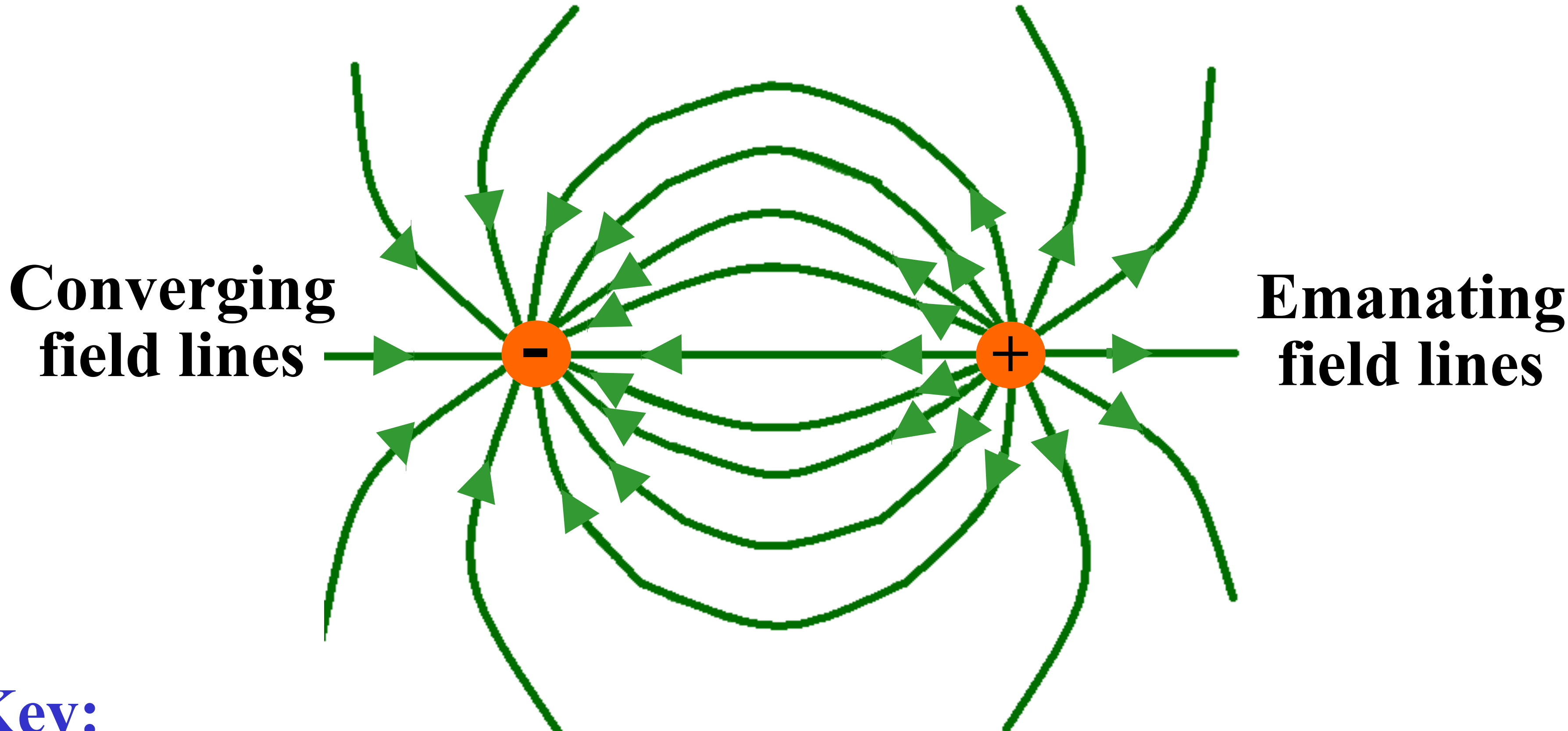


- Field lines **converge** inwards to a –ve charge.
- Force on +ve charge gives direction of field.

In both cases the strength of the electric field is given by the "**density**" of the field lines (i.e. closer together – the stronger the field /force).

Example: Electric Dipole

- Two **equal** but **opposite sign** charges…



Key:

- Field lines **originate on positive (+ve)** charge and **end up on negative (-ve)** charge.
- Field lines are **perpendicular** to charge surface.