Year 11 Term 3 Week 8
Electrostatic Force

Coulomb's Law

Charges

Two charges of the same type repel one another

Two charges of the opposite type attract one another

The two charges will experience a FORCE pushing them apart or pulling them together

How much force?

The amount of force that two charged objects experience depends on three factors

1. The charges on the objects (q_1 and q_2)

2. The distance between them (r)

3. The electrostatic constant (k) = $8.99 \times 10^9\ N{\cdot}m^2/C^2$

We use Coulomb's Law to calculate this force

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

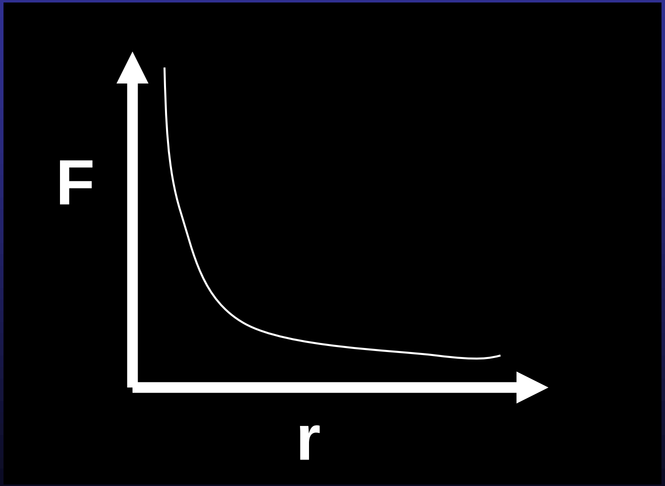
Coulomb vs. Newton

This equation looks very much like Newton's Law of Universal Gravitation!

$$F_e = \frac{kq_1q_2}{r^2}$$

$$F_g = \frac{Gm_1m_2}{r^2}$$

Both have an INVERSE SQUARE relationship between FORCE and DISTANCE



Gravitational force concerns MASS
Coulomb force is about CHARGE

Another inverse square law

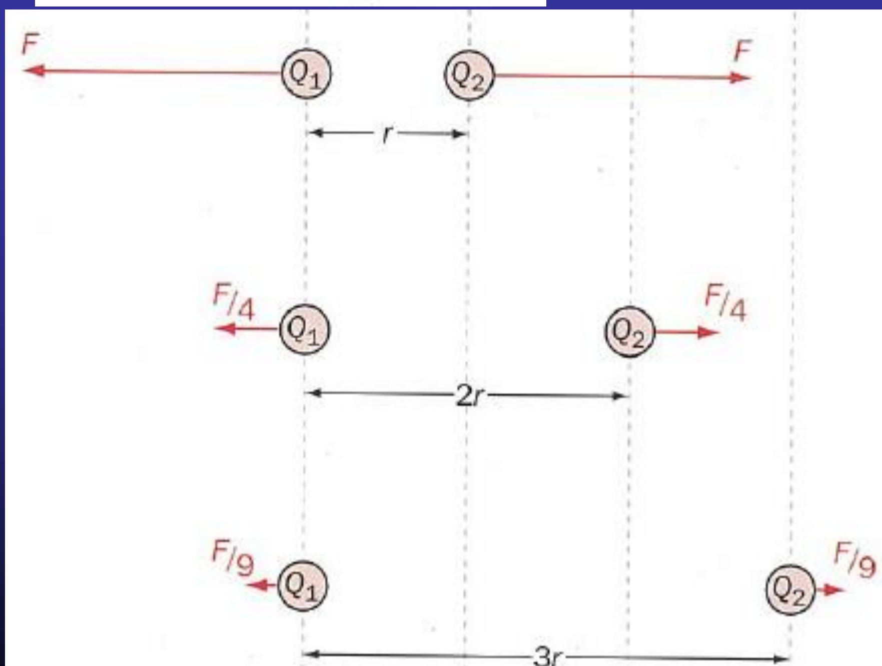
This means that if we double the distance between the charges, the force decreases to $(\frac{1}{2})^2$ or $\frac{1}{4}$ of its previous value.

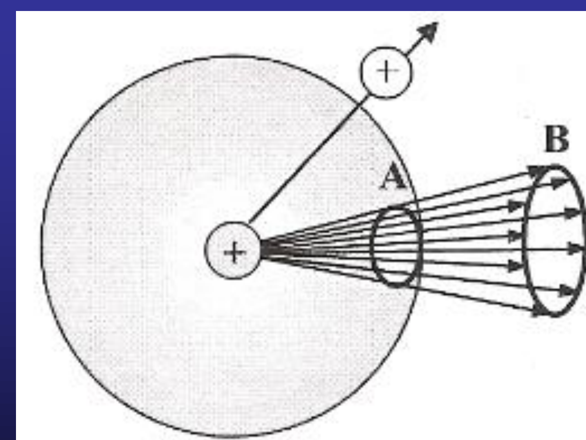
Coulomb's law:

$$F = \frac{k\, Q_1\, Q_2}{r^2}$$

Newton's law of gravitation

$$F = \frac{G\, m_1\, m_2}{r^2}$$





Coulomb's law of charge

The force is 'felt' by objects with charge.

The force is proportional to the size of the charges.

The force is inversely proportional to the square of the separation of the charges.

There is an electric field round a charge

There are two types of charge – positive and negative.

The constant is k, and its value depends on the material. In air $k = {}^{1}/_{4\pi\varepsilon_0} = 9.0 \times 10^{9}\ \mathrm{N\,m^{-2}\,C^{-2}}$

The electric force is very strong, but not normally noticed as the charges cancel out.

Coulomb's Law – Gives the electric force between two point charges.

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

Inverse Square Law

k = Coulomb's Constant = 9.0×10^9 Nm^2/C^2

q_1 = charge on mass 1

q_2 = charge on mass 2

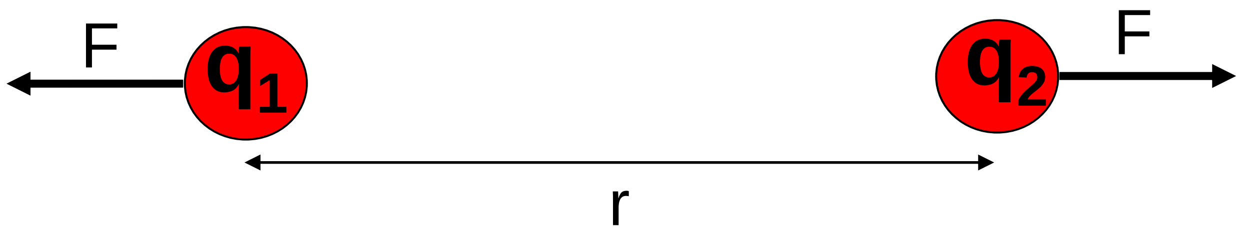
r = the distance between the two charges

The electric force is much stronger than the gravitational force.

Example

Two charges are separated by a distance r and have a force F on each other.

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



If r is doubled then F is : ¼ of F

If q_1 is doubled then F is : 2F

If q_1 and q_2 are doubled and r is halved then F is : 16F

Which is stronger?

- Consider two electrons 1μm apart
  - What is the gravitational force between them?
    - Depends on mass

$$F_g = \frac{Gm_1m_2}{r^2}$$

$$\frac{(6.67x10^{-11} N \cdot m^2/kg^2)(9.11x10^{-31} kg)(9.11x10^{-31} kg)}{(1x10^{-6} m)^2}$$

5.54 x 10^{-59} N

  - What is the electrostatic force between them?
    - Depends on charge

$$F_e = \frac{kq_1q_2}{r^2}$$

$$\frac{(8.99x10^{9} N \cdot m^2/C^2)(1.60x10^{-19} C)(1.60x10^{-19} C)}{(1x10^{-6} m)^2}$$

2.30 x 10^{-16} N

Units of Charge

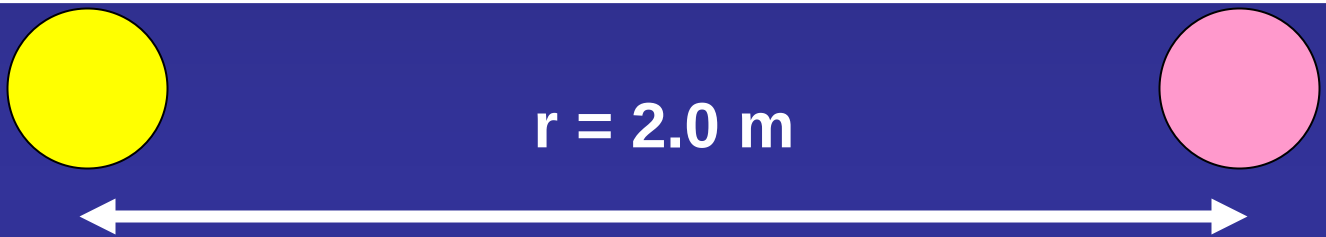
- The SI unit of charge is the ***Coulomb***.

1 Coulomb = the charge of 6.24×10^{18} electrons

Example

What is the electrostatic force between these two objects?

A negative answer shows that the force is ATTRACTIVE



q_1 = -2C

q_2 = +2C

$$F_e = \frac{kq_1q_2}{r^2}$$

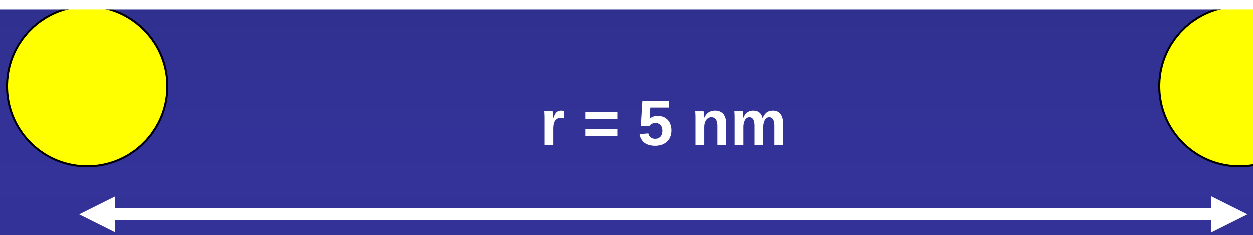
$$F_e = \frac{(8.99x10^9\ N \cdot m^2/C^2)(-2C)(+2C)}{(2m)^2}$$

$$F_e = -8.99x10^9\ N$$

Example

What is the electrostatic force between these two objects?

A positive answer shows that the force is REPULSIVE



q_1 = -5μC

q_2 = -2μC

$$F_e = \frac{kq_1q_2}{r^2}$$

$$F_e = \frac{(8.99x10^9\,N \cdot m^2/C^2)(-5x10^{-6}\,C)(-2x10^{-6}\,C)}{(5x10^{-9}\,m)^2}$$

$$F_e = 3.60x10^{15}\,N$$

Example 1

Two charges are separated by a distance of 3 cm. Charge one is 3.0×10^{-9} C whilst charge two is -12×10^{-9} C. What is the force between the two charges and is it attractive or repulsive?

$q_1 = 3.0 \times 10^{-9}$ C

$q_2 = -12 \times 10^{-9}$ C

$r = 3 \times 10^{-2}$ m

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

$$= 9.00 \times 10^{9} \frac{3.0 \times 10^{-9} \times 12 \times 10^{-9}}{(3 \times 10^{-2})^2}$$

$$= 3.6 \times 10^{-4} \text{N}$$ Attractive

Example 2

Suppose that two point charges, each with a charge of +1.00 Coulomb are separated by a distance of 1.00 metres. Determine the magnitude of the electrical force of repulsion between them.

$$F = \frac{k\,Q_1\,Q_2}{r^2}$$

$Q_1 = 1.00$ C

$Q_2 = 1.00$ C

$d = 1.00$ m

$F_{elect} = (9.0 \times 10^9\ N\bullet m^2/C^2) \bullet (1.00\ C) \bullet (1.00\ C) / (1.00\ m)^2$

$$F_{elect} = 9.0 \times 10^9\ N$$

Charge is often expressed in units of microCoulomb (µC) and nanoCoulomb (nC).

1 Coulomb = 10^6 microCoulomb

1 Coulomb = 10^9 nanoCoulomb

Example 3

Two balloons are charged with an identical quantity and type of charge: -6.25 nC. They are held apart at a separation distance of 61.7 cm. Determine the magnitude of the electrical force of repulsion between them.

$Q_1 = -6.25 \text{ nC} = -6.25 \times 10^{-9} \text{ C}$

$Q_2 = -6.25 \text{ nC} = -6.25 \times 10^{-9} \text{ C}$

$d = 61.7 \text{ cm} = 0.617 \text{ m}$

$$F_{elect} = (9.0 \times 10^{9} \text{ N} \cdot \text{m}^2/\text{C}^2) \cdot (6.25 \times 10^{-9} \text{ C}) \cdot (6.25 \times 10^{-9} \text{ C}) / (0.617 \text{ m})^2$$

$$F_{elect} = 9.23 \times 10^{-7} \text{ N}$$

The resulting "+" and "-" signs on F signifies whether the force is attractive (a "-" F value) or repulsive (a "+" F value).