GCE Physics Unit 4.2 Electrostatic and Gravitational Fields of Force

Electrostatic and gravitational fields and force have similar properties and patterns as they **both act between particles and obey the inverse square law**.

Electrostatic:

Force:

Coulomb's law states that the force between two point charges is directly proportional to the product of the charges and inversely proportional to the separation squared.

$$F = \frac{1}{4\pi\varepsilon_o}\frac{Q_1 Q_2}{r^2}$$

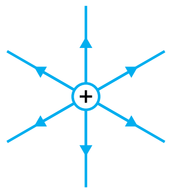
Where $\frac{1}{4\pi\varepsilon_o}$ is a constant ≈ 9 × 10^9 F m^{-1}

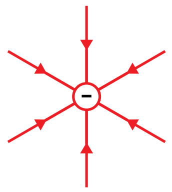
Electrical field strength, E, is defined as the **force per unit charge** on a positive test charge at that point.

$$E = \frac{1}{4\pi\varepsilon_o}\frac{Q}{r^2}$$

Both F and E, can be repulsive (positive) or attractive (negative).

Field lines:





Can be repulsive (positive) or attractive (negative).

Gravitational:

Force:

Newton's law states that the force between two masses is directly proportional to the product of the masses and inversely proportional to the separation squared.

$$F = G\frac{M_1 M_2}{r^2}$$

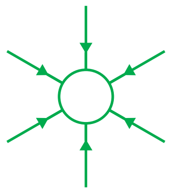
Where G = 6.67 × 10^{-11} N m^2 kg^{-2}

Gravitational field strength, g, is defined as the **force per unit mass** on a small mass at that point.

$$g = G\frac{M}{r^2}$$

F and g are only attractive. (The negative sign is rarely shown.)

Field lines:



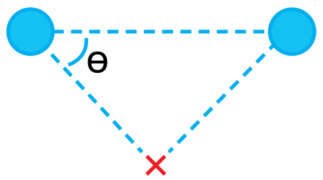
Note the field outside a spherical body is the same shape as if all the mass was concentrated at the centre.

Is always attractive.

Net field strength:

Field strength is a vector quantity. Therefore, when the fields of multiple masses or charges act at a point, the total field strength is the vector sum of the individual fields. This may require calculating vertical and horizontal components of E or g.

In this example, if both charges (or masses) are equal, the horizontal components will cancel, and the vertical components, each equal to E sinθ, will add to give the total field strength.



Electrical potential is defined as the **work** done **per unit charge** in bringing a **positive** charge from infinity to that point.

$$V_r = \frac{1}{4\pi\varepsilon_o}\frac{Q}{r}$$

Therefore, electrical potential energy is given by:

$$PE = \frac{1}{4\pi\varepsilon_o}\frac{Q_1 Q_2}{r}$$

Gravitational potential is defined as the **work** done **per unit mass** in bringing a mass from infinity to that point.

$$V_g = -G\frac{M}{r}$$

Therefore, electrical potential energy is given by:

$$PE = -G\frac{M_1 M_2}{r}$$

If the field is uniform, i.e. g **is constant**, then the gravitational potential energy can also be calculated using:

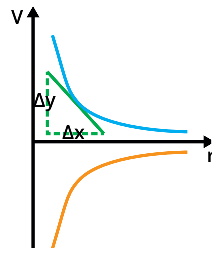
$$\Delta U_p = mg\Delta h$$

Conservation of energy means that the total energy at the start = total energy at the end.
For objects moving in any field the loss or gain in potential energy is equal to work done.

Work done: $W = q\Delta V$

As the potential at infinity must be 0, the electrical potential can be negative or positive.

In both cases, a tangent can be used to calculate the gradient at a point.



E = - slope of V_E - r graph at that point

Conservation of energy is used to calculate the **distance of closest approach to a nucleus**.

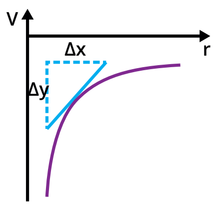
If a charged particle is fired at a nucleus, its kinetic energy is transferred to potential energy as it gets closer to the nucleus. At the nearest point, the kinetic energy at the start = potential energy gained:

$$\frac{1}{2}mv^2 = \frac{1}{4\pi\varepsilon_o}\frac{Q_1 Q_2}{r}$$

Work done: $W = m\Delta V$

As the potential at infinity must be 0, the gravitational potential can only be negative.

A tangent can be used to calculate the gradient at a point.



g = - slope of V_g - r graph at that point

Conservation of energy is used to calculate the **escape velocity** from a planet.

An object launched directly away from a planet will escape the gravitational field if it has enough kinetic energy at the start. The escape velocity is the velocity required so that the object just reaches infinity with no kinetic energy remaining:

$$\frac{1}{2}mv^2 + -G\frac{Mm}{r} = 0$$

Net potential:

Potential is a scalar quantity, therefore the **potential at a point due to multiple** charges or masses, is the **sum of the potential** due to the individual charges or masses.

F = Force in N | r = radial distance in m | E = electrical field strength in N C^{-1} | V = electrical potential in J C^{-1} = V | W = work in J

Q = charge in C | M = mass in kg | g = gravitational field strength in N kg^{-1} | PE = gravitational potential in J kg^{-1}