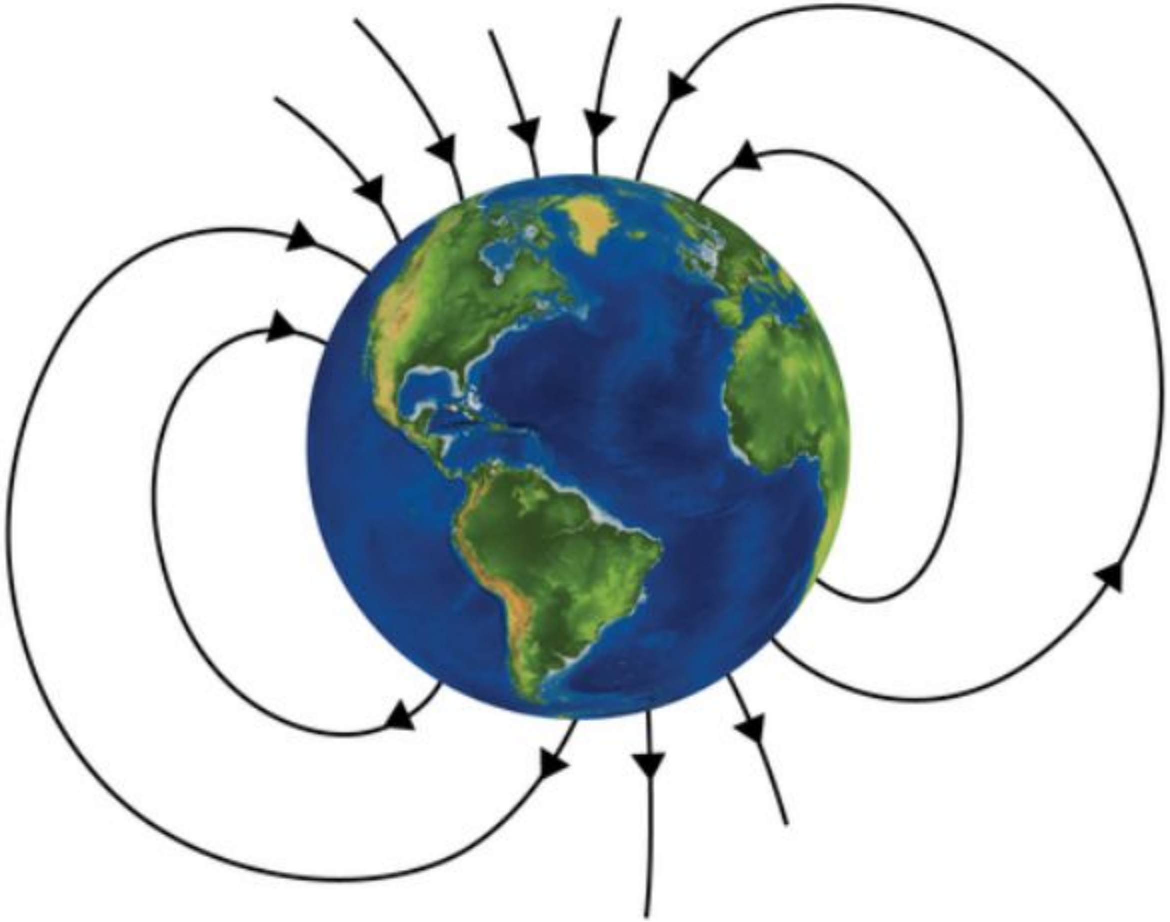
Gravitational and Electric Fields



Material Covered

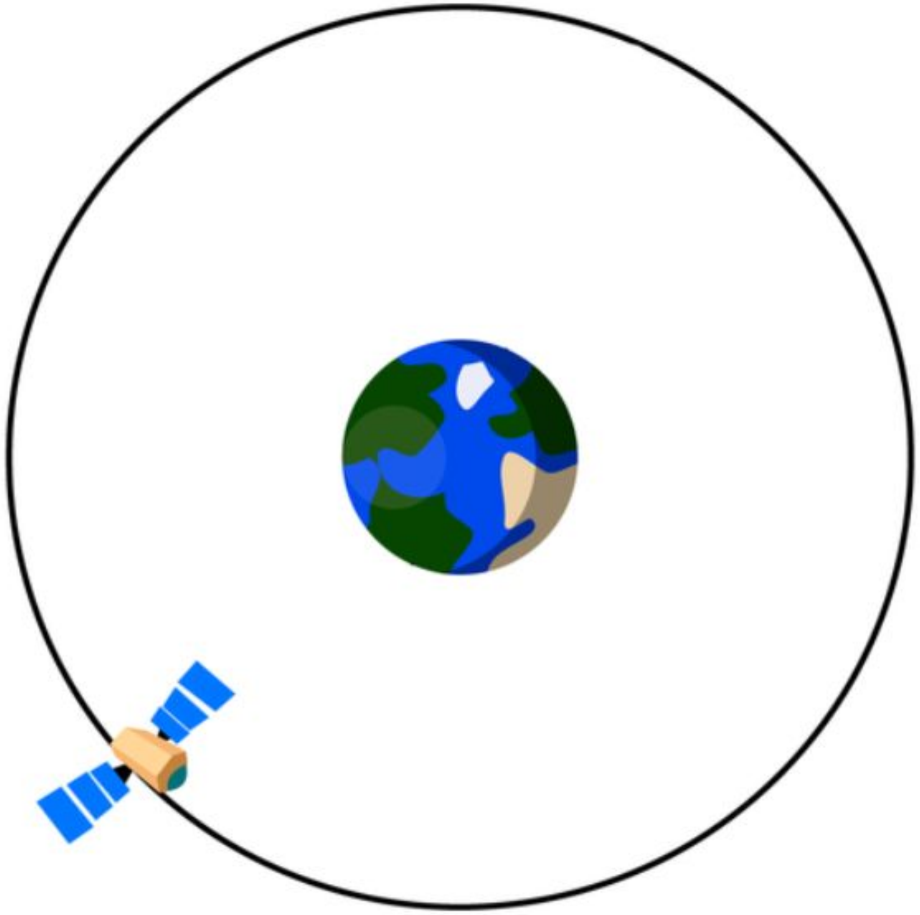
Gravitational Fields

1. Gravity.
2. Newton’s Law of Gravitation.
3. Gravitational Potential.
4. Planetary Fields.

Electric Fields

1. Electric Field Lines.
2. Coulomb's Law.
3. Electric Potential.

Gravitational Fields



Specification Points - AQA

3.7.2.3 Gravitational potential (A-level only)

Content	Opportunities for skills development
Understanding of definition of gravitational potential, including zero value at infinity. Understanding of gravitational potential difference. Work done in moving mass m given by $\Delta W = m\Delta V$ Equipotential surfaces. Idea that no work is done when moving along an equipotential surface. V in a radial field given by $V = -\frac{GM}{r}$ Significance of the negative sign. Graphical representations of variations of g and V with r. V related to g by: $g = -\frac{\Delta V}{\Delta r}$ ΔV from area under graph of g against r.	**MS 3.8, 3.9** Students use graphical representations to investigate relationships between v, r and g.

3.7.2.1 Newton's law (A-level only)

Content
Gravity as a universal attractive force acting between all matter. Magnitude of force between point masses: $F = \frac{Gm_1m_2}{r^2}$ where G is the gravitational constant.

3.7.2.2 Gravitational field strength (A-level only)

Content
Representation of a gravitational field by gravitational field lines. g as force per unit mass as defined by $g = \frac{F}{m}$ Magnitude of g in a radial field given by $g = \frac{GM}{r^2}$

3.7.2.4 Orbits of planets and satellites (A-level only)

Content	Opportunities for skills development
Orbital period and speed related to radius of circular orbit; derivation of $T^2 \propto r^3$ Energy considerations for an orbiting satellite. Total energy of an orbiting satellite. Escape velocity. Synchronous orbits. Use of satellites in low orbits and geostationary orbits, to include plane and radius of geostationary orbit.	**MS 0.4** Estimate various parameters of planetary orbits, eg kinetic energy of a planet in orbit. **MS 3.11** Use logarithmic plots to show relationships between T and r for given data.

Specification Points – OCR A

5.4.3 Planetary motion

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	Kepler's three laws of planetary motion	HSW7
(b)	the centripetal force on a planet is provided by the gravitational force between it and the Sun	
(c)	the equation $T^2 = \left(\frac{4\pi^2}{GM}\right)r^3$	Learners will also be expected to derive this equation from first principles. HSW1
(d)	the relationship for Kepler's third law $T^2 \propto r^3$ applied to systems other than our solar system	
(e)	geostationary orbit; uses of geostationary satellites.	HSW1, 2, 9, 10 Predicting geostationary orbit using Newtonian laws.

5.4.2 Newton's law of gravitation

	Learning outcomes
	Learners should be able to demonstrate and apply their knowledge and understanding of:
(a)	Newton's law of gravitation; $F = -\frac{GMm}{r^2}$ for the force between two point masses
(b)	gravitational field strength $g = -\frac{GM}{r^2}$ for a point mass
(c)	gravitational field strength is uniform close to the surface of the Earth and numerically equal to the acceleration of free fall.

5.4.1 Point and spherical masses

	Learning outcomes
	Learners should be able to demonstrate and apply their knowledge and understanding of:
(a)	gravitational fields are due to objects having mass
(b)	modelling the mass of a spherical object as a point mass at its centre
(c)	gravitational field lines to map gravitational fields
(d)	gravitational field strength; $g = \frac{F}{m}$.
(e)	the concept of gravitational fields as being one of a number of forms of field giving rise to a force.

5.4.4 Gravitational potential and energy

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	gravitational potential at a point as the work done in bringing unit mass from infinity to the point; gravitational potential is zero at infinity	
(b)	gravitational potential $V_g = -\frac{GM}{r}$ at a distance r from a point mass M; changes in gravitational potential	
(c)	force–distance graph for a point or spherical mass; work done is area under graph	HSW5
(d)	gravitational potential energy $E = mV_g = -\frac{GMm}{r}$ at a distance r from a point mass M	
(e)	escape velocity.	HSW1, HSW2 Predicting the escape velocity of atoms from the atmosphere of planets.

Specification Points – OCR B

5.1.2 Out into space

	Learning outcomes	Additional guidance
(a)	*Describe and explain:*	
	(i) changes of gravitational and kinetic energy	
	(ii) motion in a uniform gravitational field	
	(iii) the gravitational field and potential of a point mass	modelling the mass of a spherical object as a point mass at its centre
(b)	*Make appropriate use of:*	
	(i) the terms: force, kinetic and potential energy, gravitational field, gravitational potential, equipotential surface	HSW2, 8
	by sketching and interpreting:	
	(ii) graphs showing gravitational potential as area under a graph of gravitational field versus distance, graphs showing changes in gravitational potential energy as area under a graph of gravitational force versus distance between two distance values	*M3.8, M3.12* HSW5
	(iii) graphs showing force as related to the tangent of a graph of gravitational potential energy versus distance, graphs showing field strength as related to the tangent of a graph of gravitational potential versus distance	*M3.6* HSW5
	(iv) diagrams of gravitational fields and the corresponding equipotential surfaces.	

	Learning outcomes	Additional guidance
(c)	*Make calculations and estimates involving:*	
	(i) uniform gravitational field, gravitational potential energy change = *mgh*	Learners will also be expected to recall this equation
	(ii) energy exchange, work done, $\Delta E = F\Delta s$; no work done when the force is perpendicular to the displacement, resulting in no work being done whilst moving along equipotentials	*M2.1*
	(iv) the radial components: $F_{grav} = -\frac{GmM}{r^2}$, $g = \frac{F_{grav}}{m} = -\frac{GM}{r^2}$	
	(v) gravitational potential energy $E_{grav} = -\frac{GMm}{r}$	
	(vi) gravitational potential $V_{grav} = \frac{E_{grav}}{m} = -\frac{GM}{r}$.	

Specification Points - Edexcel

174.	understand that a gravitational field (force field) is defined as a region where a mass experiences a force
175.	understand that gravitational field strength is defined as $g = \frac{F}{m}$ and be able to use this equation
176.	be able to use the equation $F = \frac{Gm_1m_2}{r^2}$ (Newton's law of universal gravitation)
177.	be able to derive and use the equation $g = \frac{Gm}{r^2}$ for the gravitational field due to a point mass
178.	be able to use the equation $V_{grav} = \frac{-Gm}{r}$ for a radial gravitational field
179.	be able to compare electric fields with gravitational fields
180.	be able to apply Newton's laws of motion and universal gravitation to orbital motion.

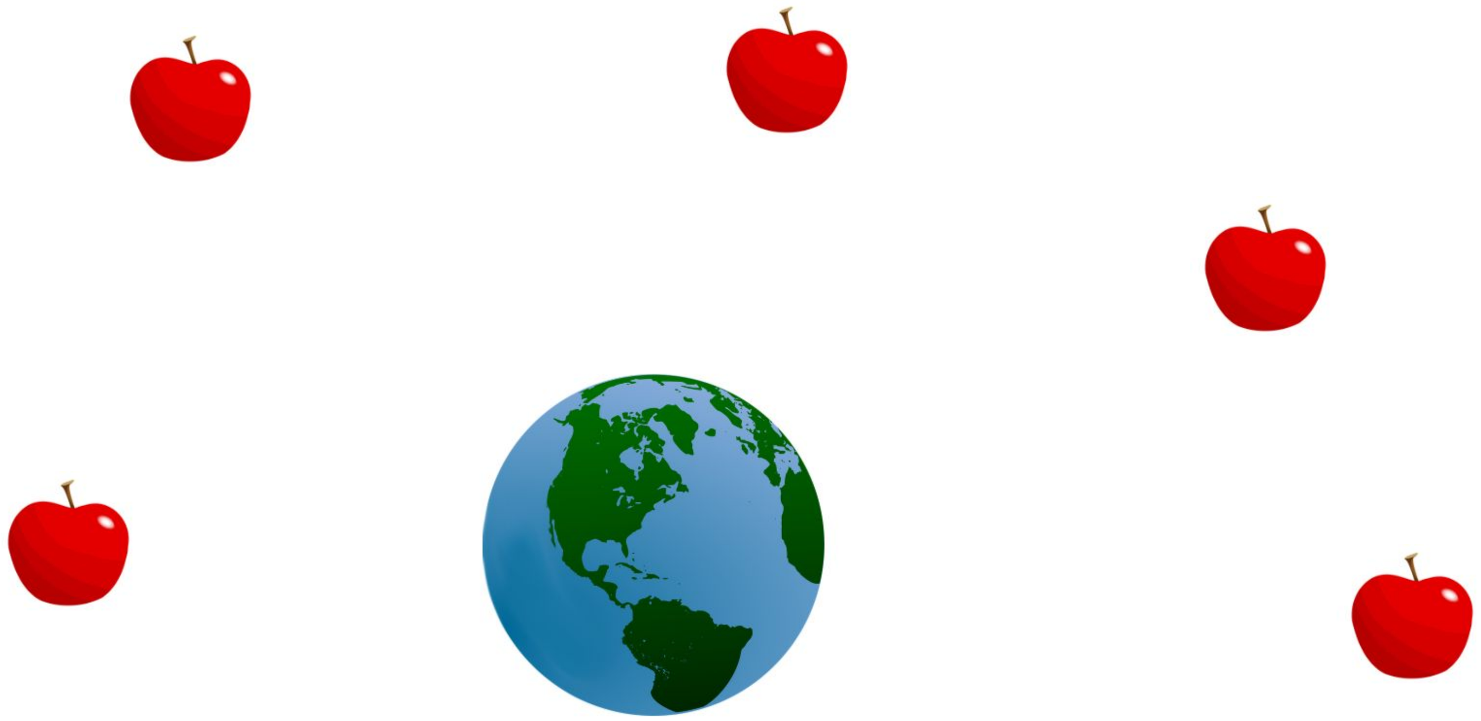
Gravity

Gravity is an **attractive force** which **acts** between any **2 bodies** with **mass**.

- The **gravitational force** of **attraction** on each **object** is **equal** and **opposite**.
- The **gravitational force** acts through an object's **centre of mass**.
- **Objects** can often be **assumed** to be **point masses** with all their **mass** residing at their **centre of mass**.

A **field** is a **region** of **space** where at **every point** we can **define** a **vector value** for the **field**.

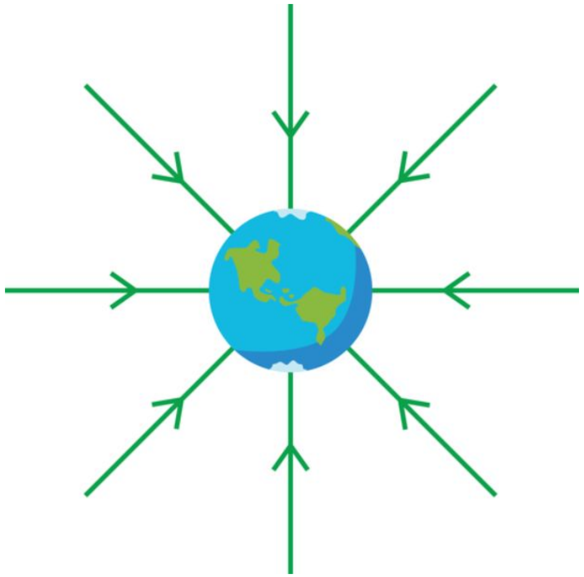
- For a **gravitational field,** this **vector** is the **gravitational force** on an **object** placed in the **field**.
- Any **body** with **mass** produces a **gravitational field** around it.



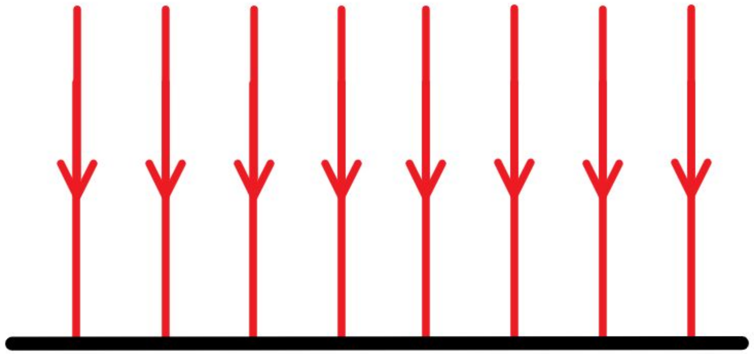
Gravitational fields can be **represented** by **gravitational field lines**.

- The **density** of these **lines represents** the **strength** of the **gravitational field**.
- The **direction** of these **field lines represent** the **direction** of the **force** on an **object** in the **field**.

For a **spherical** mass the **field lines** are **radial**.



Close to the **surface** of the **Earth**, **field lines** are almost **parallel**.



The **strength** of a **gravitational field** (g) is defined as the **gravitational force** per **unit mass** on a small **test mass** placed in the **field**.

- A **test mass** is a **mass** small enough that it does not **noticeably** affect the **field**.

The **gravitational field strength** (g) is **equal** to the **acceleration due to gravity**.

Exemplar Statement Exam Question

Context: **Gravitational fields**. Recall form of **gravitational field lines**.

Statement Question: Requires simple sentence answer.

1) Close to the surface of the Earth, its gravitational field can be considered to be uniform, but from a large distance away, the field is radial. State one similarity and one difference between these two models for the field. **[2 marks]**

Mention **both**.

1 mark for each **point**.

Similarity:

- Uniform and radial gravitational field lines both point towards centre of Earth (perpendicular to surface of Earth).

[1 Mark]

Difference:

- Uniform gravitational field lines are parallel whereas radial field lines get further apart farther from Earth (as field gets weaker).

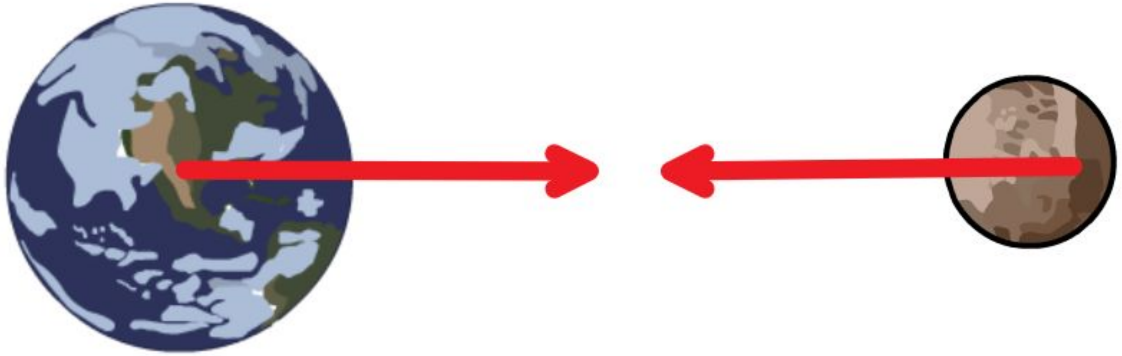
[1 Mark]

Newton's Law of Gravitation

By **studying** the **motion** of the **planets**, **Newton** established his **theory of gravitation**.

- The **magnitude** of the **gravitational force** is **proportional** to the **product** of the **masses**.
- The **magnitude** of the **force** is **inversely proportional** to the **separation squared**.

$$F_G = (-)\frac{Gm_1m_2}{r^2}$$



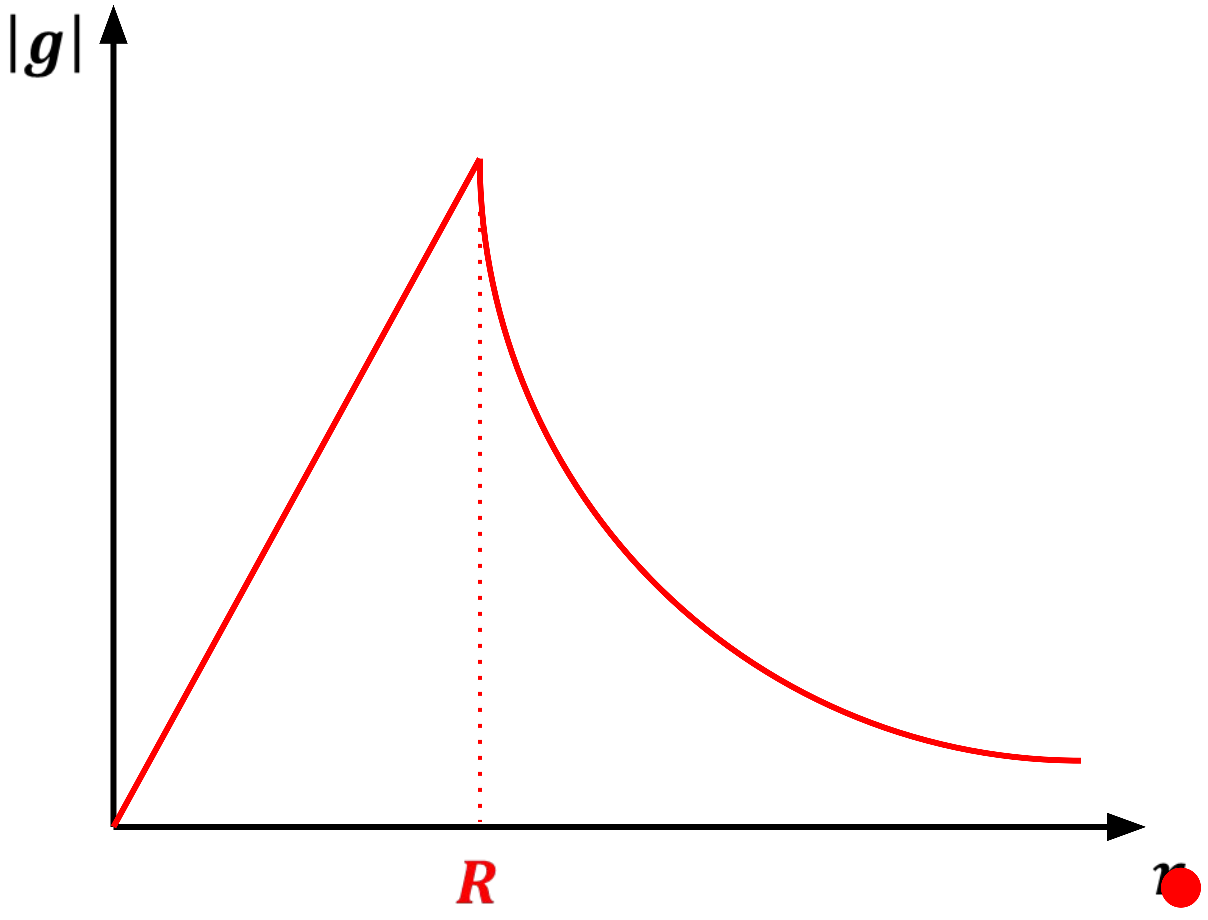
We can **determine** how g varies with **distance** using **Newton's Law of Gravitation**:

$$g = \frac{F}{m}$$

- The **dependence** of F_G and g on r are known as **inverse square laws**.

We can **plot** the **dependence** of g with **distance** r from the **centre** of a **planet** of **radius** R.

For $r > R$, g follows an **inverse square relation**.



Exemplar Calculation Exam Question

Context: Recall **Newton's Law of Gravitation**.

Calculation Question: Mathematical question – we need to show our working.

What **key data value** can we derive from this?

1) The Earth orbits the Sun at a linear speed of $\mathbf{29900\ ms^{-1}}$. Determine the gravitational force of attraction between the Earth and the Sun.
$M_{EARTH} = 5.97 \times 10^{24}\text{kg}$. $M_{SUN} = 1.99 \times 10^{30}\text{kg}$.
$G = 6.67 \times 10^{-11}\text{m}^3\text{kg}^{-1}\text{s}^{-2}$.

Key data which will be **required** for the **calculation**.

[3 marks]

Indicates that there will be about **3 steps** to our **calculation**. Any less and we may have missed something.

Answer should be a force with **units** of **Newtons** (N).

Exemplar Calculation Question Answer

Write out **Newton's Law of Gravitation**:

$$F_G = (-)\frac{Gm_1m_2}{r^2}$$

Determine radius of **orbit**:

$$v = \frac{2\pi r}{T} \quad \Rightarrow r = \frac{T \times v}{2\pi}$$

[1 Mark]

Exemplar Calculation Question Answer

$$T = (365.25 \times 24 \times 60 \times 60) = 31557600\ \text{s}$$

$$r = \frac{31557600 \times 29900}{2\pi} = 1.501\ldots \times 10^{11}\text{m}$$ **[1 Mark]**

Determine force:

$$F_G = \frac{(6.67 \times 10^{-11}) \times (1.99 \times 10^{30}) \times (5.97 \times 10^{24})}{(1.501\ldots \times 10^{11})^2}$$

$$F_G = 3.51 \times 10^{22}\ \text{N}$$ **[1 Mark]**

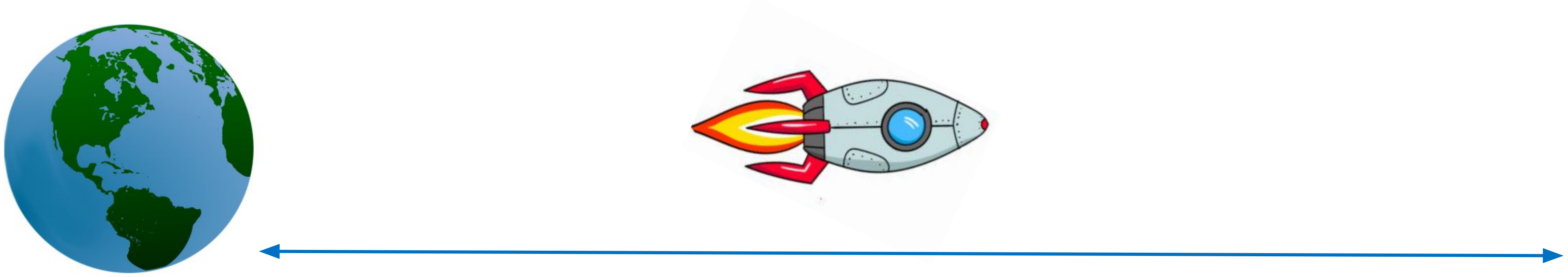
Gravitational Potential

To move a **mass** away from a **gravitational source work** must be **done** to **convert energy** to **gravitational potential energy**.

$$\Delta GPE = mg\Delta r$$

The **gravitational potential** (V) at a **point** in a **field** is **equal** to the **gravitational potential energy** per **unit mass** at that **point**.

When referring to **gravitational potential** we must **define** a **zero-point**.

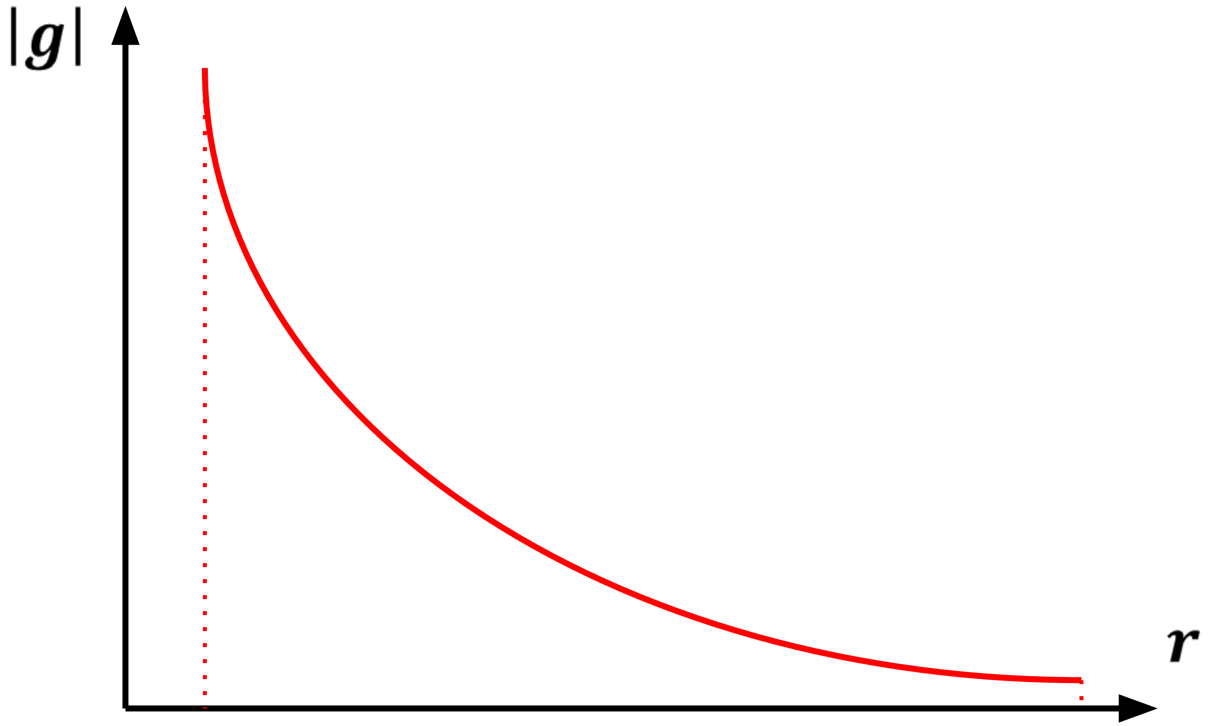


- We **define** V to be **0** at a **point infinitely** far away from the **planet's surface**.

- Any **point** closer to the **planet's surface** has a **negative value** of **potential**.

The **gravitational potential** (V) at a **point** is **equal** to the **work done** in bringing a **unit mass** from **infinity** to that **point**.

- The **area** under a g-r **graph** between **2 points** is **equal** to the **change** in **potential** between the **2 points**.



Exemplar Plot/Sketch Exam Question

Plot/Sketch Question: **Draw** a **graph** which is **neat** and **easy** for the **examiner to interpret**.

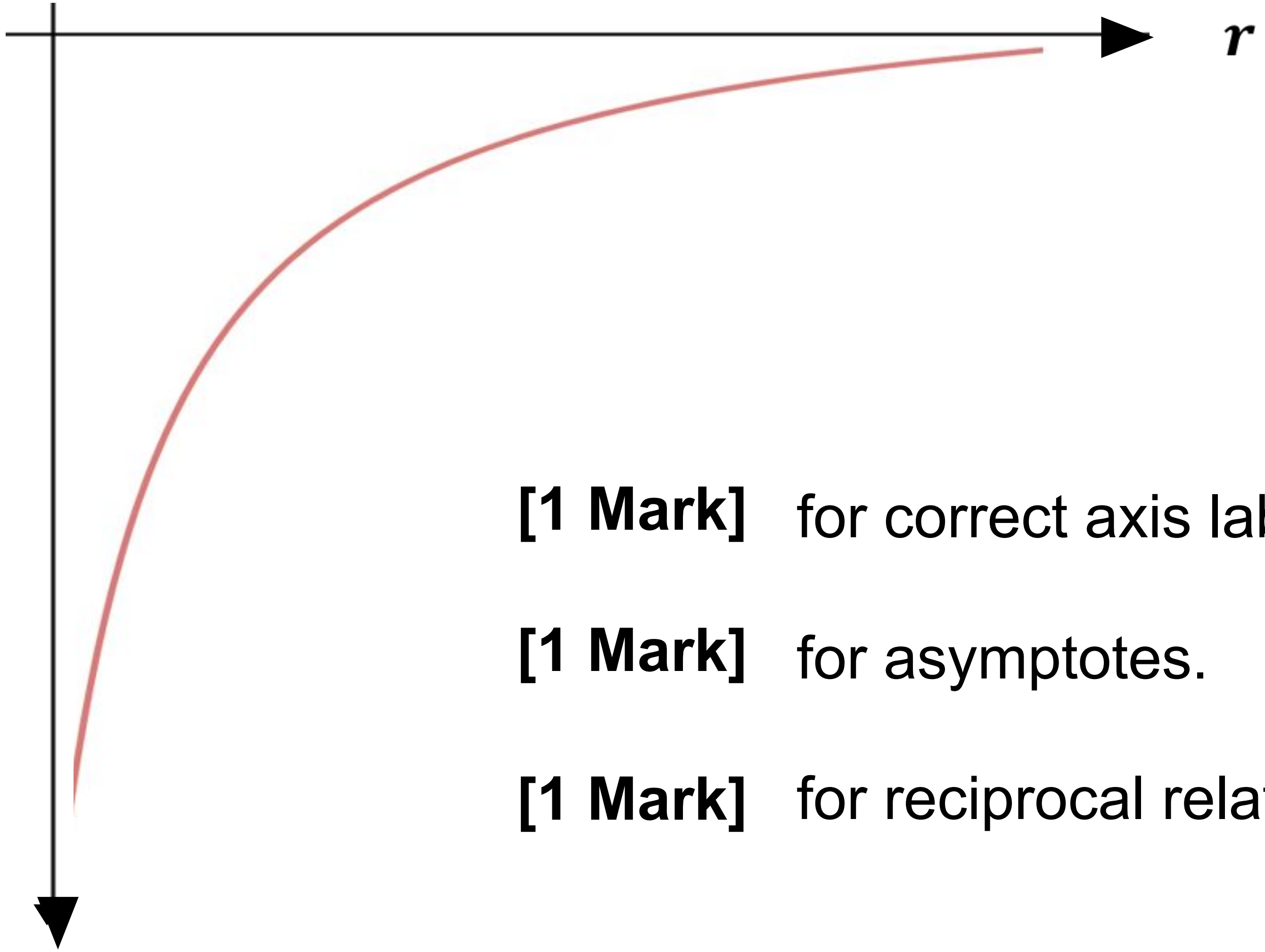
1) A rocket travels at a uniform speed away from Earth. Sketch the variation of the gravitational potential of the rocket as it gets farther away from Earth.
[3 marks]

Context: Gravitational potential. Recall equation.

Hints for **axes labels**.

Marks for **correct axes labels** and **shapes**.

$$V = -\frac{GM}{r}$$



[1 Mark] for correct axis labels.

[1 Mark] for asymptotes.

[1 Mark] for reciprocal relation.

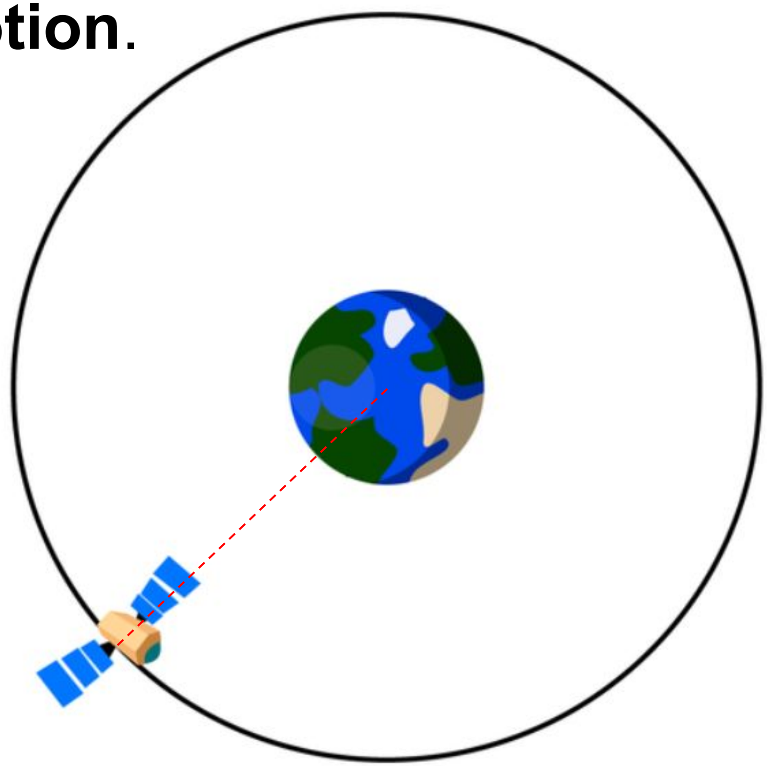
Planetary Fields

A **satellite** in **orbit** around the **Earth moves** in **circular motion**.

- Here the **centripetal force** is provided by **gravity**.

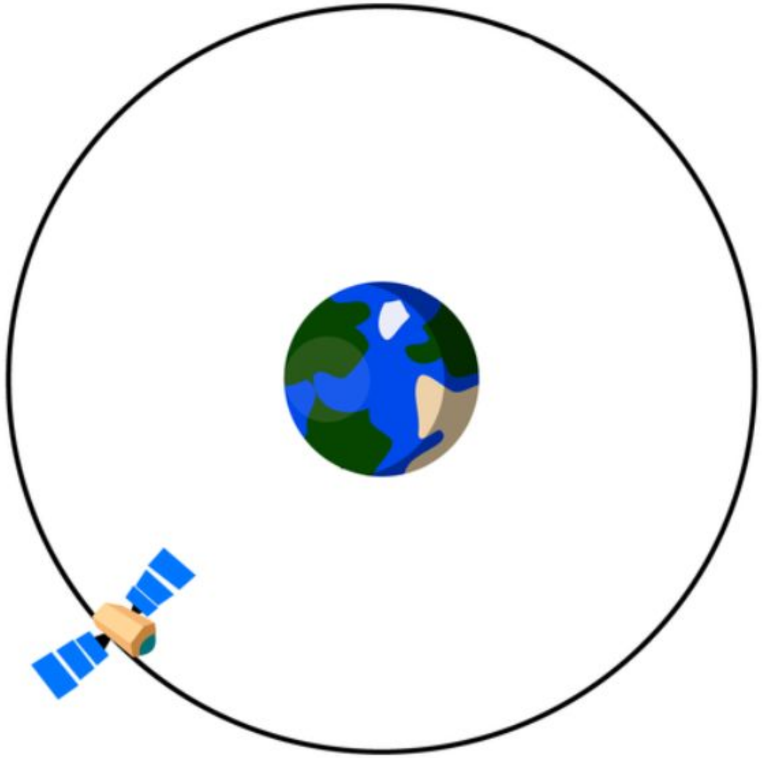
$$F_C = \frac{mv^2}{r}$$

$$F_G = -\frac{GMm}{r^2}$$



$$F_G = -\frac{GMm}{r^2}$$

$$F_C = \frac{mv^2}{r}$$

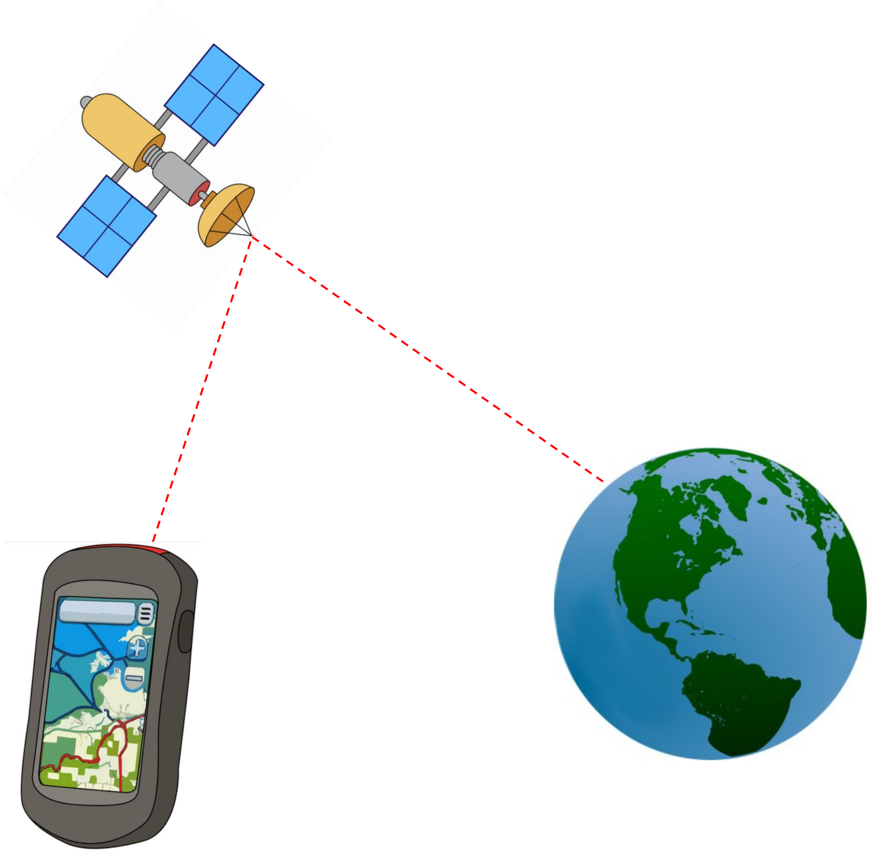


Objects can **escape** a **gravitational potential well** if they have enough **kinetic energy** (E_K).

The **escape velocity** (v_{esc}) is the **minimum velocity** that an **object** must have to **escape** a **planet's gravitational field**.

v_{esc} occurs when $E_K = W$

Satellites can be placed in **orbits** around **Earth**.



- **Geostationary orbits** have a **period** of **24 hours** around the **equator**.

Geostationary satellites remain above the **same point** of the **Earth** as the **planet spins**. They are used as **global positioning satellites** (**GPS**).

Exemplar Calculation Exam Question

Calculation Question: Mathematical question – we need to show our working.

Context: **Orbits**. Recall **Kepler's Law**.

1) Calculate the radius of orbit of a geostationary satellite.

$$G = 6.67 \times 10^{-11}\text{Nm}^2\text{s}^{-2} \qquad M_E = 5.97 \times 10^{24}\text{kg}$$

[2 marks]

Answer should be a distance with **units** of **metres** (m).

Recall **period** of **orbit**.

Indicates that there will be about 2 **steps**.

Exemplar Calculation Question Answer

Use Kepler's 3rd Law

$$r^3 = \frac{GM}{4\pi^2}T^2$$

$$T = 24\text{hr} = 24 \times 60 \times 60 = 86400\text{ s}$$

[1 Mark]

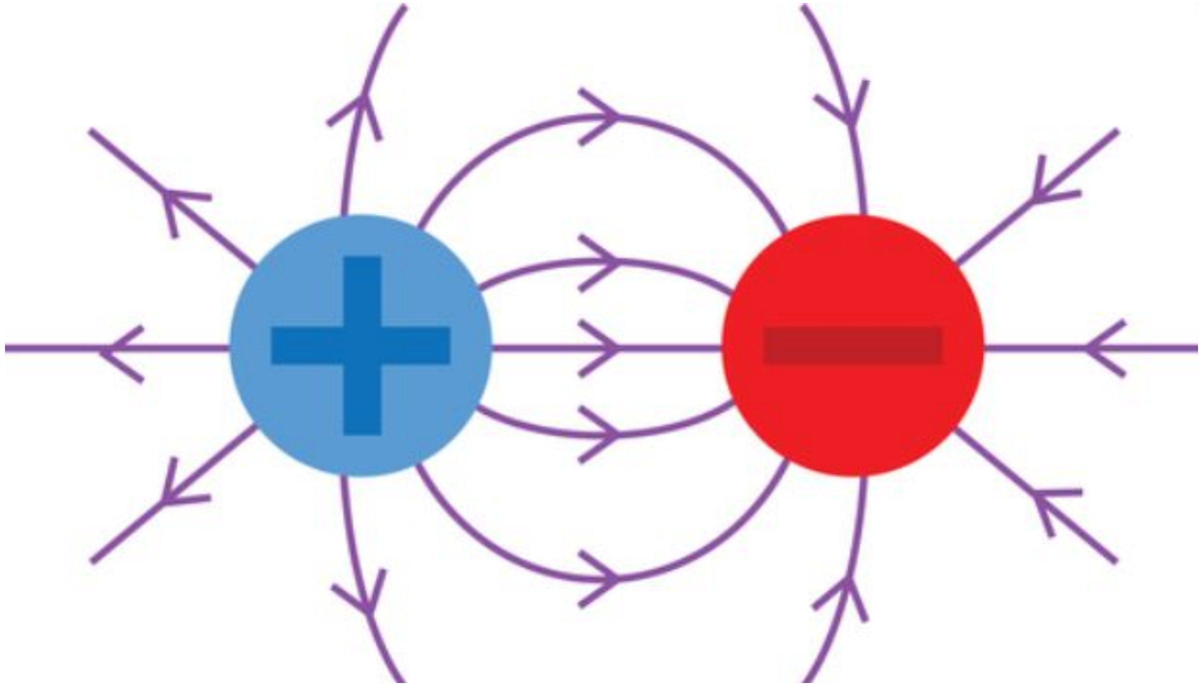
$$r^3 = \frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{4\pi^2} \times 86400^2$$

$$r^3 = 7.592 \times 10^{22}\text{m}^3$$

$$r = 4.22 \times 10^7\text{m}$$

[1 Mark]

Electric Fields



Specification Points - AQA

3.7.3.1 Coulomb's law (A-level only)

Content	Opportunities for skills development
Force between point charges in a vacuum: $F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r^2}$ Permittivity of free space, ε_0 Appreciation that air can be treated as a vacuum when calculating force between charges. For a charged sphere, charge may be considered to be at the centre. Comparison of magnitude of gravitational and electrostatic forces between subatomic particles.	**MS 0.3, 2.3** Students can estimate the magnitude of the electrostatic force between various charge configurations.

3.7.3.2 Electric field strength (A-level only)

Content	Opportunities for skills development
Representation of electric fields by electric field lines. Electric field strength. E as force per unit charge defined by $E = \frac{F}{Q}$ Magnitude of E in a uniform field given by $E = \frac{V}{d}$ Derivation from work done moving charge between plates: $Fd = Q\Delta V$ Trajectory of moving charged particle entering a uniform electric field initially at right angles. Magnitude of E in a radial field given by $E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$	**PS 1.2, 2.2 / AT b** Students can investigate the patterns of various field configurations using conducting paper (2D) or electrolytic tank (3D).

3.7.3.3 Electric potential (A-level only)

Content
Understanding of definition of absolute electric potential, including zero value at infinity, and of electric potential difference. Work done in moving charge Q given by $\Delta W = Q\Delta V$ Equipotential surfaces. No work done moving charge along an equipotential surface. Magnitude of V in a radial field given by $V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$ Graphical representations of variations of E and V with r. V related to E by $E = \frac{\Delta V}{\Delta r}$ ΔV from the area under graph of E against r.

Specification Points – OCR A

6.2.1 Point and spherical charges

Learning outcomes

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) electric fields are due to charges

(b) modelling a uniformly charged sphere as a point charge at its centre

(c) electric field lines to map electric fields

(d) electric field strength; $E = \frac{F}{Q}$.

6.2.3 Uniform electric field

Learning outcomes

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) uniform electric field strength; $E = \frac{V}{d}$

(b) parallel plate capacitor; permittivity; $C = \frac{\varepsilon_0 A}{d}$; $C = \frac{\varepsilon A}{d}$; $\varepsilon = \varepsilon_r \varepsilon_0$

(c) motion of charged particles in a uniform electric field.

6.2.2 Coulomb's law

Learning outcomes

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) Coulomb's law; $F = \frac{Qq}{4\pi\varepsilon_0 r^2}$ for the force between two point charges

(b) electric field strength $E = \frac{Q}{4\pi\varepsilon_0 r^2}$ for a point charge

(c) similarities and differences between the gravitational field of a point mass and the electric field of a point charge

(d) the concept of electric fields as being one of a number of forms of field giving rise to a force.

6.2.4 Electric potential and energy

Learning outcomes

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) electric potential at a point as the work done in bringing unit positive charge from infinity to the point; electric potential is zero at infinity

(b) electric potential $V = \frac{Q}{4\pi\varepsilon_0 r}$ at a distance r from a point charge; changes in electric potential

(c) capacitance $C = 4\pi\varepsilon_0 R$ for an isolated sphere

(d) force–distance graph for a point or spherical charge; work done is area under graph

(e) electric potential energy = $Vq = \frac{Qq}{4\pi\varepsilon_0 r}$ a distance r from a point charge Q.

Specification Points – OCR B

6.1.2 Charge and field

	Learning outcomes	Additional guidance
(a)	*Describe and explain:*	
(i)	uniform electric field $E = V/d$	*M2.3*
(ii)	the electric field of a charged object, and the force on a charge in an electric field; inverse square law for point charge	Spherically symmetrical charged conductor is equivalent to a point charge at its centre
(iii)	electrical potential energy and electric potential due to a point charge; $1/r$ relationship	
(iv)	evidence for discreteness of charge on electron	Such as the Millikan oil drop experiment HSW2, 7, 11
(vi)	similarities and differences between electric and gravitational fields.	HSW2, 8

(b) *Make appropriate use of:*

(i) the terms: charge, electric field, electric potential, equipotential surface, electronvolt

by sketching and interpreting:

(ii) graphs showing electric potential as area under a graph of electric field versus distance, graphs showing changes in electric potential energy as area under a graph of electric force versus distance between two distance values.

(iii) graphs showing force as related to the tangent of a graph of electric potential energy versus distance, graphs showing field energy versus distance, graphs showing field strength as related to the tangent of a graph of electric potential versus distance

(iv) diagrams of electric fields and the corresponding equipotential surfaces.

(c) *Make calculations and estimates involving:*

(i) for radial components

$$F_{electric} = \frac{kqQ}{r^2},\ E_{electric} = \frac{F_{electric}}{q} = \frac{kQ}{r^2}\left[k = \frac{1}{4\pi\varepsilon_0}\right]$$

(ii) $E_{electric} = -\dfrac{dV_{electric}}{dr}$,

$E_{electric} = \dfrac{V}{d}$ (for a uniform field)

(iii) electrical potential energy $= \dfrac{kQq}{r}$,

$V_{electric} = \dfrac{kQ}{r}$

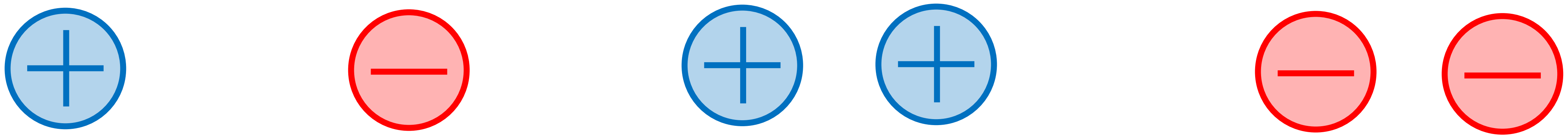
Specification Points - Edexcel

108.	understand that an electric field (force field) is defined as a region where a charged particle experiences a force
109.	understand that electric field strength is defined as $E = \frac{F}{Q}$ and be able to use this equation
110.	be able to use the equation $F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$, for the force between two charges
111.	be able to use the equation $E = \frac{Q}{4\pi\varepsilon_0 r^2}$ for the electric field due to a point charge
112.	know and understand the relation between electric field and electric potential
113.	be able to use the equation $E = \frac{V}{d}$ for an electric field between parallel plates
114.	be able to use $V = \frac{Q}{4\pi\varepsilon_0 r}$ for a radial field
115.	be able to draw and interpret diagrams using field lines and equipotentials to describe radial and uniform electric fields

Electric Fields

The **electrostatic force** acts between **charged particles**.

- **Unlike charges** have an **attractive electrostatic force**.
- **Like charges** have a **repulsive electrostatic force**.

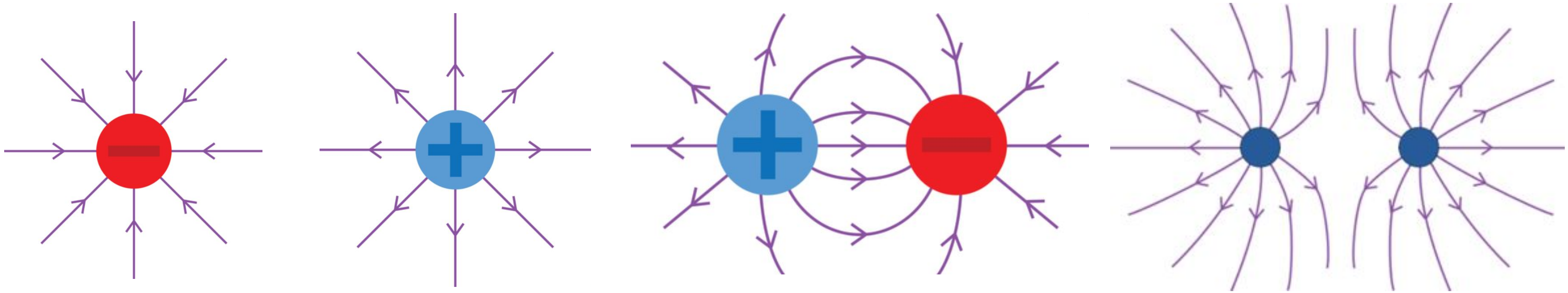


Charged particles can be treated as **point charges** with all their **charge** at their **centre**.

Electric Field Lines

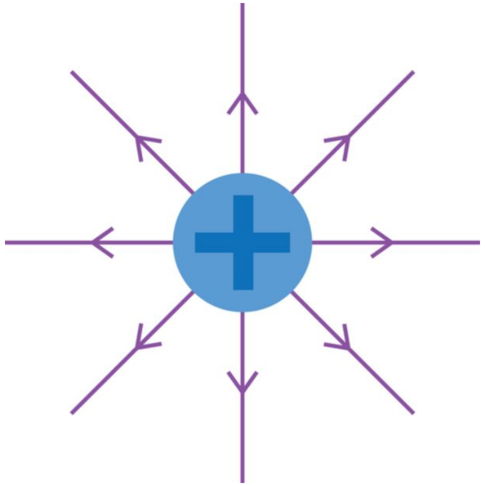
Electric fields can be **represented** by **electric field lines**.

- The **density** of these **lines represent** the **strength** of the **electric field**.
- The **direction** of these **field lines represent** the **direction** of the **force** on a **positive test charge** in the **field**.

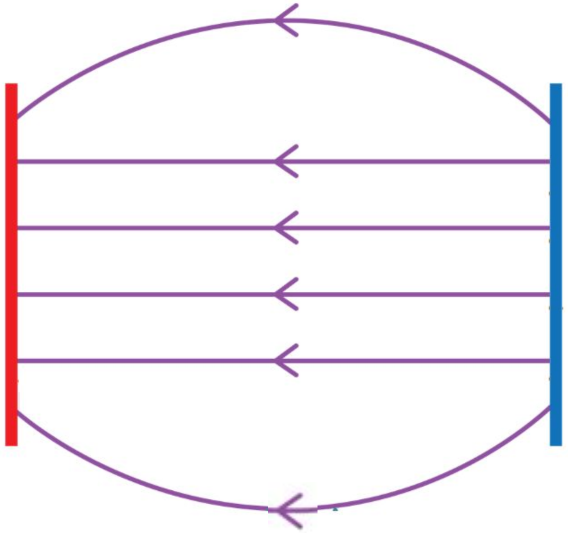


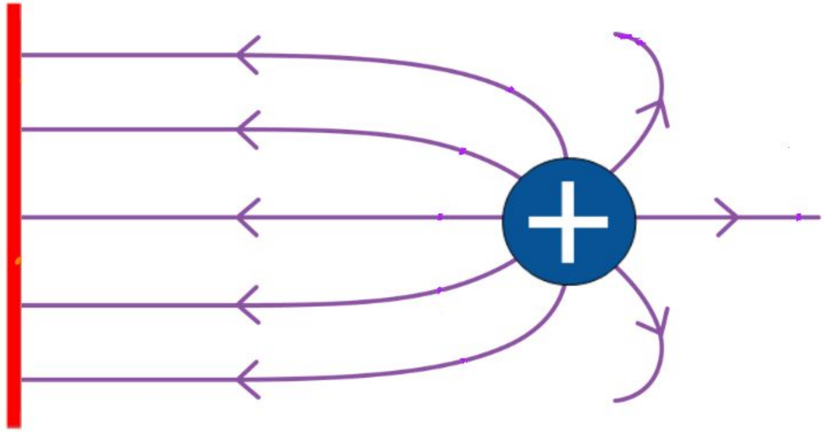
Electric Field Lines

- **Electric fields** from **point charges** are **radial**.



- **Electric fields** from **charged plates** are **uniform**.



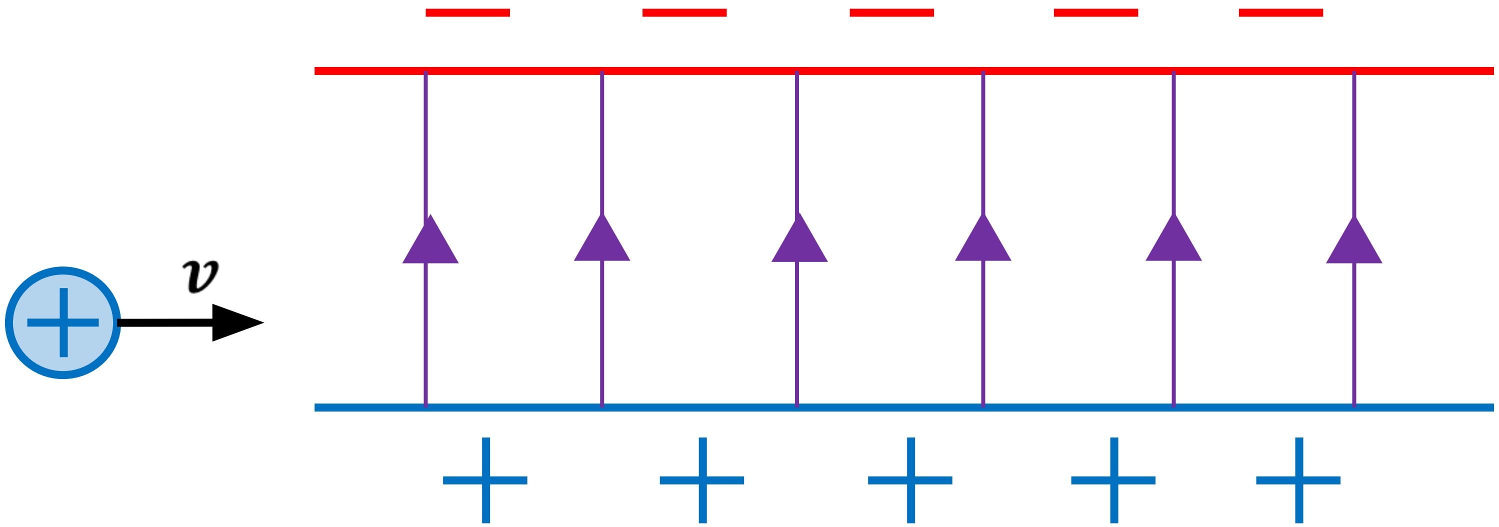


Electric Field Strength

The **strength** of an **electric field** (E) is defined as the **electrostatic force** per **unit charge** on a **positive test charge** placed in the **field**.

- A **test charge** is a **charge** small enough that it does not **noticeably** affect the **field**.
- E is a **vector** and **acts** in the **same direction** as the **electrostatic force** F.
- A **negative charge** ($-Q$) causes E to **point** in the **opposite direction**.

A **charged particle** in a **uniform electric field** will experience a **constant acceleration** due to the **electric field**.



- Once we have **determined** the **constant acceleration** we can **apply** the **SUVAT equations** to predict the **particle's motion**.

- We can **neglect** the **effect** of **gravity** as **insignificant** in **comparison**.

Exemplar Calculation Exam Question

Key information.

Answer should be a charge with **units of Coulombs** (C).

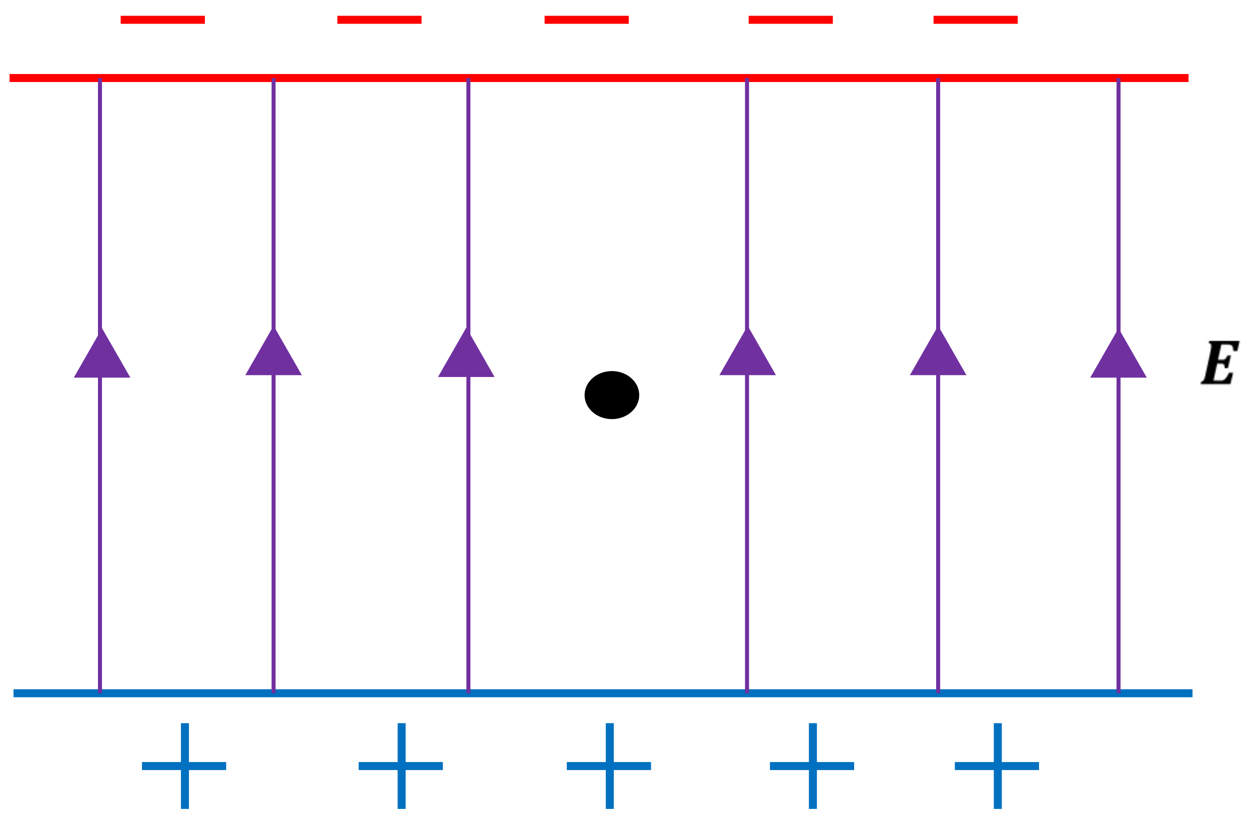
1) A spherical oil droplet of radius $\boldsymbol{r = 0.5\ \mathrm{mm}}$ has an electrostatic charge. It is suspended between 2 oppositely charged plates in a field with electric field strength $\boldsymbol{E = 5.2 \times 10^{-6}\mathrm{Vm}^{-1}}$ directed up such that the drop experiences and electrostatic force that balances its weight. Calculate the charge of the oil droplet. The density of oil is $\boldsymbol{\rho = 870\ \mathrm{kgm}^{-3}}$.

[3 marks]

Context: Recall **equation** for **electric field strength**.

Calculation Question: Mathematical question – we need to show our working.

Indicates that there will be about **3 steps** to our **calculation**.


E

Exemplar Calculation Question Answer

Write out **equation** for **electric field strength**:

Resolve forces acting on the **droplet**:

[1 Mark]

Exemplar Calculation Question Answer

Determine mass of **droplet**:

$$= 870 \times \frac{4\pi}{3}(0.5 \times 10^{-3})^3 = 4.555 \ldots \times 10^{-7}\ \text{kg}$$

[1 Mark]

Determine the **charge** of the **droplet**:

$$= 0.859\ \text{C}$$

[1 Mark]

Coulomb’s Law

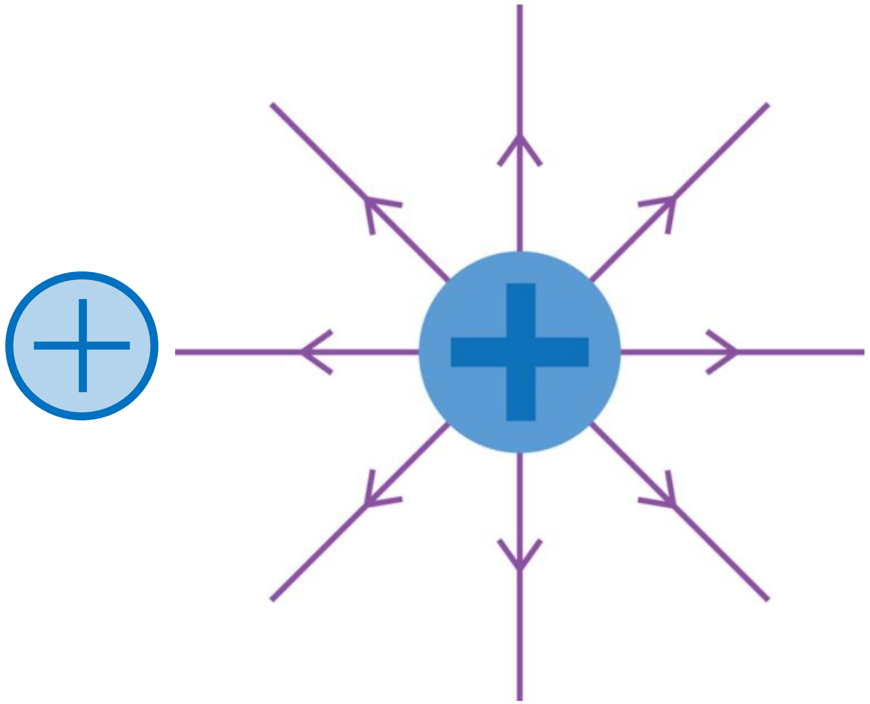
Coulomb's Law gives the **electrostatic force** (F) between **2 charges** (Q_1, Q_2).

- The **magnitude** of the **force** is **proportional** to the **product** of the **charges**.
- The **magnitude** of the **force** is **inversely proportional** to the **separation squared**.

$$F = \frac{Q_1 \times Q_2}{4\pi\varepsilon_0 r^2}$$

We can use **Coulomb's Law** to determine the **electric field strength** of a **radial field**.

$$F = \frac{Q_1 \times Q_2}{4\pi\varepsilon_0 r^2}$$



- The **electric field strength** follows an **inverse square relation**.

Properties of Electric Fields

Electric fields share some **similarities** and some **differences** with **gravitational fields**:

- **Electric fields** affect **charge** while **gravity** affects **mass**.
- **Point masses** and **point charges** both produce **radial fields**.
- **Both** provide a **force** which is **inversely proportional** to the **square** of the **distance** from **source**.
- **Gravity** is always **attractive** while the **electrostatic force** can be **attractive** or **repulsive**.
- **Electrostatic forces** can be **shielded** but **gravity** cannot be.

Exemplar Explanation Exam Question

Context: **Motion** of **charged particles**.

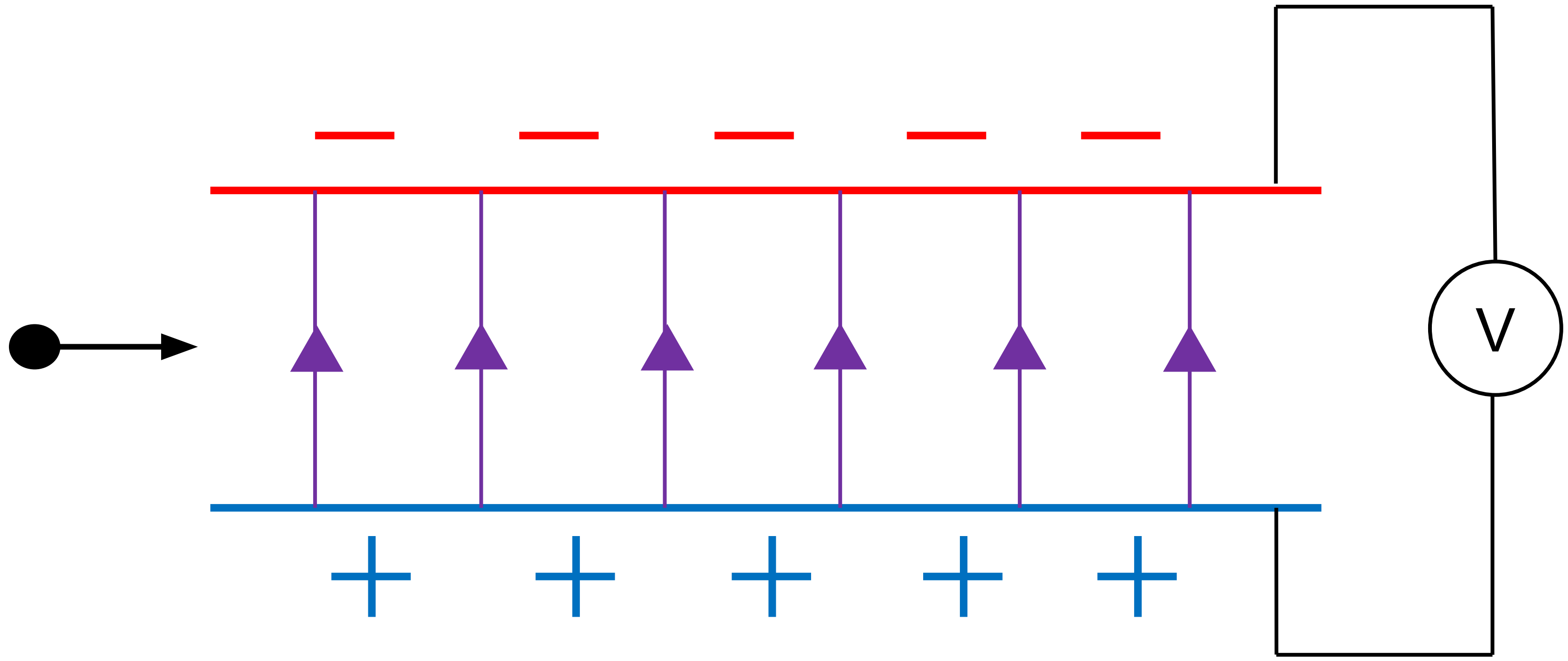
1) Charged particles are directed from radioactive isotopes through a detector consisting of 2 parallel oppositely charged plates. When a particle collides with the plate, it can be detected as a change in voltmeter reading as its charge is added to the plate. Describe and explain the path of a proton and an electron entering the detector at the same time and travelling at the same initial horizontal speed parallel to the plates and discuss how the detector would be able to distinguish between them.

[5 marks]

Include both for **full marks**!

Explanation Question: **Bullet-point** format. **Discussion** may require **comparison** between **particles**.

Indicates that we will need to mention about 5 **points**.


V

- Electron and proton have equal and opposite charges so will experience equal and opposite vertical forces travelling between plates. **[1 Mark]**

- Each particle is attracted to the oppositely charged plate and the charge on this plate is reduced when the electron/proton collides with it. **[1 Mark]**

- Change in charge of plate is equal for both particles which causes same fluctuation in the voltmeter reading. **[1 Mark]**

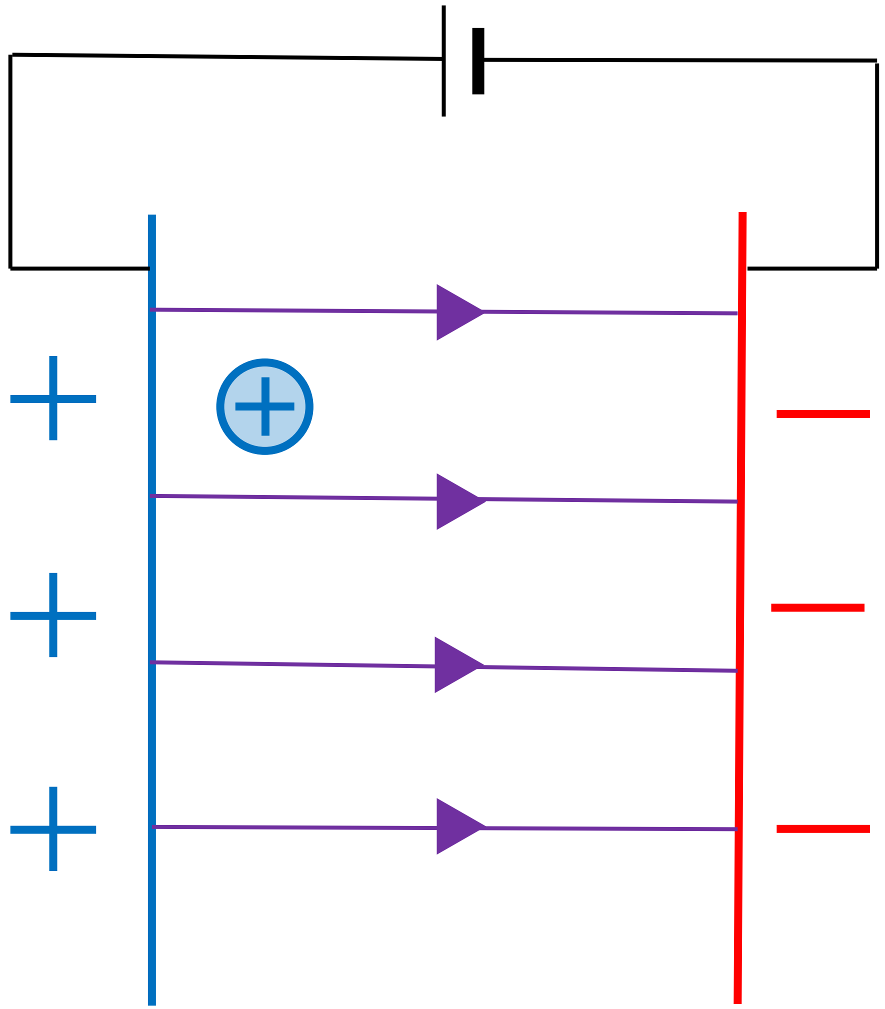
- Proton has much higher mass than electron so magnitude of its vertical acceleration is much lower.

[1 Mark]

- Therefore electron collides with detector plate first (corresponding to first signal) and proton collides with plate second (corresponding to second signal). **[1 Mark]**

Electric Potential

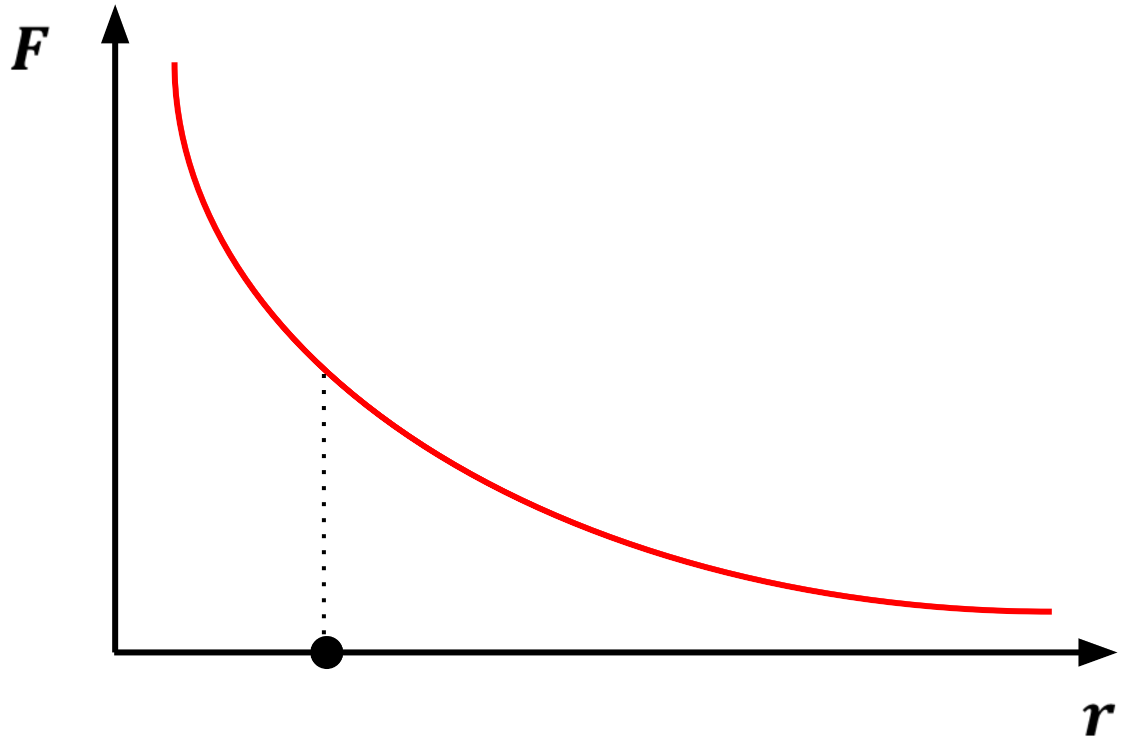
A **charged particle** moving between **charged plates** along **electric field lines** has **work** being **done** on it by the **field**.



- The **electric field strength** is equal to the **voltage** divided by **distance** between the **plates**.

The **electric potential** (V) at a **point** is defined as the **work done** per **unit charge** in bringing a **positive charge** from **infinity** to that **point**.

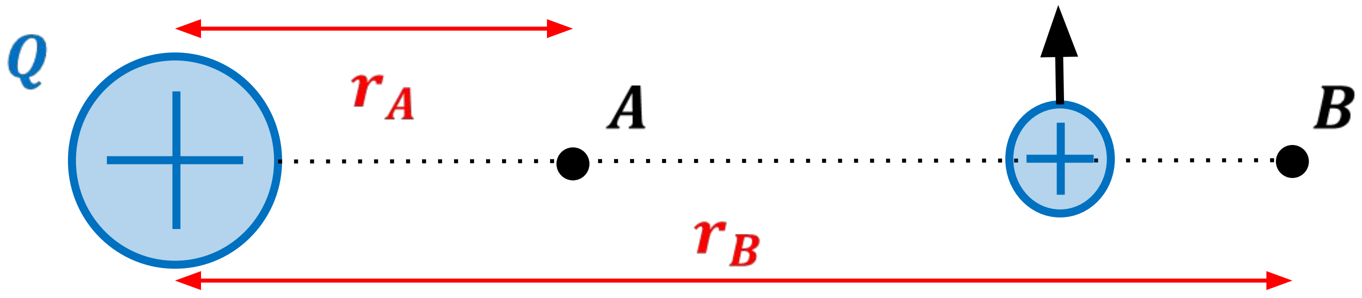
- The **work done** (W) is **equal** to the **area** under the **force-distance graph**.



- This is **equal** to the **electric potential energy** of a **charged particle** in the **field**.

$$W = \frac{Q \times q}{4\pi\varepsilon_0 r}$$

- We can use the **equation** for **electric potential** to determine the **potential difference** between **2 points** in an **electric field**.



- No **work is done** on a **charged particle** travelling **perpendicular** to the **electric field**.

Exemplar Calculation Exam Question

Key data we will **require**.

Context: **Electric fields**. **Force** is **variable** over **distance** so **solve** by **conserving energy**.

1) An electron travels towards a negatively charged sphere of total charge $Q = -1.1\ \mathrm{nC}$ at a velocity of $v = 4200\ \mathrm{kms^{-1}}$ from a distance at which the electric field of the sphere can be assumed to be zero. Determine the distance away from the sphere that the electron will halt due to the Coulomb force of repulsion from the sphere.
The mass of an electron is $m_e = 9.11 \times 10^{-31}\ \mathrm{kg}$, charge of electron $q_e = 1.6 \times 10^{-19}\mathrm{C}$ and permittivity of free space $\varepsilon_0 = 8.85 \times 10^{-12}\mathrm{C^2N^{-1}m^{-2}}$.

[3 marks]

Calculation Question: Mathematical question – we need to show our working.

Indicates that there will be about **3 steps**.

Exemplar Calculation Question Answer

Calculate initial K.E of electron

$$\mathrm{EK} = \frac{1}{2}mv^2$$

$$\mathrm{EK} = \frac{1}{2} \times (9.11 \times 10^{-31}) \times \left(4200 \times 10^3\right)^2$$

$$\mathrm{EK} = 8.03502 \times 10^{-18}\ \mathrm{J}$$

[1 Mark]

Exemplar Calculation Question Answer

Calculate electric potential energy

$$W = \frac{Qq_e}{4\pi\epsilon_0 r}$$

$$W = \frac{(-1.1 \times 10^{-9}) \times (-1.6 \times 10^{-19})}{4\pi \times (8.85 \times 10^{-12})r}$$

$$W = \frac{1.582.. \times 10^{-18}}{r}$$

[1 Mark]

Exemplar Calculation Question Answer

Use conservation of energy

$$\Delta W = \Delta KE$$

$$\frac{1.582.. \times 10^{-18}}{r} = 8.03502 \times 10^{-18}$$

$$r = 0.197 \text{ m}$$

[1 Mark]

MINI MOCK PAPER

1. Explain what is meant by the gravitational potential at a point in a gravitational field.

[2 marks]

- The work done per unit mass

[1 Mark]

- to move an object **from** that point **to** infinity.

[1 Mark]

2. In 2003 NASA launched the "Opportunity" Mars Exploration Rover to investigate potential water sources through characterisation of rock and soil. Describe and explain, by comparison of the gravitational potential on Earth and Mars, how the gravitational potential experienced by Opportunity varied on the journey from Earth to Mars.

$M_{Earth} = 5.97 \times 10^{24}$ kg $\quad R_{Earth} = 6371$ km

$M_{Mars} = 6.39 \times 10^{23}$ kg $\quad R_{Mars} = 3390$ km

$G = 6.67 \times 10^{-11}$ m^{3}kg^{-1}s^{-2}

[5 marks]

- Gravitational potential on Earth

$$V = \frac{-GM_E}{R_E} = \frac{-6.67 \times 10^{-11} \times 5 \cdot 97 \times 10^{24}}{6371 \times 10^3}$$ **[1 Mark]**

$$V = -6.25 \times 10^7 \text{ Jkg}^{-1}$$

- Gravitational potential on Mars

$$V = \frac{-GM_M}{R_M} = \frac{-6.67 \times 10^{-11} \times 6 \cdot 39 \times 10^{23}}{3390 \times 10^3}$$ **[1 Mark]**

$$V = -1.26 \times 10^7 \text{ Jkg}^{-1}$$

- Gravitational potential on Mars is approximately 20% of that on Earth.

- Leaving the surface of the Earth, the gravitational potential increases towards zero since $V \propto \frac{1}{r}$. **[1 Mark]**

- As the gravitational fields from Earth and Mars add up, the gravitational potential reaches a non-zero maximum more than halfway to Mars. **[1 Mark]**

- As Opportunity approaches Mars, the gravitational potential decreases towards 20% of the value on the Earth's surface.

[1 Mark]

1.

2.

3. The nucleus of a lead-208 atom contains 82 protons and 126 neutrons. Calculate the force experienced by an electron orbiting $\mathbf{6.4 \times 10^{-11}\ m}$ from the surface of the nucleus. State any assumptions you make.

[5 marks]

$$\boldsymbol{e} = \mathbf{1.6 \times 10^{-19}\ C}$$

$$\boldsymbol{\varepsilon_0} = \mathbf{8.85 \times 10^{-12}\ Fm^{-1}}$$

- Assume that the nucleus and the electron are both point charges.

[1 Mark]

- Assume that the other electrons do not exert any force.

[1 Mark]

- Charge on the lead nucleus

$$Q = 82 \times q = 82 \times 1.6 \times 10^{-19} = 1.312 \times 10^{-17}\ \text{C}$$

[1 Mark]

- Coulomb's Law:

$$F = \frac{Qq}{4\pi\varepsilon_0 r^2} = \frac{1.312\times10^{-17}\times-1.6\times10^{-19}}{4\pi\times8.85\times10^{-12}\times(6.4\times10^{-11})^2}$$

[1 Mark]

$$F = -4.6 \times 10^{-6}\ \text{N}$$

[1 Mark]