A LEVEL PHYSICS 9702 · A LEVEL · TOPIC 13 · ~5 MIN READ

Gravitational fields

Gravitational field strength, Newton's law of gravitation, $g = GM/r^2$, gravitational potential and potential energy, circular orbits, Kepler's third law from first principles, and geostationary satellites.

Field lines | Field strength g | Newton's law $F = GMm/r^2$ | $g = GM/r^2$ | Potential $\varphi = -GM/r$ | Potential energy | Orbits | $T^2 \propto r^3$

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Paper tag = **where it is examined** DATA & FORMULAE given in the exam C1 A1 B1 how marks are awarded

highlight = comes up again and again Test yourself at the end

IN 30 SECONDS

- **A gravitational field is a region where a mass feels a force.** Field strength g = F/m (force per unit mass).
- **Newton's law:** $F = GMm/r^2$ between point masses; outside a uniform sphere, treat its mass as concentrated at the centre.
- **Potential $\varphi = -GM/r$** is the work done per unit mass bringing a small mass from infinity to that point. It is negative because gravity is attractive.
- **Orbits:** gravity provides the centripetal force: $GMm/r^2 = mv^2/r$, so $v^2 = GM/r$ and $T^2 = (4\pi^2/GM)r^3$.

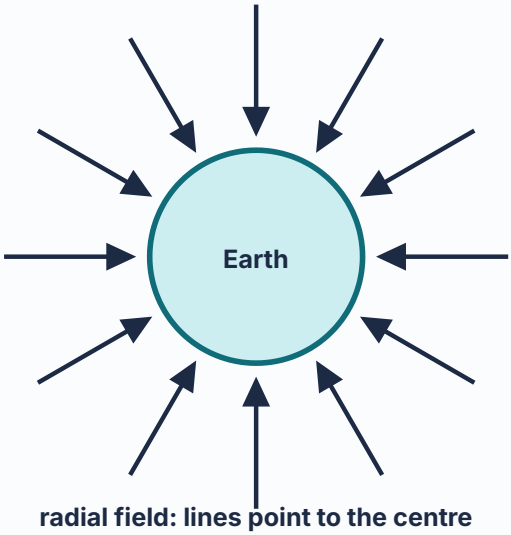
BY THE END YOU CAN

- Understand the gravitational field and field lines, and define field strength g = F/m.
- Recall and use $F = GMm/r^2$ and $g = GM/r^2$.
- Define and use gravitational potential $\varphi = -GM/r$ and potential energy $EP = -GMm/r$.
- Analyse circular orbits, including geostationary orbits, using gravity as the centripetal force.

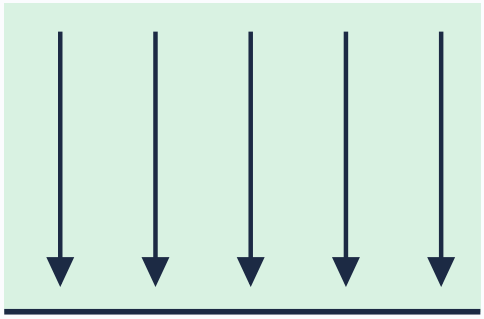
1 Field and force

Field strength

Gravitational field strength — the gravitational force per unit mass at a point: g = F/m.



radial field: lines point to the centre

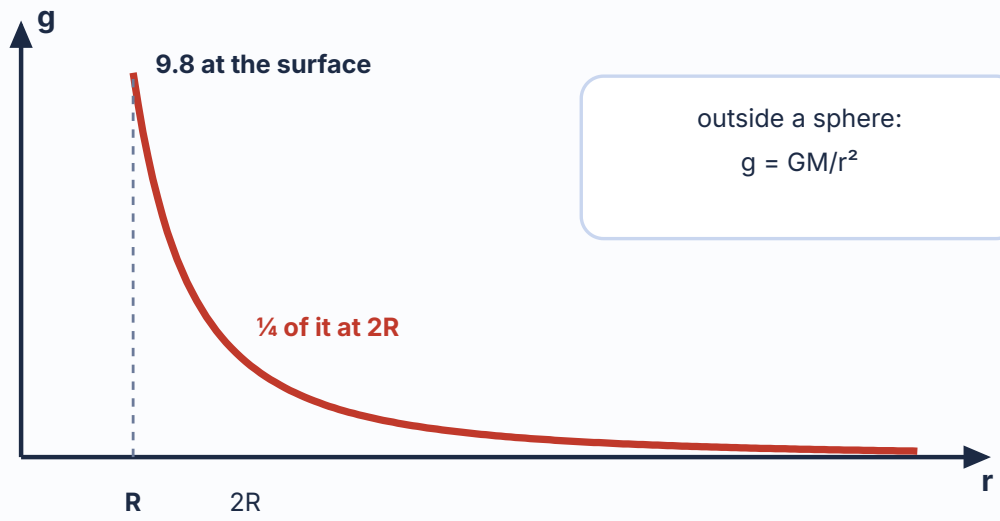


near the surface: almost uniform
(parallel, equally spaced)

Radial field lines point towards the centre; near the surface the field is almost uniform.

$$F = GMm/r^2 \; ; \; g = GM/r^2$$

$G = 6.67 \times 10^{-11}$ N m^2 kg^{-2} (r measured from the centre)



outside a sphere:

$g = GM/r^2$

Outside the planet, g falls as $1/r^2$.

WORKED EXAMPLE

Calculate g at the Earth's surface ($M = 5.97 \times 10^{24}$ kg, $R = 6.37 \times 10^6$ m).

1. $g = GM/R^2 = 6.67 \times 10^{-11} \times 5.97 \times 10^{24}/(6.37 \times 10^6)^2$ C1
2. **$g = 9.81$ N kg^{-1}** A1

COMMON MISTAKE

Using the height above the surface for r. r is the distance from the centre: r = R + h.

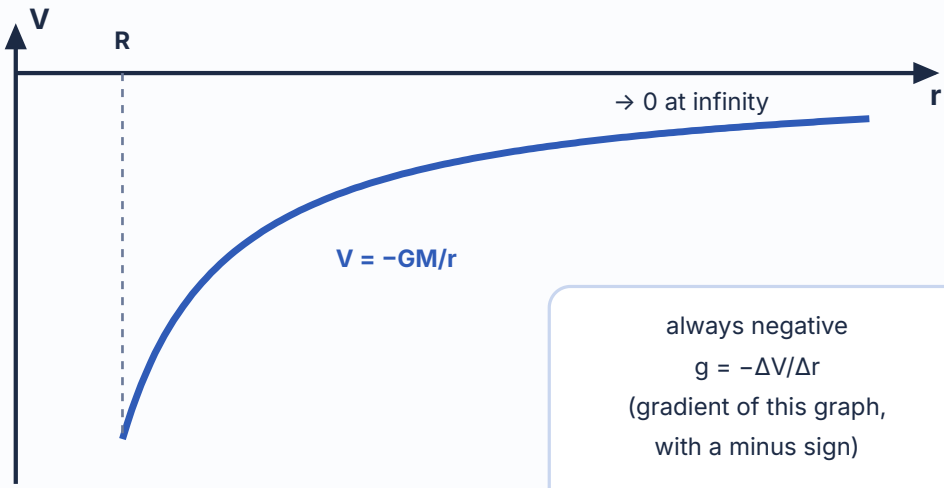
2 Potential

$\varphi = -GM/r$

Gravitational potential — the work done per unit mass in bringing a small test mass from infinity to the point.

$$\varphi = -GM/r \; ; \; EP = m\varphi = -GMm/r$$ DATA & FORMULAE

$$\Delta EP = m \, \Delta\varphi$$



φ rises towards zero as r increases. Field strength is minus the gradient of φ.

- **Why negative?** Potential is zero at infinity, and work is done by the field as a mass falls in, so potential is lower (more negative) closer in.
- **mgh** only works where g is constant (near the surface). Over large distances use Δφ.

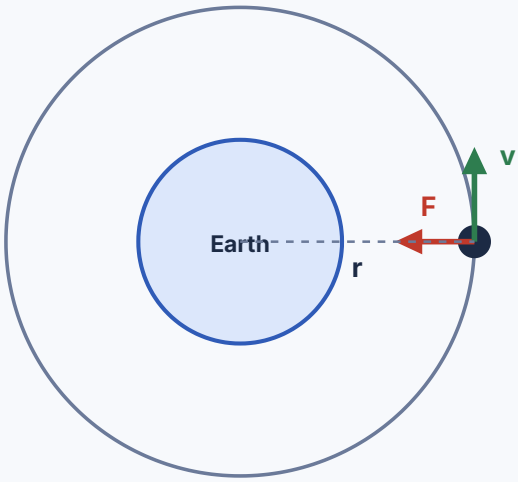
WORKED EXAMPLE

Find the energy needed to raise a 1000 kg satellite from the Earth's surface to a point at r = 2R.

1. $\Delta\varphi = GM/R - GM/(2R) = GM/(2R) = 3.13 \times 10^{7}$ J kg^{-1} C1 C1
2. **$\Delta E = m\Delta\varphi = 3.1 \times 10^{10}$ J** A1

3 Orbits

Circular orbits



$GMm/r^2 = mv^2/r$
$\Rightarrow v^2 = GM/r$
$T^2 = (4\pi^2/GM)\, r^3$
geostationary:
$T = 24$ h, $r \approx 4.2 \times 10^{7}$ m

Gravity provides the centripetal force for a circular orbit.

Gravity provides the centripetal force for a circular orbit.

$$GMm/r^2 = mv^2/r \Rightarrow v = \sqrt{(GM/r)} \; ; \; T^2 = (4\pi^2/GM)\, r^3$$

the orbit doesn't depend on the satellite's mass

WORKED EXAMPLE

A satellite orbits at $r = 7.0 \times 10^6$ m. Find its speed and period.

1. $v = \sqrt{(GM/r)} = \sqrt{(6.67 \times 10^{-11} \times 5.97 \times 10^{24}/7.0 \times 10^6)}$ = **7.5 km s^{-1}** C1 A1
2. **$T = 2\pi r/v = 5.8 \times 10^3$ s (about 97 min)** A1

Geostationary satellites

- **Three conditions:** period 24 hours, orbit above the equator, moving in the same direction as the Earth rotates (west to east). It stays above one point, so dishes don't need to track it.

WORKED EXAMPLE

Show that the radius of a geostationary orbit is about 4.2×10^7 m.

1. $r^3 = GMT^2/(4\pi^2)$ with $T = 86\,400$ s C1
2. **$r = (6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 86\,400^2/4\pi^2)^{1/3} = 4.22 \times 10^7$ m** A1 **(height $\approx 3.6 \times 10^7$ m)**

COMMON MISTAKE

Stating only "period 24 h" for geostationary. You need all three conditions: equatorial, same direction of rotation, 24 h period. The 2024 Paper 4 report noted incomplete lists.

LINKING QUESTION

The maths of circular motion is in Motion in a circle; electric fields follow the same inverse-square pattern in Electric fields.

Test yourself — cover the answers first

QUICK CHECK

1. Define gravitational field strength.
2. Why is gravitational potential negative?
3. How does g vary with r outside a planet?
4. State the period of a geostationary satellite.
5. Does the orbital speed depend on the satellite's mass?

EXAM-STYLE

6. At what height above the surface is g a quarter of its surface value?
7. Show that $T^2 \propto r^3$ for circular orbits.
8. The Moon's mass is 7.35×10^{22} kg and radius 1.74×10^6 m. Find g on its surface.

Show answers

1. force per unit mass
2. it is zero at infinity and work is done by the field as masses come together
3. $g \propto 1/r^2$
4. 24 hours
5. no
6. $r = 2R$, so $h = R = 6.37 \times 10^6$ m
7. $GMm/r^2 = m(2\pi r/T)^2/r \Rightarrow T^2 = (4\pi^2/GM)r^3$
8. $g = GM/R^2 = 1.62$ N kg^{-1}

Stuck on a question?

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