

13.3 Gravitational field of a point mass

Name: _____ Class: _____ Date: _____

Total: 26 marks

KEY WORDS gravitational field 重力场 • gravitational field strength 重力场强度 • field line 场线
 • newton's law of gravitation 万有引力定律 • mass 质量

Objective

Build the skills to answer exam questions on the **gravitational field of a point mass** — the equation $g = GM/r^2$.

You must be able to:

- derive and use $g = \frac{GM}{r^2}$
- describe how g varies with distance
- explain why g is nearly constant near the Earth's surface

1 Worked examples

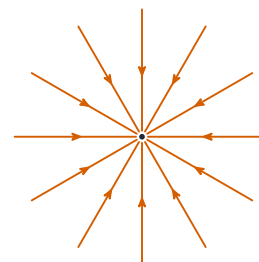
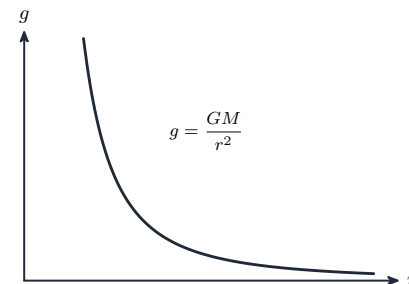
Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ Field of a point mass

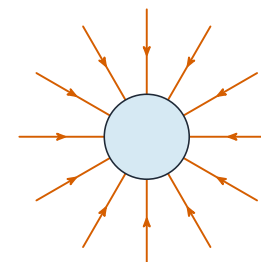
Put $F = \frac{GMm}{r^2}$ into $g = F/m$:

$$g = \frac{GM}{r^2}.$$

So g falls off as an **inverse square** of distance:



point mass



uniform sphere

Field lines around a point mass

■ Nearly constant near the surface

Rising a height $h \ll R$ changes r from R to $R + h$, but $(R + h)/R \approx 1$, so g barely changes — it is effectively constant in a lab.

2 Practice

Now apply the methods above.

2.1 Write the equation for the gravitational field strength g due to a point mass. [1]

2.2 State how g varies with distance r from a point mass. [1]

2.3 At the Earth's surface $g = 9.8 \text{ N kg}^{-1}$. Find g at a distance of $2R$ from the centre (a height R above the surface). [2]

2.4 Explain why g is **nearly constant** near the Earth's surface. [1]

3 Exam-style questions

3.1 At **twice** the distance from a point mass, g becomes: [1]

- | | |
|---|---|
| A | B |
| C | D |
- A** twice as large
B half as large
C one quarter as large
D four times as large

3.2 The Moon has mass $7.3 \times 10^{22} \text{ kg}$ and radius $1.7 \times 10^6 \text{ m}$. Calculate g at its surface. ($G = 6.67 \times 10^{-11}$.) [3]

3.3 Derive $g = \frac{GM}{r^2}$ from Newton's law of gravitation and $g = F/m$. [2]

3.4 A planet has the same mass as Earth but **twice** the radius. State its surface g as a fraction of Earth's. [1]

3.5 On the axes, **sketch** how the gravitational field strength g of a planet varies with distance r from its centre, for r from the surface ($r = R$) out to $r = 4R$. Mark the surface value g_0 . [2]

3.6 A planet of mass M and radius R has a gravitational field strength of g_0 at its surface. A satellite of mass m orbits it in a circle of radius r , where $r > R$.

(a) **State** why the gravitational field strength inside a **uniform** sphere behaves differently from the field outside it. [1]

(b) **Show that** the orbital speed of the satellite is $v = \sqrt{\frac{GM}{r}}$, and hence that it does **not** depend on the mass of the satellite. [3]

(c) **Derive** an expression for the period T of the orbit in terms of G , M and r , and state the name of the law it expresses. [3]

(d) A geostationary satellite orbits the Earth once every 24 hours. Taking $GM = 4.00 \times 10^{14} \text{ m}^3 \text{ s}^{-2}$, **determine** the radius of its orbit. [3]

(e) **State** two further conditions a geostationary orbit must satisfy, beyond having the right period. [2]