A-LEVEL PHYSICS • EXERCISE SHEET

13.2 Gravitational force between point masses

Name: _____ Class: _____ Date: _____ **Total: 16 marks**

KEY WORDS orbit 轨道 • period 周期 • satellite 卫星 • centripetal force 向心力 • geostationary 地球同步

Objective

Build the skills to answer exam questions on **Newton's law of gravitation** and orbits.

You must be able to:

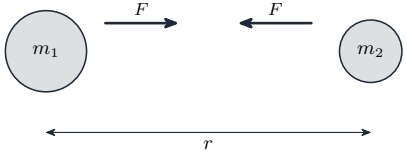
- use $F = \dfrac{Gm_1m_2}{r^2}$ and treat a sphere as a point mass
- analyse **circular orbits** (gravity provides the centripetal force)
- describe a **geostationary orbit**

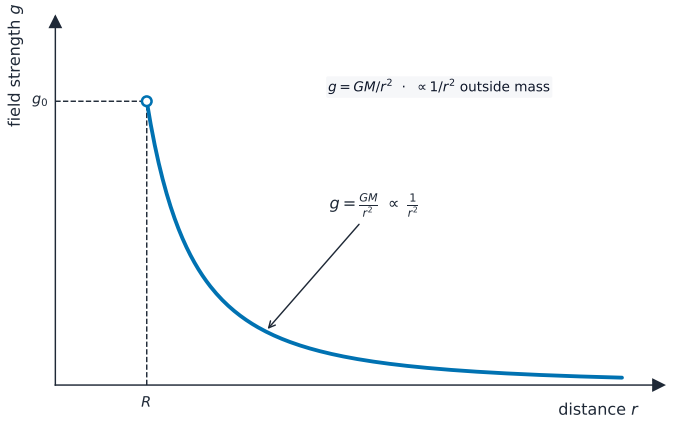
1 Worked examples

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.

■ Newton's law of gravitation

Two point masses attract with **equal, opposite** forces along the line joining them:





Gravitational field strength against distance

$$F = \frac{Gm_1m_2}{r^2}, \qquad G = 6.67 \times 10^{-11}\ \text{N m}^2\,\text{kg}^{-2}.$$

A uniform sphere acts as a **point mass at its centre** for points outside it.

■ Circular orbits

For a satellite, gravity **is** the centripetal force:

$$\frac{GMm}{r^2} = \frac{mv^2}{r} = mr\omega^2 \Rightarrow T^2 = \frac{4\pi^2 r^3}{GM}.$$

A **geostationary** satellite: period **24 h**, orbits **west→east** above the **equator**, staying over one point on Earth.

2 Practice

Now apply the methods above.

2.1 State **Newton's law of gravitation**. [2]

2.2 State the value and unit of the gravitational constant G. [1]

2.3 Two 1000 kg masses are 2.0 m apart. Find the gravitational force between them. [2]

2.4 State **two** features of a **geostationary** orbit. [2]

3 Exam-style questions

3.1 If the distance between two masses is **doubled**, the gravitational force becomes: [1]

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

3.2 Calculate the gravitational field strength at the Earth's surface. ($M = 6.0 \times 10^{24}$ kg, $R = 6.4 \times 10^{6}$ m, $G = 6.67 \times 10^{-11}$.) [3]

3.3 A satellite moves in a circular orbit of radius r around a planet of mass M. Show that gravity provides the centripetal force, and derive an expression linking the orbital **period** T to r. [4]

3.4 State why a **geostationary** satellite must orbit directly above the **equator**. [1]

Solutions

Each answer shows the steps, then the **result**.

2.1

- the gravitational force between two **point masses** is **proportional to the product of the masses**
- and **inversely proportional to the square of their separation**

2.2

- $G = 6.67 \times 10^{-11}\ \text{N m}^2\,\text{kg}^{-2}$

2.3

- $F = Gm_1m_2/r^2$

$$F = \frac{(6.67 \times 10^{-11}\ \text{N m}^2\,\text{kg}^{-2})(1000\ \text{kg})(1000\ \text{kg})}{(2.0\ \text{m})^2} = \mathbf{1.67 \times 10^{-5}}\ \text{N}$$

2.4

- any two: period of **24 h**; orbits **west to east**; stays **above the equator**; appears fixed over one point on Earth

3.1 C

- $F \propto 1/r^2$, so doubling r makes F **one quarter**
- **A** would be $1/r$; **B** is twice as far so half the force; **D** is four times larger

3.2

- $g = GM/R^2$

$$g = \frac{(6.67 \times 10^{-11}\ \text{N m}^2\,\text{kg}^{-2})(6.0 \times 10^{24}\ \text{kg})}{(6.4 \times 10^{6}\ \text{m})^2} = \mathbf{9.8}\ \text{N kg}^{-1}$$

3.3

- gravity provides the centripetal force: $GMm/r^2 = mv^2/r$
- $v = 2\pi r/T$

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

- $T^2 = 4\pi^2 r^3/(GM)$

3.4

- its orbital plane must contain the **Earth's centre**; only an equatorial orbit keeps it over a **fixed point** as the Earth spins