

13.1 Gravitational field

Name: _____ Class: _____ Date: _____

Total: 20 marks

KEY WORDS gravitational field 重力场 • field line 场线 • gravitational field strength 重力场强度
• force 力 • mass 质量

Objective

Build the skills to answer exam questions on the **gravitational field** — its definition and field lines.

You must be able to:

- define **gravitational field strength** as force per unit mass
- represent a gravitational field with **field lines**

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.

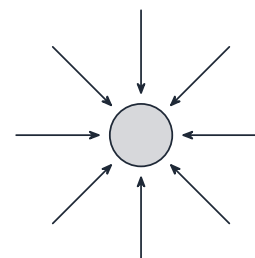
■ Field strength

A **gravitational field** is a region where a mass feels a force. The **field strength** is the force per unit mass on a small test mass:

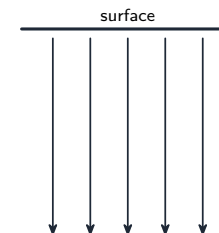
$$g = \frac{F}{m} \quad (\text{N kg}^{-1}).$$

It is a **vector**, pointing towards the source mass (the same value as the free-fall acceleration).

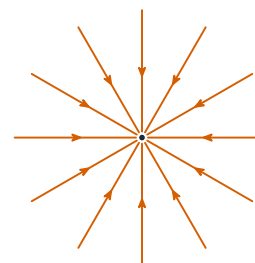
■ Field lines



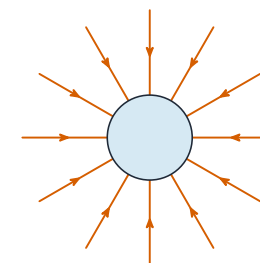
(a) radial field



(b) uniform field



point mass



uniform sphere

The radial gravitational field of a sphere

- around a **point mass** / **sphere**: **radial**, pointing **inwards**;
- near a surface (small region): **uniform** — parallel, equally spaced, pointing down.

Closer lines → stronger field.

2 Practice

Now apply the methods above.

2.1 Define **gravitational field strength**.

[1]

2.2 State the unit of gravitational field strength.

[1]

2.3 State what a gravitational **field line** represents. [1]

2.4 State the shape of the gravitational field around a **point mass**. [1]

3 Exam-style questions

3.1 Gravitational field strength is equal to: [1]

- **A** force $\times$ mass
- **B** force $\div$ mass
- **C** mass $\div$ force
- **D** mass $\times$ acceleration

3.2 A mass of 2.0 kg experiences a gravitational force of 19.6 N. Find the **gravitational field strength**. [2]

3.3 Explain what **closer** field lines indicate. [1]

3.4 Sketch the gravitational field lines (a) around a point mass and (b) near a flat surface. [2]

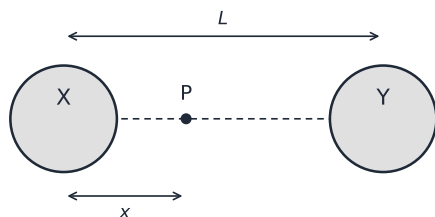
3.5 A point mass M sits at the origin. Point P is a distance x from it.

(a) **Define** the **gravitational field** at a point. [1]

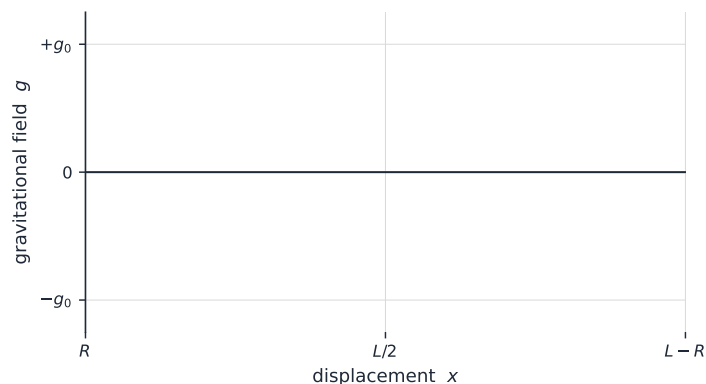
(b) By considering the force on a test mass m placed at P, **derive** an expression for the gravitational field strength g at P in terms of M and x . State the meaning of any other symbol you use. [2]

(c) Point Q lies on the **opposite** side of the mass from P, at a distance $\frac{x}{2}$ from it. **Compare** the gravitational field at Q with the field at P. [2]

(d) Two identical uniform spheres X and Y, each of radius R , have their centres a distance L apart. Point P now lies on the line joining their centres, a displacement x from the centre of X. The gravitational field strength at the surface of each sphere is g_0 .



On the axes below, **sketch** how the field g at P varies with x , from $x = R$ to $x = L - R$. Take the direction from X towards Y as positive. [3]



(e) **Explain** why the field is zero at the midpoint, even though neither sphere has been removed. [2]

Solutions

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

2.1

- the **gravitational force per unit mass** on a small test mass at that point ($g = F/m$)

2.2

- N kg^{-1}

2.3

- the **direction of the gravitational force** on a (test) mass at that point

2.4

- radial**, pointing **inwards** towards the mass

3.1 B

- $g = F/m$, so field strength is **force** $\div$ **mass**
- A** is force; **C** is GMm/r^2 without dividing by m ; **D** is potential

3.2

- $F = 19.6 \text{ N}$, $m = 2.0 \text{ kg}$; $g = F/m$

$$g = \frac{19.6 \text{ N}}{2.0 \text{ kg}} = \mathbf{9.8 \text{ N kg}^{-1}}$$

3.3

- a **stronger** gravitational field

3.4

(a) **radial** lines pointing inward to the mass

(b) **parallel, equally spaced** lines pointing down towards the surface

3.5

(a) the gravitational **force per unit mass** acting on a small test mass placed at that point

(b) the force on the test mass is $F = GMm/x^2$, where G is the gravitational constant

- field strength is the force per unit mass

$$g = \frac{F}{m} = \frac{GM}{x^2}$$

(c) the fields point in **opposite directions**, since each points towards the mass

- $g \propto 1/x^2$, so halving the distance makes the field at Q **four times** the field at P

(d) the curve starts at $(R, -g_0)$, since at X's surface the field points back towards X, i.e. negative

- it passes through zero at the midpoint $x = L/2$
- it ends at $(L - R, +g_0)$, becoming shallower up to the midpoint and steeper after it

(e) the two spheres are identical and the midpoint is equidistant from both, so their fields there are **equal in magnitude**

- and **opposite in direction**, so as a vector the two cancel to zero
- *(the gravitational potential there is not zero — only the field is)*