# Past-paper walk-through

## Gravitational field ▪ 13.1

eXercise

# Questions in this set

- 9702/41 N25 Q3 ▪ 9 marks
- 9702/44 J25 Q1 ▪ 11 marks
- 9702/43 N23 Q1 ▪ 10 marks

# Reading the mark scheme

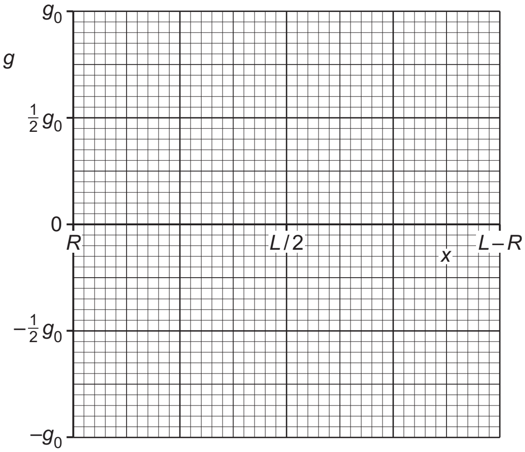
- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

# Question 3

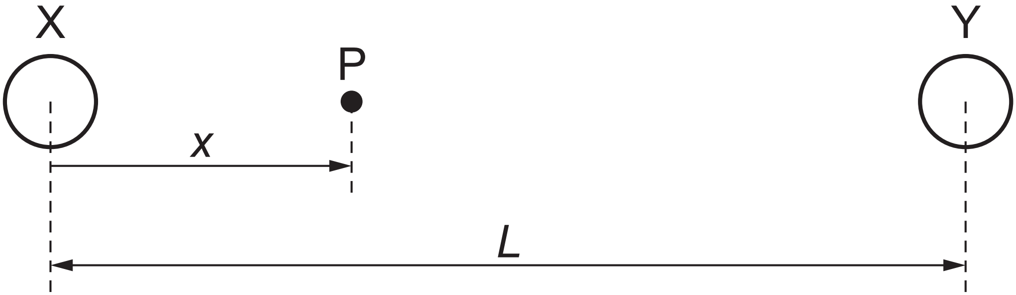
9702/41 N25 ▪ Q3 ▪ 9 marks

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

# Question 3



# Question 3



# Question 3

9702/41 N25 ▪ Q3 ▪ 9 marks

**(b)(i)** By considering the force exerted by the point mass on a test mass of mass $m$ placed at P, derive an equation for the gravitational field strength $g$ at P, in terms of $M$ and $x$. Identify any other symbols you use. **[2]**

**(b)(ii)** On Fig. 3.1, draw an arrow to indicate the direction of the gravitational field at P. **[1]**

**(b)(iii)** Point Q is at distance $\frac{x}{2}$ from the point mass, on the opposite side of the mass from P, as shown in Fig. 3.2.

Compare the gravitational field at Q with that at P. **[2]**

# Question 3

9702/41 N25 ▪ Q3 ▪ 9 marks

**(c)** Two identical isolated uniform spheres X and Y each have radius $R$. The centres of the spheres are separated by distance $L$, as shown in Fig. 3.3.

Point P lies on the line joining the centres of X and Y, and is at a variable displacement $x$ from the centre of sphere X. The gravitational field strength at the surface of each sphere is $g_0$.

On Fig. 3.4, sketch the variation with $x$ of the gravitational field $g$ at point P between $x = R$ and $x = L - R$. **[3]**

# Solution 3

## (a)

**Mark scheme**

- force per unit mass B1

# Solution 3

## (b)(i) Worked steps

"By considering the force on a test mass" fixes the route: start from Newton's law of gravitation and divide by the test mass.

- Force on the test mass at distance $x$: $F = \dfrac{GMm}{x^2}$.
- Gravitational field strength is force per unit mass: $g = \dfrac{F}{m}$.
- So $g = \dfrac{GMm}{x^2 m} = \dfrac{GM}{x^2}$, where $G$ is the gravitational constant.

# Solution 3

The mark for the derivation is the division by $m$ — quoting the formula alone answers a different question.

## Mark scheme

- F = GMm / x2 **C1**
- g = F / m g = [GMm / x2] / m = GM / x2 and G = gravitational constant **A1**

# Solution 3

## (b)(ii)

### Worked steps

- A gravitational field is always attractive, so draw the arrow at P pointing **directly towards** the point mass, along the line joining them.

### Mark scheme

- arrow drawn at P pointing directly towards the point mass B1

# Solution 3

## (b)(iii)

**Mark scheme**

- fields are in opposite directions **B1**
- field strength at Q is four times the field strength at P **B1**

# Solution 3

## (c) Worked steps

Between two equal masses the field points towards whichever sphere is nearer, so it reverses at the midpoint.

- The line starts at the surface of X, $(R, -g_0)$, and ends at the surface of Y, $(L - R, +g_0)$ — same size, opposite sign, because the spheres are identical.
- It crosses zero at the **midpoint**, $x = L/2$, where the two pulls cancel.
- The curve is shallow near the middle and steepens towards each surface, because each contribution goes as $1/x^2$.

# Solution 3

## Mark scheme

- line starting at (R, −g0) and ending at (L – R, +g0) **B1**
- line passing through (L / 2, 0) **B1**
- curve becoming shallower from R to (L / 2) and then steeper from (L / 2) to (L – R) **B1**

# Question 1

9702/44 J25 ▪ Q1 ▪ 11 marks

**1** **(a)** Define gravitational field.

# Question 1

**(b)** The gravitational field strength $g$ at a distance $x$ from the centre of a uniform spherical planet of mass $M$ is given by the expression

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

where $G$ is the gravitational constant and distance $x$ is greater than the radius of the planet.

**(i)** Describe the pattern of the field lines outside the planet that represent the gravitational field due to the planet.

# Question 1

**(ii)** Explain why, for small changes in vertical height near the surface of the planet, *g* may be assumed to be constant.

# Question 1

**(c)** Assume that the Earth is a uniform sphere. For the Earth, the product $GM$ is equal to $3.99 \times 10^{14}\,\text{m}^3\,\text{s}^{-2}$.

**(i)** Determine a value, to three significant figures, for the radius $R$ of the Earth.

# Question 1

**(ii)** Calculate the gravitational potential at the Earth's surface. Give a unit with your answer.

# Question 1

**(d)** Explain why the gravitational potential energy of two point masses is always negative.

# Question 1

[Total: 11]

# Solution 1

## (a)

**Mark scheme**

- force per unit mass

# Solution 1

**(b)(i)**

**Mark scheme**

- radial
- towards (centre of) planet

# Solution 1

## (b)(ii)

**Mark scheme**

- (changes in) height (very) much smaller than radius
- (radius + height)2 ≈ radius2
- or
- field lines are approximately parallel

# Solution 1

## (c)(i) Worked steps

At the surface the field strength and the mass product are linked by one equation, and $GM$ is given.

- $g = \dfrac{GM}{R^2}$, so $gR^2 = GM$ and $R = \sqrt{\dfrac{GM}{g}}$
- $9.81 \times R^2 = 3.99 \times 10^{14}$
- $R = \sqrt{\dfrac{3.99 \times 10^{14}}{9.81}} = 6.38 \times 10^6$ m

# Solution 1

The radius is **squared** in the field equation, so take the square root at the end. Forgetting it gives $4.07 \times 10^{13}$, which is larger than the Earth's orbit — the sense-check here is easy, because you already know the Earth's radius is a few thousand kilometres.

**Mark scheme**

- 9.81 × R2 = 3.99 × 1014
- R = 6.38 × 106 m

# Solution 1

## (c)(ii) Worked steps

Potential uses the **first** power of $r$, not the second, and it is negative.

- $\varphi = -\dfrac{GM}{R}$
- $\varphi = -\dfrac{3.99 \times 10^{14}}{6.38 \times 10^{6}}$
- $\varphi = -6.25 \times 10^{7}\ \mathrm{J\,kg^{-1}}$

# Solution 1

Three things carry the marks: the **minus sign** (potential is zero at infinity and negative everywhere else, because gravity is attractive), the **single** power of $R$, and the unit $\mathrm{J\,kg^{-1}}$ — potential is energy per unit mass, not energy.
A quick way to check you have not confused the two formulae: $\varphi = -gR$ numerically, which is $-9.81 \times 6.38 \times 10^6 = -6.26 \times 10^7$, the same answer.

**Mark scheme**

- gravitational potential = – (GM / R)
- = – (3.99 × 1014) / (6.38 × 106)
- = – 6.25 × 107 J kg–1

# Solution 1

## (d) Worked steps

Two separate statements are wanted, and together they explain the minus sign in $\varphi = -\dfrac{GM}{r}$.

- Gravitational **potential is defined as zero at infinite separation** — that is the chosen reference point, not a physical property of infinity.
- Gravitational **force is always attractive**, so work must be done *against* the field to move a mass out to infinity. Bringing it in from there therefore leaves it with less energy than zero.

# Solution 1

Put together: every point in a gravitational field is at a negative potential, and the closer you are to the mass the more negative it gets.
The contrast worth remembering is with electric potential, which uses the same zero at infinity but can be either sign, because the electric force can repel as well as attract.

**Mark scheme**

- potential (energy) zero at infinite separation
- (gravitational) force is attractive
- 9702/44
- May/June 2025

# Question 1

9702/43 N23 ▪ Q1 ▪ 10 marks

**(a)(i)** State what is indicated by the direction of the gravitational field line at a point in a gravitational field. **[1]**

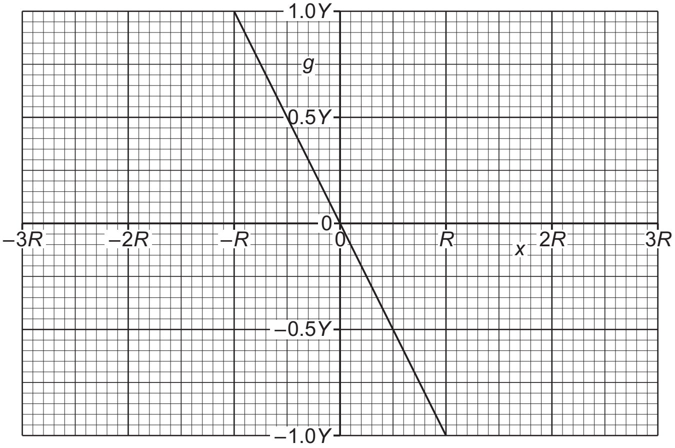
**(a)(ii)** Explain, with reference to gravitational field lines, why the gravitational field near the surface of the Earth is approximately constant for small changes in height. **[2]**

**(b)(i)** The magnitude of the gravitational field at the surface of the sphere is $Y$. Determine an expression for $Y$ in terms of $M$ and $R$. Identify any other symbols that you use. **[2]**

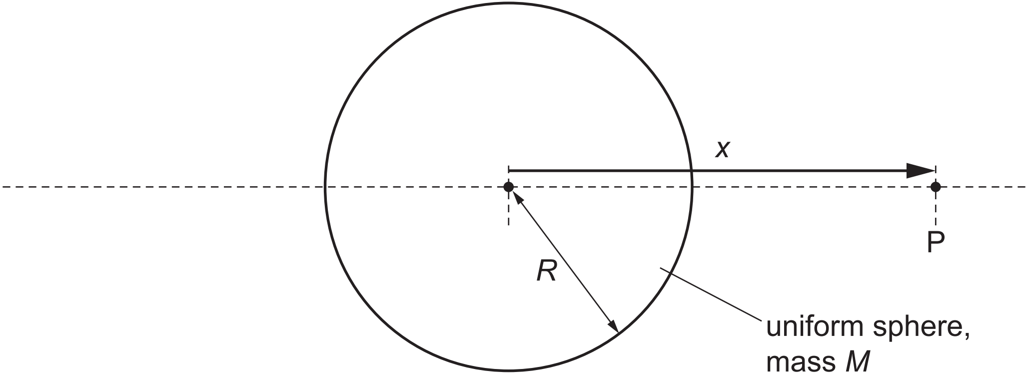
**(b)(ii)** Explain why, at the surface of the sphere, $g$ always has the opposite sign to $x$. **[2]**

**(b)(iii)** Complete Fig. 1.2 to show the variation of $g$ with $x$ for values of $x$, up to $\pm 3R$, for which point P is outside the sphere. **[3]**

# Question 1



# Question 1



# Solution 1

## (a)(i)

**Mark scheme**

- direction of the force acting on a (test) mass placed at the point **B1**

## (a)(ii)

**Mark scheme**

- change in height negligible compared with radius (of Earth) **B1**
- (so) field lines are (effectively) parallel **B1**

# Solution 1

## (b)(i) Worked steps

**Know.** Outside a uniform sphere, the gravitational field is the same as that of a point mass of the same size placed at the **centre** of the sphere. So the field at the surface is found by using the sphere's own radius as the distance.

**Equation.** $g = \dfrac{GM}{r^2}$.

**Substitute.** At the surface, $r = R$.

**Answer.** $Y = \dfrac{GM}{R^2}$, where $G$ is the **gravitational constant**.

# Solution 1

**Check.** The instruction to identify any other symbols is a mark in itself, so name $G$. Note also that $R$ is squared: writing $\dfrac{GM}{R}$ gives a gravitational **potential**, which is a different quantity with different units.

## Mark scheme

- Y = GM / R2 M1
- G is the gravitational constant A1

# Solution 1

## (b)(ii)

**Mark scheme**

- gravitational force is (always) attractive or gravitational force (always) acts towards the centre of the sphere **B1**
- force is in opposite direction to displacement or at a point to the right of the centre, force acts to the left or at a point to the left of the centre, force acts to the right **B1**

# Solution 1

## (b)(iii)

**Mark scheme**

- sketch:
- smooth curve with decreasing positive gradient, starting at (R, –Y) and reaching 3R with g still negative or smooth curve with increasing positive gradient, ending at (–R, Y) and reaching –3R with g still positive **B1**
- both of the above curves, in correct quadrants **B1**
- curve passing through ($\pm$2R, $\pm$0.25Y) and ($\pm$3R, $\pm$0.11Y) **B1**