# OCR A A Level Gravitational Fields 1 solutions

*Matching solutions and teaching prompts for the class review*

## Specification points covered

- 5.4.1(a) State what is meant by a gravitational field and represent it using field lines.
- 5.4.1(b) Model the field of a spherical mass as though the mass were concentrated at its centre.
- 5.4.1(c) Sketch and interpret gravitational field lines around one mass and between two masses.
- 5.4.1(d–e) Use $g = F/m$ and recognise that a gravitational field exerts a force on a mass.
- 5.4.2(a) Use $F = GMm/r^2$ for two point masses.
- 5.4.2(b–c) Use $g = GM/r^2$ and apply the uniform-field approximation close to Earth's surface.

**Teaching focus**

Insist on the field definition: a mass experiences a force. A field line points in the direction of the force on a small test mass.
Keep the model explicit. For an external point-mass calculation, use centre-to-centre separation and convert all distances into metres before substituting.
Use quantity language precisely: gravitational field strength decreases with distance; it does not 'lose gravity' or 'accelerate'.

## 1. Mapping a gravitational field

**1. State what is meant by a gravitational field. State what the direction of an arrow on a gravitational field line represents. [2 marks]**

**Answer / mark points:** A gravitational field is a region of space in which a mass experiences a force. The arrow shows the direction of the force on a small test mass; for gravity it points towards the attracting mass.

**Teacher prompt / common error:** Require 'mass experiences a force'; do not accept a vague statement that gravity is a force. Direction is towards the mass.

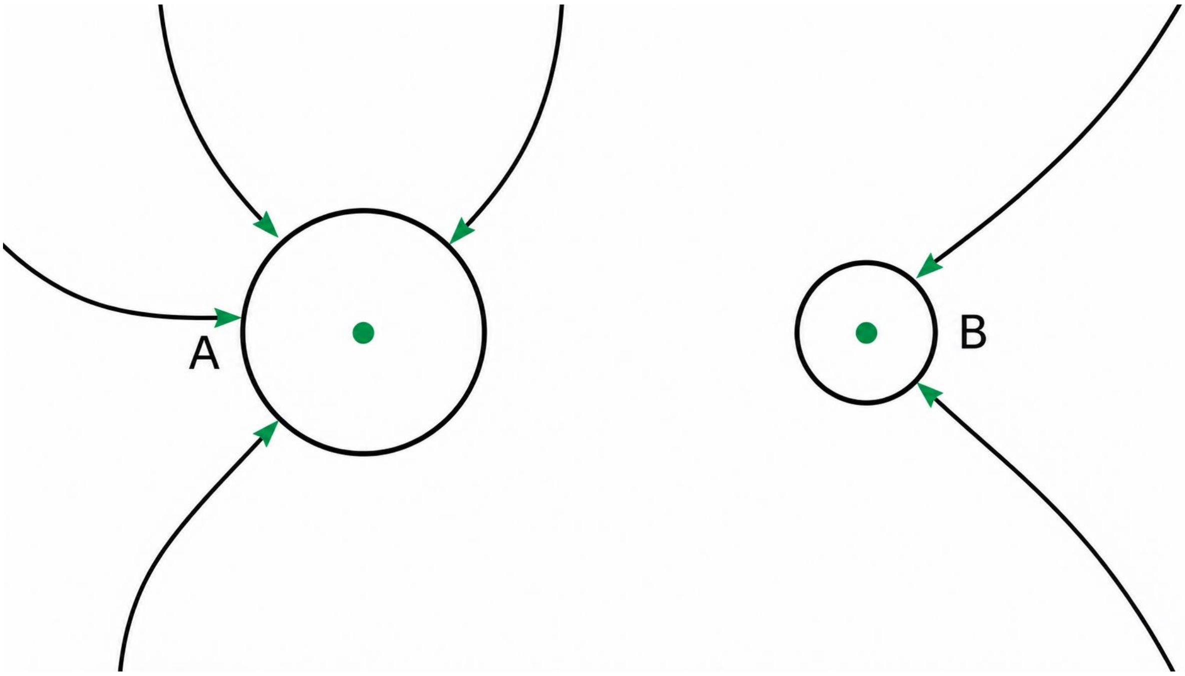


**Figure 1 solution: one valid indicative field-line pattern**

**2. Figure 1 shows the binary asteroid pair. On the figure, draw a possible pattern of gravitational field lines for the region. Include arrowheads and use more field lines terminating on A than on B. State what a closer spacing of field lines represents. [4 marks]**

**Answer / mark points:** A valid sketch has non-crossing lines directed towards the asteroid surfaces, with arrowheads pointing inwards. A has more lines terminating on it than B. The lines are closer together where the gravitational field strength is greater.

**Teacher prompt / common error:** Lines should not cross, arrowheads must point inward, and a larger mass should have more lines. Accept a variety of physically sensible curved patterns.

**3. Outside each asteroid, the team models it as a point mass at its centre. Explain why this is a suitable model for this calculation. Explain why the separation in $F = GMm/r^2$ is measured from centre to centre, rather than from surface to surface. [3 marks]**

**Answer / mark points:** Each asteroid is nearly spherical and the calculation point is outside it, so its external field can be modelled as that of a point mass at its centre. In the point-mass model r is the separation of the two masses, so it is the centre-to-centre separation. Surface separation would not be the separation of the modelled point masses.

**Teacher prompt / common error:** This tests the difference between a real extended body and its point-mass model. The distance is not the gap between surfaces.

**4. Write the equation linking gravitational field strength g, force F and mass m. State the SI unit of gravitational field strength. [2 marks]**

**Answer / mark points:** $g = F/m$, or $F = mg$. The SI unit is $N\ kg^{-1}$. This is equivalent to $m\ s^{-2}$, but $N\ kg^{-1}$ is the standard field-strength unit.

**Teacher prompt / common error:** $N\ kg^{-1}$ is preferred for field strength. It is numerically equal to $m\ s^{-2}$ but communicates the field concept more clearly.

## 2. Field strength and gravitational force

**5. Calculate the gravitational field strength at the surface of asteroid A. [3 marks]**

**Answer / mark points:** $r = 1.50$ km $= 1.50 \times 10^3$ m. $g = GM/r^2 = (6.67 \times 10^{-11} \times 6.00 \times 10^{12})/(1.50 \times 10^3)^2 = 1.78 \times 10^{-4}$ N kg$^{-1}$.

**Teacher prompt / common error:** The most common error is leaving the radius in kilometres. Ask pupils to label r in metres before substitution.

**6. A calibration sensor of mass 280 kg rests at the surface of A. Calculate the magnitude of the gravitational force acting on it. [2 marks]**

**Answer / mark points:** $F = mg = 280 \times 1.78 \times 10^{-4} = 4.98 \times 10^{-2}$ N. The force is towards the centre of A.

**Teacher prompt / common error:** Use the field strength calculated in Question 5 and retain a sensible unit. Direction is to A's centre.

**7. Calculate the magnitude of the gravitational force between asteroids A and B. State the direction of the force on A due to B. [3 marks]**

**Answer / mark points:** $F = GM_aM_\beta/r^2 = (6.67 \times 10^{-11} \times 6.00 \times 10^{12} \times 1.50 \times 10^{12})/(8.00 \times 10^3)^2 = 9.38 \times 10^6$ N. The force on A is towards B.

**Teacher prompt / common error:** Use the 8.00 km centre-to-centre separation. Forces form a Newton's-third-law pair with equal magnitude and opposite direction.

**8. A 1.00 kg test mass is 3.00 km from the centre of A, where the field strength due to A is $4.45 \times 10^{-5}$ N kg$^{-1}$. State the magnitude and direction of the gravitational force on the test mass. [2 marks]**

**Answer / mark points:** $F = mg = 1.00 \times 4.45 \times 10^{-5} = 4.45 \times 10^{-5}$ N, directed towards the centre of A.

**Teacher prompt / common error:** A field direction is not optional. A test mass has a force towards A, not an acceleration 'towards gravity'.

## 3. The inverse-square field around asteroid A

**Table 1 solution: gravitational field strength due to asteroid A**

| Distance from A's centre / km | 1.50 | 3.00 | 4.50 | 6.00 |
|---|---|---|---|---|
| g due to A / $10^{-5}$ N kg$^{-1}$ | 17.8 | 4.45 | 1.98 | 1.11 |

**9. Table 1 gives field strengths due to A at several distances from its centre. (a) Calculate the missing value. (b) Use the values at 1.50 km and 3.00 km to show that the data are consistent with an inverse-square relationship. (c) Use field-line language to explain why the field strength decreases with distance. [5 marks]**

**Answer / mark points:** (a) At 4.50 km, $g = (6.67 \times 10^{-11} \times 6.00 \times 10^{12})/(4.50 \times 10^3)^2 = 1.98 \times 10^{-5}$ N kg$^{-1}$. (b) Doubling r from 1.50 km to 3.00 km reduces g from $17.8 \times 10^{-5}$ to $4.45 \times 10^{-5}$ N kg$^{-1}$: g becomes one quarter, consistent with $g \propto 1/r^2$. (c) The field lines spread out as distance from A increases, so their density decreases and the field is weaker.

**Teacher prompt / common error:** Inverse square means a factor of four for a doubling of distance. Connect field-line density to field strength precisely.

**10. At 3.00 km from the centre of A, $g = 4.45 \times 10^{-5}$ N kg$^{-1}$. At what distance from the centre will $g = 1.11 \times 10^{-5}$ N kg$^{-1}$? Show your reasoning. [2 marks]**

**Answer / mark points:** The field strength falls from $4.45 \times 10^{-5}$ to $1.11 \times 10^{-5}$ N kg$^{-1}$, approximately a factor of four. Since $g \propto 1/r^2$, r must double. Distance = 6.00 km.

**Teacher prompt / common error:** Let pupils use either a ratio argument or algebra; both must conclude that distance doubles.

## 4. Comparing a local and a large-scale field

**11. A separate Earth-orbiting instrument is $4.00 \times 10^5$ m above Earth's surface. Calculate the gravitational field strength there. Explain why a laboratory calculation involving a vertical displacement of 2.0 m can treat Earth's field as uniform. [4 marks]**

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| **Answer / mark points:** $r = 6.37 \times 10^6 + 4.00 \times 10^5 = 6.77 \times 10^6$ m. $g = GM_e/r^2 = (6.67 \times 10^{-11} \times 5.97 \times 10^{24})/(6.77 \times 10^6)^2 = 8.69$ N kg$^{-1}$. A 2.0 m displacement is negligible compared with Earth's radius, so the change in r and hence in g is negligible; field lines are effectively parallel over that small region. |
| **Teacher prompt / common error:** The uniform-field approximation is local. It is inappropriate across hundreds of kilometres, as the first part shows. |

## 5. A constrained survey route

**Table 2: primary-field data provided for the route choice**

| Station | Distance from A's centre / km | g due to A / N kg$^{-1}$ |
|---|---|---|
| P | 3.00 | $4.45 \times 10^{-5}$ |
| Q | 4.50 | $1.98 \times 10^{-5}$ |
| R | 6.00 | $1.11 \times 10^{-5}$ |

**12. For a low-altitude survey pass, a 750 kg craft must experience a force due to A below 0.020 N and remain no more than 5.00 km from A's centre. Table 2 gives primary-field data; ignore the field due to B for this route choice. Select the suitable station and justify your choice with calculations and the distance condition. State one limitation of this simplified route model. [5 marks]**

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| **Answer / mark points:** Station P: $F = 750 \times 4.45 \times 10^{-5} = 3.34 \times 10^{-2}$ N, which is too large. Station Q: $F = 750 \times 1.98 \times 10^{-5} = 1.49 \times 10^{-2}$ N, below 0.020 N, and Q is 4.50 km away, within 5.00 km. Station R has a sufficiently small force but is 6.00 km away, outside the distance condition. Choose Q. A limitation is that the calculation ignores B's gravitational field; alternatives include treating A as perfectly spherical or ignoring rotation and other bodies. |
| **Teacher prompt / common error:** A sound decision checks both constraints, then states a model limitation. The table deliberately removes B for the numerical decision, but the omitted field remains a valid limitation. |

### Language and model check

Say 'the gravitational field strength decreases as distance increases'; do not describe the field strength as accelerating.
For an outside spherical body, the point-mass model uses the centre of the body. It does not use the body's surface as the location of the mass.
The uniform-field approximation is a local approximation near Earth's surface, not a description of the whole Earth–space system.