

# 16.2 Gravitational fields (full D.1, HL)

Name: \_\_\_\_\_ Class: \_\_\_\_\_ Date: \_\_\_\_\_

**Total: 31 marks**

**KEY WORDS** gravitational field strength

• Kepler's laws

• gravitational potential

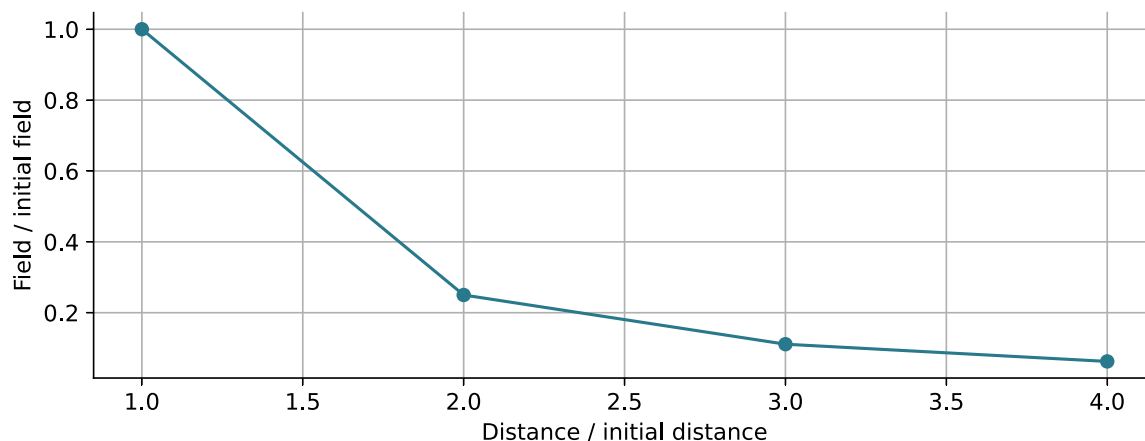
• gravitational constant

• escape speed

## Objective

Practise the full guide D.1 toolkit including AHL: Newton's law of gravitation  $F = Gm_1m_2/r^2$  with the point-mass condition, gravitational field strength  $g = GM/r^2$ , field-line patterns, resultant fields along the line of two bodies, and Kepler's three laws including  $T^2 \propto r^3$  in problems; at higher level also potential  $V_g = -GM/r$ , potential energy  $E_p = -Gm_1m_2/r$ , the potential gradient, equipotential surfaces, escape and orbital speeds, and satellite energetics. Original practice; not an official IB paper.

## 1 Key knowledge and worked examples



### ■ The D.1 rule set (HL)

$$F = \frac{Gm_1m_2}{r^2} \quad g = \frac{GM}{r^2} \quad V_g = -\frac{GM}{r} \quad g = -\frac{\Delta V_g}{\Delta r} \quad v_{esc} = \sqrt{\frac{2GM}{r}} \quad v_{orbital} = \sqrt{\frac{GM}{r}}$$

Field lines point inward, never cross, and crowd where the field is stronger. A spherical body of uniform density acts as a point mass at its centre. Kepler: ellipses with the central body at a focus; equal areas in equal times;  $T^2 \propto r^3$ .

■ **Worked example: Kepler with real bodies**

Mars orbits at 1.52 AU:  $T = 1.52^{3/2} = 1.87$  Earth years. Earth's surface:  $g = GM/r^2 = (6.67 \times 10^{-11} \times 6.0 \times 10^{24})/(6.4 \times 10^6)^2 = 9.8 \text{ m/s}^2$ . Two habits: measure  $r$  from the centre of the mass, not from the surface; and for period comparisons cube the radius ratio before taking its square root.

## 2 Practice

**2.1** State Newton's law of gravitation, naming the quantities in the equation. [2]

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**2.2** Mars has mass  $6.4 \times 10^{23} \text{ kg}$  and radius  $3.4 \times 10^6 \text{ m}$ . Calculate the gravitational field strength at its surface ( $G = 6.67 \times 10^{-11}$ ). [3]

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**2.3** State Kepler's third law, and calculate the orbital period of a planet at 9.5 AU, in Earth years. [3]

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**2.4** Describe two features of the gravitational field-line pattern around a spherical planet. [2]

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**2.5** A satellite orbits Earth ( $M = 6.0 \times 10^{24} \text{ kg}$ ) at  $r = 4.2 \times 10^7 \text{ m}$ . Calculate its orbital speed and its escape speed from that orbit. [3]

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### 3 Exam-style questions

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**3.1** Calculate the gravitational field strength at a point a distance  $2R$  from Earth's centre, where  $R = 6.4 \times 10^6$  m is Earth's radius and surface  $g = 9.8$  m/s<sup>2</sup>. [3]

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**3.2** A geostationary satellite orbits at  $r = 4.2 \times 10^7$  m from Earth's centre ( $M = 6.0 \times 10^{24}$  kg). Use  $T^2 = 4\pi^2 r^3 / GM$  to show its period is about one day. [4]

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**3.3** A comet's orbit has perihelion 0.59 AU and aphelion 35 AU. Estimate its orbital period using Kepler's third law, stating one assumption the estimate makes. [4]

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**3.4** Explain when a planet may be treated as a point mass for gravitation calculations, and describe how the field strength varies along a line moving away from its surface. [3]

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**3.5** A 1200 kg satellite is raised from Earth's surface ( $r = 6.4 \times 10^6$  m) to a parking orbit at  $r = 1.28 \times 10^7$  m. Calculate the increase in its gravitational potential energy, and state what happens to the total energy of a bound circular orbit as its radius increases. [4]

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