OCR A A Level Gravitational Fields 3 worksheet

35–40 minutes independent practice + 15–20 minutes review | 32 marks

Specification points covered

- 5.4.4(a) Define gravitational potential at a point as work done per unit mass in bringing a small test mass from infinity to the point.
- 5.4.4(b) Use $V_g = -GM/r$ and relate changes in potential to energy.
- 5.4.4(c) Interpret force-distance graphs for point or spherical masses and relate the area under a curve to work done.
- 5.4.4(d) Define gravitational potential energy $E_g = mV_g = -GMm/r$.
- 5.4.4(e) Define escape velocity and apply it to planetary and atomic-scale examples.

Asteria Return mission

Asteria is a roughly spherical rocky body. The Asteria Return team plans to collect an ice-rich sample and send it back to a waiting spacecraft.
Take Asteria's mass as 2.40×10^{17} kg, its radius as 2.00×10^{3} m and the sample canister mass as 18.0 kg. Take $G = 6.67 \times 10^{-11}$ N m² kg⁻².
Unless stated otherwise, distances are measured from Asteria's centre. Ignore Asteria's rotation, drag and the gravitational effects of all other bodies.

1. Potential and potential energy

1. Define the gravitational potential at a point in a gravitational field. [2 marks]

2. Calculate the gravitational potential V_g at the surface of Asteria. [2 marks]

3. Calculate the gravitational potential energy E_g of the 18.0 kg sample canister when it is at Asteria's surface. [2 marks]

2. Raising the sample canister

4. The canister is raised slowly to a distance of 6.00 km from Asteria's centre. Calculate (a) the gravitational potential at this distance and (b) the change in gravitational potential from the surface to this distance. Include the sign of the change. [3 marks]

5. Calculate the minimum energy supplied by the transfer actuator to move the 18.0 kg canister slowly from the surface to a distance of 6.00 km from Asteria's centre. [2 marks]

6. Explain why the gravitational potential at both the surface and 6.00 km from Asteria's centre is negative, even though the potential increases during the transfer. [2 marks]

3. Work from a force-distance graph

7. Figure 1 shows the force required to hold a 1.00 kg test package stationary at different distances from Asteria's centre. State the force required when r = 4.00 km. [1 mark]

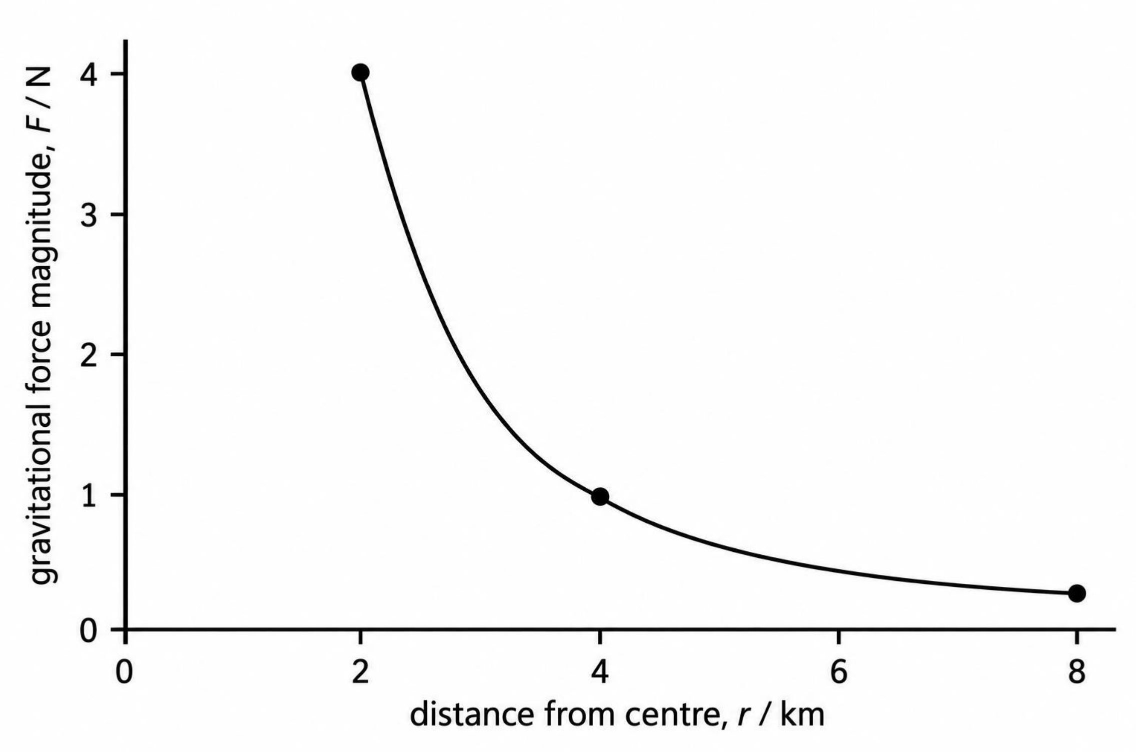

Figure 1: force required to hold a 1.00 kg test package stationary at a distance r from Asteria's centre

8. State what the area under the curve in Figure 1 between r = 2.00 km and r = 6.00 km represents. Relate it to the change in gravitational potential energy of the 1.00 kg test package. [2 marks]

9. Using Figure 1, state which transfer needs more work: from r = 2.00 km to r = 4.00 km, or from r = 4.00 km to r = 6.00 km. Explain your answer using the graph. [2 marks]

10. The transfer actuator moves the test package outwards at constant speed. State the direction of the actuator force. Explain why the actuator supplies energy even though the package's kinetic energy does not change. [2 marks]

4. Leaving Asteria

11. Define the escape velocity from the surface of a spherical body. [2 marks]

12. At the minimum escape speed from the surface of a body of mass M and radius R, the total energy of an object is zero. Use $E_k = \frac{1}{2}mv^2$ and $E_g = -GMm/R$ to show that $v_{esc} = \sqrt{(2GM/R)}$. [2 marks]

13. Calculate the escape velocity from Asteria's surface. [2 marks]

14. A launcher releases a canister radially outwards from Asteria's surface at 180 m s^{-1}. Neglecting drag and further propulsion, calculate its speed when it is a very large distance from Asteria. State whether it escapes. [3 marks]

5. Atomic-scale escape

15. A small leak releases helium atoms from the return craft. One atom moves directly away from Asteria at 140 m s^{-1}; another moves directly away at 90.0 m s^{-1}. State the likely fate of each atom, neglecting collisions. Explain why a collection of gas atoms with a range of speeds can gradually be depleted from Asteria. [3 marks]