D.1 Gravitational fields

Practice Worksheet — name: ________________________ date: _____________

FORMULAS FOR THIS TOPIC

NEWTON'S LAW OF GRAVITATION $F = G\frac{m_1 m_2}{r^2}$ GRAVITATIONAL FIELD STRENGTH $g = \frac{F}{m} = G\frac{M}{r^2}$

GRAVITATIONAL PE (HL) $E_p = -G\frac{m_1 m_2}{r}$ GRAVITATIONAL POTENTIAL (HL) $V_g = -\frac{GM}{r}$

POTENTIAL GRADIENT (HL) $g = -\frac{\Delta V_g}{\Delta r}$ WORK DONE (HL) $W = m\Delta V_g$ ESCAPE SPEED (HL) $v_{\text{esc}} = \sqrt{\frac{2GM}{r}}$

ORBITAL SPEED (HL) $v_{\text{orbital}} = \sqrt{\frac{GM}{r}}$

SECTION A — MULTIPLE CHOICE

A1. The gravitational field strength at the surface of a planet is g. At a height equal to the planet's radius above the surface, it is:

- A $g/2$
- B $g/4$
- C $g/8$
- D $g/16$

A2. According to Kepler's third law, a planet orbiting at 4 times Earth's orbital radius has a period of:

- A 4 years
- B 8 years
- C 16 years
- D 64 years

A3. Gravitational potential is always negative because:

- A Gravity always repels
- B The zero is defined at infinity and gravity is attractive, so work is released bringing a mass inward
- C It is a vector pointing towards the mass
- D Potential energy cannot be positive

SECTION B — SHORT ANSWER

B1. Using $g = GM/r^2$ at the Earth's surface ($g = 9.81 \text{ m s}^{-2}$, $R = 6.37 \times 10^6 \text{ m}$), estimate the mass of the Earth. [3 marks]

B2. Show that the escape speed from a planet is $\sqrt{2}$ times the orbital speed for a circular orbit at its surface. [3 marks]

B3. A satellite in low orbit experiences slight atmospheric drag. Explain why its speed increases even though a resistive force acts on it. [3 marks]

ANSWER KEY

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Section A

A1: $g/4$ — Field strength follows the inverse square law from the planet's CENTRE. At height R the distance from the centre is $2R$, so $g' = g/2^2 = g/4$ — measure r from the centre, not the surface.

A2: 8 years — $T^2 \propto r^3$: $T^2 = 4^3 = 64$, so $T = 8$ years. Cube the radius ratio, then square-root.

A3: The zero is defined at infinity and gravity is attractive, so work is released bringing a mass inward — With $V_g = 0$ at infinite separation and an attractive force doing positive work on an inbound mass, every point closer than infinity sits below zero. The negative sign encodes being bound in a potential well.

Section B

B1: $M = gR^2/G = \frac{9.81\times(6.37\times10^6)^2}{6.67\times10^{-11}} \approx 6.0 \times 10^{24}$ kg — Cavendish's "weighing the Earth" in one line.

B2: Escape: total energy zero, $\frac{1}{2}mv_{esc}^2 = GMm/R$, so $v_{esc} = \sqrt{2GM/R}$. Orbit: gravity as centripetal force, $mv^2/R = GMm/R^2$, so $v_{orb} = \sqrt{GM/R}$. Ratio: $v_{esc}/v_{orb} = \sqrt{2}$.

B3: Drag removes mechanical energy, so the satellite descends to a lower orbit. But orbital speed $v = \sqrt{GM/r}$ increases as r decreases: the loss in potential energy exceeds the energy removed by drag, and the surplus appears as kinetic energy. Gravity, not drag, does the accelerating.