A Level Mechanics
Practice Test 1: Gravitational Fields

Instructions:
Answer all questions. Show your working clearly.
Calculators may be used unless stated otherwise.
Draw diagrams where appropriate to illustrate your solutions.
Time allowed: 2 hours 45 minutes

Section A: Newton's Law of Universal Gravitation [30 marks]

Question 1 [12 marks]

(a) State Newton's Law of Universal Gravitation in words. **[3 marks]**

(b) Write the mathematical expression for the gravitational force between two point masses. **[2 marks]**

(c) Define the gravitational constant G, stating its value and units. **[3 marks]**

(d) Explain why gravitational forces are always attractive, never repulsive. **[2 marks]**

(e) State two conditions under which Newton's law applies to extended objects like planets. **[2 marks]**

Question 2 [18 marks] Two point masses of 800 kg and 1200 kg are placed 6.0 m apart in space.

(a) Calculate the gravitational force between these masses. **[4 marks]**

(b) If the distance between them is doubled to 12.0 m, calculate the new gravitational force. **[3 marks]**

(c) What happens to the gravitational force if one mass is tripled while keeping the distance constant? **[3 marks]**

(d) Calculate the gravitational force between Earth (mass 5.97×10^2 kg) and a 70 kg person standing on its surface. Take Earth's radius as 6.37×10 m. **[4 marks]**

(e) Compare this force with the person's weight calculated using $g = 9.81$ m/s^2. **[2 marks]**

(f) Explain why these two values should be the same. **[2 marks]**

Section B: Gravitational Field Strength [35 marks]

Question 3 [15 marks]

(a) Define gravitational field strength and state its SI units. **[3 marks]**

(b) Write the equation that relates gravitational field strength to gravitational force. **[2 marks]**

(c) Show that for a point mass M, the gravitational field strength at distance r is given by $g = GM/r^2$. **[4 marks]**

(d) Explain why gravitational field strength is a vector quantity. **[2 marks]**

(e) Describe how gravitational field strength varies with distance from a point mass. **[2 marks]**

(f) Sketch a graph showing how g varies with distance r from the center of a uniform sphere. **[2 marks]**

Question 4 [20 marks] The Moon has mass 7.35×10^{22} kg and radius 1.74×10 m.

(a) Calculate the gravitational field strength on the Moon's surface. **[4 marks]**

(b) Find the gravitational field strength at a height of 500 km above the Moon's surface. **[4 marks]**

(c) An astronaut has mass 85 kg. Calculate their weight on the Moon's surface. **[3 marks]**

(d) Compare this with their weight on Earth's surface. **[3 marks]**

(e) At what height above the Moon's surface would the gravitational field strength be half its surface value? **[4 marks]**

(f) Calculate the gravitational field strength at the center of the Moon. Explain your answer. **[2 marks]**

Section C: Gravitational Potential Energy [40 marks]

Question 5 [18 marks]

(a) Define gravitational potential energy. **[2 marks]**

(b) Explain why we choose gravitational potential energy to be zero at infinite separation. **[3 marks]**

(c) Derive the expression $U = -GMm/r$ for the gravitational potential energy of mass m at distance r from mass M. **[6 marks]**

(d) Explain why gravitational potential energy is negative. **[3 marks]**

(e) Show that the change in gravitational potential energy equals the negative of the work done by the gravitational force. **[4 marks]**

Question 6 [22 marks] A satellite of mass 1500 kg orbits Earth at a height of 800 km above the surface.

(a) Calculate the satellite's distance from Earth's center. **[2 marks]**

(b) Find the gravitational potential energy of the satellite in this orbit. **[4 marks]**

(c) Calculate the satellite's gravitational potential energy when on Earth's surface. **[3 marks]**

(d) Determine the change in potential energy required to move the satellite from Earth's surface to its orbital position. **[3 marks]**

(e) Calculate the minimum work that must be done to move the satellite to this orbit. **[2 marks]**

(f) If the satellite moves to a higher orbit at 1200 km altitude, calculate the additional change in potential energy required. **[4 marks]**

(g) What is the escape velocity from Earth's surface? **[4 marks]**

Section D: Gravitational Potential [25 marks]

Question 7 [12 marks]

(a) Define gravitational potential and state its SI units. **[3 marks]**

(b) Write the relationship between gravitational potential V and gravitational potential energy U. **[2 marks]**

(c) Show that the gravitational potential due to a point mass M at distance r is V = -GM/r. **[3 marks]**

(d) Explain the relationship between gravitational field strength and gravitational potential. **[2 marks]**

(e) Why is gravitational potential a scalar quantity while gravitational field strength is a vector? **[2 marks]**

Question 8 [13 marks]

(a) Calculate the gravitational potential at Earth's surface. **[3 marks]**

(b) Find the gravitational potential at a height of 1000 km above Earth's surface. **[4 marks]**

(c) Calculate the potential difference between these two positions. **[2 marks]**

(d) A 2.0 kg mass moves from Earth's surface to the 1000 km height. Calculate the change in potential energy. **[2 marks]**

(e) Verify your answer using the potential difference and the definition of potential. **[2 marks]**

Section E: Orbital Motion [35 marks]

Question 9 [18 marks]

(a) For a satellite in circular orbit, what force provides the centripetal force? **[2 marks]**

(b) Derive the expression v = (GM/r) for circular orbital velocity. **[5 marks]**

(c) Show that the orbital period is given by T = $2(r^3/GM)$. **[4 marks]**

(d) Explain why orbital velocity decreases as orbital radius increases. **[3 marks]**

(e) For a satellite in circular orbit, derive the relationship between kinetic energy and potential energy. **[4 marks]**

Question 10 [17 marks] A satellite orbits Earth at a height of 600 km above the surface in a circular orbit.

(a) Calculate the orbital radius from Earth's center. **[2 marks]**

(b) Find the orbital velocity of the satellite. **[4 marks]**

(c) Calculate the orbital period in hours. **[4 marks]**

(d) Determine the centripetal acceleration of the satellite. **[3 marks]**

(e) For a satellite of mass 2000 kg in this orbit, calculate:

(i) The kinetic energy. **[2 marks]**

(ii) The gravitational potential energy. **[2 marks]**

Section F: Geostationary Satellites and Applications [25 marks]

Question 11 [15 marks]

(a) State the conditions required for a geostationary satellite orbit. **[3 marks]**

(b) Calculate the orbital radius for a geostationary satellite above Earth's center. **[5 marks]**

(c) Find the height of a geostationary satellite above Earth's surface. **[2 marks]**

(d) Calculate the orbital velocity of a geostationary satellite. **[3 marks]**

(e) Explain why geostationary satellites cannot be placed in polar orbits. **[2 marks]**

Question 12 [10 marks] Compare satellites in different Earth orbits:

(a) Calculate the orbital period for a satellite at height 400 km (Low Earth Orbit). **[4 marks]**

(b) Find the orbital velocity for this satellite. **[3 marks]**

(c) Compare the orbital velocities of satellites in Low Earth Orbit (400 km) and geostationary orbit. **[2 marks]**

(d) State one advantage and one disadvantage of Low Earth Orbit compared to geostationary orbit. **[1 mark]**

Section G: Energy and Escape Velocity [20 marks]

Question 13 [12 marks]

(a) Define escape velocity. **[2 marks]**

(b) Derive the expression $\mathrm{v}_e = (2GM/r) for escape velocity from the surface of a planet.$ **[5 marks]** $Calculate the es$

(c) Calculate the escape velocity from the Moon's surface. **[2 marks]**

Question 14 [8 marks] A rocket is launched vertically from Earth's surface with an initial speed of 8.0 km/s.

(a) Will this rocket escape Earth's gravitational field? Justify your answer. **[3 marks]**

(b) Calculate the maximum height reached by the rocket. **[5 marks]**

Physics Data and Formulae

Gravitational Force:
Newton's Law: $F = \frac{Gm_1m_2}{r^2}$

Gravitational Field:
Field strength: $g = \frac{F}{m} = \frac{GM}{r^2}$
Field-potential relationship: $g = -\frac{dV}{dr}$

Gravitational Potential Energy and Potential:
Potential energy: $U = -\frac{GMm}{r}$
Potential: $V = \frac{U}{m} = -\frac{GM}{r}$

Orbital Motion:

Circular orbital velocity: $v = \sqrt{\frac{GM}{r}}$

Orbital period: $T = 2\pi\sqrt{\frac{r^3}{GM}}$

Escape velocity: $v_e = \sqrt{\frac{2GM}{r}}$

Energy in Orbits:

Kinetic energy: $KE = \frac{1}{2}mv^2 = \frac{GMm}{2r}$

Potential energy: $PE = -\frac{GMm}{r}$

Total energy: $E = -\frac{GMm}{2r}$

Centripetal Motion:

Centripetal force: $F_c = \frac{mv^2}{r}$

Centripetal acceleration: $a_c = \frac{v^2}{r}$

Physical Constants:

Gravitational constant: $G = 6.67 \times 10^{-11}$ Nm^2/kg^2

Earth's mass: $M_E = 5.97 \times 10^{24}$ kg

Earth's radius: $R_E = 6.37 \times 10^6$ m

Moon's mass: $M_M = 7.35 \times 10^{22}$ kg

Moon's radius: $R_M = 1.74 \times 10^6$ m

Acceleration due to gravity: $g = 9.81$ m/s^2

END OF TEST

Total marks: 210

Grade boundaries: A* 189, A 168, B 147, C 126, D 105, E 84

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