Class 11 Physics · Chapter 7: Gravitation

Answer key and marking scheme · 20 marks · about 40 minutes · based on NCERT

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1. Two small spheres attract each other with a gravitational force F. If the mass of each sphere is doubled and the distance between their centres is tripled, the new force is [1]

(a) $\frac{4}{9}$ F (b) $\frac{2}{3}$ F

(c) $\frac{4}{3}$ F (d) $\frac{9}{4}$ F

Answer: (a) $F \propto m_1 m_2 / r^2$. The product of masses becomes $2 \times 2 = 4$ times and r^2 becomes 9 times, so $F' = (4/9)F$. 2/3 F treats the distance as entering to the first power; 9/4 F inverts the ratio.

2. A satellite in a circular orbit around the Earth has kinetic energy 5.0×10^9 J. Taking the potential energy to be zero at infinity, its total energy is [1]

(a) 5.0×10^9 J (b) -1.0×10^{10} J

(c) -2.5×10^9 J (d) -5.0×10^9 J

Answer: (d) In a circular orbit P.E. : K.E. : E = −2 : 1 : −1, so E = −K.E. = -5.0×10^9 J. -1.0×10^{10} J is the potential energy, not the total.

3. An astronaut inside a satellite orbiting the Earth feels weightless because [1]

(a) the astronaut and the satellite are both in free fall towards the Earth

(b) the gravitational force of the Earth is zero at that height

(c) the Moon's pull cancels the Earth's pull at that height

(d) the walls of the satellite shield the astronaut from the Earth's gravity

Answer: (a) Gravity at the orbit is not small, and gravitational shielding is not possible. Both the astronaut and the satellite fall freely towards the Earth with the same acceleration, so the floor presses nothing on the astronaut.

4. Treating the Earth as a uniform sphere, the acceleration due to gravity is greatest [1]

(a) at the centre of the Earth (b) on the surface of the Earth

(c) at a height R_E above the surface (d) at a depth $R_E/2$ below the surface

Answer: (b) Inside a uniform Earth g grows in proportion to r and is zero at the centre; outside it falls as $1/r^2$. So g is greatest at $r = R_E$, on the surface, and decreases whether one goes up or down.

5. The dimensional formula of the universal gravitational constant G is [1]

(a) $[M L^3 T^{-2}]$ (b) $[M^{-1} L^3 T^{-2}]$

(c) $[M^{-1} L^2 T^{-2}]$ (d) $[M L^2 T^{-2}]$

Answer: (b) $G = Fr^2/(m_1 m_2)$, so $[G] = [M L T^{-2}][L^2]/[M^2] = [M^{-1} L^3 T^{-2}]$. $[M L^2 T^{-2}]$ is the dimension of energy.

6. Starting from $W(r) = -GM_E m/r$, show that the gain in potential energy when a body of mass m is raised from the Earth's surface to a small height h is approximately mgh. [2]

$\Delta W = -GM_E m/(R_E + h) + GM_E m/R_E = GM_E m h/[R_E(R_E + h)]$. For $h << R_E$, $R_E + h \approx R_E$, so $\Delta W \approx (GM_E/R_E^2)mh = mgh$, using $g = GM_E/R_E^2$.

- $\Delta W = GM_E m h/[R_E(R_E + h)]$ (1)
- $h << R_E$ and $g = GM_E/R_E^2$ give mgh (1)

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7. Two point masses A and B are fixed 12 m apart. A small body placed on the line AB at 3 m from A experiences no net gravitational force. Find the ratio m_B/m_A. [2]

At the point, $Gm_A\,m/3^2 = Gm_B\,m/9^2$, since the body is 3 m from A and 12 − 3 = 9 m from B. So $m_B/m_A = 81/9 = 9$.

- equates the two attractions with distances 3 m and 9 m (1)
- $m_B/m_A = 9$ (1)

8. A 100 kg satellite moves around the Earth with angular momentum 4.0×10^{12} kg m^2 s^{-1} about the Earth's centre. Find the area swept out per second by the line joining the satellite to the Earth's centre. Does this rate change as the satellite moves along an elliptical orbit? [2]

$\Delta A/\Delta t = L/2m = 4.0 \times 10^{12}/(2 \times 100) = 2.0 \times 10^{10}$ m^2 s^{-1}. Gravity is a central force, so L is constant and the areal speed does not change along the orbit.

- $\Delta A/\Delta t = L/2m = 2.0 \times 10^{10}$ m^2 s^{-1} (1)
- constant, since L is conserved under a central force (1)

9. A 1 kg particle is at the origin. A 4 kg mass is fixed at (2 m, 0) and a 9 kg mass at (0, 3 m). Find the magnitude and direction of the resultant gravitational force on the 1 kg particle. Take $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}. [3]

From the 4 kg mass: $F_1 = G \times 4 \times 1/2^2 = G = 6.67 \times 10^{-11}$ N along +x. From the 9 kg mass: $F_2 = G \times 9 \times 1/3^2 = G$ along +y. By vector addition, $F = \sqrt{2}\,G = 9.43 \times 10^{-11}$ N, directed at 45° to the +x axis, between the two masses.

- $F_1 = G$ along +x (1)
- $F_2 = G$ along +y (1)
- resultant $\sqrt{2}\,G \approx 9.4 \times 10^{-11}$ N at 45° (1)

10. Show that the period of a satellite in a circular orbit of radius r around the Earth varies as $r^{3/2}$. A satellite close to the surface has period T_0. At what height above the surface (R_E = 6400 km) is the period $2\sqrt{2}\,T_0$? [3]

Gravity provides the centripetal force: $GM_E\,m/r^2 = mV^2/r$, so $V = \sqrt{(GM_E/r)}$, and $T = 2\pi r/V = 2\pi r^{3/2}/\sqrt{(GM_E)}$, so $T \propto r^{3/2}$. For $T/T_0 = 2\sqrt{2} = 2^{3/2}$, $r/R_E = 2$, so $r = 2R_E$ and $h = R_E = 6400$ km.

- $V^2 = GM_E/r$ from gravity as centripetal force (1)
- $T = 2\pi r^{3/2}/\sqrt{(GM_E)}$ (1)
- $r = 2R_E$, h = 6400 km (1)

11. Show that the areal velocity of a planet about the Sun is L/2m, where L is its angular momentum and m its mass. Hence explain why the law of areas holds for any central force. [3]

In time Δt the radius vector sweeps a triangle of area $\Delta A = \tfrac{1}{2}(r \times v\Delta t)$. So $\Delta A/\Delta t = \tfrac{1}{2}(r \times p)/m = L/2m$. A central force acts along r, so its torque $r \times F = 0$ and L is constant. Hence $\Delta A/\Delta t$ is constant for any central force, not only the inverse square force.

- $\Delta A = \tfrac{1}{2}\, r \times v\Delta t$ (1)
- $\Delta A/\Delta t = L/2m$ (1)
- central force: zero torque, L constant, so equal areas (1)