PRACTICE WORKSHEET · CLASS 11 PHYSICS

Gravitation

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Section A · Multiple Choice

Choose the correct option. Questions 1–31

1 The value of the gravitational constant for two objects in vacuum is $6.67 \times 10^{-11}\ \text{N m}^2\,\text{kg}^{-2}$. Its value in a dense medium of density 10^{10} g cm^{-3} will be:

(a) $6.67 \times 10^{-11}\ \text{N m}^2\,\text{kg}^{-2}$ (b) $6.67 \times 10^{-10}\ \text{N m}^2\,\text{kg}^{-2}$
(c) $6.67 \times 10^{-11}\ \text{N m}^2\,\text{kg}^{2}$ (d) $6.67 \times 10^{-21}\ \text{N m}^2\,\text{kg}^{-2}$

2 If the radius of the Earth shrinks by 1% but its mass remains the same, then the acceleration due to gravity on the Earth's surface will:

(a) Decrease (b) Remain the same
(c) Increase (d) Cannot be determined

3 At a certain place, the value of g is 9.8 m/s². If a part of the Earth suddenly shrinks to half its size but the mass remains unchanged, then at that same place (assuming the distance r of this place from the center of the Earth remains the same), the value of g will be:

(a) 4.9 m/s² (b) 9.8 m/s² (c) 3.1 m/s² (d) 19.6 m/s²

4 The change in the value of g at a height h above the Earth's surface is the same as the change at a depth x inside the Earth (where both x and h are very small compared to the radius of the Earth). Then:

(a) $x = h$ (b) $x = 2h$ (c) $x = h/2$ (d) $x = h^2$

5 Suppose a light planet revolves around a very massive star in a circular orbit of radius R with a time period T. If the gravitational force between the star and the planet is proportional to $R^{-5/2}$, then:

(a) $T^2 \propto R^3$ (b) $T^2 \propto R^{3/2}$ (c) $T^2 \propto R^{5/2}$ (d) $T^2 \propto R^{7/2}$

6 Two successive satellites of masses m_1 and m_2 are revolving in orbits of radii r_1 and r_2 respectively. If $r_1 > r_2$, then which of the following relations regarding the speeds of the satellites v_1 and v_2 is true?

(a) $v_1 = v_2$ (b) $v_1 > v_2$ (c) $v_1 < v_2$ (d) $v_1/r_1 = v_2/r_2$

7 The escape velocity for a rocket on Earth is 11.2 km/s. On a planet where the acceleration due to gravity is twice that of Earth and the diameter of the planet is twice the diameter of Earth, its value in km/s will be:

(a) 11.2 (b) 5.6 (c) 22.4 (d) 33.6

8 The escape velocity from the surface of Earth is 11 km/s. If the radius of another planet is twice the radius of Earth but its mean density is the same as Earth's, then the value of escape velocity from that planet will be:

(a) 12 km/s (b) 22 km/s (c) 5.5 km/s (d) 15.5 km/s

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9 Two satellites A and B are revolving around a planet P in circular orbits of radii $4R$ and R respectively. If the speed of satellite A is $3V$, then the speed of satellite B will be:

(a) $12V$ (b) $6V$ (c) $4V/3$ (d) $3V/2$

10 The radius of the Earth is 4000 miles. At a height of 10 miles above its surface, the change in acceleration due to gravity will be:

(a) $g/4000$ (b) $g/400$ (c) $g/200$ (d) $g/100$

11 If two objects of masses M and m revolve in circular paths of radii R and r respectively around their center of mass due to mutual gravitational attraction, then which of the following formulas will apply?

(a) $\frac{GMm}{R+r} = m\omega^2 r$ (b) $\frac{GMm}{R^2} = m\omega^2 r$ (c) $\frac{GMm}{(R+r)^2} = m\omega^2 r$ (d) $\frac{GMm}{R+r^2} = m\omega^2 r$

12 The escape velocity of an object of mass 1 kg on a planet is 100 m/s. The potential energy of the object on that planet will be:

(a) -5000 J (b) -1000 J (c) -2400 J (d) -10000 J

13 The height of a geostationary TV satellite will be (where T is the duration of a day and R is the radius of the Earth):

(a) $\left(\frac{4\pi^2 GM}{T^2}\right)^{1/3}$ (b) $\left(\frac{4\pi^2 GM}{R^2}\right)^{1/3} - R$

(c) $\left(\frac{GMT^2}{4\pi^2}\right)^{1/3} - R$ (d) $\left(\frac{GMT^2}{4\pi^2}\right)^{1/3} + R$

14 Two objects of masses M and m ($M > m$) revolve in circular orbits of radii R and r ($r > R$) about their center of mass. The angular velocity ω_1 of M and the angular velocity ω_2 of m are related as:

(a) $\omega_1 > \omega_2$ (b) $\omega_1 < \omega_2$ (c) $\omega_1 = \omega_2$ (d) $M\omega_1/R = m\omega_2/r$

15 The binding energy of the Earth–Moon system can be represented as:

(a) $\frac{GM_eM_m}{2r}$ (b) $-\frac{GM_eM_m}{r}$ (c) $\frac{GM_eM_m}{r}$ (d) $-\frac{GM_eM_m}{2r}$

16 In planetary motion:

(a) Rotational kinetic energy remains conserved (b) Angular momentum remains conserved

(c) Linear kinetic energy remains conserved (d) Potential energy remains conserved

17 If a planet of mass m revolving around the Sun has an angular momentum L, then the areal velocity (area swept per second by the line joining the planet to the Sun) will be:

(a) $\frac{mL}{2}$ (b) $2mL$ (c) $\frac{L}{2m}$ (d) $\frac{L}{m}$

18 A particle falls from infinity towards the Earth. Its velocity upon reaching the surface of the Earth will be:

(a) Infinity (b) $\sqrt{gR}$ (c) $\sqrt{2gR}$ (d) gR

19 If a person can jump 2 meters high on the surface of the Earth, then on a satellite where the acceleration due to gravity is 1.96 m/s², his jump height will be:

(a) 5 m (b) 10 m (c) 20 m (d) 2 m

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20 The ratio of kinetic energy to potential energy of a satellite is:

(a) 1 : 4 (b) 4 : 1 (c) 1 : 2 (d) 2 : 1

21 At a point located at a distance of 8000 km from the center of the Earth, the intensity of the gravitational field is 6 N/kg. The gravitational potential at that point is:

(a) 8×10^8 (b) 2.4×10^2 J (c) 4.8×10^7 J/kg (d) 6.4×10^{14} J

22 The escape velocity of a planet is V_0. The value of escape velocity for a planet of the same density but twice the radius will be:

(a) $0.5V_0$ (b) V_0 (c) $2V_0$ (d) $4V_0$

23 The speed of a 500 kg satellite at a height of 10^3 km from the Earth is 7.36×10^3 m/s. If the orbit of the satellite is circular, the gravitational force of the Earth on the satellite is:

(a) 4×10^2 (b) 3.66×10^3 (c) 3.75×10^4 (d) 5×10^2

24 The minimum energy required to launch a 250 kg satellite from the surface of the Earth into an orbit at a height of $2R_e$ will be:

(a) 0.5×10^{10} J (b) 1.3×10^{10} J (c) 2.5×10^{10} J (d) 5×10^{10} J

25 The ratio of the radii of two planets is p and the ratio of their acceleration due to gravity is q, then the ratio of the escape velocities of these planets will be:

(a) $(p/q)^{1/2}$ (b) $(q/p)^{1/2}$ (c) pq (d) $\sqrt{pq}$

26 Two bodies of masses M_1 and M_2 are dropped from the same height, then the ratio of their momenta at the surface of the Earth will be:

(a) $\sqrt{\frac{M_1}{M_2}}$ (b) $\frac{M_1^2}{M_2^2}$ (c) $\frac{M_2}{M_1}$ (d) $\frac{M_1}{M_2}$

27 The percentage change in the weight of a body when moved from the equator to the poles on the surface of the Earth will be:

(a) 4.5 (b) 1.2 (c) 0.43 (d) 0.04

28 What should be the rotational velocity of the Earth about its own axis so that the weight of a body at the equator becomes $3/5$ of its present weight? (Radius of the Earth at the equator is R.)

(a) $\sqrt{\frac{5g}{2R}}$ (b) $\sqrt{\frac{2g}{5R}}$ (c) $\sqrt{\frac{3g}{5R}}$ (d) $\sqrt{\frac{5g}{3R}}$

29 On Earth, the pressure of a barometer and the height of the column are 10^5 pascal and 760 mm respectively. If it is taken to the Moon, the height of the column will be:

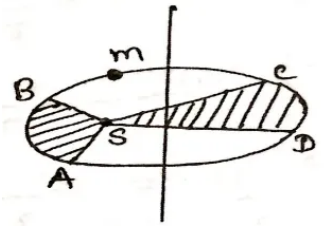
(a) Zero (b) 76 mm (c) 126 mm (d) 760 mm

30 The escape velocity of a body from the Earth is 11.2 km/s. If it is projected at an angle of 45° with the horizontal, the value of the escape velocity will be:

(a) 11.2 km/s (b) 22.4 km/s (c) $11.2/\sqrt{2}$ km/s (d) $11.2\sqrt{2}$ km/s

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31 The figure shows the elliptical orbit of a planet m relative to the Sun S. The shaded area SCD is twice the shaded area SAB. If the time taken by the planet to move from C to D is t_1 and the time taken to move from A to B is t_2, then:



(a) $t_1 = t_2$ (b) $t_1 < t_2$ (c) $t_1 = 4t_2$ (d) $t_1 = 2t_2$

Section B · Short Answer & Numericals

Show all steps. Questions 32–35

32 A mass M is divided into two parts, xM and $(1-x)M$. For a fixed distance between them, what should be the value of x so that the gravitational force between the two parts is maximum?

33 The escape velocity of Earth is 11.2 km/s. Compared to Earth, the radius and mass of Mars are approximately half and 1/10th respectively. What will the escape velocity from Mars be?

34 Infinite masses, each of 1 kg, are placed along the x-axis at $x = \pm 1$ m, ± 2 m, ± 4 m, ± 8 m, ± 16 m, … What is the magnitude of the resultant gravitational potential at the origin ($x = 0$), in terms of the gravitational constant G?

35 A rocket is fired vertically with a speed of 5 km/s from the Earth's surface. How far from the Earth does the rocket go before returning to the Earth? Mass of the Earth $= 6 \times 10^{24}$ kg; mean radius of the Earth $= 6.4 \times 10^{6}$ m; $G = 6.67 \times 10^{-11}\ \mathrm{N\,m^2\,kg^{-2}}$.

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Formula Sheet · Gravitation

Quick revision

Newton's law of gravitation

Force between two masses	$F = \dfrac{Gm_1m_2}{r^2}$
Gravitational constant	$G = 6.67 \times 10^{-11}\ \dfrac{\mathrm{m}^3}{\mathrm{kg}\cdot\mathrm{s}^2}$

Acceleration due to gravity (g)

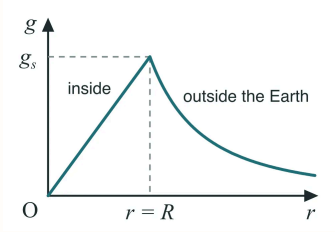
At the surface	$g = \dfrac{GM}{R^2} = \dfrac{4}{3}\pi\rho GR$
(i) Due to the shape of the Earth	$\dfrac{g_e}{g_p} = \dfrac{R_p^2}{R_e^2}, \quad g_p = g_e + 0.018\ \mathrm{m/s^2}$
(ii) At height h	$g_h = \dfrac{GM}{(R+h)^2}$
At height h, if $h \ll R$	$g_h = g_s\left(1 - \dfrac{2h}{R}\right), \quad \dfrac{\Delta g}{g} = -\dfrac{2h}{R}$
(iii) At depth d	$g_d = \dfrac{GM(R-d)}{R^3} = g_s\left(1 - \dfrac{d}{R}\right), \quad \dfrac{\Delta g}{g} = -\dfrac{d}{R}$

Effect of the Earth's rotation on g

(iv) At latitude λ	$g' = g - \omega^2 R\cos^2\lambda$
Poles and equator	$g_p - g_e = \omega^2 R = 0.034\ \mathrm{m/s^2}$
Weightlessness at the equator ($\lambda = 0$)	$g' = 0 \ \Rightarrow\ \omega = \sqrt{\dfrac{g}{R}} = 1.25 \times 10^{-3}\ \mathrm{rad/s}$
Length of the day then	$T = 1.40\ \mathrm{h} = 5026.5\ \mathrm{s}$
For weightlessness, the Earth must rotate	17 times faster

Variation of g with distance r from the Earth's center

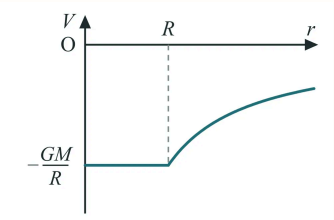
Inside ($0 < r \le R$)	$g = \dfrac{GM}{R^3}\,r$
Outside ($r > R$)	$g = \dfrac{GM}{r^2}$



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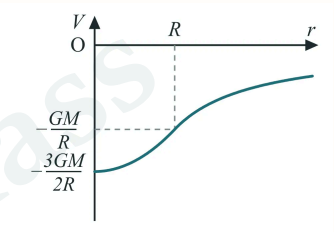
Gravitational potential: point mass & spherical shell

Due to a point mass	$V = -\dfrac{GM}{r}$
Shell, outside ($r > R$)	$V = -\dfrac{GM}{r}$
Shell, surface ($r = R$)	$V = -\dfrac{GM}{R}$
Shell, inside ($r < R$)	$V = -\dfrac{GM}{R}$



Potential due to a solid sphere

Outside ($r > R$)	$V = -\dfrac{GM}{r}$
At the surface ($r = R$)	$V = -\dfrac{GM}{R}$
Inside ($r < R$)	$V = -\dfrac{GM(3R^2 - r^2)}{2R^3}$
At the center	$V_{\text{center}} = \dfrac{3}{2} V_{\text{surface}}$



Potential due to a thin ring

At a distance X on the axis	$V = -\dfrac{GM}{\sqrt{R^2 + X^2}}$
At the center	$V = -\dfrac{GM}{R}$

Gravitational potential energy (U)

Two point masses	$U = -\dfrac{GM_1M_2}{r}$
Uniform thin spherical shell	$U = -\dfrac{GM^2}{2R}$
Uniform solid sphere	$U = -\dfrac{3}{5}\dfrac{GM^2}{R}$
Change in P.E.	$\Delta U = -GMm\left[\dfrac{1}{r_2} - \dfrac{1}{r_1}\right]$
At a height h from the Earth's surface	$U_h = -\dfrac{GMm}{R+h} = \dfrac{-mgR}{1+\dfrac{h}{R}}$
Work done against gravity	$W = \dfrac{mgh}{1+\dfrac{h}{R}}$

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Escape velocity (V_e)

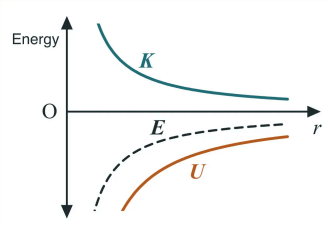
Escape velocity	$V_e = \sqrt{\dfrac{2GM}{R}} = \sqrt{2Rg} = R\sqrt{\dfrac{8}{3}\pi\rho G}$
Maximum height attained by a body thrown with speed V	$h = \dfrac{R}{\dfrac{V_e^2}{V^2} - 1}$
If $V > V_e$ (thrown faster than the escape velocity)	$V' = \sqrt{V^2 - V_e^2}$

Orbital velocity & path of a satellite

For a nearby planet/satellite	$V_0 = \sqrt{\dfrac{GM}{R}} = \dfrac{V_e}{\sqrt{2}}$
Spiral path	$V < V_0$
Circular path	$V = V_0$
Elliptical path	$V_0 < V < V_e$
Parabolic path	$V = V_e$
Hyperbolic path	$V > V_e$
If $F \propto 1/r^n$	$V \propto \dfrac{1}{r^{(n-1)/2}}, \quad T \propto r^{(n+1)/2}$

Energies of a satellite

Potential energy	$U = -\dfrac{GMm}{r} = -\dfrac{L^2}{mr^2}$
Kinetic energy	$K = \dfrac{GMm}{2r} = \dfrac{L^2}{2mr^2}$
Total (mechanical) energy	$E = -\dfrac{GMm}{2r} = -\dfrac{L^2}{2mr^2}$
Binding energy	$\text{B.E.} = -E = \dfrac{GMm}{2r}$
Energy to shift its orbit from R_1 to R_2 (change in total energy)	$\Delta E = \dfrac{GMm}{2}\left(\dfrac{1}{R_1} - \dfrac{1}{R_2}\right)$



To make a satellite escape from its orbit

Double its orbital kinetic energy	$K \to 2K \quad (100\%\ \text{increase})$
Supply energy equal to its orbital energy (in magnitude)	$\lvert E \rvert = \dfrac{GMm}{2r}$
Multiply its orbital velocity by $\sqrt{2}$	$V \to \sqrt{2}\,V \quad (41.4\%\ \text{increase})$

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Kepler's laws & time period of a satellite

1st law (law of orbits)	Elliptical path, Sun at one focus
2nd law (law of areas): areal velocity	$\frac{dA}{dt} = \frac{L}{2m} = \frac{1}{2} rv = \text{constant}$
3rd law (law of periods)	$T^2 \propto a^3, \quad a = \frac{r_{\max} + r_{\min}}{2}$
Velocity at aphelion	$V_a = \sqrt{\frac{GM}{a}\left(\frac{1-e}{1+e}\right)}$
Velocity at perihelion	$V_p = \sqrt{\frac{GM}{a}\left(\frac{1+e}{1-e}\right)}$
Time period (basic)	$T = \frac{2\pi r}{V}$
Time period (expanded)	$T = \frac{2\pi r^{3/2}}{\sqrt{GM}} = 2\pi\sqrt{\frac{(R+h)^3}{gR^2}}$

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