NEET — Physics Formula Series
GRAVITATION
Complete Formula Sheet

All formulas, conditions, and key results at one place

G	g (surface)	Key Values
$6.67 \times 10^{-11}\ \mathrm{N\,m^2\,kg^{-2}}$	$9.8 \approx 10\ \mathrm{m/s^2}$	$M_E = 6 \times 10^{24}$ kg, $R_E = 6.4 \times 10^6$ m

1. Newton's Law of Gravitation

$$\text{Gravitational Force:} \quad F = \frac{Gm_1m_2}{r^2}$$

$$\text{Vector Form:} \quad \vec{F}_{12} = -\frac{Gm_1m_2}{r^2}\hat{r}_{12} \quad (\text{attractive, along } \hat{r})$$

$$\text{Superposition:} \quad \vec{F}_{\text{net}} = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14} + \cdots$$

> ★ **Important:** G is a universal constant. Gravitational force is always attractive, acts along the line joining the two masses, and obeys Newton's Third Law.

2. Acceleration Due to Gravity (g)

At Latitude λ: $\quad g_\lambda = g - \omega^2 R\cos^2\lambda$

On Surface: $\quad g = \dfrac{GM}{R^2}$

At Height h: $\quad g_h = \dfrac{GM}{(R+h)^2} = g\left(1 + \dfrac{h}{R}\right)^{-2} \approx g\left(1 - \dfrac{2h}{R}\right), \; h \ll R$

At Equator (min): $\quad g_{\text{eq}} = g - \omega^2 R$

At Depth d: $\quad g_d = g\left(1 - \dfrac{d}{R}\right) \Rightarrow g_d = 0$ at centre

At Poles (max): $\quad g_{\text{pole}} = g \quad$ (no rotation effect)

> ★ **Important:** g is maximum at poles and minimum at equator. $g = 0$ at the centre of the Earth. g decreases both above and below the surface, but the rate of decrease is different.

3. Gravitational Field Intensity ($\vec{g}$ or $\vec{E}$)

Outside Solid Sphere $(r > R)$: $\quad g = \dfrac{GM}{r^2}$

Definition: $\quad \vec{g} = \dfrac{\vec{F}}{m} \quad$ (force per unit test mass)

Due to Point Mass M: $\quad g = \dfrac{GM}{r^2} \quad$ (towards M)

Inside Solid Sphere $(r < R)$: $\quad g = \dfrac{GMr}{R^3}$

Inside Hollow Shell: $g = 0$

Outside Hollow Shell: $g = \frac{GM}{r^2}$

Relation with Potential: $\vec{g} = -\frac{dV}{dr} \Rightarrow \vec{g} = -\nabla V$

4. Gravitational Potential (V)

At Centre of Solid Sphere: $V_c = -\frac{3GM}{2R} = \frac{3}{2}V_{\text{surface}}$

Definition: $V = \frac{W}{m} = -\int_{\infty}^{r} \vec{g}\cdot d\vec{r}$ (always negative)

Due to Point Mass: $V = -\frac{GM}{r}$

Inside/On Hollow Shell: $V = -\frac{GM}{R}$ (constant everyw

Outside Solid Sphere $(r > R)$: $V = -\frac{GM}{r}$

Inside Solid Sphere $(r < R)$: $V = -\frac{GM}{2R^3}(3R^2 - r^2)$

Outside Hollow Shell: $V = -\frac{GM}{r}$

> ★ **Important:** Gravitational potential is always negative (taking $V = 0$ at infinity). The potential inside a hollow shell is constant and equal to the surface value.

5. Gravitational Potential Energy (U)

At Height h : $U_h = -\frac{GMm}{R+h}$

Two Point Masses: $U = -\frac{Gm_1m_2}{r}$

Mass m near Earth: $U = -\frac{GMm}{r}$

Change in PE $(h \ll R)$: $\Delta U = U_h - U_s = mgh$

On Earth's Surface: $U_s = -\frac{GMm}{R} = -mgR$

System of n masses: $U = -G\sum_{i<j}\frac{m_im_j}{r_{ij}}$

6. Escape Velocity (v_e)

At Height h : $v_e(h) = \sqrt{\frac{2GM}{R+h}}$

From Surface: $v_e = \sqrt{\frac{2GM}{R}} = \sqrt{2gR}$

Relation: $v_e = \sqrt{2}\,v_o \Rightarrow v_e : v_o = \sqrt{2} : 1$

Numerical: $v_e \approx 11.2$ km/s (Earth)

In terms of g_h : $v_e = \sqrt{2g_h(R+h)}$

> ★ **Important:** Escape velocity is independent of the mass and direction of projection. It depends only on the mass and radius of the planet.

7. Orbital Motion of Satellites

In terms of g, R : $v_o = R\sqrt{\frac{g}{R+h}}$

Orbital Velocity: $v_o = \sqrt{\frac{GM}{r}} = \sqrt{\frac{GM}{R+h}}$

Near Surface $(h \approx 0)$: $v_o = \sqrt{gR} \approx 7.9$ km/s

Time Period: $T = \dfrac{2\pi r}{v_o} = 2\pi\sqrt{\dfrac{r^3}{GM}} = 2\pi\sqrt{\dfrac{(R+h)^3}{GM}}$

Near Surface: $T_{\text{min}} = 2\pi\sqrt{\dfrac{R}{g}} \approx 84$ min

Height from Period: $h = \left(\dfrac{GMT^2}{4\pi^2}\right)^{1/3} - R$

8. Energy of a Satellite in Circular Orbit

KE: $KE = \dfrac{1}{2}mv_o^2 = \dfrac{GMm}{2r}$ (always positive)

PE: $PE = -\dfrac{GMm}{r}$ (always negative)

Total Energy: $E = KE + PE = -\dfrac{GMm}{2r}$ (always nega

Binding Energy: $BE = -E = \dfrac{GMm}{2r}$

Key Ratio: $KE = -E$; $PE = 2E$; $PE = -2\,KE$

★ **Important:** Total energy of a satellite is always negative, indicating a bound system. The magnitude of KE equals the Binding Energy. As orbit radius increases, KE decreases but $|E|$ also decreases, so total energy increases (becomes less negative).

9. Kepler's Laws of Planetary Motion

First Law (Orbit): Each planet moves in an elliptical orbit with the Sun at one focus.

Second Law (Area): $\dfrac{dA}{dt} = \dfrac{L}{2m} =$ constant (Equal areas swept in equal times ⇒ Angular momentum is conserved)

Third Law ($T^2 \propto a^3$):

$$T^2 = \frac{4\pi^2}{GM}a^3 \;\Rightarrow\; \frac{T_1^2}{T_2^2} = \frac{a_1^3}{a_2^3}$$

$$\text{For Circular Orbit } (a = r): \quad T^2 = \frac{4\pi^2}{GM}r^3$$

Velocity at Perihelion: $v_p \cdot r_p = v_a \cdot r_a$ (conservation of L) Semi-major axis: $a = \dfrac{r_p + r_a}{2}$

10. Geostationary and Polar Satellites

Geostationary Orbit: Time period $T = 24$ hours, orbits in equatorial plane, same direction as Earth's rotation.

Height of Geostationary: $h \approx 36{,}000$ km $= 3.6 \times 10^7$ m

Radius of Orbit: $r_g \approx 42{,}400$ km

Polar Satellite: Orbits at ≈ 500–800 km height, $T \approx 100$ min, passes over both poles — used for remote sensing.

11. Weightlessness

Condition: Apparent weight $= m(g - a) = 0$ when $a = g$ (free fall condition).

In Satellite: Both satellite and astronaut are in free fall with same acceleration $= \dfrac{GM}{r^2}$ — hence weightlessness.

At Earth's Centre: $g = 0$ at centre ⇒ weight $= 0$.

NOT the same as: Zero gravity — gravity still acts, but the normal reaction from the surface becomes zero.

12. Quick Comparison — Solid Sphere vs Hollow Shell

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shaderow g inside	$\frac{GMr}{R^3}$ (varies with r)	0 (zero everywhere)
g outside	$\frac{GM}{r^2}$	$\frac{GM}{r^2}$
shaderow V inside	$-\frac{GM}{2R^3}(3R^2 - r^2)$ (varies)	$-\frac{GM}{R}$ (constant)
V outside	$-\frac{GM}{r}$	$-\frac{GM}{r}$
shaderow V at centre	$-\frac{3GM}{2R}$	$-\frac{GM}{R}$
V at surface	$-\frac{GM}{R}$	$-\frac{GM}{R}$

13. Master Formula List at a Glance

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shaderow 1	Gravitational Force	$F = \frac{Gm_1m_2}{r^2}$
2	g on Surface	$g = \frac{GM}{R^2}$
shaderow 3	g at Height h	$g_h \approx g\left(1 - \frac{2h}{R}\right)$
4	g at Depth d	$g_d = g\left(1 - \frac{d}{R}\right)$
shaderow 5	g at Latitude λ	$g_\lambda = g - \omega^2 R \cos^2\lambda$
6	Gravitational Potential	$V = -\frac{GM}{r}$
shaderow 7	Gravitational PE	$U = -\frac{GMm}{r}$
8	Escape Velocity	$v_e = \sqrt{\frac{2GM}{R}} = \sqrt{2gR}$
shaderow 9	Orbital Velocity	$v_o = \sqrt{\frac{GM}{r}} = \sqrt{\frac{gR^2}{R+h}}$
10	Time Period	$T = 2\pi\sqrt{\frac{r^3}{GM}}$
shaderow 11	KE of Satellite	$KE = \frac{GMm}{2r}$
12	PE of Satellite	$PE = -\frac{GMm}{r}$
shaderow 13	Total Energy	$E = -\frac{GMm}{2r}$
14	Binding Energy	$BE = \frac{GMm}{2r}$

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shaderow 15	Kepler's Third Law	$T^2 = \frac{4\pi^2}{GM}a^3$
16	Areal Velocity	$\frac{dA}{dt} = \frac{L}{2m} = \text{const}$
shaderow 17	v_e vs v_o Relation	$v_e = \sqrt{2}\, v_o$
18	V inside Solid Sphere	$V = -\frac{GM}{2R^3}(3R^2 - r^2)$
shaderow 19	V at Centre	$V_c = -\frac{3GM}{2R}$
20	Gravitational Field	$\vec{g} = -\frac{dV}{dr}\hat{r}$