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CHAPTER NOTES

Gravitation Class 11 Notes | CBSE Physics Chapter 7

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Gravitation Class 11 Notes | CBSE Physics Chapter 7

Gravitation is Chapter 7 of CBSE Class 11 Physics — the chapter that explains the single force responsible for an apple falling, the Moon orbiting Earth, and entire galaxies holding together. It begins with Kepler's three laws of planetary motion and builds up to Newton's universal law of gravitation, satellites, and escape velocity. Master this chapter and you unlock a steady stream of one- and two-mark scoring questions in boards and a guaranteed question in JEE and NEET.

By the end of these notes you will be able to state Kepler's laws, apply the universal law of gravitation, calculate how g changes with altitude, depth, and latitude, and confidently solve numericals on escape velocity, orbital velocity, geostationary satellites, and the energy of an orbiting satellite. This is a high-weightage chapter carrying roughly 6–8 marks in boards and a reliable scorer once the formulas are clear.

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Key Concepts

1. Kepler's Laws of Planetary Motion

Before Newton explained *why* planets move, Johannes Kepler described *how* they move using three laws based on Tycho Brahe's observations.

- **First law (Law of Orbits):** Every planet moves around the Sun in an elliptical orbit with the Sun at one focus.
- **Second law (Law of Areas):** The line joining a planet to the Sun sweeps out equal areas in equal intervals of time. This means a planet moves faster when nearer the Sun and slower when farther — it is a direct consequence of conservation of angular momentum (areal velocity $dA/dt = L/2m$ is constant).
- **Third law (Law of Periods):** The square of the time period of a planet is proportional to the cube of the semi-major axis of its orbit. $T^2 \propto a^3$, i.e. $T^2/a^3 = \text{constant}$.

[DIAGRAM: An elliptical orbit with the Sun at one focus; two shaded sectors of equal area near and far from the Sun showing equal areas swept in equal times.]

2. Newton's Universal Law of Gravitation

Every body in the universe attracts every other body with a force directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

$$F = G \cdot m_1 m_2 / r^2$$

- The force acts along the line joining the two masses and is always attractive.
 - It is a vector quantity and obeys Newton's third law — the two bodies pull each other equally.
 - Gravitation is a **central force** and a **conservative force**.
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3. Universal Gravitational Constant (G)

The constant **G** is numerically equal to the force of attraction between two unit masses placed unit distance apart.

- **Value:** $G = 6.674 \times 10^{-11} \text{ N} \cdot \text{m}^2 / \text{kg}^2$
- **Dimensional formula:** $[M^{-1}L^3T^{-2}]$
- G is a **universal constant** — same everywhere, independent of the medium, masses, and nature of the bodies. It was first measured by Henry Cavendish.

Note: Do not confuse G (universal constant) with g (acceleration due to gravity, which varies from place to place).

4. Acceleration Due to Gravity (g)

The acceleration produced in a body due to the gravitational pull of the Earth is called **acceleration due to gravity (g)**.
From $F = mg$ and $F = GMm/R^2$:

$$g = GM/R^2$$

- **M** = mass of Earth, **R** = radius of Earth.
- Average value on Earth's surface: **$g \approx 9.8 \text{ m/s}^2$** .
- g is independent of the mass of the falling body — a feather and a stone fall equally fast in vacuum.

Also, $g = (4/3)\pi R \rho G$, where ρ is the mean density of the Earth.

5. Variation of g with Altitude, Depth and Latitude

The value of g is not constant — it changes as you move above, below, or across the surface of the Earth.

With Altitude (height h above surface)

$$g_h = g(1 - 2h/R), \text{ for } h \ll R.$$

g decreases as you go up. The exact form is $g_h = g \cdot R^2 / (R + h)^2$.

With Depth (depth d below surface)

$$g_d = g(1 - d/R)$$

g also decreases as you go down, and becomes **zero at the centre** of the Earth ($d = R$).

With Latitude (rotation of Earth)

$g' = g - \omega^2 R \cos^2 \lambda$, where λ is the latitude and ω is the Earth's angular speed.

- g is **maximum at the poles** ($\lambda = 90^\circ$, $\cos \lambda = 0$, so no reduction).
 - g is **minimum at the equator** ($\lambda = 0^\circ$, maximum reduction).
-

6. Gravitational Potential Energy

Gravitational potential energy (U) of a body is the work done in bringing it from infinity to a point in the gravitational field.

$$U = -GMm/r$$

- It is always **negative** (taking $U = 0$ at infinity), because gravity is attractive.
 - Near the Earth's surface, the change in PE for a small height h is the familiar **$U = mgh$** .
-

7. Gravitational Potential

Gravitational potential (V) at a point is the work done in bringing a unit mass from infinity to that point.

$$V = -GM/r$$

- SI unit:** J/kg. It is a **scalar** quantity.
 - Relation with potential energy: $U = mV$.
 - Relation with field: gravitational field intensity $E = -dV/dr$.
-

8. Escape Velocity

Escape velocity (v_e) is the minimum velocity with which a body must be projected so that it escapes the Earth's gravitational field and never returns.

$$v_e = \sqrt{2GM/R} = \sqrt{2gR}$$

- For Earth, $v_e \approx 11.2 \text{ km/s}$.
 - It is independent of the mass and the direction of projection of the body.
 - In terms of density: $v_e = R\sqrt{8\pi G\rho/3}$.
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9. Orbital Velocity of a Satellite

Orbital velocity (v_o) is the velocity needed to keep a satellite revolving in a stable circular orbit. The required centripetal force is provided by gravity.

$$v_o = \sqrt{GM/r} = \sqrt{[GM/(R + h)]}$$

- For a satellite close to the Earth's surface ($h \ll R$): $v_o = \sqrt{gR} \approx \mathbf{7.9 \text{ km/s}}$.
- Important relation:** $v_e = \sqrt{2} \cdot v_o$ — escape velocity is $\sqrt{2}$ times the orbital velocity of a near-Earth satellite.

Time Period of a Satellite

$T = 2\pi\sqrt{[(R + h)^3/GM]}$ — this is Kepler's third law in disguise.

10. Satellites — Geostationary and Polar

Feature	Geostationary Satellite	Polar Satellite
Orbit plane	Equatorial plane	Passes over the poles (perpendicular to equator)
Time period	24 hours (same as Earth's rotation)	≈ 100 minutes (much shorter)
Height	$\approx 36,000$ km above surface	Low altitude ($\approx 500\text{--}800$ km)
Use	Communication, TV, weather	Remote sensing, spying, mapping

A **geostationary satellite** appears stationary from the ground because its period matches the Earth's rotation, so it stays above the same point on the equator.

11. Energy of an Orbiting Satellite

A satellite of mass m in an orbit of radius r has both kinetic and potential energy.

- Kinetic energy:** $KE = \frac{1}{2}mv_o^2 = +GMm/2r$
- Potential energy:** $PE = -GMm/r$
- Total energy:** $E = KE + PE = -GMm/2r$

Key idea: The total energy is negative, which shows the satellite is bound to the Earth. Binding energy $= +GMm/2r$ is the energy needed to remove the satellite to infinity. Also, $E = -KE$ and $PE = 2E$.

12. Weightlessness

Weightlessness is the state in which a body experiences zero apparent weight. It occurs when the body and its support fall freely under gravity together, so the normal reaction becomes zero.

- An astronaut in an orbiting satellite feels weightless because both the satellite and the astronaut are in free fall toward the Earth with the same acceleration.
- Weightlessness does **not** mean gravity is absent — g is still significant in orbit; it means there is no reaction force from the floor.

Weightage in Board & Entrance Exams

Exam	Typical Weightage	Most-Tested Areas
CBSE Board (Class 11)	6–8 marks	Kepler's laws, variation of g , escape & orbital velocity, satellite energy
JEE Main / Advanced	1–2 questions	Orbital velocity, satellite energy, gravitational potential, variation of g
NEET	1–2 questions	Kepler's third law, escape velocity, g with altitude/depth, weightlessness

[TABLE: Question-type split — VSA (1 mark): definitions of G , g , escape velocity; SA (2–3 marks): variation of g , Kepler's laws, orbital velocity; LA (5 marks): derivation of escape/orbital velocity and energy of a satellite.]

Important Definitions

Term	Definition
Universal law of gravitation	Force between two masses: $F = Gm_1m_2/r^2$ — attractive, along the line joining them
Gravitational constant (G)	Force between unit masses unit distance apart: $G = 6.674 \times 10^{-11} \text{ N}\cdot\text{m}^2/\text{kg}^2$
Acceleration due to gravity (g)	Acceleration of a freely falling body due to Earth's pull: $g = GM/R^2$
Kepler's third law	Square of period proportional to cube of semi-major axis: $T^2 \propto a^3$
Gravitational potential energy	Work done to bring a mass from infinity to a point: $U = -GMm/r$
Gravitational potential	Work done to bring unit mass from infinity to a point: $V = -GM/r$
Escape velocity	Minimum velocity to escape Earth's field: $v_e = \sqrt{2gR} \approx 11.2 \text{ km/s}$
Orbital velocity	Velocity for a stable orbit: $v_o = \sqrt{GM/r}$; near surface $\approx 7.9 \text{ km/s}$
Geostationary satellite	Satellite with a 24-hour period that appears fixed over the equator
Weightlessness	State of zero apparent weight during free fall (normal reaction = 0)

Solved Examples

Example 1

Two masses of 10 kg and 20 kg are placed 1 m apart. Find the gravitational force between them. ($G = 6.674 \times 10^{-11} \text{ N}\cdot\text{m}^2/\text{kg}^2$)

Answer: $F = Gm_1m_2/r^2 = (6.674 \times 10^{-11} \times 10 \times 20)/1^2 = \mathbf{1.33 \times 10^{-8} \text{ N}}$.

Example 2

At what height above the Earth's surface will the value of g become one-fourth of its value on the surface? ($R = 6400 \text{ km}$)

Answer: $g_h = g \cdot R^2/(R + h)^2$. For $g_h = g/4$, we need $(R + h)^2 = 4R^2$, so $R + h = 2R$, giving **$h = R = 6400 \text{ km}$** .

Example 3

Calculate the escape velocity from the surface of the Earth. ($g = 9.8 \text{ m/s}^2$, $R = 6.4 \times 10^6 \text{ m}$)

Answer: $v_e = \sqrt{2gR} = \sqrt{2 \times 9.8 \times 6.4 \times 10^6} = \sqrt{1.254 \times 10^8} \approx \mathbf{11.2 \times 10^3 \text{ m/s} = 11.2 \text{ km/s}}$.

Example 4

A satellite orbits the Earth close to its surface. Find its orbital velocity. ($g = 9.8 \text{ m/s}^2$, $R = 6.4 \times 10^6 \text{ m}$)

Answer: $v_o = \sqrt{gR} = \sqrt{9.8 \times 6.4 \times 10^6} = \sqrt{6.272 \times 10^7} \approx \mathbf{7.92 \times 10^3 \text{ m/s} = 7.9 \text{ km/s}}$.

Example 5

How does the value of g change at a depth equal to half the radius of the Earth?

Answer: $g_d = g(1 - d/R) = g(1 - (R/2)/R) = g(1 - 1/2) = \mathbf{g/2}$. The value of g is halved.

Example 6

A satellite of mass 200 kg revolves around the Earth in an orbit of radius 7000 km. Find its total energy. ($GM = 4 \times 10^{14} \text{ m}^3/\text{s}^2$)

Answer: $E = -GMm/2r = -(4 \times 10^{14} \times 200)/(2 \times 7 \times 10^6) = -(8 \times 10^{16})/(1.4 \times 10^7) \approx \mathbf{-5.7 \times 10^9 \text{ J}}$ (negative, so the satellite is bound).

Important Questions for Board Exams

1-Mark Questions (VSA)

1. Define gravitational constant G and give its SI unit.
2. Why does the value of g become zero at the centre of the Earth?
3. What is the relation between escape velocity and orbital velocity of a near-Earth satellite?
4. Why is gravitational potential always negative?
5. At what place on Earth is the value of g maximum?

2–3-Mark Questions (SA)

1. State Kepler's three laws of planetary motion.
2. Derive an expression for the variation of g with altitude (height h above the surface).
3. Show that the escape velocity is $\sqrt{2}$ times the orbital velocity of a satellite near the Earth's surface.
4. What is a geostationary satellite? List two of its uses and one condition it must satisfy.

5-Mark Questions (LA)

1. Derive an expression for the orbital velocity and time period of a satellite revolving close to the Earth's surface.
 2. Obtain expressions for the kinetic energy, potential energy, and total energy of a satellite in orbit, and explain why the total energy is negative.
 3. Define escape velocity and derive the expression $v_e = \sqrt{2GM/R}$. Hence calculate its value for the Earth.
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Quick Revision Points

- Kepler: orbits are ellipses; equal areas in equal times; $T^2 \propto a^3$
 - Universal law: $F = Gm_1m_2/r^2$; always attractive, central, conservative
 - $G = 6.674 \times 10^{-11} \text{ N}\cdot\text{m}^2/\text{kg}^2$ (universal); $g = GM/R^2 \approx 9.8 \text{ m/s}^2$ (varies)
 - g with altitude: $g_h = g(1 - 2h/R)$; with depth: $g_d = g(1 - d/R)$
 - g is max at poles, min at equator; zero at Earth's centre
 - Gravitational PE: $U = -GMm/r$; potential $V = -GM/r$ (scalar, J/kg)
 - Escape velocity: $v_e = \sqrt{2gR} \approx 11.2 \text{ km/s}$ (independent of mass)
 - Orbital velocity: $v_o = \sqrt{GM/r}$; near surface $\approx 7.9 \text{ km/s}$; $v_e = \sqrt{2}\cdot v_o$
 - Satellite energy: KE = $+GMm/2r$, PE = $-GMm/r$, total E = $-GMm/2r$
 - Geostationary: 24 h period, equatorial, $\approx 36,000 \text{ km}$; polar: low, $\approx 100 \text{ min}$
 - Weightlessness: free fall makes normal reaction zero, not zero gravity
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Next Chapter: Chapter 8 — Mechanical Properties of Solids



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