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Oscillations Class 11 Notes | CBSE Physics Chapter 13

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Oscillations Class 11 Notes | CBSE Physics Chapter 13

Oscillations is Chapter 13 of CBSE Class 11 Physics — the chapter that teaches you the maths of anything that swings, bounces, or vibrates. From a child on a swing to the quartz crystal in your watch, all repeating motion is built on one elegant idea: **simple harmonic motion (SHM)**. Master it here and you have already unlocked half of the Waves chapter and most of AC circuits in Class 12.

By the end of these notes you will be able to write the equation of SHM, find displacement, velocity and acceleration at any instant, work out the energy of an oscillator, and derive the time period of a pendulum and a spring. This is a high-weightage chapter carrying roughly 6–8 marks in boards, and a guaranteed source of questions in JEE and NEET.

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Key Concepts

1. Periodic and Oscillatory Motion

Periodic motion is any motion that repeats itself after a fixed interval of time, called the **time period (T)**. The hands of a clock, the Earth around the Sun, and a vibrating string are all periodic.

Oscillatory (or vibratory) motion is a special kind of periodic motion in which a body moves to and fro about a fixed mean (equilibrium) position. Every oscillatory motion is periodic, but not every periodic motion is oscillatory — the Earth's orbit is periodic but not oscillatory.

- **Time period (T)**: time for one complete oscillation. SI unit: second.
 - **Frequency (v)**: number of oscillations per second; $v = 1/T$. SI unit: hertz (Hz).
 - **Angular frequency (ω)**: $\omega = 2\pi v = 2\pi/T$. SI unit: rad/s.
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2. Simple Harmonic Motion (SHM)

Simple harmonic motion is the simplest oscillatory motion, in which the restoring force on the body is directly proportional to its displacement from the mean position and is always directed towards that mean position.

The displacement of a particle in SHM is described by:

$$y = A \sin(\omega t + \phi_0) \quad \text{or} \quad y = A \cos(\omega t + \phi_0)$$

- **A** = amplitude — the maximum displacement from the mean position.
- **ω** = angular frequency.
- **$(\omega t + \phi_0)$** = phase; **ϕ_0** = initial phase (epoch).

A particle moving in a circle at constant speed, when projected on a diameter, traces SHM — this is the link between circular motion and SHM.

3. Displacement, Velocity and Acceleration in SHM

Taking displacement **$y = A \sin \omega t$** , we differentiate to get velocity and acceleration.

Velocity: $v = dy/dt = A\omega \cos \omega t = \omega\sqrt{A^2 - y^2}$

Acceleration: $a = dv/dt = -A\omega^2 \sin \omega t = -\omega^2 y$

- Velocity is **maximum at the mean position** ($y = 0$): $v_{\text{max}} = A\omega$.
- Velocity is **zero at the extreme positions** ($y = \pm A$).
- Acceleration is **zero at the mean position** and **maximum at the extremes**: $a_{\text{max}} = A\omega^2$.

[DIAGRAM: Three curves on the same time axis — displacement (sine), velocity (cosine, leading by 90°), and acceleration (negative sine, opposite to displacement).]

4. Phase in SHM

The **phase** ($\omega t + \phi_0$) of an oscillating particle specifies its state of motion — both its position and direction — at any instant. It is measured as an angle in radians.

The **initial phase** or **epoch** (**ϕ_0**) is the phase at $t = 0$; it fixes the starting point of the oscillation. Two SHMs of the same frequency may differ in phase, and the **phase difference** tells how much one leads or lags the other.

- Velocity leads displacement by a phase of $\pi/2$.
 - Acceleration leads displacement by a phase of π (they are exactly out of phase).
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5. Force Law for SHM

From $a = -\omega^2 y$ and Newton's second law $F = ma$, the force in SHM is:

$F = -m\omega^2 y = -ky$, where $k = m\omega^2$ is the force constant.

The negative sign shows the force is a **restoring force** — always opposite to displacement, pulling the body back to the mean position. From $k = m\omega^2$ we get the central result:

$$\omega = \sqrt{k/m} \quad \text{and} \quad T = 2\pi\sqrt{m/k}$$

Key idea: Any system whose restoring force is proportional to displacement ($F \propto -y$) executes SHM.

6. Energy in SHM

An oscillator continuously exchanges energy between kinetic and potential forms, but its total mechanical energy stays constant (for an ideal, undamped system).

Kinetic energy: $KE = \frac{1}{2}mv^2 = \frac{1}{2}m\omega^2(A^2 - y^2)$

Potential energy: $PE = \frac{1}{2}ky^2 = \frac{1}{2}m\omega^2 y^2$

Total energy: $E = KE + PE = \frac{1}{2}m\omega^2 A^2 = \frac{1}{2}kA^2$

- KE is maximum at the mean position ($y = 0$); PE is zero there.
- PE is maximum at the extreme positions ($y = \pm A$); KE is zero there.
- Total energy is **independent of y** and proportional to the square of the amplitude ($E \propto A^2$) and the square of the frequency.

[DIAGRAM: KE and PE plotted against displacement y — KE an inverted parabola peaking at the centre, PE an upright parabola, their sum a flat horizontal line equal to total energy E .]

7. Simple Pendulum

A **simple pendulum** is an ideal point mass (bob) suspended by a weightless, inextensible string from a rigid support. For small angular displacements ($\theta < \text{about } 4^\circ$), its motion is SHM.

The restoring force is the tangential component of gravity, $mg \sin \theta \approx mg \theta$ for small angles, which leads to:

$$T = 2\pi\sqrt{L/g}$$

- The time period depends only on length L and acceleration due to gravity g .
- It is **independent of the mass** of the bob and of the amplitude (for small angles).
- A pendulum clock runs slow in summer (L increases) and fast in winter (L decreases).

Seconds pendulum: a pendulum with $T = 2$ s; its length on Earth is about 1 m.

8. Oscillations of a Spring

A mass m attached to a spring of force constant (spring constant) k executes SHM when displaced and released. The spring provides the restoring force $F = -kx$.

$$T = 2\pi\sqrt{m/k}$$

The time period is independent of the value of g , so a spring-mass oscillator keeps the same period on the Moon as on the Earth.

Springs in Series and Parallel

Combination	Effective spring constant	Effect on T
Series	$1/k_{\text{eff}} = 1/k_1 + 1/k_2$ (k_{eff} smaller)	T increases (softer)
Parallel	$k_{\text{eff}} = k_1 + k_2$ (k_{eff} larger)	T decreases (stiffer)

Cutting a spring into n equal parts makes each piece n times stiffer (k becomes nk), so its period falls.

9. Damped Oscillations

Real oscillators lose energy to friction and air resistance, so their amplitude gradually decreases with time. This is **damped oscillation**.

The damping force is proportional to velocity, $F_d = -bv$, where b is the damping constant. The displacement becomes:

$$x(t) = A e^{(-bt/2m)} \cos(\omega' t + \phi)$$

- The amplitude decays exponentially as $A e^{(-bt/2m)}$.
- The angular frequency of damped motion $\omega' = \sqrt{(k/m - b^2/4m^2)}$ is slightly less than the natural frequency.
- The energy of the oscillator also decreases exponentially with time.

10. Free, Forced Oscillations and Resonance

Free oscillations occur at a body's own **natural frequency** (ω_0) once it is disturbed and left to itself — with no external driving force and (ideally) no damping.

Forced oscillations occur when an external periodic force of frequency ω_d is continuously applied. The body then oscillates at the driving frequency ω_d , not its natural frequency.

Resonance is the special case of forced oscillation when the driving frequency equals the natural frequency ($\omega_d = \omega_0$). The amplitude then becomes very large.

- Resonance lets a singer's voice shatter a glass and a child pump a swing higher with small timed pushes.

- Soldiers break step on a bridge to avoid resonance (the Tacoma Narrows bridge collapse is the classic example).
- Greater damping gives a smaller, broader resonance peak.

Weightage in Board & Entrance Exams

Exam	Typical Weightage	Most-Tested Areas
CBSE Board (Class 11)	6–8 marks (Unit: Oscillations & Waves)	SHM equations, energy in SHM, pendulum & spring T
JEE Main / Advanced	1–2 questions	Spring combinations, energy, phase, damped/forced SHM
NEET	1–2 questions	Time period of pendulum/spring, velocity-acceleration in SHM, resonance

[TABLE: Question-type split — VSA (1 mark): definitions, ω –T–v relations; SA (2–3 marks): velocity/acceleration of SHM, energy, spring combinations; LA (5 marks): pendulum/spring time-period derivations, energy of SHM derivation.]

Important Definitions

Term	Definition
Periodic motion	Motion that repeats after a fixed time interval (the time period)
Oscillatory motion	To-and-fro periodic motion about a fixed mean position
Simple harmonic motion	Oscillation where restoring force $\propto$ displacement and is directed to the mean position: $F = -ky$
Amplitude (A)	Maximum displacement of the particle from its mean position
Time period (T)	Time for one complete oscillation; $T = 2\pi/\omega$
Frequency (ν)	Number of oscillations per second; $\nu = 1/T$ (unit: hertz)
Phase	The quantity $(\omega t + \phi_0)$ that fixes the state of the oscillating particle
Restoring force	Force directed towards the mean position: $F = -ky$
Damped oscillation	Oscillation whose amplitude decreases with time due to resistive forces
Resonance	Large-amplitude forced oscillation when driving frequency = natural frequency

Solved Examples

Example 1

A particle executes SHM of amplitude 5 cm and time period 2 s. Find its maximum velocity and maximum acceleration.

Answer: $\omega = 2\pi/T = 2\pi/2 = \pi$ rad/s. $v_{\text{max}} = A\omega = 0.05 \times \pi = \mathbf{0.157 \text{ m/s}}$. $a_{\text{max}} = A\omega^2 = 0.05 \times \pi^2 = \mathbf{0.493 \text{ m/s}^2}$.

Example 2

The displacement of a particle is $y = 4 \sin(2\pi t)$ cm. Find its amplitude, time period and frequency.

Answer: Comparing with $y = A \sin \omega t$: $A = \mathbf{4 \text{ cm}}$, $\omega = 2\pi$ rad/s, so $T = 2\pi/\omega = \mathbf{1 \text{ s}}$ and $\nu = 1/T = \mathbf{1 \text{ Hz}}$.

Example 3

A spring of force constant 200 N/m carries a mass of 2 kg. Find the time period of oscillation.

Answer: $T = 2\pi\sqrt{(m/k)} = 2\pi\sqrt{(2/200)} = 2\pi\sqrt{0.01} = 2\pi \times 0.1 = \mathbf{0.628 \text{ s}}$.

Example 4

Find the length of a seconds pendulum ($T = 2 \text{ s}$) at a place where $g = 9.8 \text{ m/s}^2$.

Answer: $T = 2\pi\sqrt{(L/g)} \Rightarrow L = gT^2/(4\pi^2) = (9.8 \times 4)/(4 \times 9.87) = 39.2/39.48 \approx \mathbf{0.993 \text{ m}}$.

Example 5

A particle in SHM has amplitude 10 cm and angular frequency 4 rad/s. Find its velocity when the displacement is 6 cm.

Answer: $v = \omega\sqrt{(A^2 - y^2)} = 4\sqrt{(0.10^2 - 0.06^2)} = 4\sqrt{(0.01 - 0.0036)} = 4\sqrt{0.0064} = 4 \times 0.08 = \mathbf{0.32 \text{ m/s}}$.

Example 6

A body of mass 0.5 kg executes SHM of amplitude 0.1 m and angular frequency 10 rad/s. Find its total energy.

Answer: $E = \frac{1}{2}m\omega^2A^2 = \frac{1}{2} \times 0.5 \times 10^2 \times 0.1^2 = \frac{1}{2} \times 0.5 \times 100 \times 0.01 = \mathbf{0.25 \text{ J}}$.

Important Questions for Board Exams

1-Mark Questions (VSA)

1. Define simple harmonic motion.
2. What is the phase relation between displacement and acceleration in SHM?

3. Write the relation between time period, frequency and angular frequency.
4. Does the time period of a simple pendulum depend on the mass of the bob?
5. At what position in SHM is the kinetic energy maximum?

2–3-Mark Questions (SA)

1. Show that the velocity of a particle in SHM is $v = \omega\sqrt{A^2 - y^2}$ and find where it is maximum.
2. Derive expressions for the kinetic and potential energy of a particle in SHM and show that total energy is constant.
3. Two springs of constants k_1 and k_2 are joined (a) in series and (b) in parallel to a mass m . Find the time period in each case.
4. What is resonance? Give two everyday examples and explain why soldiers break step on a bridge.

5-Mark Questions (LA)

1. Define SHM and derive the expressions for displacement, velocity and acceleration of a particle executing SHM.
 2. Derive an expression for the time period of a simple pendulum and state the assumptions made.
 3. Show that the oscillation of a loaded spring is simple harmonic and derive $T = 2\pi\sqrt{m/k}$. Discuss damped and forced oscillations.
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Quick Revision Points

- Oscillatory motion is periodic to-and-fro motion about a mean position
 - $\omega = 2\pi\nu = 2\pi/T$; frequency $\nu = 1/T$ (unit: hertz)
 - SHM: $F = -ky$, $a = -\omega^2y$; restoring force $\propto$ displacement, towards mean position
 - Displacement $y = A \sin(\omega t + \phi_0)$; velocity $v = \omega\sqrt{A^2 - y^2}$; acceleration $a = -\omega^2y$
 - v is max at mean position ($A\omega$); a is max at extremes ($A\omega^2$)
 - Velocity leads displacement by $\pi/2$; acceleration is π out of phase with displacement
 - Energy: $KE = \frac{1}{2}m\omega^2(A^2 - y^2)$, $PE = \frac{1}{2}m\omega^2y^2$, total $E = \frac{1}{2}m\omega^2A^2 = \frac{1}{2}kA^2$ (constant, $\propto A^2$)
 - Simple pendulum: $T = 2\pi\sqrt{L/g}$; independent of mass and amplitude (small angles)
 - Spring-mass: $T = 2\pi\sqrt{m/k}$; independent of g
 - Springs in series: k smaller, T larger; in parallel: k larger, T smaller
 - Damped SHM: amplitude decays as $A e^{-(bt/2m)}$; resonance when $\omega_d = \omega_0$
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Next Chapter: Chapter 14 — Waves



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