OSCILLATION AND WAVES

Wave is a kind of disturbance from an equilibrium condition that propagates from one region of space to another.

Types:

Mechanical waves: need medium to propagate. Sound waves, waves on the water surface, waves in a stretched string /spring etc.
Electromagnetic waves: Don't require medium to propagate. They can travel through vacuum and several media. Light waves, X rays, radio waves etc.

TYPES OF WAVE MOTION:

LONGITUDINAL WAVES: In these waves, the particles of the medium oscillate along the direction of wave propagation. Example – Sound waves, compressional waves in a spring.
TRANSVERSE WAVES: In these waves, the particles of the medium oscillate perpendicular to the direction of wave propagation. Example – waves in a stretched string

In gases and liquids, transverse waves can't be transmitted (except on the surface of water).They don't have rigidity but only volume elasticity. Therefore only compressions and rarefactions travel in them. For this reason longitudinal waves are also called pressure waves.

SPEED OF TRANSVERSE WAVES: The speed of transverse waves in a stretched string is given by the formula $v = \sqrt{T/m}$, where T is the tension in the string and m is the mass per unit length.

SPEED OF LONGITUDINAL WAVES: The speed of longitudinal waves in a medium of elasticity E and density ρ is given by $v = \sqrt{E/\rho}$

The density of a solid is much larger than the density of a gas but the elasticity is larger by a greater factor.Hence longitudinal waves in a solid travel much faster than that in a gas.In a liquid the speed is in between the two. i.e.

$$V_{solid} > V_{liquid} > V_{gases}$$

Newton's Formula and Laplace's correction:

Newton assumed that propagation of sound in a gas takes place under **ISOTHERMAL CONDITIONS. Since E isothermal = P, the pressure of the gas, we have the Newton's formula**

$$v = \sqrt{P/\rho}$$

AT S.T.P. (In air) v = 280 m/s.This value is about 16% less than the actual value, which is 332 m/s.This large error shows that Newton's formula is not correct.

Laplace's assumed that when sound travels through a gaseous medium, the changes are adiabatic in nature hence the speed of sound in a gas is given by Laplace's formula is

$$v = \sqrt{\gamma P/\rho}$$

For air $\gamma=1.4$ therefore v = 280 X 1.4 = 330 m/s.

EFFECT OF EXTERNAL FACTORS ON SPEED OF SOUND:

1. **Pressure:** There is no effect of change of pressure (at Constant Temperature) because the density also changes proportionality.
2. **Density:** Speed of sound is inversely proportional to the square root of the density of the medium.
3. **Temperature:** Speed of sound is directly proportional to the square root of the temperature of the medium.Infact the velocity increases by about 0.61m/s for every degree rise of temperature.
4. **Humidity:** Speed increases with increase of humidity. it is because dry air is more dense than moist air.

EQUATION OF A HARMONIC WAVE

The Displacement y of a particle at position x at time t is given by **Y = A sin (ωt – kx)**

Where ω= 2π/T and k = 2π/λ, called the wave number.

Two alternative forms of the equation are

$$y = A \{\sin 2\pi (\frac{t}{T} - \frac{x}{\lambda})\}$$

$$y = A \{\sin\frac{2\pi}{\lambda} (vt - x)\}$$

INTENSITY LEVEL AND LOUDNES OF SOUND: The term loudness describes the human perception of sound. A sound wave of higher intensity is perceived as a louder sound than a wave of lower intensity.

The intensity level of sound is defined by an arbitrary scale that corresponds roughly to the sensation of loudness. Its unit is decibel (dB) and is given by

$$\textbf{Intensity Level in dB} = 10 \log \frac{t}{t0}$$

PITCH AND QUALITY: It is defined with the frequency- the higher the frequency, the higher is the pitch.

A musical instrument vibrates with many frequencies at the same time – a lowest frequency, called the fundamental tone and its multiples called the overtones. The quality of any musical sound is determined by the number of overtones and their relative intensities. The sound of different instruments are said to differ in quality.

Audible, Infrasonic and Ultrasonic Waves:

Longitudinal mechanical waves have a large range of frequencies. The frequency range **20 Hz to 20,000 Hz** causes the sensation of hearing in human beings and is therefore called the Audible Range. Waves of frequency **below 20 Hz are called Infrasonic** waves and those **above 20,000 Hz are Ultrasonic waves**. Audible waves are generated by vibrating strings, air columns. Plates and membranes. Infrasonic waves are usually generated by large sources i.e. earthquake waves. Ultrasonic waves are produced by piezo-electric effect, magnetostriction method and Galton's whistle. Some animals can hear Ultrasound. Ultrasounds have various applications, i.e. medical diagnosis and therapy, echo sounding, finding flaws in materials, destruction of living cells suspended in liquids, removal of grease and dirt etc.

SIMPLE HARMONIC MOTION

A special type of oscillatory motion in which the restoring force is proportional to the displacement from the mean position.
If F is the restoring force for displacement y, then

$$F = -ky$$

Where K is called force constant of the system.It is defined as restoring force per unit displacement.SI unit og K is N/m.
SHM can be represented as $y = A \sin(\omega t - \Phi_0)$

The following quantities characterizes the SHM –

1. **AMPLITUDE (A)**: Maximum displacement from the mean position is called amplitude.
2. **TIME PERIOD (T):** It is the smallest interval of time after which the motion repeats itself.

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

3. **FREQUENCY (f)** : It is equal to number of oscillations per second. Mathematically **f =1/T**
4. **ANGULAR FREQUENCY:** $\omega = 2\pi/T = \sqrt{\frac{k}{m}}$
5. **PHASE (Φ**) The quantity $\Phi = \omega t + \Phi_0$ is called the phase of the oscillation at time t.where Φ_0 is called initial phase.

VELOCITY OF A PARTICLE IN SHM: $v = A\omega \cos \omega t$ OR $v = \omega \sqrt{A^2 - y2}$

ACCELERATION EQUATION OF SHM: Acceleration $a = -\omega^2 y$

ENERGY OF A PARTICLE IN SHM: During SHM, the particle possesses PE and KE both.The PE is due to its distance from the mean position at any time t is given by

$$PE = U = \frac{1}{2} m \omega^2 y^2$$

and KE by the virtue of its motion is given by $KE = K = \frac{1}{2} m \omega^2 (A^2 - y2$¿

$$\text{TOTAL ENERGY in SHM} = E = \frac{1}{2} m \omega^2 A^2$$

TIME PERIOD OF A SIMPLE PENDULUM: $T = 2\pi\sqrt{l/g}$ where l is the effective length of the pendulum and g is acceleration due to gravity.

Mass-Spring system: When a mass m is attached to the free end of a spring of spring constant K oscillates simple harmonically, then time period of oscillation is given by

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

Effective spring constant in series Combination of two springs of spring constant K_1 and K_2 is $K_{series} = \frac{k1k2}{k1+k2}$ and in Parallel combination $K_{parallel} = K_1 + K_2$

MULTIPLE CHOICE QUESTIONS

1. Sound travels fastest in
(a) Steel (b) air (c) water (d) vacuum

2. Transverse wave can propagate
(a) both in a gas and in a metal (b) in a gas but not in a metal
(c) not in a gas but in a metal (d) neither in a gas nor in a metal

3. The speed of a wave represented by $y = A \sin(\omega t - kx)$ is
(a) k/ω (b) ω/k (c) ωk (d) $1/\omega k$

4. The ratio of the velocity of sound in hydrogen and oxygen at S.T.P. is
(a) 16:1 (b) 1:6 (c) 1:8 (d) 1:72

5. Laplace's correction in the Newton's formula was needed because sound waves
(a) are longitudinal (b) propagate isothermally
(c) propagate adiabatically (d) have long wavelengths

6. With the rise of temperature, the speed of sound in a gas
(a) increases (b) decreases (c) remains same (d) may increase or decrease depending upon the corresponding change in pressure
.
7. The velocity of sound in air is affected by change in the
(a) Atmospheric pressure (b) moisture content of air
(c) temperature of air (d) composition of air

8. Two strings A and B, made of the same material have same thickness. The length of A is half that of B while the tension on A is twice that on B.The ratio of the velocities of transverse waves in A and b is
(a) $\sqrt{2}:1$ (b) 2:1 (c) $1:\sqrt{2}$ (d) 1:2

9. When a sound wave of frequency 300 Hz passes through a medium, the maximum displacement of a particle of the medium is 0.1 cm.The maximum velocity of the particle is equal to
(a) 60π cm/s (b) 30π cm/s (c) 30 cm/s (d) 60 cm/s

10. With the propagation of a longitudinal wave in a material medium, the quantities transferred in the direction of wave propagation are
(a) energy, momentum and mass (b) energy and momentum
(c) energy and mass (d) energy only

11. If the amplitude of sound is doubled and the frequency reduced to one-fourth, the intensity will
(a) increase by a factor of 2 (b) decrease by a factor of 2
(c) decrease by a factor of 4 (d) remains unchanged

12. If the amplitude of a wave at a distance r from the point source is A, the amplitude at a distance 2r will be
(a) 2A (b) A (c) A/2 (d) A/4

13. When a source of sound is in motion towards a stationary observer, the effect observed is
(a) increase in the velocity of sound only
(b) decrease in the velocity of sound only
(c) increase in frequency of sound only
(d) increase in both

14. When an aeroplane attains the speed higher than the speed of sound in air, a loud bang is heard. This is because
(a) it explodes (b) its wings vibrate so violently that the bang is heard
(c) the normal engine noises undergo a Doppler shift to generate the bang.
(d) it produces a shock wave which is received as the bang.

15. The quantity of sound produced by an instrument depend on the
(a) frequency (b) intensity (c) number of overtones (d) none of these

16. The same notes being played on Veena nad sitar are differ in
(a) quality (b) pitch (c) both quality and Pitch (d) neither quality nor pitch

17. Decibal is a
(a) musical note (b) musical instrument (c) unit of intensity
(d) unit of intensity level

18. A wave is reflected from a rigid support. The change of phase on reflection will be
(a) 0 (b) $\pi/4$ (c) $\pi/2$ (d) π

19. When a wave goes from one medium to another, there is no change in the
(a) velocity (b) amplitude (c) frequency (d) wavelength

20. To raise the pitch of a stringed musical instrument the player can
(a) loosen the string (b) tighten the string
(c) Shorten the string (d) lengthen the string

21. The musical interval between two tones of frequencies 320 Hz and 240 Hz is
(a) 80 (b) 4/3 (c) 16/9 (d) none of these

22. Two waves are given by $y_1 = a \sin(\omega t - kx)$ and $y_2 = a \cos(\omega t - kx)$.The phase difference between them is
(a) $\pi/4$ (b) π (c) $\pi/8$ (d) $\pi/2$

23. Pitch of sound depends on
(a) frequency (b) wavelength (c) amplitude (d) speed

24. A wave travels in a medium according to the equation of displacement given by $y(x,t) = 0.03 \sin[\pi \{2t - 0.01x\}]$, where y and x are in metres and t is in seconds. the wavelength of the wave is
(a) 200 m (b) 100 m (c) 20 m (d) 10 m.

25. The velocity of sound in solids in generally greater than in gases because
(a) the density of solids is high and the elasticity is low
(b) both the density and the elasticity of solids are very low
(c) the density of solids is low but the elasticity is high
(d) the elasticity of solids is very high

26. A mass M attached to a spring oscillates with a period of 2 s.If the mass is increases by 2 kg, the period increases by 1 s.The magnitude of initial mass M is
(1) 2.0 kg (b) 1.6 kg (c) 5 kg (d) 3.2 kg

27. A particle executing S.H.M. has an acceleration of 128 m/s^2.The time period of oscillation of particle, when its displacement from the mean position is 8 cm
(a) 1.33 s (b) 1.67 s (c) 1.57 s (d) 5 s

28. A particle is executing S.H.M.Then the graph of acceleration as a function of displacement is
(a) straight line (b) circle (c) ellipse (d) hyperbola

29. A particle is executing S.H.M.Then the graph of velocity as a function of displacement is
(a) straight line (b) circle (c) ellipse (d) hyperbola

30. A body falling freely on a planet covers 8 m in 2 s. The time period of a 1 m long simple pendulum on this planet be
(a) 1.57 s (b) 3.14 s (c) 6.28 s (d) none of these

31. The total energy of a particle in SHM of amplitude A is proportional to
(a) A^2 (b) A-2 (c) A (d) 1/A

32. The time period of a simple pendulum is T.If its length increased by 2%, the new time period becomes
(a) 0.98 s (b) 1.02 s (c) 0.99 s (d) 1.01 s

33. A particle executing SHM has an acceleration of 64 m/s2 when its displacement is 4 cm.Its time period in seconds is
(a) π/2 (b) π/4 (c) π (d) 2π

34. The amplitude at resonance of a vibrating body situated in air becomes
(a) infinite (b) zero (c) large but finite (d) small but non-zero

35. The velocity of a particle in S.H.M.is v at the mean position. If its amplitude is doubled, the velocity at the mean position will be
(a) 2 v (b) 3 v (c) $2\sqrt{2}$ v (d) 4 v

Answer key
Waves and Oscillations

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
a	c	b	c	c	a	b.c,d	a	a	b
11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
c	c	c	d	c	a	d	d	c	b,c
21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
b	d	a	a	d	b	c	a	c	b
31	32	33	34	35	-	-	-	-	-
a	d	a	c	a	-	-	-	-	-