ASSIGNMENT-2 SOLUTION

Subject Name & Code:

Physics- BE01R00021

Waves, Motion & Acoustics

1) Define: Linear Motion, Uniform Motion, periodic motion.

Answer:

- **Linear Motion:** Linear motion is the most basic type of motion. It describes the movement of an object along a straight line. The path is a straight line, and all parts of the object move the same distance in the same direction. Examples include a car moving on a straight road, a train on a straight track, or a piston moving inside a cylinder.
- **Uniform Motion:** Uniform motion is a type of motion where an object covers **equal distances in equal intervals of time**, regardless of the direction. The key point is that the velocity (speed and direction) of the object is constant. Since velocity is constant, acceleration is zero. Example: A car cruising on a highway at a steady 60 km/h in a straight line.
- **Periodic Motion:** Periodic motion is a motion that repeats itself at **regular intervals of time**. The object returns to its initial position after a fixed time period, called the **time period (T)**. The motion is cyclic. Examples include the swinging of a pendulum, the vibration of a guitar string, the motion of a bouncing ball (in an ideal scenario), or the orbit of a planet.

2) Distinguish between Uniform & Non- Uniform motions.

Answer:

Basis of Difference	Uniform Motion	Non-Uniform Motion
Definition	Motion where an object covers equal distances in equal intervals of time.	Motion where an object covers unequal distances in equal intervals of time.
Speed	Constant (unchanging).	Variable (changing).
Velocity	Constant (both magnitude and direction are constant).	Variable (either magnitude, direction, or both change).
Acceleration	Zero acceleration.	Non-zero acceleration.

Basis of Difference	Uniform Motion	Non-Uniform Motion
Distance-Time Graph	A straight-line graph.	A curved or zig-zag line.
Example	A clock's (seconds hand).	A car negotiating city traffic.

3) Derive the expressions for Simple Harmonic motion.

Answer:

Simple Harmonic Motion (SHM) is a special type of periodic motion where the restoring force is directly proportional to the displacement from the mean position and is always directed towards the mean position.

Derivation:

1. **Defining Condition:** The restoring force F is proportional to the displacement x and opposite in direction.
   $F \propto -x$
   $F = -k x$ ...(1)
   where k is a constant called the **force constant**.
2. **From Newton's Second Law:** We know F = m a, where m is mass and a is acceleration.
   $m a = -k x$
   $a = -(k/m) x$ ...(2)
3. **Differential Equation:** Acceleration is the second derivative of displacement with respect to time ($a = d^2x/dt^2$).
   $d^2x/dt^2 = -(k/m) x$
   Let $\omega^2 = k/m$, where ω is the **angular frequency**.
   $\therefore d^2x/dt^2 + \omega^2 x = 0$ ...(3)
   This is the **standard differential equation for SHM**.
4. **General Solution:** The solution to this second-order differential equation is:
   $x(t) = A \sin(\omega t + \varphi)$ ...(4)
   or
   $x(t) = A \cos(\omega t + \varphi)$ ...(5)
   where:
   - x(t) is the displacement at time t.
   - A is the **Amplitude** (maximum displacement).
   - ω is the **angular frequency** (rad/s).
   - φ is the **phase constant** or initial phase (radians), which depends on initial conditions.
5. **Velocity and Acceleration:**
   - **Velocity (v):** $v = dx/dt = A\omega \cos(\omega t + \varphi)$
     - Maximum velocity, $v_{max} = A\omega$
   - **Acceleration (a):** $a = dv/dt = d^2x/dt^2 = -A\omega^2 \sin(\omega t + \varphi) = -\omega^2 x$
     - Maximum acceleration, $a_{max} = A\omega^2$

4) Define: Free vibrations, Damped & Forced Vibrations.

Answer:

- **Free Vibrations:** These are vibrations where a system is disturbed from its equilibrium position and then allowed to oscillate **without any external interference**. The system oscillates at its own natural frequency, which depends on its intrinsic properties (mass and stiffness). Example: A simple pendulum set in motion and left alone.
- **Damped Vibrations:** In reality, oscillations cannot continue forever due to the presence of dissipative forces like friction, air resistance, or viscous drag. These forces **dampen** the motion, causing the amplitude of oscillation to decrease gradually over time until the system comes to rest. This is called damped vibration.
- **Forced Vibrations:** These occur when a system is subjected to a **continuous periodic external force**. The system is forced to vibrate at the frequency of this external driving force, not its natural frequency. Example: A building vibrating during an earthquake, or the floor vibrating due to a running washing machine.

5) Derive the periodic time formula for SHM by spring and Mass.

Answer:

Consider a mass m attached to a spring of spring constant k, placed on a frictionless surface.

1. **Restoring Force:** When the mass is displaced by a distance x from its mean (equilibrium) position, the restoring force exerted by the spring is given by Hooke's Law:
   $F = -k x$
2. **Equation of Motion:** From Newton's second law:
   $F = m a$
   $m a = -k x$
   $m (d^2x/dt^2) = -k x$
   $d^2x/dt^2 + (k/m) x = 0$
3. **Comparing with SHM equation:** This is of the form $d^2x/dt^2 + \omega^2 x = 0$.
   Therefore, $\omega^2 = k/m$
   $\omega = \sqrt{(k/m)}$ (angular frequency)
4. **Periodic Time (T):** The time period T is the time taken for one complete oscillation. It is related to angular frequency by $T = 2\pi / \omega$.
   $T = 2\pi / \sqrt{(k/m)}$
   $\therefore T = 2\pi \sqrt{(m/k)}$

This is the formula for the time period of a mass-spring system executing SHM.

6) Derive the formula for Damped Harmonic Motion and explain under damped, critical & over damped harmonic oscillations.

Answer:

In damped harmonic motion, a damping force (often proportional to velocity, e.g., $F_{damping} = -b v$, where b is the damping coefficient) opposes the motion.

Derivation:

The net force on the oscillator is: $F_{net} = -k x - b v$
Applying Newton's second law: $m\, d^2x/dt^2 = -k x - b\, dx/dt$
Rearranging: $m\, d^2x/dt^2 + b\, dx/dt + k x = 0$
Dividing by m: $d^2x/dt^2 + (b/m)\, dx/dt + (k/m) x = 0$
Let $2\beta = b/m$ (damping term per unit mass) and $\omega_0^2 = k/m$ (natural angular frequency).
The equation becomes: $d^2x/dt^2 + 2\beta\, dx/dt + \omega_0^2 x = 0$ ...(1)
This is the differential equation for a damped harmonic oscillator. The solution depends on the relative values of β and ω_0.

Types of Damping:

1. **Underdamped ($\beta^2 < \omega_0^2$):** This is the most common case. The system oscillates, but the amplitude decreases exponentially with time. The solution is:
   $x(t) = A e^{-\beta t} \cos(\omega_d t + \varphi)$
   where $\omega_d = \sqrt{\omega_0^2 - \beta^2}$ is the frequency of the damped oscillation. The system makes several oscillations before stopping.
2. **Critically Damped ($\beta^2 = \omega_0^2$):** The system returns to equilibrium in the shortest possible time **without oscillating**. The solution is of the form:
   $x(t) = (A + B t) e^{-\beta t}$
   This is desirable for systems like car shock absorbers and electrical meters to prevent overshooting.
3. **Overdamped ($\beta^2 > \omega_0^2$):** The system returns to equilibrium **very slowly without oscillating**. The damping force is so strong that it prevents oscillation. The solution is a sum of two decaying exponentials:
   $x(t) = A e^{-(\beta - \sqrt{\beta^2 - \omega_0^2})t} + B e^{-(\beta + \sqrt{\beta^2 - \omega_0^2})t}$
   It takes longer to return to equilibrium than in the critical case.

7) Derive the expression for forced harmonic oscillations.

Answer:

In forced oscillations, an external periodic driving force $F(t) = F_0 \cos(\omega t)$ is applied, where F_0 is the amplitude and ω is the driving frequency.
The equation of motion becomes:
$m\, d^2x/dt^2 = -k x - b\, dx/dt + F_0 \cos(\omega t)$
Rearranging: $m\, d^2x/dt^2 + b\, dx/dt + k x = F_0 \cos(\omega t)$
Dividing by m: $d^2x/dt^2 + 2\beta\, dx/dt + \omega_0^2 x = (F_0/m) \cos(\omega t)$ ...(1)
The solution to this equation has two parts: a **transient solution** (which dies out due to damping) and a **steady-state solution**. We are interested in the steady-state where the system oscillates with the driving frequency ω.
The steady-state solution is: $x(t) = A \cos(\omega t - \delta)$ ...(2)
where A is the amplitude of the forced oscillation and δ is the phase lag of the displacement behind the driving force.

Finding Amplitude (A) and Phase (δ):

Substitute equation (2) and its derivatives into equation (1). After solving (a lengthy process involving trigonometry and algebra), we get:

- **Amplitude:**
  $A = (F_0 / m) / \sqrt{(\omega_0^2 - \omega^2)^2 + (2\beta\omega)^2}$
  $A = F_0 / \sqrt{(m(\omega_0^2 - \omega^2))^2 + (b\omega)^2}$
- **Phase Difference:**
  $\tan \delta = (2\beta\omega) / (\omega_0^2 - \omega^2)$
  $\delta = \tan^{-1}[(2\beta\omega) / (\omega_0^2 - \omega^2)]$

8) Write short note on Resonance.

Answer:

Resonance is a phenomenon of **dramatically increased amplitude** that occurs when the frequency of a periodically applied force (driving frequency) is equal or very close to the natural frequency of the system on which it acts.

- **Cause:** From the amplitude formula of forced oscillation $A = F_0 / \sqrt{(m(\omega_0^2 - \omega^2))^2 + (b\omega)^2}$, the amplitude A becomes maximum when the denominator is minimum. The denominator is minimum when $\omega_0^2 - \omega^2 = 0$, i.e., when $\boldsymbol{\omega = \omega_0}$ (the driving frequency equals the natural frequency). At this point, $A_{max} = F_0 / (b\,\omega_0)$.
- **Importance:** Resonance is a double-edged sword.
  - **Useful:** It is crucial in tuning musical instruments, in radio and TV receivers to select a particular frequency, in microwave ovens to heat food, and in magnetic resonance imaging (MRI).
  - **Destructive:** It can cause catastrophic failures. Examples include the collapse of the Tacoma Narrows Bridge in 1940 due to wind forces matching its natural frequency, and engineers ensuring the natural frequency of buildings and machines does not match prevalent vibration frequencies (like earthquakes or machinery).

9) Distinguish between transverse and longitudinal wave motion.

Answer:

Basis of Difference	Transverse Wave Motion	Longitudinal Wave Motion
Definition	A wave in which the particles of the medium vibrate **perpendicular** to the direction of wave propagation.	A wave in which the particles of the medium vibrate **parallel** to the direction of wave propagation.
Particle Motion	Up and down, or side to side.	Back and forth (compressions and rarefactions).
Consists of	Crests and Troughs.	Compressions (high density) and Rarefactions (low density).
Medium Required	Can only travel through solids and surfaces of liquids, **not through gases or liquids** (except surface waves).	Can travel through all media - solids, liquids, and gases.
Example	Waves on a string, waves on the surface of water, electromagnetic waves.	Sound waves in air, seismic P-waves.
Polarization	Can be polarized.	Cannot be polarized.

10) Write short note on Loudness.

Answer:

Loudness is a **subjective** measure of the listener's perception of the intensity of a sound. It is how loud or soft a sound seems to a person.

- **Dependence:** It depends primarily on the **sound intensity** (objective physical quantity) but is also influenced by the **frequency** and **waveform** of the sound, as well as the sensitivity of the listener's ear.
- **Unit:** Since it's a subjective perception, it doesn't have a fundamental SI unit. However, the **phon** and the **sone** are units used to express the subjective loudness of a sound.
- **The Decibel (dB) Scale:** While intensity is measured in W/m^2, the large range of human hearing (from 10^{-12} W/m^2 to 10 W/m^2) makes this scale impractical. Therefore, a logarithmic **Sound Intensity Level (SIL)** scale is used, measured in decibels (dB):
  SIL (in dB) = $10 \log_{10}(I / I_0)$
  where I is the sound intensity and I_0 is the reference intensity (10^{-12} W/m^2, the threshold of hearing). This dB scale corresponds more closely to how we perceive loudness. A 10 dB increase is perceived as approximately a doubling of loudness.

11) Explain: Reverberation, Reverberation time, Pitch,Weber Fechner law.

Answer:

- **Reverberation:** It is the phenomenon of **persistence of sound in an enclosed space** after the original source of sound has stopped. It is caused by the multiple reflections of sound waves from the walls, ceiling, floor, and other surfaces until the sound energy is gradually absorbed and dies out.
- **Reverberation Time (T or RT_{60}):** It is the **time taken for the sound intensity in a room to decay by 60 dB** (i.e., to one-millionth of its original intensity) after the source has been switched off. It is a crucial parameter in architectural acoustics. An optimal reverberation time is necessary for clarity and richness of sound (e.g., a shorter RT for speech, a longer RT for music).
- **Pitch:** Pitch is the **subjective perception** of the frequency of a sound wave. A higher frequency sound is perceived as a higher pitch (e.g., a whistle), and a lower frequency sound is perceived as a lower pitch (e.g., a drum). It is not identical to frequency but is primarily determined by it.
- **Weber-Fechner Law:** This is a principle in psychophysics that describes the relationship between the physical magnitude of a stimulus and its perceived intensity. It states that **the perceived change (ΔL) in a stimulus is proportional to the relative change in the physical intensity.**
  Mathematically: $\Delta L = k (\Delta I / I)$
  where ΔL is the change in sensation (loudness), ΔI is the change in stimulus intensity, I is the original intensity, and k is a constant. Integrating this leads to the conclusion that sensation (loudness) is proportional to the **logarithm** of the stimulus (intensity). This is why the decibel (logarithmic) scale is used for sound measurement.

12) Write the difference between Sound Intensity and Loudness.

Answer:

Basis of Difference	Sound Intensity	Loudness
Nature	It is an **objective** physical quantity.	It is a **subjective** psychological sensation.
Definition	The sound power transmitted per unit area, perpendicular to the direction of propagation.	The human ear's perception of the intensity of a sound.
Measurability	Can be **directly measured** using instruments like a sound level meter.	**Cannot be measured directly**; it is perceived by the listener.
SI Unit	Watt per square meter (W/m^2).	Phon or Sone.
Dependence	Depends only on the physical characteristics of the sound wave (amplitude).	Depends on intensity **but also** on the frequency and sensitivity of the listener's ear.
Scale	Linear scale (covers a vast range, 10^{-12} W/m^2 to 10^2 W/m^2).	Logarithmic scale (closely related to the decibel scale).

13) Write short note on Coefficient of Absorption.

Answer:

The **Coefficient of Absorption** (or **Sound Absorption Coefficient**), denoted by **α** (alpha), is a measure of the effectiveness of a material in absorbing sound energy. It is defined as the **ratio of the sound energy absorbed by a surface to the sound energy incident upon it.**

- **Value Range:** It is a dimensionless number between 0 and 1.
  - $\alpha = 0$ implies **perfect reflection** (no absorption, e.g., a concrete wall).
  - $\alpha = 1$ implies **perfect absorption** (no reflection, e.g., an open window is considered a perfect absorber with $\alpha = 1$).
- **Dependence:** The value of α depends on the **frequency** of the sound. A material may be a good absorber at high frequencies but a poor absorber at low frequencies, and vice-versa.
- **Application (Sabine's Formula):** This coefficient is fundamental in architectural acoustics for calculating the reverberation time of a room. Sabine's reverberation formula is:
  $T = 0.161\ V / (\Sigma\ \alpha_i S_i)$
  where T is reverberation time (s), V is the volume of the room (m^3), S_i is the surface area of each material (m^2), and α_i is the absorption coefficient of that material. The

term $\Sigma \alpha_i S_i$ is the **total absorption** of the room, measured in metric sabins.
I hope this detailed, textbook-style breakdown provides you with an excellent resource for your assignment and exam preparation. Good luck with your studies

14) Write Sabine's Formula for reverberation time and explain the terms used in it and what are the limitations of Sabine's Formula.

Answer:
Sabine's Formula is the fundamental equation used in architectural acoustics to calculate the approximate reverberation time of an enclosed space. It was empirically derived by Wallace Clement Sabine, the founder of the field of architectural acoustics.
The Formula:
$T = (0.161 * V) / (\Sigma \alpha_i S_i)$
Explanation of Terms:

- T: The **Reverberation Time** (in seconds). Specifically, it is the time taken for the sound intensity in the room to decay by 60 dB after the source has stopped.
- 0.161: A **dimensional constant** derived from the speed of sound in air at room temperature (~343 m/s). Its units are s/m. ($0.161 = 0.16 * \ln(10^6) / c$, simplified for air).
- V: The **Volume** of the enclosed space (in cubic meters, m^3). A larger room generally has a longer reverberation time.
- $\Sigma \alpha_i S_i$: The **Total Absorption** of the room (in metric sabins or m^2). This is the sum of the products of the absorption coefficient and the area for every surface in the room.
  - α_i: The **Absorption Coefficient** of a specific material on a surface (e.g., carpet on the floor, plaster on the walls, audience in seats). It is a dimensionless number between 0 (perfect reflector) and 1 (perfect absorber).
  - S_i: The **Surface Area** (in square meters, m^2) covered by that specific material.

Limitations of Sabine's Formula:
While revolutionary and still widely used for initial estimates, Sabine's formula has several limitations:

1. **Assumption of Diffuse Field:** It assumes a perfectly **diffuse sound field**, meaning the sound energy is perfectly uniform and randomly distributed throughout the room. In reality, most rooms have uneven energy distribution, especially at low frequencies or in oddly shaped rooms.
2. **Inaccurate for High Absorption:** The formula becomes increasingly inaccurate in very **"dead" rooms** (rooms with very high total absorption, $\Sigma \alpha S > 0.5$). It tends to predict a reverberation time that is too long. Other formulae, like Eyring's, are better suited for such spaces.
3. **Doesn't Account for Absorption Distribution:** The formula only considers the total absorption, not *where* the absorption is placed in the room. The placement of absorptive materials can significantly affect the reverberation time characteristics.
4. **Frequency Dependence:** The absorption coefficient α is highly frequency-dependent. A proper analysis requires performing the calculation for multiple octave bands (e.g., 125 Hz, 250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz) to get a full picture of the room's acoustics. Sabine's formula itself is not the limitation here, but its simplistic application without considering frequency can be.
5. **Neglects Air Absorption:** For very large volumes (e.g., concert halls, cathedrals), the absorption of sound by the air itself (especially at high frequencies) becomes significant. The standard Sabine formula does not account for this.

15) Explain how the reverberation time of a hall is affected by
(a) Size (b) Nature of its wall (c) Audience (d) Shape

Answer:

- **(a) Size (Volume, V):** The reverberation time T is **directly proportional to the volume** V of the hall. A larger hall has a longer reverberation time because the sound waves have to travel farther between reflections, resulting in fewer reflections per second and thus a slower rate of energy decay. This is why cathedrals have very long RTs and small classrooms have short ones.
- **(b) Nature of its walls (Total Absorption, ΣαS):** The reverberation time T is **inversely proportional to the total absorption** in the hall. Walls made of hard, reflective materials like concrete, plaster, and glass have low absorption coefficients ($\alpha \approx 0.01\text{-}0.05$), so they add little to the total absorption, leading to a long RT. Walls covered with soft, porous materials like acoustic foam, drapes, or carpet have high absorption coefficients ($\alpha \approx 0.5\text{-}0.9$), which increase the total absorption significantly, resulting in a short RT.
- **(c) Audience:** An audience is one of the most significant sources of sound absorption in a hall. People absorb sound through their clothing and bodies. An **audience provides a large, highly absorptive surface area**. Therefore, a fully occupied hall will have a much **shorter reverberation time** than the same hall when empty. This is a critical factor for hall design; architects must design for the occupied condition. Upholstered seats are often designed to have absorption coefficients similar to a person to minimize this change between empty and full.
- **(d) Shape:** The shape of a hall affects the **distribution of sound energy** and the **path length between reflections**, which in turn influences RT.
  - **Focussing Shapes:** Concave surfaces (like domes) can focus sound energy into specific areas, creating "hot spots" and "dead spots." This breaks up the diffuse field, making Sabine's formula less accurate and often leading to uneven reverberation.
  - **Non-Parallel Walls:** Shapes that avoid large, parallel, reflective surfaces (e.g., fan-shaped halls, walls with diffusers) help to prevent distinct echoes and **flutter echoes** (a rapid, buzzing repetition of sound), promoting a more diffuse field and a smoother decay of sound.
  - **Volume-to-Surface Area Ratio:** While two halls may have the same volume V, a long, narrow hall will have a larger total surface area S than a cubic hall. This can affect the total absorption calculation.

16) List the factors affecting the Reverberation time of auditorium and explain.

Answer:

The factors affecting reverberation time can be directly derived from Sabine's formula, $T = 0.161V / A$ (where A = total absorption).

1. **Volume of the Room (V):** This is the most fundamental factor. **Larger volume**

means longer reverberation time.

2. **Total Absorption ($A = \Sigma \alpha_i S_i$):** This is the sum of all absorption in the room. **Higher total absorption means shorter reverberation time.** This is determined by:
    - **Surface Materials:** The absorption coefficients of all finishing materials (walls, ceiling, floor, seats, banners).
    - **Surface Area:** The total area of each material.
    - **Occupancy:** The number of people in the audience, which is a major absorptive element.
    - **Furnishings:** Curtains, carpets, upholstered seats, and other porous items.
    - **Air Absorption:** At high frequencies and in very large rooms, humid air itself absorbs sound energy.
3. **Shape of the Room:** While not directly in Sabine's formula, shape influences the assumption of a diffuse field. Shapes that cause focussing or uneven distribution of sound can make the measured RT differ from the calculated one.
4. **Frequency of the Sound:** The absorption coefficient α of nearly every material (including air and an audience) is **frequency-dependent**. Therefore, a room has not one but multiple reverberation times:
    - **Low Frequencies:** Materials are generally less absorptive. RT is longer, leading to a "boomy" or "muddy" sound.
    - **Mid & High Frequencies:** Materials are more absorptive. RT is shorter. A well-designed hall will have a relatively uniform RT across all frequencies for a balanced sound.

ULTRASONIC

17) Explain Magnetostriction Method for Production of Ultrasonic sound.

Answer:

The **Magnetostriction Effect** is the property of ferromagnetic materials (like iron, nickel, cobalt) to undergo a small change in their dimensions when placed in a magnetic field.

Principle of the Method: This effect is used to generate ultrasonic waves by causing a ferromagnetic rod to vibrate at its natural frequency of longitudinal vibration.

Construction and Working:

1. A rod of ferromagnetic material (e.g., nickel) is clamped at its midpoint.
2. A coil of wire (the primary coil) is wound around the ends of the rod. This coil is connected to an electronic oscillator circuit that produces a high-frequency alternating current (in the ultrasonic range).
3. The alternating current passing through the coil produces an alternating magnetic field along the length of the rod.
4. Due to the magnetostriction effect, the rod alternately expands and contracts with the frequency of the alternating magnetic field (i.e., the frequency of the oscillator).
5. The frequency of the oscillator is adjusted to match the **natural longitudinal frequency** of the rod. When this happens, **mechanical resonance** occurs, and the rod vibrates vigorously along its length with large amplitude.
6. These intense mechanical vibrations are transferred to a medium (like water) in contact with one end of the rod, generating powerful ultrasonic waves of the same frequency.

Characteristics:

- It is a robust and simple method.
- It produces ultrasonic waves of high power but relatively low frequency (typically up to 100 kHz).
- The frequency is controlled by the length of the rod and the oscillator circuit.
- It is used in ultrasonic cleaning, sonar, and industrial applications.

18) Explain Piezoelectric Method for Production of Ultrasonic sound.

Answer:

The **Piezoelectric Effect** is the property of certain crystalline materials (e.g., Quartz, Rochelle salt, Barium titanate, PZT - Lead Zirconate Titanate) to generate an electric potential when mechanical stress is applied (direct effect), and conversely, to vibrate or undergo mechanical strain when an electric field is applied (inverse effect).
Principle of the Method: The inverse piezoelectric effect is used to generate ultrasonic waves by applying a high-frequency alternating voltage to a piezoelectric crystal, causing it to vibrate.
Construction and Working:

1. A thin plate or disc is cut from a piezoelectric crystal (like quartz) in a specific crystallographic orientation.
2. The two opposite faces of the crystal are coated with a thin layer of silver to act of electrodes.
3. These electrodes are connected to the output of a high-frequency radio frequency (R.F.) oscillator circuit.
4. When the alternating voltage from the oscillator is applied across the crystal, it causes the crystal to mechanically expand and contract at the same frequency due to the inverse piezoelectric effect.
5. The frequency of the oscillator is adjusted to match the **natural frequency** of the crystal, which depends on its thickness (t). At resonance, $f = v / (2t)$, where v is the speed of sound in the crystal.
6. At resonance, the amplitude of vibration becomes maximum, and the crystal efficiently transmits these intense mechanical vibrations into the surrounding medium, producing powerful ultrasonic waves.

Characteristics:

- This method can produce very high-frequency ultrasonics (up to 500 MHz or even higher).
- It is highly efficient.
- It is the most common method used today, found in applications like medical ultrasonography, flaw detectors, and underwater acoustics.

19) Write short note on Ultrasonic wave Velocity determined using Acoustic diffraction method.

Answer:

This method, often called the **Acoustic Grating Method**, is a precise optical technique for measuring the velocity of ultrasonic waves in liquids and solids. It is based on the principle of diffraction of light by ultrasonic waves.
Principle: When ultrasonic waves are passed through a liquid, they create a periodic series of compressions and rarefactions. This results in a periodic variation in the density (and hence

the refractive index) of the liquid. This regular, alternating pattern of high and low refractive index acts like a **moving diffraction grating**, known as an **acoustic grating**.

Experimental Setup and Working:

1. A piezoelectric crystal (Q) is placed inside a glass cell containing the experimental liquid.
2. The crystal is set into vibration at a high frequency (f) using an R.F. oscillator, generating ultrasonic waves that travel through the liquid, forming an acoustic grating.
3. A monochromatic beam of light (from a source S, rendered parallel by a lens L_1) is passed perpendicularly through this cell.
4. The acoustic grating diffracts the light waves. This results in a diffraction pattern (multiple sharp spectral lines) observed on the screen using a telescope or another lens (L_2).
5. The diffraction pattern is similar to that produced by a standard transmission grating. The grating element (distance between two successive compressions or rarefactions) is equal to the **wavelength of the ultrasonic wave (λultrasonic)**.

Calculation of Velocity:

The formula for a diffraction grating is: d sin θn = n λlight

where:

- d = grating element = λultrasonic
- θn = angle of diffraction for the n^{th} order
- λlight = wavelength of the light used

Therefore, λultrasonic sin θn = n λlight

For small angles, sin θn ≈ θn ≈ xn / D, where xn is the distance of the n^{th} order from the central maxima and D is the distance from the cell to the screen.

Thus, λultrasonic = (n λlight D) / xn

Once the ultrasonic wavelength λultrasonic is found, the velocity v of the ultrasonic wave in the liquid is calculated using the fundamental wave equation:

v = f * λultrasonic

where f is the known frequency of the ultrasonic generator.

This method is highly accurate because it relies on the precise measurement of optical wavelengths.

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