

**SOUND WAVE**

1. An ideal gas is in thermodynamic equilibrium. The number of degrees of freedom of a molecule of the gas is  $n$ . The internal energy of one mole of the gas is  $U_n$  and the speed of sound in the gas is  $v_n$ . At a fixed temperature and pressure, which of the following is the correct option ? **[JEE(Advanced) 2023]**

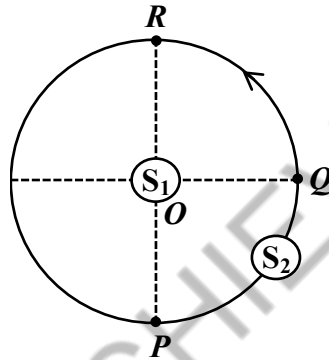
- (A)  $v_3 < v_6$  and  $U_3 > U_6$  (B)  $v_5 > v_3$  and  $U_3 > U_5$   
 (C)  $v_5 > v_7$  and  $U_5 < U_7$  (D)  $v_6 < v_7$  and  $U_6 < U_7$

**Paragraph For Question No. 2**

$S_1$  and  $S_2$  are two identical sound sources of frequency 656 Hz. The source  $S_1$  is located at  $O$  and  $S_2$  moves anti-clockwise with a uniform speed  $4\sqrt{2} \text{ ms}^{-1}$  on a circular path around  $O$ , as shown in the figure. There are three points  $P$ ,  $Q$  and  $R$  on this path such that  $P$  and  $R$  are diametrically opposite while  $Q$  is equidistant from them. A sound detector is placed at point  $P$ . The source  $S_1$  can move along direction  $OP$ .

[Given: The speed of sound in air is  $324 \text{ ms}^{-1}$ ]

**[JEE(Advanced) 2023]**



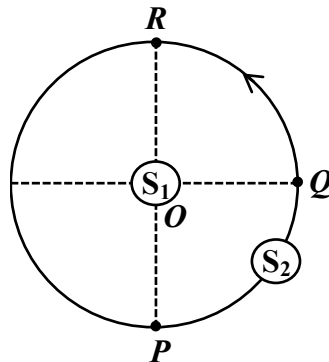
2. When only  $S_2$  is emitting sound and it is at  $Q$ , the frequency of sound measured by the detector in Hz is \_\_\_\_\_.

**Paragraph For Question No. 3**

$S_1$  and  $S_2$  are two identical sound sources of frequency 656 Hz. The source  $S_1$  is located at  $O$  and  $S_2$  moves anti-clockwise with a uniform speed  $4\sqrt{2} \text{ ms}^{-1}$  on a circular path around  $O$ , as shown in the figure. There are three points  $P$ ,  $Q$  and  $R$  on this path such that  $P$  and  $R$  are diametrically opposite while  $Q$  is equidistant from them. A sound detector is placed at point  $P$ . The source  $S_1$  can move along direction  $OP$ .

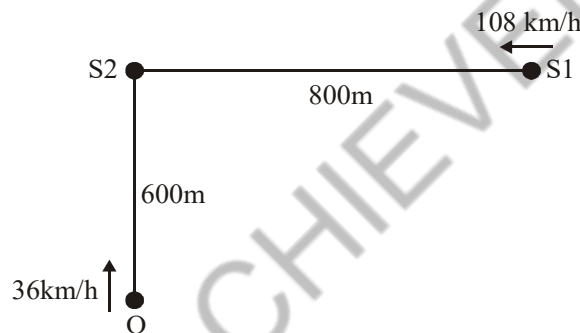
[Given: The speed of sound in air is  $324 \text{ ms}^{-1}$ ]

**[JEE(Advanced) 2023]**



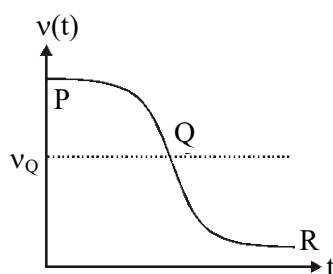
3. Consider both sources emitting sound. When  $S_2$  is at  $R$  and  $S_1$  approaches the detector with a speed  $4 \text{ ms}^{-1}$ , the beat frequency measured by the detector is \_\_\_\_\_ Hz.

4. A source, approaching with speed  $u$  towards the open end of a stationary pipe of length  $L$ , is emitting a sound of frequency  $f_s$ . The farther end of the pipe is closed. The speed of sound in air is  $v$  and  $f_0$  is the fundamental frequency of the pipe. For which of the following combination(s) of  $u$  and  $f_s$ , will the sound reaching the pipe lead to a resonance ? **[JEE(Advanced) 2021]**
- (A)  $u = 0.8 v$  and  $f_s = f_0$  (B)  $u = 0.8 v$  and  $f_s = 2f_0$   
 (C)  $u = 0.8 v$  and  $f_s = 0.5 f_0$  (D)  $u = 0.5 v$  and  $f_s = 1.5 f_0$
5. A stationary tuning fork is in resonance with an air column in a pipe. If the tuning fork is moved with a speed of  $2 \text{ ms}^{-1}$  in front of the open end of the pipe and parallel to it, the length of the pipe should be changed for the resonance to occur with the moving tuning fork. If the speed of sound in air is  $320 \text{ ms}^{-1}$ , the smallest value of the percentage change required in the length of the pipe is \_\_\_\_\_. **[JEE(Advanced) 2020]**
6. A train S1, moving with a uniform velocity of  $108 \text{ km/h}$ , approaches another train S2 standing on a platform. An observer O moves with a uniform velocity of  $36 \text{ km/h}$  towards S2, as shown in figure. Both the trains are blowing whistles of same frequency  $120 \text{ Hz}$ . When O is  $600 \text{ m}$  away from S2 and distance between S1 and S2 is  $800 \text{ m}$ , the number of beats heard by O is \_\_\_\_\_. **[JEE(Advanced) 2019]**  
 [Speed of the sound =  $330 \text{ m/s}$ ]

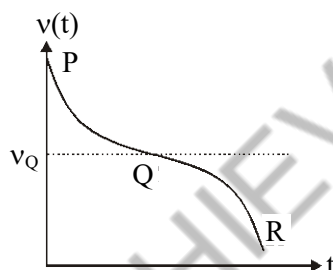


7. Two men are walking along a horizontal straight line in the same direction. The man in front walks at a speed  $1.0 \text{ ms}^{-1}$  and the man behind walks at a speed  $2.0 \text{ ms}^{-1}$ . A third man is standing at a height  $12 \text{ m}$  above the same horizontal line such that all three men are in a vertical plane. The two walking men are blowing identical whistles which emit a sound of frequency  $1430 \text{ Hz}$ . The speed of sound in air is  $330 \text{ ms}^{-1}$ . At the instant, when the moving men are  $10 \text{ m}$  apart, the stationary man is equidistant from them. The frequency of beats in  $\text{Hz}$ , heard by the stationary man at this instant, is \_\_\_\_\_. **[JEE(Advanced) 2018]**
8. In an experiment to measure the speed of sound by a resonating air column, a tuning fork of frequency  $500 \text{ Hz}$  is used. The length of the air column is varied by changing the level of water in the resonance tube. Two successive resonances are heard at air columns of length  $50.7 \text{ cm}$  and  $83.9 \text{ cm}$ . Which of the following statements is (are) true ? **[JEE(Advanced) 2018]**
- (A) The speed of sound determined from this experiment is  $332 \text{ ms}^{-1}$   
 (B) The end correction in this experiment is  $0.9 \text{ cm}$   
 (C) The wavelength of the sound wave is  $66.4 \text{ cm}$   
 (D) The resonance at  $50.7 \text{ cm}$  corresponds to the fundamental harmonic
9. A stationary source emits sound of frequency  $f_0 = 492 \text{ Hz}$ . The sound is reflected by a large car approaching the source with a speed of  $2 \text{ ms}^{-1}$ . The reflected signal is received by the source and superposed with the original. What will be the beat frequency of the resulting signal in  $\text{Hz}$  ?  
 (Given that the speed of sound in air is  $330 \text{ ms}^{-1}$  and the car reflects the sound at the frequency it has received). **[JEE(Advanced) 2017]**

10. Two loudspeakers M and N are located 20 m apart and emit sound at frequencies 118 Hz and 121 Hz, respectively. A car is initially at a point P, 1800 m away from the midpoint Q of the line MN and moves towards Q constantly at 60 km/hr along the perpendicular bisector of MN. It crosses Q and eventually reaches a point R, 1800 m away from Q. Let  $v(t)$  represent the beat frequency measured by a person sitting in the car at time  $t$ . Let  $v_P$ ,  $v_Q$  and  $v_R$  be the beat frequencies measured at locations P, Q and R, respectively. The speed of sound in air is  $330 \text{ ms}^{-1}$ . Which of the following statement(s) is(are) true regarding the sound heard by the person? **[JEE(Advanced) 2016]**
- (A) The plot below represents schematically the variation of beat frequency with time



- (B) The plot below represents schematically the variations of beat frequency with time



- (C) The rate of change in beat frequency is maximum when the car passes through Q
- (D)  $v_P + v_R = 2v_Q$
11. Four harmonic waves of equal frequencies and equal intensities  $I_0$  have phase angles  $0, \pi/3, 2\pi/3$  and  $\pi$ . When they are superposed, the intensity of the resulting wave is  $nI_0$ . The value of  $n$  is. **[JEE(Advanced) 2015]**

12. A student is performing an experiment using a resonance column and a tuning fork of frequency  $244 \text{ s}^{-1}$ . He is told that the air in the tube has been replaced by another gas (assume that the column remains filled with the gas). If the minimum height at which resonance occurs is  $(0.350 \pm 0.005) \text{ m}$ , the gas in the tube is **[JEE(Advanced) 2014]**

(Useful information :  $\sqrt{167RT} = 640 \text{ J}^{1/2} \text{ mole}^{-1/2}$ ;  $\sqrt{140RT} = 590 \text{ J}^{1/2} \text{ mole}^{-1/2}$ . The molar masses  $M$  in grams are given in the options. Take the values of  $\sqrt{\frac{10}{M}}$  for each gas as given there.)

- (A) Neon  $\left( M = 20, \sqrt{\frac{10}{20}} = \frac{7}{10} \right)$  (B) Nitrogen  $\left( M = 28, \sqrt{\frac{10}{28}} = \frac{3}{5} \right)$
- (C) Oxygen  $\left( M = 32, \sqrt{\frac{10}{32}} = \frac{9}{16} \right)$  (D) Argon  $\left( M = 36, \sqrt{\frac{10}{36}} = \frac{17}{32} \right)$

**SOLUTIONS**

1. **Ans. (C)**

**Sol.**  $U = \frac{1}{2} \rho v \lambda T = \frac{\rho T}{2} \lambda v$

∴ A and B are wrong.

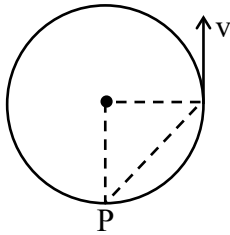
$$v_{\text{sound}} = \sqrt{\frac{\gamma RT}{M}} = \sqrt{\left(\frac{2}{f} + 1\right) \frac{RT}{M}}$$

⇒ more 'f', less 'v'

∴  $v_5 > v_7$

2. **Ans. (648.00)**

**Sol.**



$$f' = \frac{C}{C + v \cos 45^\circ} f$$

$$= \frac{324}{324 + 4\sqrt{2} \times \frac{1}{\sqrt{2}}} \times 656 = 648 \text{ Hz}$$

3. **Ans. (8.00 to 8.40)**

**Sol.**  $f_{P \text{ from } S_2} = 656 \text{ Hz}$

$$f_{P \text{ from } S_1} = \frac{C}{C - V} f = \frac{656 \times 324}{324 - 4} = 664.2$$

$$\Delta f = 664.2 - 656 = 8.2 \text{ Hz}$$

4. **Ans. (A, D)**

**Sol.**  $f = f_s \left( \frac{v}{v - u} \right)$

(A)  $f = f_0 \left( \frac{v}{v - 0.8v} \right) = 5f_0$

(B)  $f = 2f_0 \left( \frac{v}{v - 0.8v} \right) = 10f_0$

(C)  $f = 0.5f_0 \left( \frac{v}{v - 0.8v} \right) = 2.5f_0$

(D)  $f = 1.5f_0 \left( \frac{v}{v - 0.5v} \right) = 3f_0$

close

All odd harmonics are available in closed pipe therefore correct Answer (A, D).

5. **Ans. (0.62 to 0.64)**

**Sol.**  $f \propto \frac{1}{l_1} \Rightarrow f = \frac{k}{l_1}$  ....(1)

( $l_1 \Rightarrow$  initial length of pipe)

$$\left( \frac{V}{V - V_T} \right) f = \frac{k}{l_2}$$

{ $V_T$  Speed of tuning fork,  $l_2 \rightarrow$  new length of pipe}

....(2)

(1) ÷ (2)

$$\frac{V - V_T}{V} = \frac{l_2}{l_1}$$

$$\frac{l_2}{l_1} - 1 = \frac{V - V_T}{V} - 1$$

$$\frac{l_2 - l_1}{l_1} = \frac{-V_T}{V}$$

$$\frac{l_2 - l_1}{l_1} \times 100 = \frac{-2}{320} \times 100 = -0.625$$

Therefore smallest value of percentage change required in the length of pipe is 0.625.

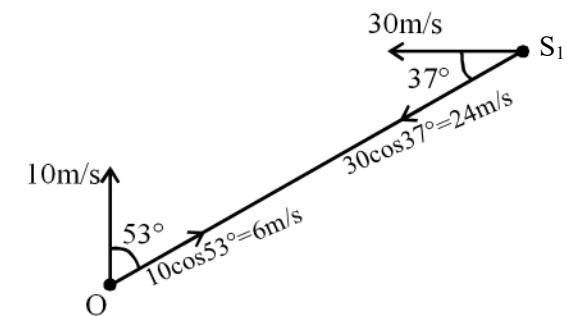
6. **Ans. (7.00 to 10.00)**

**Sol.** Frequency observed by O from  $S_2$

$$f_2 = \frac{330 + 10}{330} \times 120 = \frac{340}{330} \times 120 = 123.63 \text{ Hz}$$

frequency observed by O from  $S_1$

$$f_1 = \frac{330 + 6}{330 - 24} \times 120 = \frac{336}{306} \times 120 \approx 131.76 \text{ Hz}$$

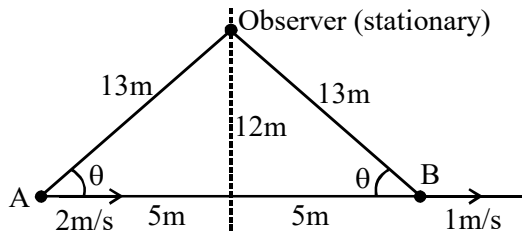


beat frequency =  $131.76 - 123.63$

$$= 8.128 \approx 8.12 \text{ to } 8.13 \text{ Hz}$$

7. **Ans. (5.00)**

**Sol.**



$$\cos \theta = \frac{5}{13}$$

$$f_A = 1430 \left[ \frac{330}{330 - 2 \cos \theta} \right] = 1430 \left[ \frac{1}{1 - \frac{2 \cos \theta}{330}} \right]$$

$$= 1430 \left[ 1 + \frac{2 \cos \theta}{330} \right]$$

(By binomial expansion)

$$f_B = 1430 \left[ \frac{330}{330 + 1 \cos \theta} \right] = 1430 \left[ 1 - \frac{\cos \theta}{330} \right]$$

$$\Delta f = f_A - f_B = 1430 \left[ \frac{3 \cos \theta}{330} \right] = 13 \cos \theta$$

$$= 13 \left( \frac{5}{13} \right) = 5.00 \text{ Hz}$$

8. **Ans. (A, C or A, B, C)**

**Sol.** Let  $n_1$  harmonic is corresponding to 50.7 cm &  $n_2$  harmonic is corresponding 83.9 cm. since both one consecutive harmonics.

$$\therefore \text{their difference} = \frac{\lambda}{2}$$

$$\therefore \frac{\lambda}{2} = (83.9 - 50.7) \text{ cm}$$

$$\frac{\lambda}{2} = 33.2 \text{ cm} = 66.4 \text{ cm}$$

$$\therefore \frac{\lambda}{4} = 16.6 \text{ cm}$$

length corresponding to fundamental mode must be close to  $\frac{\lambda}{4}$  & 50.7 cm must be closed

to an odd multiple of this length as  $16.6 \times 3 = 49.8 \text{ cm}$ . therefore 50.7 is 3<sup>rd</sup> harmonic

If end correction is  $e$ , then

$$e + 50.7 = \frac{3\lambda}{4}$$

$$e = 49.8 - 50.7 = -0.9 \text{ cm}$$

speed of sound,  $v = f\lambda$

$$\therefore v = 500 \times 66.4 \text{ cm/sec} = 332.000 \text{ m/s}$$

9. **Ans. (6)**

**Sol.** Frequency of sound as received by large car approaching the source.

$$f_1 = \frac{C + V_0}{C} f_0 = \left( \frac{330 + 2}{330} \right) 492 \text{ Hz.}$$

This car now acts as source for reflected sound wave

$$\therefore f_{\text{reflected}} = f_1$$

frequency of sound received by source,

$$f_2 = \left( \frac{C}{C - V_0} \right) f_{\text{reflected}}$$

$$= \left( \frac{330}{330 - 2} \right) \times f_1 = \frac{330}{328} \times \frac{332}{330} \times 492 \text{ Hz}$$

$$\therefore \text{Beat frequency} = |f_0 - f_2|$$

$$= \left( \frac{332}{328} - 1 \right) \times 492 \text{ Hz}$$

$$= 6 \text{ Hz}$$

10. **Ans. (A, C, D)**

**Sol.**  $f_M = \frac{C + V \cos \theta}{C} f_1$

$$f_N = \frac{C + V \cos \theta}{C} f_2$$

$$\Delta f = f_N - f_M$$

$$= \frac{C + V \cos \theta}{C} (f_2 - f_1)$$

$$\frac{d(\Delta f)}{dt} = -\frac{V}{C} (f_2 - f_1) \sin \theta \frac{d\theta}{dt}$$

$$\therefore \& \frac{d(\Delta f)}{dt} \text{ is maximum when } \theta = 90^\circ$$

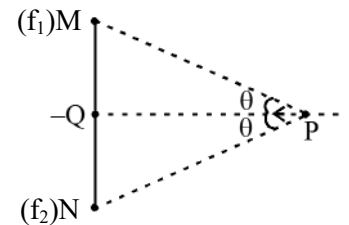
[ $\therefore$  C is correct]

$$v_P = \left( 1 + \frac{V}{C} \cos \theta \right) \Delta f$$

$$v_Q = \Delta f$$

$$v_R = \left( 1 - \frac{V}{C} \cos \theta \right) \Delta f$$

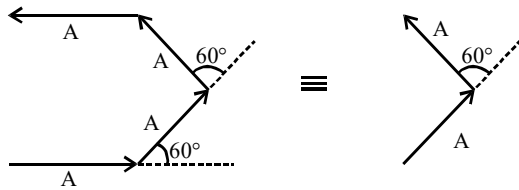
$$\therefore v_P + v_R = 2v_Q$$



**11. Ans. (3)**

**Sol.** Let amplitude of individual wave is  $A$ .

then by using phasor method



So resultant amplitude  $A_r^2 = A^2 + A^2 + 2A^2 \cos 60$

$$\therefore A_r^2 = 3A^2$$

$$\therefore I_r = 3I_0$$

**12. Ans. (D)**

**Sol.**  $V = \sqrt{\frac{\gamma RT}{m}}$  [m should be taken in Kg]

Neon and argon are monoatomic gas  $\Rightarrow \gamma = 1.67$

Nitrogen and oxygen are diatomic gas  $\Rightarrow \gamma = 1.4$

$$\therefore V = \sqrt{\frac{1.67 \times RT \times 1000}{m}} \quad (\text{m is in grams})$$

$$\therefore \text{For Neon, } V = \sqrt{167RT \times \frac{10}{20}} = 640 \times \frac{7}{10} \text{ m/s} \\ = 448 \text{ m/s}$$

$$\text{For nitrogen, } V = \sqrt{140RT \times \frac{10}{28}} = 590 \times \frac{3}{5} \text{ m/s} \\ = 354 \text{ m/s}$$

$$\text{For oxygen, } V = \sqrt{140RT \times \frac{10}{32}} = 590 \times \frac{9}{16} \text{ m/s} \\ = 331.875 \text{ m/s}$$

$$\text{For argon, } V = \sqrt{167RT \times \frac{10}{36}} = 640 \times \frac{17}{32} \text{ m/s} \\ = 340 \text{ m/s.}$$

From the given information,  $f = 244 \text{ Hz}$

$$\left. \frac{\lambda}{4} \right|_{\text{max}} = 0.350 + 0.005 = 0.355 \text{ m} \quad \left. \frac{\lambda}{4} \right|_{\text{min}} \\ = 0.350 - 0.005 = 0.345 \text{ m}$$

$$\therefore \lambda_{\text{max}} = 1.420 \text{ m} \quad \lambda_{\text{min}} = 1.380 \text{ m}$$

$$\therefore V_{\text{max}} = 244 \times \lambda_{\text{max}} = 346.48 \text{ m/sec}$$

$$V_{\text{min}} = 244 \times \lambda_{\text{min}} = 336.72 \text{ m/sec}$$

Only Argon is between them