Example 2.2 : The ultrasonic pulse echo method is employed to detect possible defects in a steel bar of thickness 40 cm. If the pulse arrival times are 30 and 80 microseconds, find the distance of the defect from the end of the bar at which the ultrasonic pulse enters the bar.

Solution :

Here, Thickness = 40×10^{-2} m

Echo times are 30 and 80 μs

If x metre is the distance of the possible defect in steel bar from the end of the bar at which the ultrasonic pulse enters the bar, then the pulse covers a distance of $2x$ in arriving back to the end after being reflected from the defect. Therefore,

$$30 \times 10^{-6} = \frac{2x}{v} \quad \ldots \quad \ldots \quad \ldots (2.43)$$

The second pulse will arrive after being reflected from far end of the bar. Thus it will cover a distance of 2 × 40 cm in 80 μs. Then,

$$80 \times 10^{-6} = \frac{2 \times 40 \times 10^{-2}}{v} \quad \ldots \quad \ldots \quad \ldots (2.44)$$

Dividing Eq. (2.43) by Eq. (2.44),

$$\frac{80 \times 10^{-6}}{30 \times 10^{-6}} = \frac{2 \times 40 \times 10^{-2}}{v} \times \frac{v}{2x}$$

$$\text{or} \quad x = \frac{120 \times 10^{-2}}{8} = 15 \text{ cm}$$

$\therefore$ The distance of the flaw from near end = 15 cm

Example 2.3 : In determining the thickness of a steel plate by an ultrasonic beam, the difference between the first two adjacent harmonic frequencies was found to be 50 kHz. If the velocity of sound in steel is 5000 m/s, calculate the thickness of the steel plate.

Solution :

Here, Difference between the first two adjacent harmonic frequencies = 50 kHz,

v = 5000 m/s

Let t be the thickness of the steel plate. In the lowest mode of vibration, the distance between the two faces of the plate will be $\lambda/2$. Therefore, $t = \lambda/2$

Hence the lowest frequency,

$$f_1 = \frac{v}{\lambda} = \frac{v}{2t}$$

The next mode of vibration, $f_2 = 2f_1 = \frac{2v}{2t}$

$$\therefore \quad (f_2 - f_1) = \frac{2v}{2t} - \frac{v}{2t} = \frac{v}{2t}$$

$$\therefore \quad t = \frac{v}{2(f_2 - f_1)} = \frac{5000}{2 \times 50 \times 10^3} = 0.05\ m$$

$\therefore$ Thickness of steel plate = 0.05m

Example 2.4 : Calcualte the capacitance to produce ultrasonic waves of 10^6 Hz with an inductance of 1 henry.

Solution :

Here, Frequency = 10^6 Hz

L = 1 henry

$$f = \frac{1}{2\pi}\sqrt{\frac{1}{LC}} \quad \text{or} \quad C = \frac{1}{4\pi^2 f^2 L}$$

$$C = \frac{1}{4\pi^2 \times \left(10^6\right)^2 \times 1^2} = 0.025 \times 10^{-12}$$

$= 0.025$ pF

$\therefore$ The capacitance = 0.025 pF

Example 2.5 : A quartz crystal of thickness of 0.001 metre is vibrating at resonance. Calculate the fundamental frequency. Given Y for quartz = 7.9×10^{10} Newton/m^2 and ρ for quartz = 2650 kg/^{3}.

Solution :

We known that $v = \sqrt{(Y/\rho)}$

Substituting the given values, we get

$$v = \sqrt{\left(\frac{7.9\times10^{10}}{2650}\right)} = 5461 \text{ m/sec.}$$

For the fundamental mode of vibration the thickness should be equal to $\lambda/2$. Hence

$$\lambda = 2t = 2 \times 0.001 = 0.002 \text{ metre}$$

Now $v = n\lambda$ or $n = v/\lambda$

$$\therefore \quad n = \frac{5461}{0.002} = 2.730 \times 10^6 \text{ Hz} = 2730 \text{ kHz}$$

Example 2.6 : A metal disc oscillates in its own plane about an axis passing through a point on its edge. What is the length of the equivalent simple pendulum ?

Solution :

Let the disc of radius r oscillate about an axis through the point P on its edge as shown in above fig. 2.16.

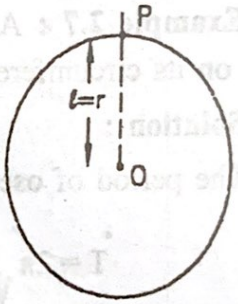

Fig. 2.16

The periodic time of the disc is given by

$$t = 2\pi\sqrt{\frac{I}{mgl}} \qquad \ldots \ldots \ldots (2.45)$$

Where I is its M.I. about the axis through P, m is its mass and l its length.

Here pendulum length l = radius r of the disc

Hence,

$$t = 2\pi\sqrt{\frac{I}{mgr}} \qquad \ldots \ldots \ldots (2.46)$$

Now, using the parallel axis theorem

$$I = I_o + mr^2 \qquad \ldots \ldots \ldots (2.47)$$

Where I_o is the M.I. of the disc about a parallel axis through O.

i.e. $I_o = \frac{1}{2}mr^2$

So that, $I = \frac{1}{2} mr^2 + mr^2$

$$I = \frac{3}{2} mr^2$$

substituting this value of I in equation (2.46) we get

$$t = 2\pi\sqrt{\frac{3/2\, mr^2}{mgr}} = 2\pi\sqrt{\frac{3r/2}{g}} \quad \ldots \quad \ldots \quad \ldots (2.48)$$

comparing this equation with the time period of simple pendulum

$$t = 2\pi\sqrt{\frac{L}{g}} \quad \ldots \quad \ldots \quad \ldots (2.49)$$

we get $L = \frac{3}{2} r$ $\ldots \quad \ldots \quad \ldots (2.50)$

This is the length of equivalent simple pendulum.

Example 2.7 : A circular disc of radius 20 cm oscillates as a pendulum about a point on its circumference. Calculate the period of oscillation.

Solution :

The period of oscillation of the disc about the axis through its edge is given by

$$T = 2\pi\sqrt{\frac{3r/2}{g}}$$

Here, r = 20 cm and g = 980 cm/sec^2

$$T = 2\pi\sqrt{\frac{3\times 20/2}{980}}$$

$\therefore$ T = 1.099 sec.

Example 2.8 : A disc of radius R with plane vertical can be made to swing about a horizontal axis passing through any one of a series of holes bored along a diameter. Show that the minimum time period is given by

$$t = 2\pi\sqrt{\frac{1.414\,R}{g}}$$

Solution :

The time period of a compound pendulum is minimum when $l_1 = l_2$

Also, $k = \sqrt{l_1 l_2} = \sqrt{l_1^2}$

$\therefore \quad k^2 = l_1^2$

In a circular disc

$$mk^2 = \frac{1}{2} mR^2$$

$$\therefore \quad k^2 = \frac{R^2}{2}$$

$$\therefore \quad l_1^2 = \frac{R^2}{2}$$

$$\therefore \quad l_1 = \frac{R}{\sqrt{2}} = \frac{R}{1.414}$$

For minimum time period

$$t = 2\pi \sqrt{\frac{k^2 + l_1^2}{l_1 g}}$$

$$= 2\pi \sqrt{\frac{R^2/2 + R^2/2}{\frac{Rg}{1.414}}}$$

$$\therefore \quad t = 2\pi \sqrt{\frac{1.414\,R}{g}}$$

Exercise

1. Bats emits ultrasonic waves. The shortest wavelength emitted in air by a bat is about 0.33 cm. What is the highest frequency that a bat can emit ?

   [Ans. : 1.05×10^5 Hz]

2. A piezoelectric crystal has a thickness of 0.002 m.If the velocity of sound waves in a crystal is 5750 m/s, calculate the fundamental frequency of the crystal.

   [Ans. : 1.44 MHz]

3. A quartz crystal of thickness 0.005 m is vibrating at resonance. Calculate the fundamental frequency. Given the Young's modulus for quartz as 7.9×10^{10} N/m^2 and density of quartz 2650 kg/m^3.

   [Ans. : 5.46 × 105 Hz]

4. A uniform circular disc of diameter 20 cm vibrates about a horizontal axis perpendicular to its plane and at a distance of 5 cm from the centre. Calculate the time period of oscillation and the equivalent length of the simple pendulum.

[**Ans. :** 0.782 sec, 15 cm]

Question Bank

Multiple Choice Questions :

1. The sound wave having frequency between 20Hz to 20Khz are called _____ waves
   (a) infrasonic (b) Audible (c) Supersonic (d) Ultrasonic
2. The sound wave having frequency less than 20Hz to 20Khz are called _____ waves
   (a) infrasonic (b) Audible (c) Supersonic (d) Ultrasonic
3. Ultrasonic waves are _____
   (a) Longitudinal waves (b) Progressive wave
   (c) Transverse waves (d) Inverse waves
4. Ultrasonic waves are _____
   (a) Mechanical waves (b) Progressive wave
   (c) Transverse waves (d) Non-mechanical waves
5. Ultrasonic waves can have frequency _____
   (a) < 20 Hz (b) > 20 KHz (c) < 20 KHz (d) > 20 MHz
6. Ultrasonic waves move faster than the sound waves. The sentence is _____
   (a) True (b) False (c) Irrelevant (d) none of these
7. Ultrasonic waves move with the same velocity as the sound waves. The statement is _____
   (a) True (b) False (c) Irrelevant (d) none of these
8. Ultrasonic waves are also called _____
   (a) Super Position Waves (b) SONAR waves
   (c) Super Sonic Waves (d) Infra Sonic Waves
9. In the phenomenon of Magnetostriction the length of the ferromagnetic rod _____
   (a) Increases (b) Decreases (c) Changes (d) Remain same
10. Which one of the following materials is not a ferromagnetic material?
    (a) Quartz (b) Nickel (c) cobalt (d) Iron

11. _____ and _____ discovered the piezoelectric effect
    (a) Maxwell and Boltzmann (b) Bose and Einstein
    (c) Fermi and Dirac (d) Pierre Curie and Jacques Curie
12. In 1917, _____ has designed a piezoelectric generator
    (a) Pierre Curie and Jacques Curie (b) Langevin
    (c) G W Pierce (d) Piezo
13. Which one of the following materials is not a Piezo-electric material?
    (a) Quartz (b) Tourmaline (c) Rochelle Salt (d) Aluminum
14. The magnetostriction effect is also known as _____
    (a) Peltier effect (b) Sibac effect
    (c) Joule effect (d) Compton effect
15. The speed of ultrasonic waves in a solid medium depends upon _____
    (a) Length (b) Height (c) Volume (d) Density
16. Ultrasonic waves can be transmitted over long distances without any appreciable loss of energy because of their _____ wavelength
    (a) Variable (b) Small (c) Medium (d) large
17. In a liquid bath, ultrasonic waves make a _____
    (a) plane diffraction prism (b) plane reflection prism
    (c) plane diffraction grating (d) plane reflection grating
18. Ultrasonic waves produce _____ in liquid
    (a) Interference (b) Diffraction
    (c) non-destructive effects in liquids (d) disruptive effects
19. _____ has designed a magnetostriction generator
    (a) Pierre Curie and Jacques Curie (b) Langevin
    (c) G W Pierce (d) Piezo
20. If we increase the length of simple pendulum its time period will _____
    (a) Increase (b) Decrease
    (c) Remain same (d) becomes infinite
21. The period of simple pendulum is doubled when _____
    (a) Its length is doubled (b) Its length is halved
    (c) The length is made four times (d) Mass of the bob is doubled

22. The time period of simple pendulum having infinite length is _____
(a) zero (b) One (c) infinite (d) Half

23. If we increase the mass of the bob of simple pendulum its time period will _____
(a) Increase (b) Remain same (c) Decrease (d) becomes infinite

24. There are _____ points collinear with the centre of gravity of a compound pendulum about which its times of oscillations are equal
(a) 2 (b) 6 (c) 4 (d) 8

25. The periodic time of a compound pendulum will be _____ when the length of the pendulum is equal to it's radius of gyration about a horizontal axis passing through its centre of gravity
(a) Remain same (b) Maximum
(c) None of these (d) Minimum

26. The periodic time of a compound pendulum will be _____ when the axis of rotation passing through the CG
(a) Remain same (b) Maximum
(c) None of these (d) Minimum

27. The compound pendulum is also known as _____ pendulum
(a) Simple (b) Physical (c) Keter's (d) Torsional

28. The distance between point of suspension and centre of oscillation is called _____
(a) Length of pendulum
(b) Length of body
(c) Length of equivalent simple pendulum
(d) Length of simple pendulum

29. The equivalent simple pendulum length is always greater than _____
(a) Length of body (b) Simple pendulum length
(c) Breadth of the body (d) Height of the body

30. The centre of suspension and centre of oscillations are _____
(a) interchange (b) Do no interchange
(c) coincide (d) Overlap

31. The centre of oscillation lie below at a distance _____ from C.G.
(a) $\frac{k^3}{l}$ (b) $\frac{k}{l}$ (c) $\frac{k^2}{l}$ (d) $\frac{k^2}{l^2}$

32. The centre of percussion and centre of oscillation are _____
    (a) interchange (b) Coincide
    (c) Do not interchange (d) At infinite

33. The centre of percussion lie below at a distance _____ from C.G.
    (a) $\frac{k^3}{l}$ (b) $\frac{k}{l}$ (c) $\frac{k^2}{l}$ (d) $\frac{k^2}{l^2}$

34. The centre of percussion and centre of oscillation lie at a distance _____ from the point of suspension
    (a) $l + \frac{k^3}{l}$ (b) $l + \frac{k^2}{l}$ (c) $\frac{k^2}{l}$ (d) $\frac{k^3}{l}$

35. No shock will be felt to the cricketer when ball strikes to _____ on the bat
    (a) Point of suspension (b) Center of gravity
    (c) Centre of percussion (d) Center of the bat

36. The bar pendulum is also known as _____ pendulum
    (a) Simple (b) Compound (c) Keter's (d) Torsional

37. In 1928, _____ has suggested alternate method for determination of 'g' and 'k' using bar pendulum
    (a) Ferguson (b) Kater's (c) Newton (d) Laplace

38. The effective distance of the particle of a body from its axis of rotation is called _____.
    (a) Radius of body (b) Radius of gyration
    (c) Radius of circle (d) Radius of ellipse

39. The time period of compound pendulum do not depends on _____ of the body
    (a) size (b) Shape (c) length (d) Mass

40. The Kater's pendulum is also known as _____ pendulum
    (a) Simple (b) conical (c) reversible (d) Torsional

Short Questions :

1. What are ultrasonic ?
2. Define audible, infrasonic and ultrasonic waves.
3. Distinguish between audible, infrasonic and ultrasonic waves.
4. Explain the mechanical generator of ultrasonic waves.

5. Explain the electrical generator of ultrasonic waves.
6. Define magnetostriction effect.
7. What is Joule effect?
8. Define piezoelectric effect.
9. Explain the phenomenon of Magnetostriction effect.
10. Explain the phenomenon of piezo-electric effect.
11. Give the advantages of piezoelectric generator.
12. State the limitation of piezoelectric generator.
13. State the advantages and disadvantages of piezoelectric generator.
14. Write the merits and demerits of magnetostriction generator.
15. How will you detect ultrasonic wave by the Kundt's tube method?
16. Describe the thermal detector method for detection of ultrasonic wave.
17. Give the sensitive flame method for detection of ultrasonic sound.
18. Explain the quartz crystal method for detection of ultrasonic wave.
19. Explain any two methods for detection of ultrasonic wave.
20. State some properties of ultrasonic waves.
21. Enlist any five applications of ultrasonic waves.
22. Explain the function of SONAR.
23. How will ultrasonic used in medical science?
24. Enlist the various methods of detection of ultrasonic waves.
25. How is the depth of sea measured using ultrasonic?
26. How will you compare the piezoelectric and magnetostriction generator of ultrasonic?
27. What is an acceleration due to gravity?
28. What is simple pendulum?
29. State the drawbacks of a simple pendulum.
30. What is a compound pendulum?
31. Distinguish between simple pendulum and compound pendulum.
32. Define the radius of gyration. Write its expression.
33. What is the length of equivalent simple pendulum?
34. Explain the centre of oscillation.
35. Show the centre of suspension and oscillation are interchangeable.

36. What is centre of percussion?
37. What you meant by collinear point on the body?
38. Write the conditions for maximum and minimum time period.
39. Show that the periodic time of a compound pendulum will be minimum when the length of the pendulum is equal to it's radius of gyration.
40. Prove that the periodic time of a compound pendulum will be maximum when the axis of rotation passing through the CG.
41. Find the conditions for maximum and minimum time period of compound pendulum.
42. What is bar pendulum?
43. Plot the experimental curve of bar pendulum for determination of 'g' and 'k'.
44. What is Keter's reversible pendulum?
45. What is the Ferguson correction for determination of 'g' and 'k'?

Long Questions :

1. How will you produce ultrasonic using a piezoelectric oscillator?
2. Describe the ultrasonic generator using a magnetostriction oscillator.
3. What are ultrasonic waves? How are they produced?
4. Describe the various properties of ultrasonics.
5. Describe the different methods of detection of ultrasonic.
6. Discuss the applications of ultrasonic.
7. What are ultrasonic? Explain the terms megnetostriction and piezoelectric effect. Discuss any one method of production and detection of ultrasonic.
8. With figure, explain the phenomenon of megnetostriction and discuss the megnetostriction method of production of ultrasonic waves in detail.
9. Discuss piezo-electric effect and magnetostriction effects.
10. Discuss the piezo-electric method of production of ultrasonic waves with the help of necessary figures.
11. Write a note on detection of ultrasonic waves in detail.
12. Give a detailed account of properties of ultrasonic waves.
13. Discuss the various applications of ultrasonic waves in detail.
14. What is simple pendulum? Derive an expression for the periodic time of a simple pendulum. Also give its limitation.

15. Discuss the drawbacks of a simple pendulum.
16. What is a compound pendulum? Deduce an expression for its periodic time.
17. Discuss the motion of compound pendulum and derive it's equation of motion.
18. Derive the expression of time period of compound pendulum in terms of equivalent simple pendulum length.
19. Discuss the centre of oscillation and center of percussion.
20. In case of compound pendulum, show that centers of suspension and oscillation are reversible (or interchangeable).
21. Obtain the collinear points with the centre of gravity about which the same time period.
22. Show that there are four points collinear with the centre of gravity of a compound pendulum about which its times of oscillations are equal, hence obtain the length of an equivalent simple pendulum.
23. Draw diagram of bar pendulum and explain how to determine g using bar pendulum?
24. What is bar pendulum? Describe the experiment for determination of 'g' and 'k'. Also give Ferguson correction for the determination of 'k'.
25. Describe Kater's reversible pendulum and derive the necessary expression of acceleration due to gravity.

Answer key of MCQ

1.	(b)	2.	(a)	3.	(a)	4.	(a)
5.	(b)	6.	(a)	7.	(b)	8.	(c)
9.	(c)	10.	(a)	11.	(d)	12.	(b)
13.	(d)	14.	(c)	15.	(d)	16.	(b)
17.	(c)	18.	(d)	19.	(b)	20.	(a)
21.	(c)	22.	(c)	23.	(b)	24.	(c)
25.	(d)	26.	(b)	27.	(b)	28.	(c)
29.	(b)	30.	(a)	31.	(c)	32.	(b)
33.	(c)	34.	(b)	35.	(c)	36.	(b)
37.	(a)	38.	(b)	39.	(b)	40.	(c)