WAVE MOTION
ACOUSTICS

POINTS TO REMEMBER

1. The branch of physics that deals with the process of generation, reception and propagation of sound is called 'Acoustics'.
2. **Absorption coefficient**,

$$a = \frac{energy\ absorbed\ by\ the\ surface}{Energy\ absorbed\ by\ an\ open\ window\ of\ same\ area\ in\ the\ same\ time} \quad \text{or} \quad \alpha = \frac{E_s}{E_w}$$

3. **Reverberation**: The persistence of sound in a room (or) enclosure as a result of continuous reflections of sound from the walls, floor, ceiling etc of the room even after the source of sound is cut off is called 'Reverberation'.
4. **Reverberation time:** The time required by the sound intensity in a enclosure to decrease to threshold of audibility from an initial intensity of 10^6 times of this, after the sound is turned off is called reverberation time.
5. **Reverberation time depends on**
   a) Size of the (enclosure) room or auditorium.
   b) Nature of reflecting materials on the wall, floor and ceiling.
   c) The area of reflecting surface.
   d) Intensity (or loudness of sound produced)
6. **Reverberation times is independent of**
   a) Shape of the enclosure.
   b) Position of the source of sound and listener.
   c) Position of the absorbent in the enclosure
7. From Sabine's formula, reverberation time $T = \frac{0.17V}{\sum_i a_i s_i}$
8. In reverberation chamber method, absorption coefficient,

$$\alpha = \frac{0.17V}{S}\left[\frac{1}{T_2} - \frac{1}{T_1}\right] + \alpha_0$$

9. In stationary wave method. $\alpha = \frac{4i_1 i_2}{\left[i_1 + i_2\right]^2}$ where $i_1\ and\ i_2$ are maximum and minimum currents.

SHORT ANSWER QUESTIONS

1. Define "Absorption coefficient" and "Reverberation time". State and explain Sabine's formula for reverberation time in a closed auditorium.

A. **Absorption coefficient:**

The ratio of sound energy absorbed by a surface to the sound energy absorbed by an open window of equal area in the same time is called absorption coefficient of the surface. It is denoted by 'a'

$\therefore a = \frac{E_s}{E_w}$ Where E_s = sound absorbed by a surface and E_w = sound absorbed by an open window

Reverberation time:

The time gap between the initial direct source and sound due to the multiple reflection until the intensity falls from 10^6 times the threshold of audibility to the threshold of audibility after the source of sound is cut off is called reverberation time.

Sabine's formula: Sabine's formula states that reverberation time is directly proportional to the volume of enclosure $(T \alpha V)$ and inversely proportional to the total absorption $\left(T \alpha \frac{1}{A}\right)$ $\therefore T = \frac{KV}{A}$

S = Surface area; V = volume of the enclosure; a = absorption coefficient

Reverberation time $T = \frac{0.17V}{\sum aS}$

2. What are the conditions required for a good auditorium?

A. **Conditions for a good auditorium:**

1. There should be uniform loudness at all parts of the building.
2. Loud speakers are arranged in the hall to have uniform distribution of sound intensity.
3. Loud speakers must be kept at a height above the head of the speaker.
4. The noise produced by machinery, vehicles and footsteps from outside the hall should not reach into it through doors and windows.
5. The auditorium must be free from curved surfaces to avoid focusing of sound at some points. Some times parabolic surfaces are preferred to spherical surfaces.
6. If reverberation time is too high, syllables of the words cannot be heard with clarity. If it is too low the sound from low intensity sources can be heard properly Thus reverberation time is maintained at optimum value.
7. If there are large number of reflecting surfaces like flight of stairs in the hall. The sharp sound produced by a person in front of it may produce a musical sound note. This is called "Echelon effect". This can be avoided by converting staircases with carpets.

VERY SHORT ANSWER QUESTIONS:

1. What is reverberation? Write Sabine's formula for reverberation time in a closed room.

A. Reverberation is the persistence of sound in an enclosure as a result of multiple reflections of sound at the walls even after the source of sound is turned off.
Sabine's formula: If "T" is the reverberation time of an enclosure and 'V' is its volume with total absorption 'A' then

$$T = \frac{0.17V}{A} = \frac{0.17V}{\sum as}$$

Where 'a' is absorption coefficient and 's' is surface area

2. What is 'Absorption coefficient'? Which is a better absorber of sound, glass or fiber glass?(March2006)

AS. The absorption coefficient of a surface is the ratio of sound energy absorbed by it (E_s) to the sound energy absorbed by an open window of equal area (E_w) in the same time $a = \frac{E_s}{E_w}$

The absorption coefficient of fiber glass (0.69) is more than the absorption coefficient of glass (0.028).Hence fibre glass is a better absorber of sound.

3. What are focusing and echelon effects?

A. **Focusing effect**: It is the concentration of sound at a point in the enclosure due to reflection of sound from curved surfaces.

Echelon effect: When sound waves are reflected from different points in regular intervals of time (like stair case) then the reflected sound will produce some musical note. This effect is called echelon effect.

SOLVED PROBLEMS

1. A hall of volume $4\times6\times10m^3$ has a reverberation time 1.5 s. (a) what is the total sound absorption of the hall? B) 40 visitors are in the hall and each is equivalent to 0.5 metric Sabine sound absorption. Find the new reverberation time of the hall.

A. i) Volume of the hall = $4\times6\times10 = 240m^3$

Reverberation time $T = 1.5s$

Total absorption of the hall $A_1 = \frac{0.17V}{T} = \frac{0.17\times240}{1.5} = 27.2$ metric Sabine.

ii) Volume of the hall = $240m^3$

Number of visitors in the hall = 40

Sound absorption of each visitor = 0.5 metric Sabine

Absorption of 40 visitors = $40\times0.5 = 20$ metric Sabine

Absorption of the hall = 27.2 metric Sabine

$\therefore$ Total absorption = (absorption of the hall + absorption due to the visitors)

= 27.2 + 20.0 = 47.2 metric Sabine

$\therefore$ Reverberation time = $\frac{0.17V}{A} = \frac{0.17\times240}{47.2} = 0.8644s$

2. A rectangular closed room whose internal dimensions are $20\times30\times16\ m^3$ has a surface whose average absorption coefficient is 0.04. Calculate the time of reverberation of the room. When a material of area $2000m^2$ is brought into

the room, the time of reverberation falls to 3 s. Calculate the absorption coefficient of the material introduced.

A. Volume of the room $V = 20\times30\times16 = 9600m^3$

Absorption coefficient a = 0.04

Surface area of the room = area of the (walls + top + bottom)

$$= 2h(l+b)+lb+lb = \left[2h(l+b)+2lb\right]$$

$$= \left[2\times16(20+30)+2(20)(30)\right]$$

$$= \left[(32\times50)+1200\right] = \left[1600+1200\right]m^2 = 2800m^2$$

Absorption of sound of empty room $A_1 = as = 0.014\times2800 = 112$ metric Sabine

Reverberation Time $T = \dfrac{0.17V}{A_1} = \dfrac{0.17\times9600}{112} = 14.57s$

After introducing the material , reverberation time $T_1 = 3s$

$\therefore$ Total absorption $A_2 = \dfrac{0.17V}{T_1} = \dfrac{0.17\times9600}{3} = 544$ metric Sabine

Total absorption = absorption of empty room + Absorption of material

Absorption due to $S_1\left(2000m^2\right)$ of the material $= A_2 - A_1 = 544-112 = 432$ metric Sabine

Absorption coefficient of the material $= \dfrac{A_2 - A_1}{S_1} = \dfrac{432}{2000} = 0.216$

The reverberation time of the room = 14.57 s

Absorption coefficient of the material = 0.216

Exercise 1

1. A rectangular class room of volume $20\times15\times10m^3$ has a surface whose average absorption co-efficient is 0.035 metric Sabine. Calculate the time of reverberation of the room. When a material of area $1500m^2$ is brought into the room, the reverberation time falls to 2.5 seconds, calculate the absorption co-efficient of the material.

A. Volume of room $V = 20\times15\times10 = 300m^3$

Average absorption =0.035 metric Sabine

Surface area = 2(lb + bh + hl)$= 2\left(20\times15+15\times10+10\times20\right) = 1300m^2$

a) Reverberation time T_1

$$= \frac{0.17\times V}{\sum as} = \frac{0.17\times3000}{0.035\times1300} = 11.21\text{sec}$$

b) When the material is introduced in to the room

Total absorption, $\sum as$ = absorption of room + absorption of material.

$$= 0.035 \times 1300 + a^1 s^1 = 1500 m^2$$

Reverberation time, $T^1 = \dfrac{0.17v}{a.s + a^1 s^1}$ = 2.5s

$$a^1 s^1 = \left(\frac{0.17v}{T^1} - as \right) = \left(\frac{0.17 \times 3 \times 10^3}{2.5} \right) - \left(0.035 \times 1300 \right)$$

$$a^1 s^1 = 204 - 45.5 = 158.5$$

$$\therefore a^1 = \frac{158.5}{1500} = 0.1056$$

2. A meeting hall of volume $100 \times 30 \times 10 m^3$ has a reverberation time of 3 seconds

i) What is the total absorption of the hall ii) if 1000 visitors are in the hall, calculate the absorption of the hall. The sound absorption of each visitor is 0.5. Find the new reverberation time of the theatre.

A. Volume of hall $V = 100 \times 30 \times 10 = 3 \times 10^4 m^3$

Initial reverberation time $T_1 = 3 \text{sec}$

$$T_1 = \frac{0.17V}{A_1} \Rightarrow A_1 = \frac{0.17V}{T_1} = \frac{0.17 \times 3 \times 10^4}{3}$$

$\therefore A_1 = 1700$ Metric Sabine

Number of visitors (n) = 1000

$S_2 = 1000 m^2$

Absorption coefficient of each visitor = $a_2 = 0.5$

$\therefore$ Absorption of the all visitors = $a_2 s_2$ = 500 metric Sabine

Final reverberation time $T_2 = \dfrac{0.17V}{A_2} = \dfrac{0.17V}{A_1 + a_2 s_2} = \dfrac{0.17 \times 3 \times 10^4}{1700 + 500}$ = 2.318sec