WHAT IS NOISE POLLUTION?

- **Sound** that is **unwanted** or **disrupts one's quality of life** is called as noise. When there is lot of noise in the environment, it is termed as noise pollution.

- Sound becomes **undesirable** when it **disturbs** the **normal activities** such as working, sleeping, and during conversations.

- It is an **underrated environmental problem** because of the fact that we can't see, smell, or taste it.

- **World Health Organization** stated that "Noise must be recognized as a **major threat to human well-being**"

HEALTH EFFECTS

- There are direct links between noise and health. Also, noise pollution **adversely affects the lives** of millions of people.
- Noise pollution can **damage physiological and psychological health**.
- **High blood pressure**, **stress** related illness, **sleep disruption**, **hearing loss**, and **productivity loss** are the problems related to noise pollution.
- It can also cause **memory loss**, **severe depression**, and **panic attacks**.

SOURCES OF NOISE POLLUTION

- **Transportation systems** are the main source of noise pollution in **urban** areas.

- Construction of buildings, highways, and streets cause a lot of noise, due to the usage of air compressors, bulldozers, loaders, dump trucks, and pavement breakers.

- **Industrial noise** also adds to the already unfavorable state of noise pollution.

- **Loud speakers**, plumbing, boilers, generators, air conditioners, fans, and vacuum cleaners add to the existing noise pollution.

SOLUTIONS FOR NOISE POLLUTION

- **Planting** bushes and **trees** in and around sound generating sources is an effective solution for noise pollution.
- **Regular servicing** and tuning of **automobiles** can effectively reduce the noise pollution.
- Buildings can be **designed** with suitable **noise absorbing material** for the walls, windows, and ceilings.
- **Workers** should be provided with equipments such as **ear plugs** and earmuffs for hearing protection.

SOLUTIONS FOR NOISE POLLUTION

- Similar to automobiles, **lubrication of the machinery** and servicing should be done to minimize noise generation.
- **Soundproof doors and windows** can be installed to block unwanted noise from outside.
- **Regulations** should be imposed to restrict the usage of play loudspeakers in crowded areas and **public places**.
- **Factories and industries** should be **located far from** the **residential areas**.

Physics of Sound

- Theory
  - The vibration of a source causes pressure changes in air which result in pressure waves
  - Perceived sound is comprised of numerous pressure waves of varying characteristics

Physics of Sound

- Pressure wave characteristics
  - *Amplitude*—The amount of sound pressure measured in decibels (dB)
  - *Frequency*—The rate of vibration per unit time measured in cycles per second, more commonly known as *hertz (Hz)*; range of normal perception for young person is 20–20,000 Hz

Sound Pressure

- Pressure is fundamental to acoustics
- Definition
  - Pressure = force per unit of area
- Units
  - *Newtons per square meter (N/m_2)*—Called a *Pascal* (modern unit)
  - *Dynes per square centimeter (D/cm^2)*—Not commonly used

Sound Pressure

- Human hearing covers a wide range of sound pressures
  - Threshold of hearing: 0.00002 Pa
  - Loud noise: 200 Pa

Levels and the Decibel

The sound pressure of the faintest sound that a normal healthy individual can hear is about 0.00002 Pa. The sound pressure produced by a Saturn rocket at liftoff is greater than 200 Pa. Even in scientific notation this is an "astronomical" range of numbers.

To cope with this problem, a scale based on the logarithm of the ratios of the measured quantities is used. Measurements on this scale are called levels. The unit for these types of measurement scales is the **bel,** which was named after Alexander Graham Bell:

$$L' = \log \frac{Q}{Q_0} \qquad (15\text{–}7)$$

where L' = level, bels
Q = measured quantity
Q_0 = reference quantity
$\log$ = logarithm in base 10

A bel turns out to be a rather large unit, so for convenience it is divided into 10 subunits called **decibels** (dB). Levels in decibels are computed as follows:

$$L = 10 \log \frac{Q}{Q_0} \qquad (15\text{–}8)$$

The decibel does not represent any physical unit. It merely indicates that a logarithmic transformation has been performed.

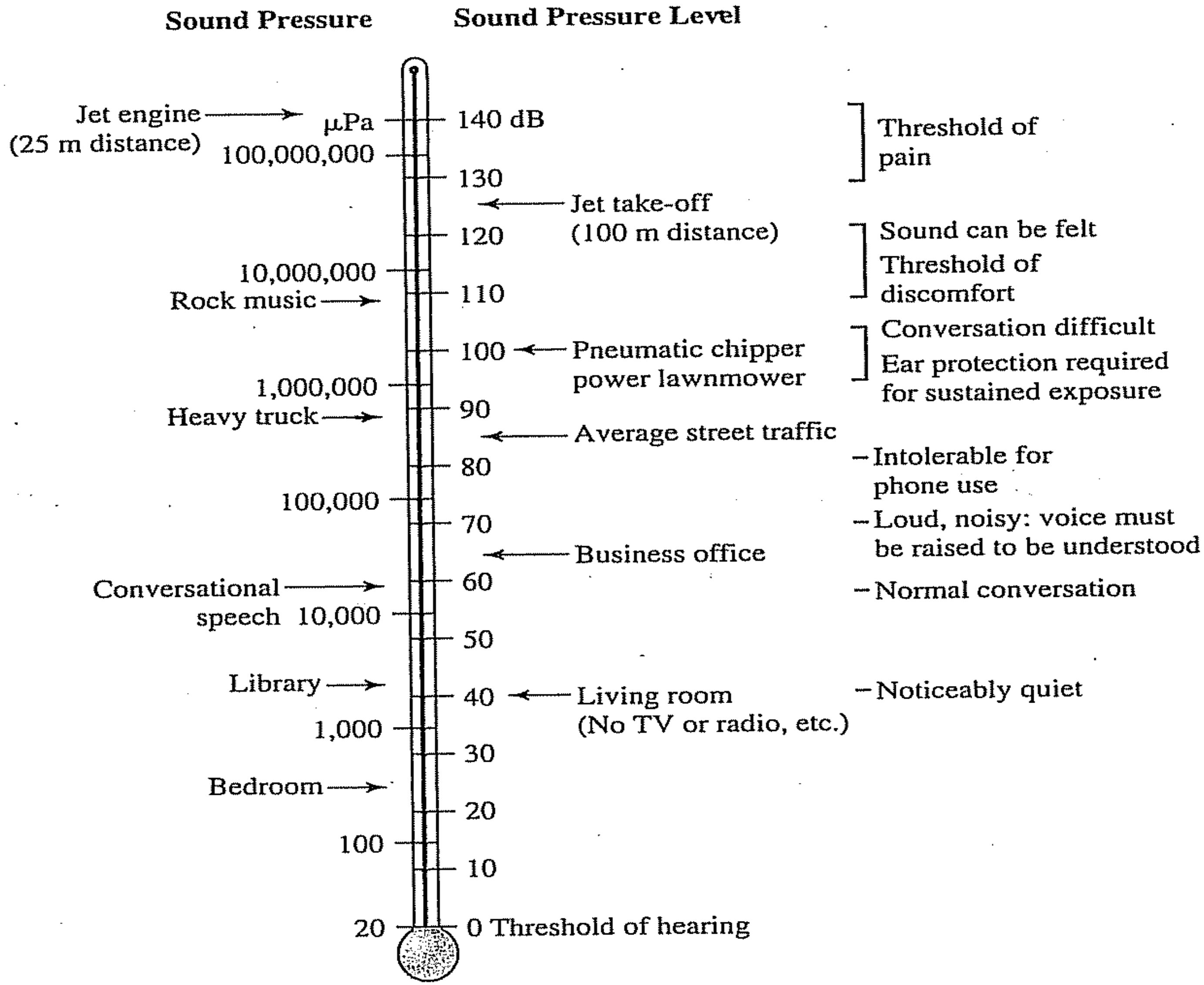
Decibel Scale

- Which is the same as

$$dB = 10\log\left(\frac{p}{p_o}\right)^2 = 20\log\left(\frac{p}{p_o}\right)$$

  - Where p is the sound pressure, and p_o is the reference which is equal to the threshold of human hearing (i.e., 0.00002 Pa or 20 uPa)

SOUND PRESSURE FOR KNOWN SOUNDS



Sound Pressure Exercises

- If sound pressure is 0.02 Pa, what is the sound pressure level?

$$\boxed{20 \times \mathrm{Log}\left(\frac{0.02Pa}{0.00002Pa}\right) = \quad dB}$$

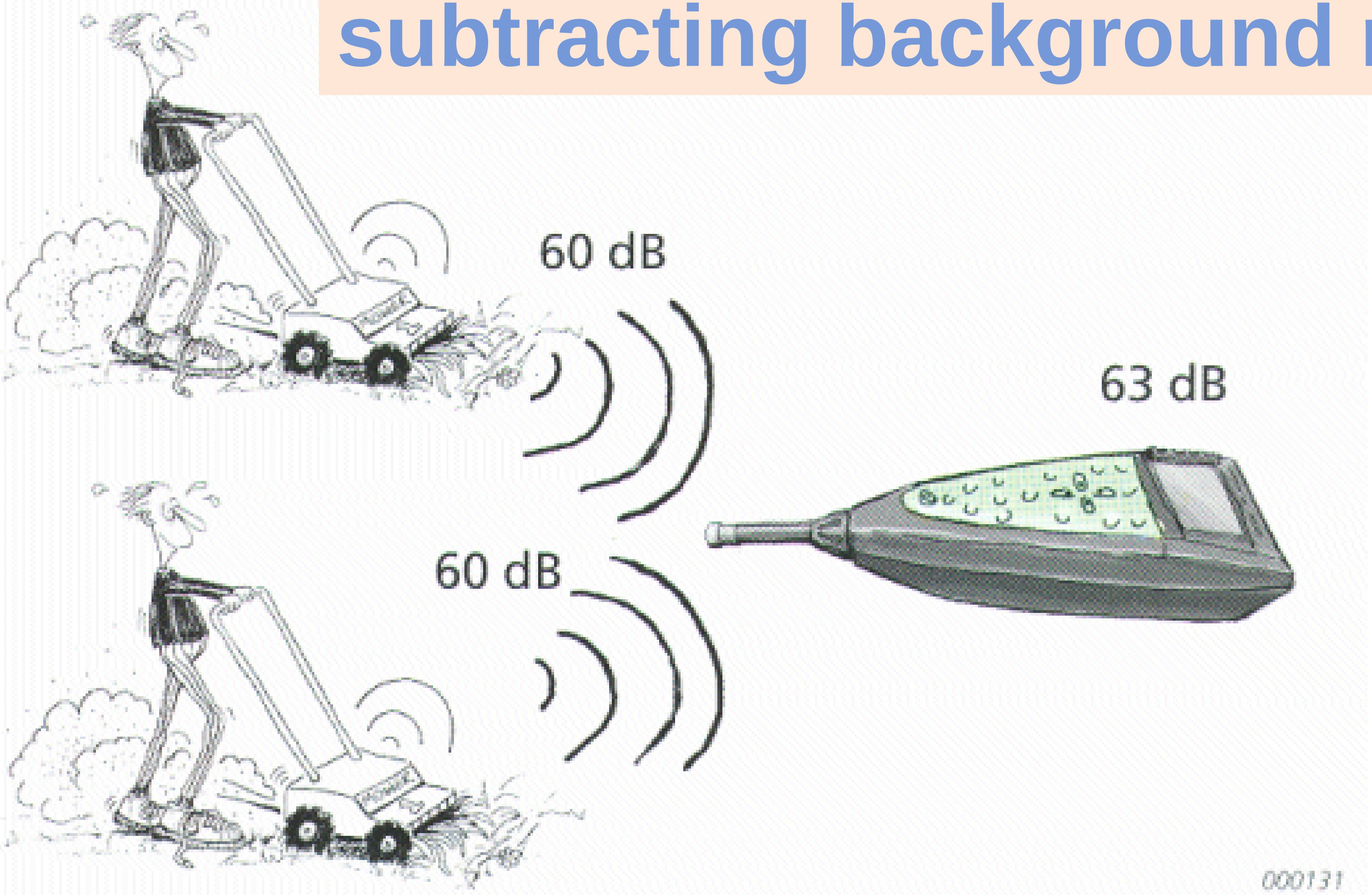
Sound Pressure Exercises

- If sound pressure is 0.06 Pa, what is the sound pressure level?

$$20 \times \mathrm{Log}\left(\frac{0.06Pa}{0.00002Pa}\right) = \qquad dB$$

$$L_{presult} = 10 \cdot \log\left(10^{\frac{L_{p1}}{10}} + 10^{\frac{L_{p2}}{10}} + 10^{\frac{L_{p3}}{10}} + \ldots + 10^{\frac{L_{pn}}{10}}\right) \rightarrow L_{presult} = 10 \cdot \log\left(10^{\frac{L_{ptot}}{10}} - 10^{\frac{L_{pbackground}}{10}}\right)$$

Adding noise sources and subtracting background noise



10 log 2 = 3 dB

Adding Sound Pressure Levels

- Since SPLs are based on a log scale, they cannot be added directly
  - I.e., 80 dB + 80 dB $\neq$ 160 dB

$$SPL_T = 10 \times \mathrm{Log}\left(\sum_{i=1}^{n} 10^{\left(\frac{SPL_i}{10}\right)}\right)$$

  - Where: SPL_T is the total sound pressure level, and SPL_i is the ith sound pressure level to be summed

Adding Sound Pressure Levels

- Given two machines producing 80 dB each, what is the total SPL?

$$SPL_T = 10 \times Log\left(\sum_{i=1}^{n} 10^{\left(\frac{SPL_i}{10}\right)}\right)$$

$$= 10 \times Log\left(10^{(80/10)} + 10^{(80/10)}\right)$$

$$= 10 \times Log\left(2 \times 10^{8}\right)$$

$$= 83\,dB$$

Adding Sound Pressure Levels

- Important rule of thumb …
- Adding two sound pressure levels of equal value will always result in a 3 dB increase!
  - 80 dB + 80 dB = 83 dB
  - 100 dB + 100 dB = 103 dB
  - 40 dB + 40 dB = 43 dB

Adding Sound Pressure Levels

- Given four machines producing 100 dB, 91dB, 90 dB, and 89 dB respectively, what is the total sound pressure level?

$$SPL_T = 10 \times \text{Log}\left(\sum_{i=1}^{n} 10^{\left(\frac{SPL_i}{10}\right)}\right)$$

$$= 10 \times \text{Log}\left(10^{(100/10)} + 10^{(91/10)} + 10^{(90/10)} + 10^{(89/10)}\right)$$

Addition of sound levels: The effective sound levels form two or more sources cannot be simply added algebraically. For example, the effective sound level from two air conditioners 60 dB(A) each, say is not 60 + 60 = 120 dB (A) but 60 + 3 = 63 dB(A). (See table 1). Similarly, the effective sound level of 57 dB, 63 dB, 63 dB, 66 dB and 69 dB is 72 dB. The computation is illustrated below.

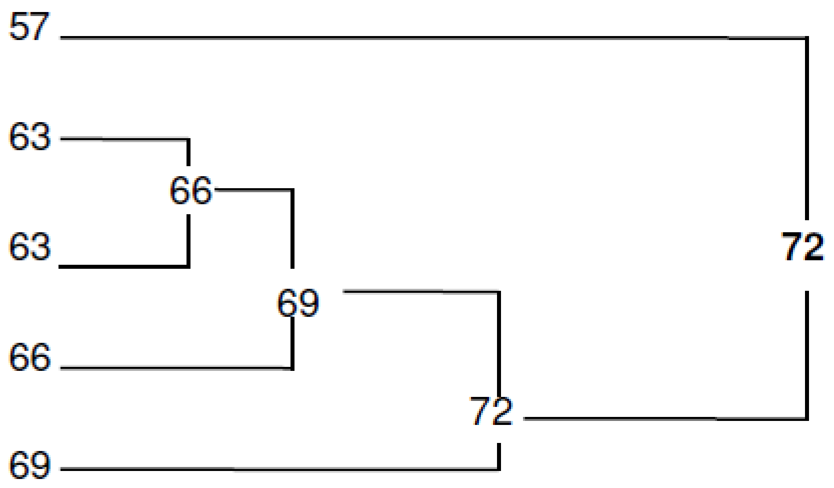


Table 1 Addition of sound levels, L_1 and L_2 ($L_1 > L_2$)

L_1 - L_2, dB	Add to L_1
0 or 1	3 dB
2 or 3	2 dB
4 - 8	1 dB
9 or more	0 dB

Calculating % Noise Dose

$$\%\,\text{Dose} = \left(\frac{C_1}{T_1} + \frac{C_2}{T_2} + \ldots + \frac{C_n}{T_n} \right) \times 100$$

- C = the actual time exposed at each dB level
- T = the time allowed to be exposed at each dB level

% Noise Dose

Exercise 1A

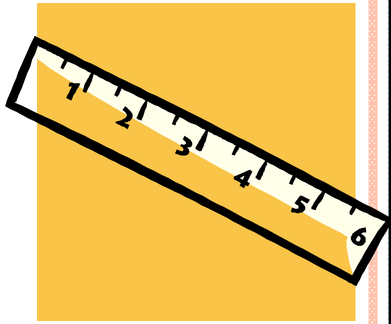
- Given four hours of 90 dBA exposure, two hours of 95 dBA exposure, and two hours of 85 dBA exposure, what is the % dose using the PEL? (Is this person overexposed compared to PEL?)

$$\boxed{\left(\frac{4}{8}+\frac{2}{4}+\frac{2}{\infty}\right)\times 100 = 100\% \text{ of PEL}}$$

Permissible Exposure Limit

- Answer: Borderline, since dose = 100%

How sound is measured



- Pressure, P, usually Pascals
- Frequency, f, usually Hertz
- Intensity, I, usually W/m^2
- Bels, L’, derived from logarithmic ratio
- Decibels, L, derived from bels

$P = 1/f$

$I = W/A$

$L' = \log (Q/Qo)$

$L = 10*\log (Q/Qo)$

E.g. Implications of the decibel scale: doubling sound level would mean that the sound will increase by 10*log2 = +3dB
Ten times the sound level = 10*log10 = +10dB

Table 2 Equipment used in the measurement of noise levels

S.No.	Equipment	Specification/Area of usage
1.	Sound level meter	Type-0 : Laboratory reference standard Type-1: Lab use and field use in specified controlled environment Type-2: General field use (Commonly used) Type-3: Noise survey
2.	Impulse meters	For measurement of impulse noise levels e.g. hammer blows, punch press strokes etc.
3.	Frequency analysers	For detailed design and engineering purpose using a set of filters.
4.	Graphic recorders	Attached to sound level meter. Plots the SPL as a function of time on a moving paper chart.
5.	Noise dosimeters	Used to find out the noise levels in a working environment. Attached to the worker
6.	Calibrators	For checking the accuracy of sound level meters.

Source: Ref. (3)

How it is computed?

The intensity of sound is measured in sound pressure levels (SPL) and common unit of measurement is decibel, dB. The community (ambient) noise levels are measured in the A - weighted SPL, abbreviated dB(A). This scale resembles the audible response of human ear. Sounds of frequencies from 800 to 3000 HZ are covered by the A - weighted scale. If the sound pressure level, L_1 in dB is measured at r_1 meters, then the sound pressure level, L_2 in dB at r_2 meters is given by,

$L_2 = L_1 - 20 \log_{10} (r_2/r_1)$ ...... (1)

If the sound levels are measured in terms of pressure, then, sound pressure level, L_P is given by,

$L_P = 20 \text{ Log}_{10} (P/P_o)$ dB(A) ...... (2)

The L_p is measured against a standard reference pressure, $P_o = 2 \times 10^{-5}$ N/m^2 which is equivalent to zero decibels. The sound pressure is the pressure exerted at a point due to a sound producing source (see. Fig. 2)

o))))) *) SPL

Fig. 2 Definition of sound pressure

Day-night equivalent noise levels (Ldn): The day night equivalent noise levels of a community can be expressed as -

$$Ldn\text{ , dB(A)} = 10 \times \log_{10} [15/24\ (10^{Ld/10}) + 9/24\ (10^{(Ln + 10)/10})] \text{ .... (3)}$$

where, Ld = day-equivalent noise levels (from 6AM - 9 PM), dB (A)
Ln = night equivalent noise levels (from 9 PM - 6 AM), dB (A)

The day hours in respect to assessment of noise levels, is fixed from 6 AM - 9 PM (i.e., 15 hrs) and night hours from 9 PM - 6 AM (i.e., 9 hrs). A sound level of 10 dB is added to Ln due to the low ambient sound levels during night for assessing the Ldn values.

Table 4 Typical noise levels of some point sources

Source	Noise level dB(A)	Source	Noise level, dB(A)
Air compressors	95-104	Quiet garden	30
110 KVA diesel generator	95	Ticking clock	30
Lathe Machine	87	Computer rooms	55-60
Milling machine	112	Type institute	60
Oxy-acetylene cutting	96	Printing press	80
Pulveriser	92	Sports car	80-95
Riveting	95	Trains	96
Power operated portable saw	108	Trucks	90-100
Steam turbine (12,500 kW)	91	Car horns	90-105
Pneumatic Chiseling	118	Jet takeoff	120

Source: Ref. 3,4

The Sound levels exceeding 10%, 50% and 90% of the total time intervals during a particular period are designated as L_{10}, L_{50} and L_{90} respectively.

From figure, it can be seen that, 90% of the sound levels are about 64 dB(A). Local disturbances increased the sound levels (L_{10}) to 76 dB(A), i.e., during 10% of the total time. L_{90} represents the background noise levels.

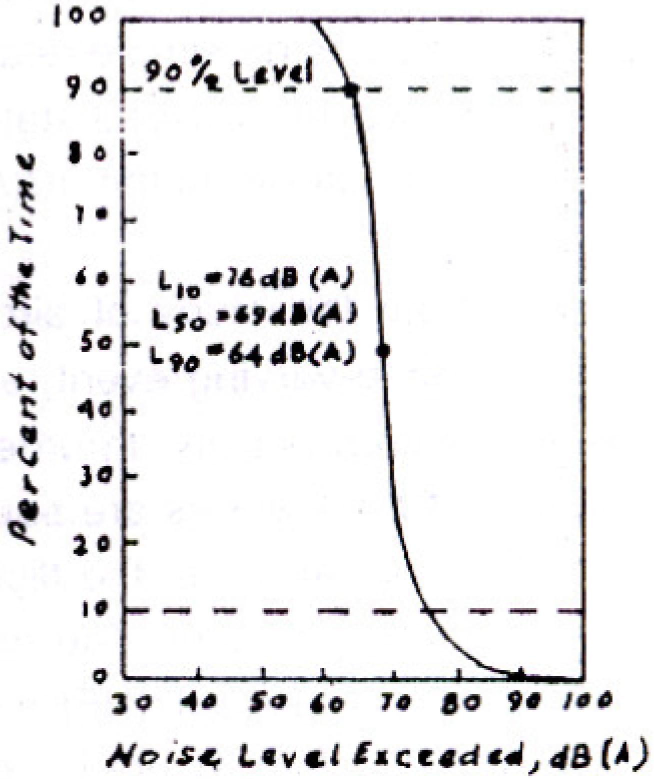


Fig. 3 Statistical distribution of noise levels

The equivalent noise levels, Leq can also be calculated as [5]

$$Leq = L_{50} + (L_{10} - L_{90})^2 / 60$$

Noise Climate (NC): It is the range over which the sound levels are fluctuating in an interval of time [5]

$$NC = L_{10} - L_{90}$$

Hence, Leq in the above example is -

$$Leq = 69 + (76 - 64)^2 /60 = 71.4 \ \text{dB}.$$

and noise climate, NC = 76 - 64 = 12 dB/sampling time.

Think a bit and do it

- Observe the activities in your house which produces annoyance to you. Try to record the frequency of their occurrence in a day/week/month etc.
- Identify the noise generating sources in your neighborhood.
- Compute reduction of effective noise levels at your house from your neighborhood using equation (1).
- Tabulate and analyse. what did you find?

Impacts of noise

Why bother about noise? Often neglected, noise induces a severe impact on humans and on living organisms. Some of the adverse effects are summarised below.

- **Annoyance:** It creates annoyance to the receptors due to sound level fluctuations. The aperiodic sound due to its irregular occurrences causes displeasure to hearing and causes annoyance.
- **Physiological effects:** The physiological features like breathing amplitude, blood pressure, heart-beat rate, pulse rate, blood cholesterol are effected.
- **Loss of hearing:** Long exposure to high sound levels cause loss of hearing. This is mostly unnoticed, but has an adverse impact on hearing function.
- **Human performance:** The working performance of workers/human will be affected as they'll be losing their concentration.
- **Nervous system:** It causes pain, ringing in the ears, feeling of tiredness, thereby effecting the functioning of human system.
- **Sleeplessness:** It affects the sleeping there by inducing the people to become restless and loose concentration and presence of mind during their activities
- **Damage to material :** The buildings and materials may get damaged by exposure to infrasonic / ultrasonic waves and even get collapsed.

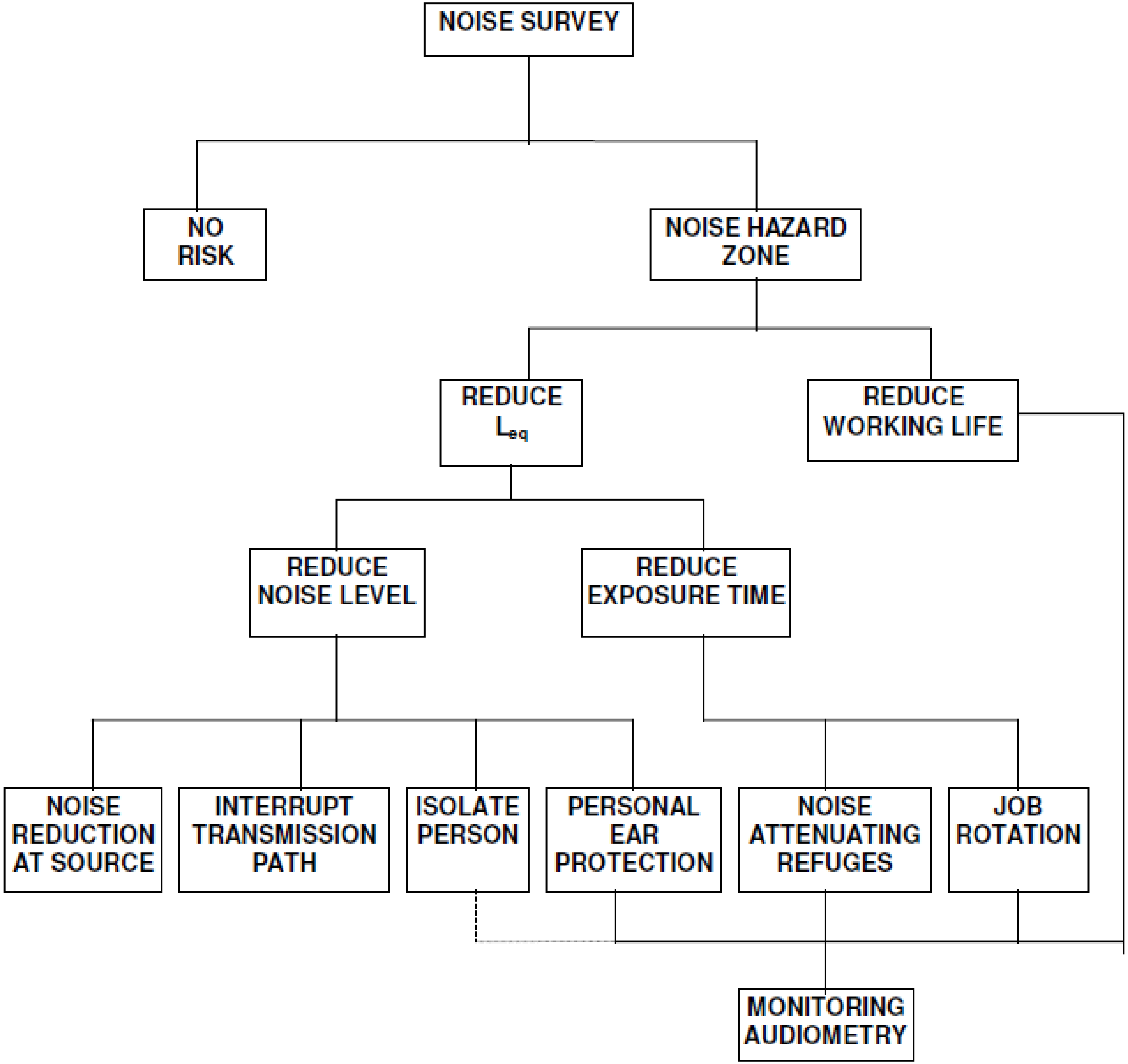


Fig. 4 Noise Management Strategy *(Source : Ref :)*

Installation of barriers: Installation of barriers between noise source and receiver can attenuate the noise levels. For a barrier to be effective, its lateral width should extend beyond the line-of-sight at least as much as the height (See Fig. 5). It may be noted that, the frequencies, represented on the X-axis of the graph in Fig. 5, are the centre frequencies of the octave band. The barrier may be either close to the source or receiver, subject to the condition that, R <<D or in other words, to increase the traverse length for the sound wave. It should also be noted that, the presence of the barrier itself can reflect sound back towards the source. At very large distances, the barrier becomes less effective because of the possibility of refractive atmospheric effects. Another method, based on the length of traverse path of the sound wave is given at Fig. 6.

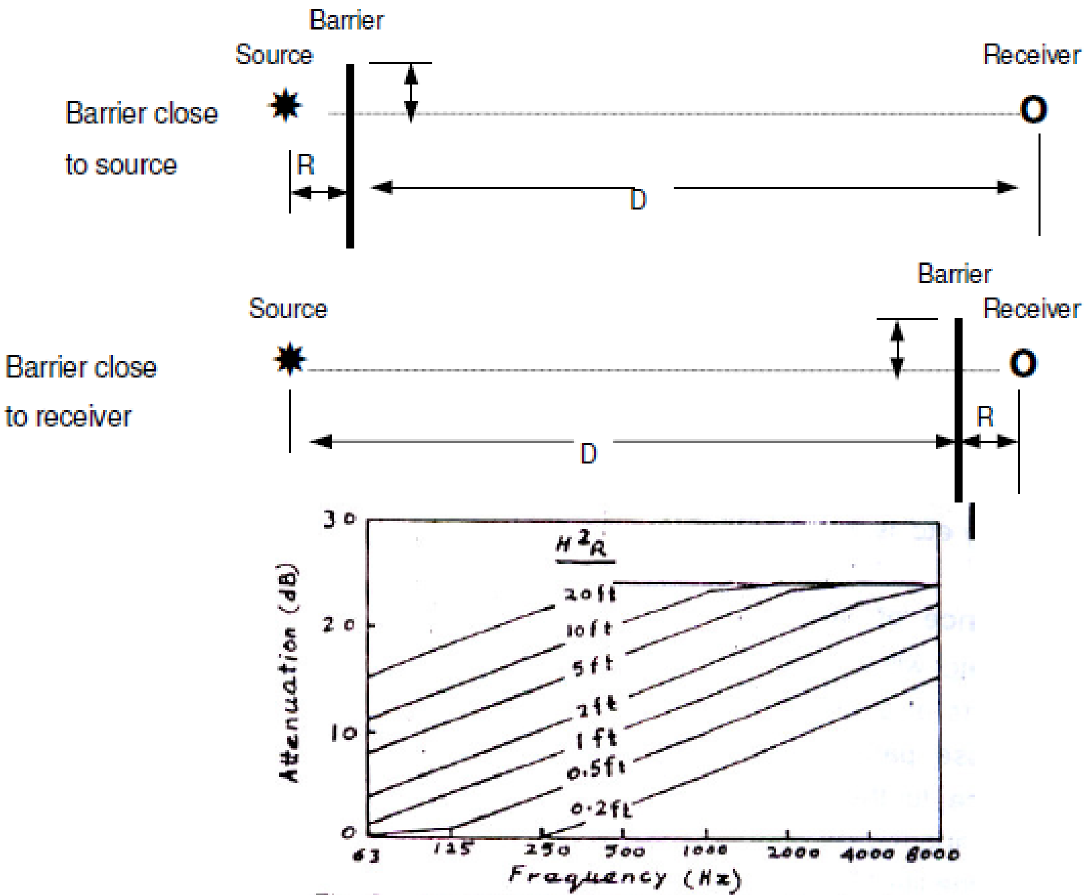
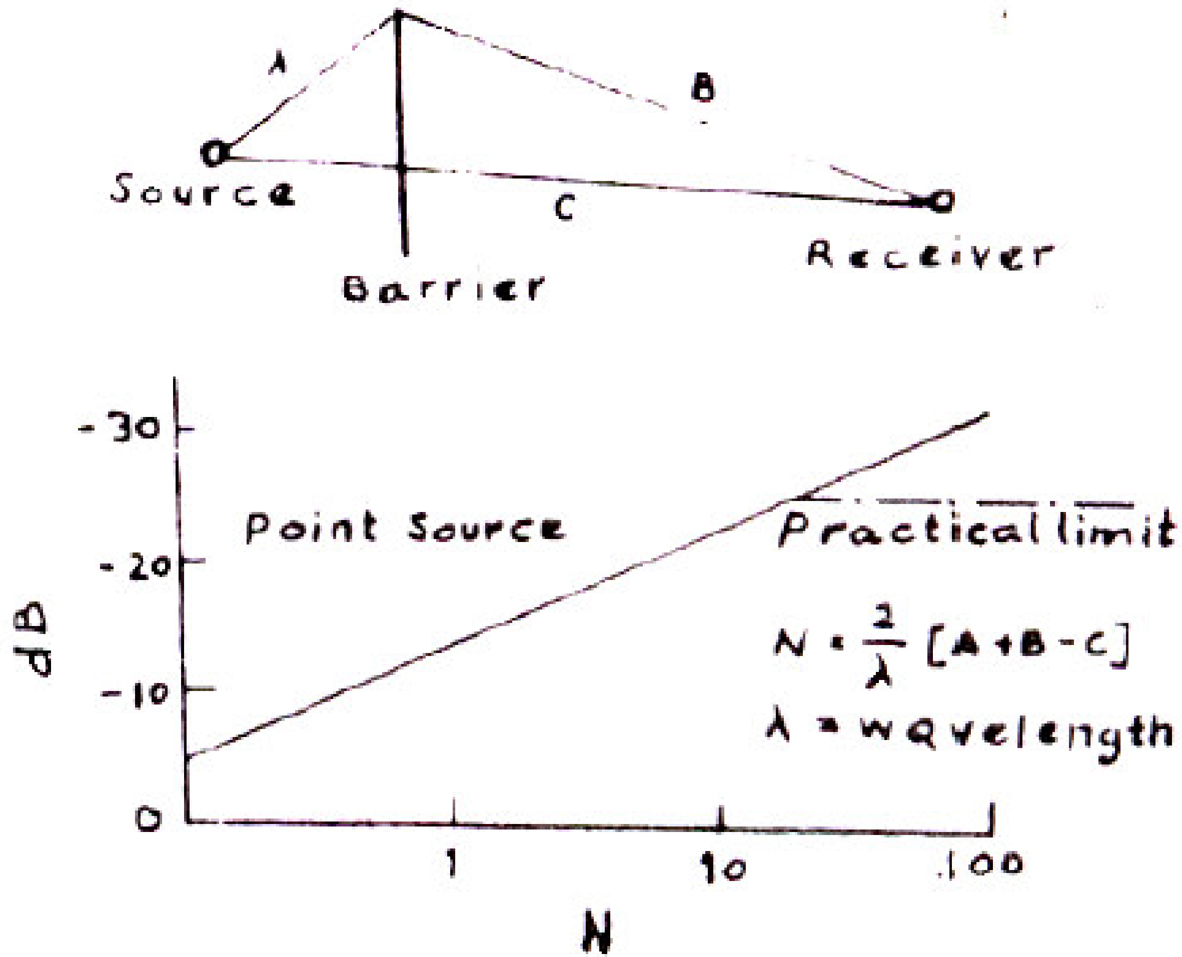
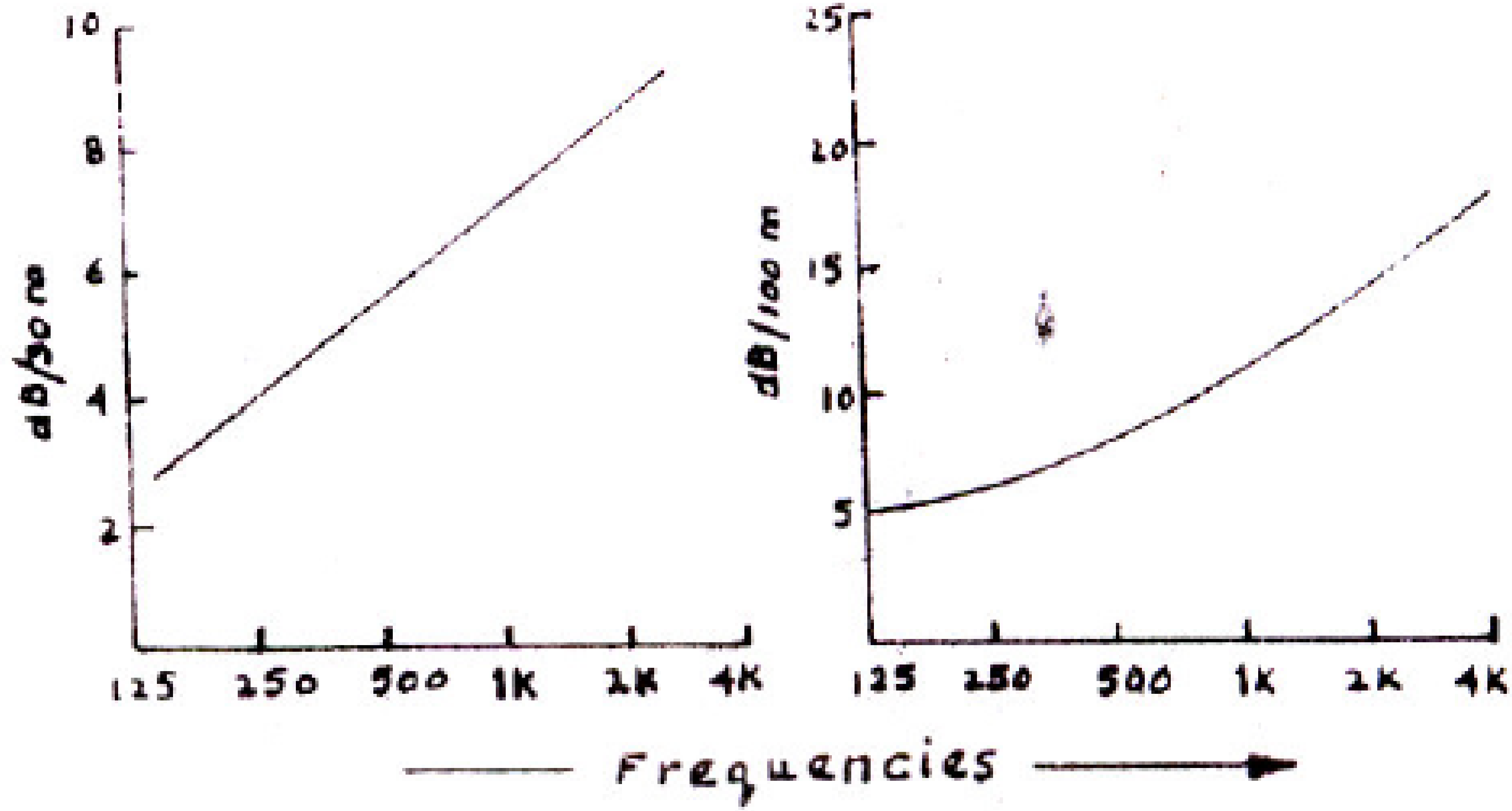


Fig. 5 Attenuation of noise levels using barriers



Attenuation of noise levels using barriers



(b) Noise level attenuation by shrubs and trees

Solved examples To Practice

Ex 1: If the distance from a noise source is doubled, find out the noise levels.

Sol: Given, $r_2 = 2r_1$

We have, $L_2 = L_1 - 20\log_{10}(r_2/r_1)$

Substituting, we get,

$L_2 = L_1 - 20\log_{10}(2r_1/r_1)$

$= L_1 - 20\log_{10}(2)$

i.e., $L_2 = L_1 - 20 \times 0.301$

$= L_1 - 6.02$

i.e., the noise level will decrease by 6 dB for doubling of distance from the source.

Ex 2: The noise levels at a particular location are 65dB, 70dB and 78dB measured during an hour of the day. Find out the average noise levels at the location.

Sol: Given, $L_1 = 65$dB, $L_2 = 70$dB, $L_3 = 75$dB

The noise levels are to be logarithmacally averaged.

Average of L_1, L_2 & L_3 = L (say). Convert the noise levels from decibels to bels.

i.e. $L_1 = 65$dB or 6.5 bels,

$L_2 = 70$dB or 7.0 bels

$L_3 = 78$dB or 7.8 bels

$L = 10 \times \log_{10}([10^{6.5} + 10^{7.0} + 10^{7.8}] / 3)$

$= 10 \times \log_{10}[25419337.37]$

$= 10 \times 7.405 = 74.05$dB.

$\therefore$ Average noise level is 74.05 dB.

Ex 3: The sound pressure level is measured at 5×10^{-4} N/m^2. Find out the noise level in dB.

Sol: Given, $P_1 = 5 \times 10^{-4}$ N/m^2

We know $P_0 = 2 \times 10^{-5}$ N/m^2 (reference pressure)

Noise level in decibels, $L = 10 \log_{10} [P_1/P_0]^2$ dB.

$\therefore L = 10 \log_{10} \ (5 \times 10^{-4}) / (2 \times 10^{-5})$

$= 10 \log_{10} [625] = 10 \times 2.795$

$= 27.95$dB.

Ex 4: It is required to find out the day-night equivalent noise levels at a location. The three-hourly day average values in dB are 48, 54, 56, 52, 61 and three-hourly night average values in dB are 36,42,48. Compute Ldn.

Sol : (i) Find out day equivalent noise levels.

$$Lde = 10 \times \log_{10} ([10^{4.8} + 10^{5.4} + 10^{5.6} + 10^{5.2} + 10^{6.1}]/5)$$
$$= 56.29 \text{ dB.}$$

(ii) Find out night - equivalent noise levels.

$$Lne = 10 \times \log_{10} ([10^{3.6} + 10^{4.2} + 10^{4.8}]/3)$$
$$= 44.41\text{dB.}$$

(iii) Find out day-night equivalent noise level, Ldn.

$$Ldn = 10 \times \log_{10} [15/24 \, (10^{Lde/10}) + 9/24 \, (10^{((Lne+10)/10)})]$$
$$= 10 \times \log_{10} [15/24 \times 10^{5.629} + 9/24 \times 10^{5.441}]$$
$$= 10 \times \log_{10} \{265999 + 103522\}$$
$$= 55.68\text{dB.}$$

Ex.5. What barrier dimensions are necessary in order that the barrier provide 20 dB attenuation at 500 HZ.

Sol: From fig 1.5, we see that, H^2/R must be atleast 10ft in order to achieve the desired attenuation. This can be accomplished by selecting different values for H and R for example,

H = 5.5 ft, R = 3ft; H = 10 ft, R= 10 ft; H = 17.5 ft, R = 30 ft etc.

Assignments

(To Be Submitted by 04th November 2015)

1. Find out the reduction in noise levels if the source is at (i) 2m (ii) 4m, (iii) 6m (iv) 10m (v) 100m from your place (Hint: use equation (1))
2. Find out the noise levels in decibels, if the sound pressure level measured in N/m^2 was

2×10^{-4} (ii) 6×10^{-3} (iii) 8×10^{-2} (iv) 10×10^{-3} (v) 3×10^{-1}.

3. Find out the day-night equivalent noise levels if Ld = 70 dB(A) and Ln = 52 dB(A). If Ldn value were to be in safe limits, which is the best suited habitant zone. Give reasons.
4. Find out the barrier dimensions required for a noise reduction of 15 dB at (a) 500 Hz (b) 1000 Hz (c) 2000 Hz (d) 4000 Hz (e) 8000 Hz
5. Find out the effective noise level from five sources of 50dB, 55 dB, 62 dB, 64 dB and 65 dB noise generation.