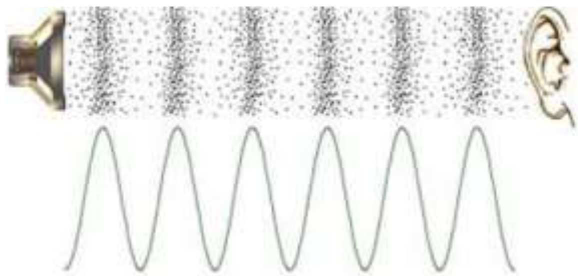
# Fundamentals of Sound



CHAPTER 1

## For built environment

- **Human comfort (Visual, thermal and acoustics ) ……………**

# Why studying Acoustics in buildings ?

1. quality acoustic environments are required for high productivity and comfort in buildings
2. Proper acoustic design responses early in the design process are critically important, as after-the-fact acoustic “repair” is often difficult (and, therefore, costly) and sometimes impossible without substantial structural alterations (which are very costly)
3. Proper design efforts, wanted sounds can be heard properly and unwanted sounds (noise) can be attenuated or masked to the point where they do not cause annoyance

# Sound definition

Sound can be defined in a number of different ways (physical Wave)

or, more simply, as a mechanical vibration, or simply as a series of pressure variations in an elastic medium. (Audible pressure variation) .

For airborne sounds, the medium is air

For structure-borne sounds, the medium may be concrete, steel, wood, glass, or combinations of these materials.

**Pressure variation Speech / Music / Noise** → **Medium Air / Water / Structure** → **Receiver Human ear / sound sensors**

## Speed of Sound, Wavelength and Frequency

**TABLE 17.1 Speed of Sound Propagation in Various Media**

| Medium | Speed: Meters per Second | Speed: Feet per Second |
|---|---|---|
| Air | 344 | 1130 |
| Water | 1410 | 4625 |
| Wood | 3300 | 10,825 |
| Brick | 3600 | 11,800 |
| Concrete | 3700 | 12,100 |
| Steel | 4900 | 16,000 |
| Glass | 5000 | 16,400 |
| Aluminum | 5800 | 19,000 |

- temperature [ºC]
- Density [$Kg/m^3$]
- Atmospheric Pressure [$\rho_s$]

$$\lambda = \frac{c}{f}$$

where

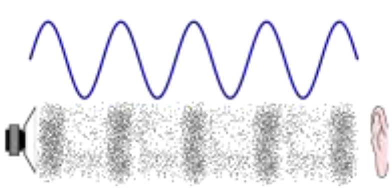
$\lambda$ = wavelength, ft (m)

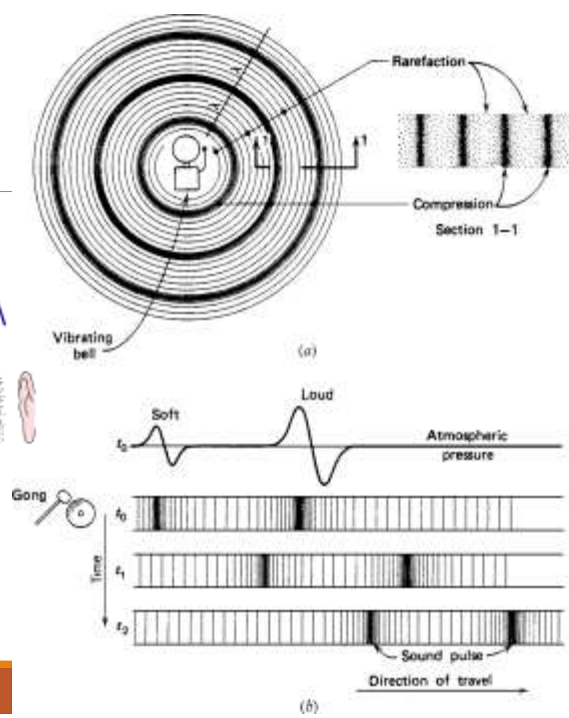
$c$ = velocity of sound, fps (m/s)

$f$ = frequency of sound, Hz

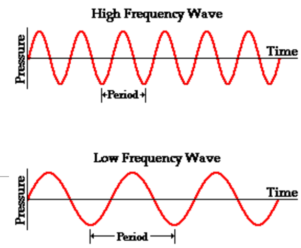
| Temperature[ºC] | Speedof sound[m/s] |
|---|---|
| -10 | 325 |
| 0 | 331 |
| 10 | 337 |
| 20 | 343 |
| 30 | 349 |

## Wave length



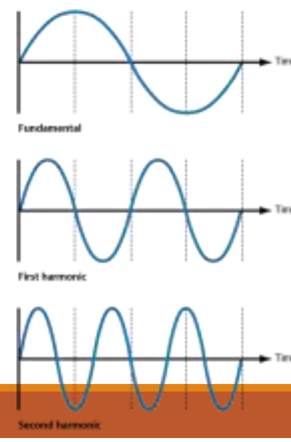


# Frequency



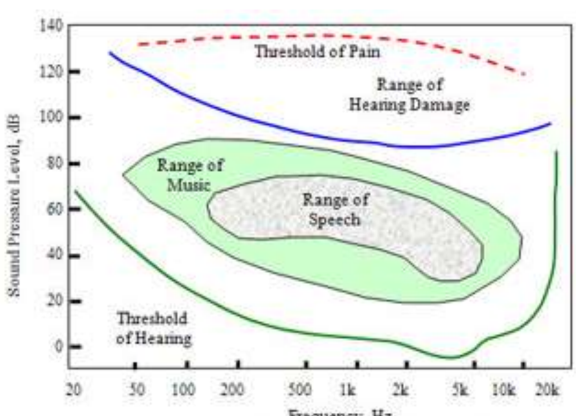

The number of times that a cycle of compression and rarefaction of air occurs in a given unit of time.

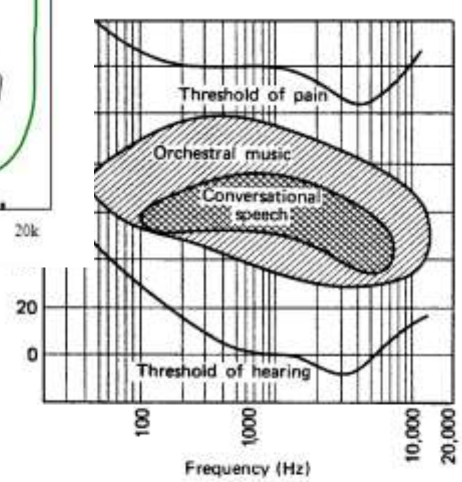
For example, if there are 1000 such cycles in 1 second, the frequency of the sound is 1000 cps—1000 Hertz (Hz).




The approximate frequency range of a healthy young person’s hearing is 20 to 20,000 Hz

The human speaking voice has a range of approximately 100 to 600 Hz

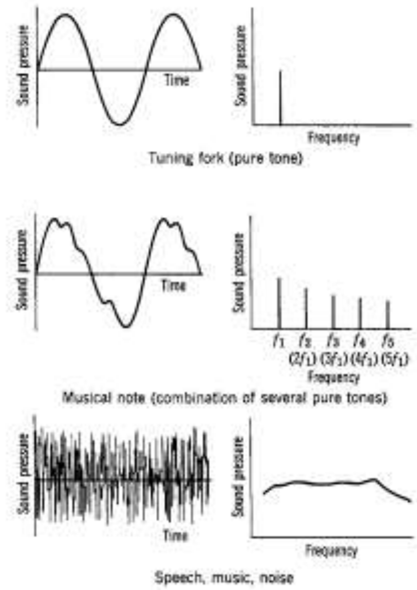


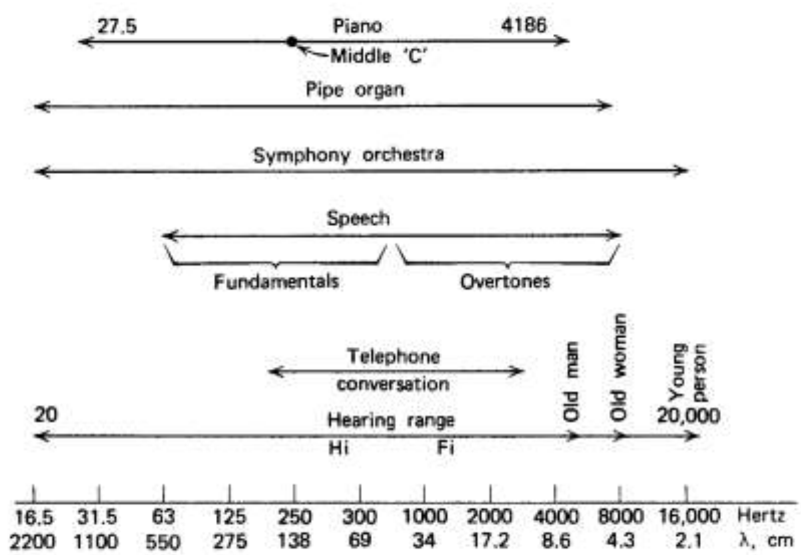



# Frequency – Tone

A sound composed of only one frequency is called a *pure tone. Except for the sound generated* by a tuning fork, few sounds are truly pure.

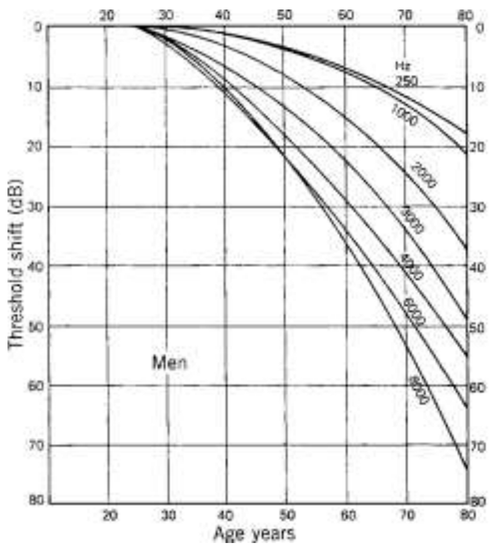
Musical sounds (tones) are composed of a fundamental frequency and integral multiples of the fundamental frequency

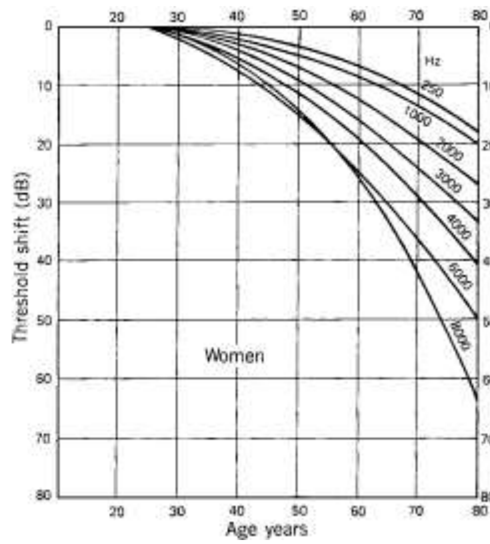


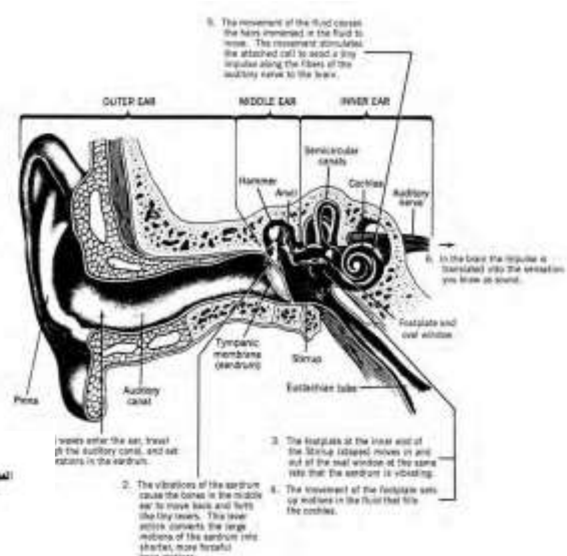
## Sound Propagation

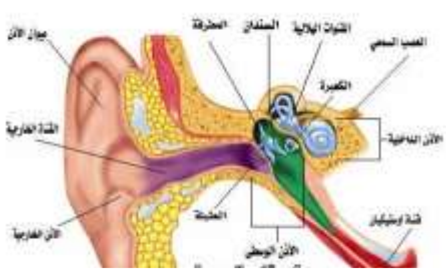
N.B.: no propagation is possible in vacuum



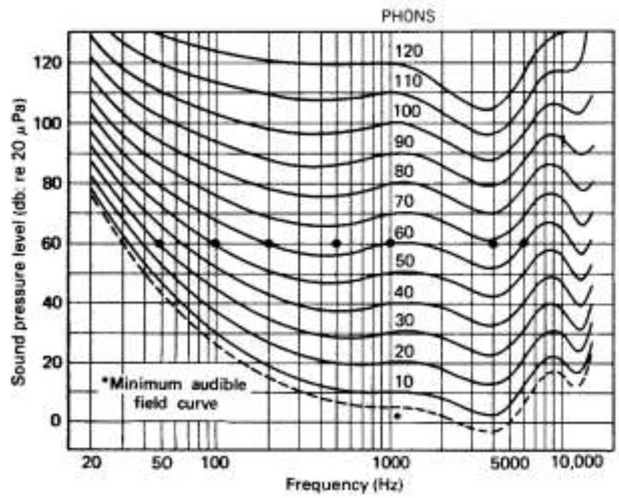

## The Ear

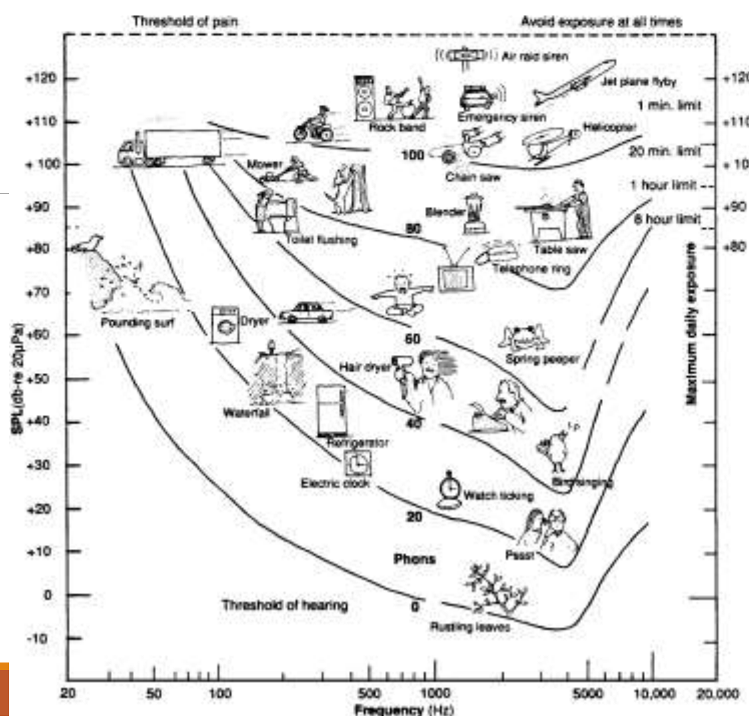


## *Standard equal-loudness contours*

1. Sensitivity drops off sharply at low frequencies
2. Maximum sensitivity occurs between 3 and 4 kHz—precisely the frequencies that convey the most information in human speech
3. In a normal listening range of 45 to 85 dB, and in the most often used frequency range of 150 Hz to 6 kHz, the contour is substantially flat



## Masking, Directivity, Discrimination, and Sound Sources

**Speech :** Most speech energy is concentrated in the 100 to 600-hertz range.

The male voice centers its energy at around 500Hz, the female voice at around 900 Hz

**Other Sounds:**

**Noise**

## SOUND MAGNITUDE

1. **Sound power,** **(**watts)
2. **Sound pressure, (**Pascal (Pa) [N/m2])
3. **and Sound intensity (**W/m2)

**Are absolute measures**

- **Sound power level, (dB)**
- **Sound pressure level, (dB)**
- **and sound intensity level, (dB)**

**Are ratio values**

## Sound power

1. Sound source that quantifies the source's acoustical output
2. Sound power is constant for any given source operating under defined conditions
3. Sound power is expressed in watts (of acoustical power)

The threshold of hearing is 10 to the power -12

- a jet engine, 100,000 W;
- a symphony orchestra, 10 W;
- a loud radio, 0.1 W;
- normal speech, 0.000010 W.

Note the wide range of values just in this sample: from $10_5$ to $10_{-6}$ W.

## Sound pressure

1. the deviation from ambient air pressure that is caused by sound waves
2. is modified by the environment between the source and the receiver
3. Sound power is a characteristic of a source; sound pressure is the effect of a source as experienced at some specific location
4. pressure will usually vary from location to location in a room.

Reference value 2*10 to the power -5 N/m²

- near a jet plane 200 Pa;
- the threshold of pain, 20 Pa;
- a loud nightclub,2 Pa;
- next to a highway, 0.2 Pa;
- and normal speech, 0.02 Pa

| Sound pressure[N/m2] | Environment | Subjective evaluation |
|---|---|---|
| 200 | Airplane taking off | simply too much!! |
| 20 | Machine room in a cargo ship | too much |
| 2 | Metro shelter | very noisy |
| $2 \times 10^{-1}$ | Sidewalk in a noisy street | noisy |
| $2 \times 10^{-2}$ | Restaurant | Noisy |
| $2 \times 10^{-3}$ | Countryside | calm |
| $2 \times 10^{-4}$ | background noise in a recording studio | very calm |

# Sound intensity

1. Sound intensity diminishes over distance
2. The maximum sound intensity that the ear can accept without damage is approximately $10^{-3}$ W/cm2
3. the minimum sound intensity (*I*) that a normal ear can detect—is $10^{-16}$ W/cm2

- The threshold of pain is 0.001 w/cm2,
- Shouting at 1.5 m is 0.0000001 w/cm2,
- Speech at 1m is 0.000000001 w/cm2

$$I = \frac{P}{A} \qquad (17.2)$$

where

$I$ = sound (power) intensity, W/cm²

$P$ = acoustic power, W

$A$ = area, cm²*

**TABLE 17.3 Comparison of Decimal, Exponential, and Logarithmic Statements of Various Acoustic Intensities**

| *Intensity (W/cm²)* | | | |
|---|---|---|---|
| **Decimal Notation** | **Exponential Notation** | **Intensity Level, Logarithmic Notation (dB)** | **Examples** |
| 0.001 | $10^{-3}$ | 130 | Painful |
| 0.0001 | $10^{-4}$ | 120 | |
| 0.00001 | $10^{-5}$ | 110 | 75-piece orchestra |
| 0.000001 | $10^{-6}$ | 100 | |
| 0.0000001 | $10^{-7}$ | 90 | Shouting at 5 ft (1.5 m) |
| 0.000000001 | $10^{-9}$ | 70 | Speech at 3 ft (0.9 m) |
| 0.00000000001 | $10^{-11}$ | 50 | Average office |
| 0.0000000000001 | $10^{-13}$ | 30 | Quiet, unoccupied office |
| 0.00000000000001 | $10^{-14}$ | 20 | Rural ambient |
| 0.000000000000001 | $10^{-15}$ | 10 | |
| 0.0000000000000001 | $10^{-16}$ | 0 | Threshold of hearing |

## The Decibel

Two problems rise when dealing with quantities of the type encountered with sound power, pressure, and intensity

1. The numbers themselves are very small or very large.
2. the human ear responds logarithmically, not arithmetically, to sound pressure (or intensity); that is, doubling the intensity of a sound does not double its loudness

$$IL = 10 \log \frac{I}{I_0} \qquad (17.6)$$

where

$IL$ = intensity level, dB

$I$ = intensity, W/cm²

$I_0$ = base intensity (i.e., $10^{-16}$ W/cm², the threshold of hearing)

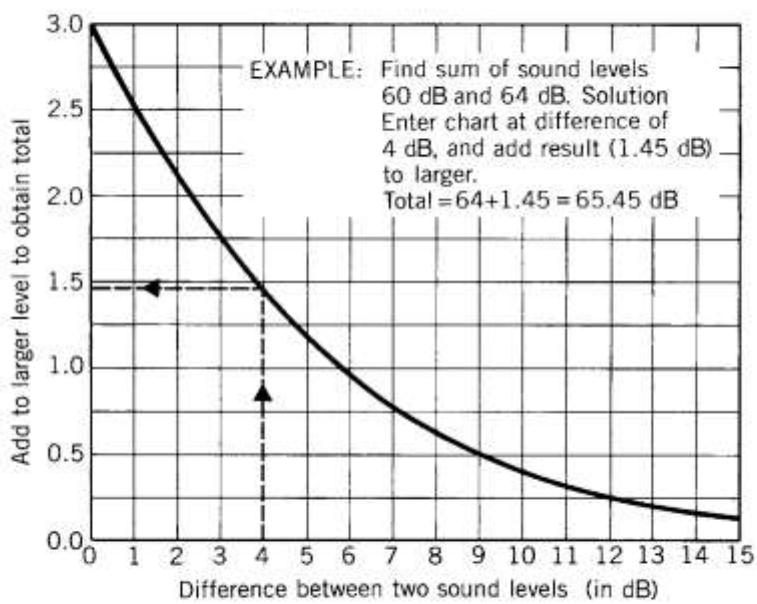
log = logarithm to base 10

Subtracting decibel, adding decibel

$$\Delta IL = IL_2 - IL_1 = 10 \log \frac{I_2}{I_0} - 10 \log \frac{I_1}{I_0}$$

Therefore,

$$\Delta IL = 10 \log \frac{I_2}{I_1} \text{dB}$$



• When the difference between two sources is 1 dB or less, add 3 dB to the higher decibel level to obtain the total.

• When the difference is 2 to 3 dB, add 2 dB

• When the difference is 4 to 8 dB, add 1 dB

• When the difference is 9 dB or more, ignore the lower-level source (add 0 to the higher).

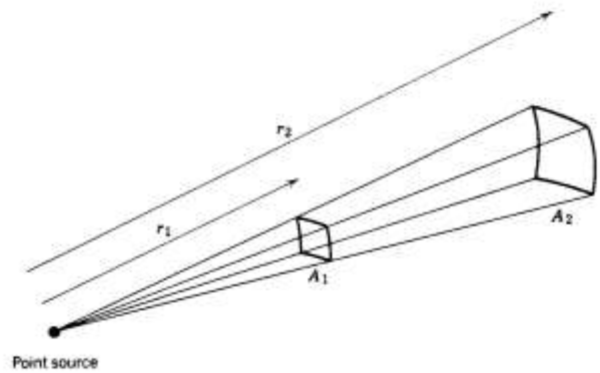
**TABLE 17.4 Addition of Uncorrelated Sound Pressure Levels**

| *dB Levels* | | *Sum* | |
|---|---|---|---|
| Lower | Higher | Approximate[a] | Accurate[b] |
| 60 | 60 | 63 | 63.0 |
| 60 | 62 | 64 | 64.4 |
| 60 | 64 | 65 | 65.5 |
| 60 | 66 | 67 | 67.0 |
| 60 | 68 | 69 | 68.7 |
| 60 | 70 | 70 | 70.5 |

**TABLE 17.5 Common Sound Pressure Levels**

| Sound Pressure Level (dBA) | Typical Sound | Subjective Impression |
|---|---|---|
| 150 | | (Short exposure can cause hearing loss) |
| 140 | Jet plane takeoff | |
| 130 | Artillery fire, riveting, machine gun | (Threshold of pain) |
| 120 | Siren at 100 ft (30 m), jet plane (passenger ramp), thunder, sonic boom | Deafening |
| 110 | Woodworking shop, hard-rock band, accelerating motorcycle | Sound can be felt (threshold of discomfort) |
| 100 | Subway (steel wheels), loud street noise, power lawnmower, outboard motor | |
| 90 | Noisy factory, unmuffled truck, train whistle, machine shop, kitchen blender, pneumatic jackhammer | Very loud, conversation difficult; ear protection required for sustained occupancy |
| 80 | Printing press, subway (rubber wheels), noisy office, supermarket, average factory | (Intolerable for phone use) |
| 70 | Average street noise, quiet typewriter, freight train at 100 ft (30 m), average radio, department store | Loud, noisy; voice must be raised to be understood |
| 60 | Noisy home, hotel lobby, average office, restaurant, normal conversation | |
| 50 | General office, hospital, quiet radio, average home, bank, quiet street | Usual background; normal conversation easily understood |
| 40 | Private office, quiet home | |
| 30 | Quiet conversation, broadcast studio | Noticeably quiet |
| 20 | Empty auditorium, whisper | |
| 10 | Rustling leaves, soundproof room, human breathing | Very quiet |
| 0 | | Intolerably quiet<br>Threshold of audibility |

In class examples and HW




$$I = \frac{P}{4\pi r^2} \text{ W/cm}^2 \qquad (17.3)$$

$$\frac{I_1}{I_2} = \frac{r_2^{\,2}}{r_1^{\,2}} \qquad (17.5)$$

# NOISE

*Noise* is variously defined as unwanted sound, or sound with no intelligible content,

There are two basic negative effects of noise;

**a psychological-practical one**

noise levels that cause annoyance and disturbance to daily activities, including work, relaxation, and rest

**purely physiological one.**

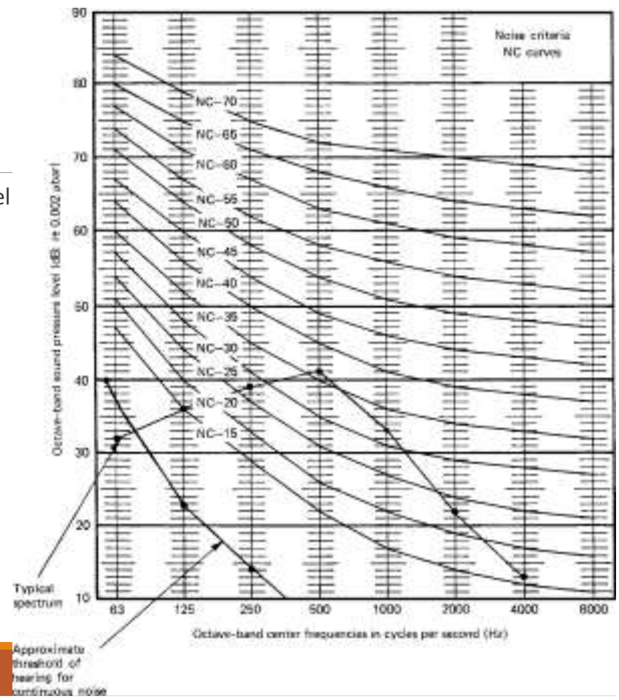
the physical impact of noise on the body, including hearing loss and other deleterious conditions.

headache, digestive problems, tachycardia, high blood pressure, anxiety, and nervousness— an extensive catalog of human illnesses

## Noise Criteria

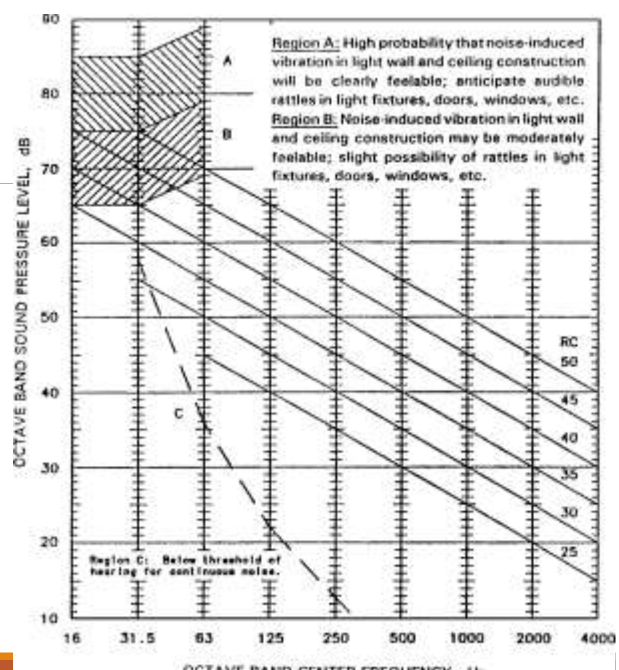
criteria for *acceptable background noise*

most people prefer to speak at a level no greater than 22 dB above the background noise level




## Room Criteria Curves

- They are straight lines.
- Their slope is constant at −5 dB per octave (determined from extensive tests, mostly in the range of 40 to 50 dB).
- Regions labeled A and B as in Fig. 17.18 address the problem of very low frequencies and high sound pressure levels



Room Criterion Curves

# High Noise Levels

| Duration per day, hours | Sound level dBA slow response |
|---|---|
| 8 | 90 |
| 6 | 92 |
| 4 | 95 |
| 3 | 97 |
| 2 | 100 |
| 1½ | 102 |
| 1 | 105 |
| ½ | 110 |
| ¼ or less | 115 |

**TABLE 17.6 Typical Industrial Noise Levels[a]**

| Equipment | dBA |
|---|---|
| Printing press plant (medium-sized automatic) | 86 |
| Heavy diesel-propelled vehicle (about 25 ft [7 m] away) | 92 |
| Heavy-duty grinder | 93 |
| Air compressor | 94 |
| Plastic chipper | 96 |
| Cutoff saw | 97 |
| Multiple spot welder | 98 |
| Turbine condenser | 98 |
| 15-cu-ft (425-L) air compressor | 100 |
| Drive gear | 103 |
| Banging of steel plate | 104 |
| Magnetic drill press | 106 |
| Air chisel | 106 |
| Positive displacement blower | 107 |
| Air hammer | 107 |
| Vacuum pump | 108 |
| Jolt squeeze hammer | 122 |