

## **BASIC CONSIDERATIONS**

### **I. Wave:** <sup>(83)</sup>

A wave is disturbance or oscillation that travels through matter or space, accompanied by a transfer of energy. Wave motion transfers energy from one point to another, often with no permanent displacement of the particles of the medium.

#### **I.1. Main types of waves:**

There are two main types of waves:

##### **I.1.1. Electromagnetic waves:**

Which include visible light, radio waves, microwaves, ultraviolet radiation, X-rays, and gamma rays, are a self-sustaining oscillation of the electromagnetic field. Electromagnetic waves require no material medium and can travel through a vacuum.

##### **I.1.2. Mechanical waves:**

Waves which can travel only within a material medium, such as air or water. Two mechanical waves that are familiar with are sound waves and water waves.

###### **I.1.2.1. Medium:** <sup>(83)</sup>

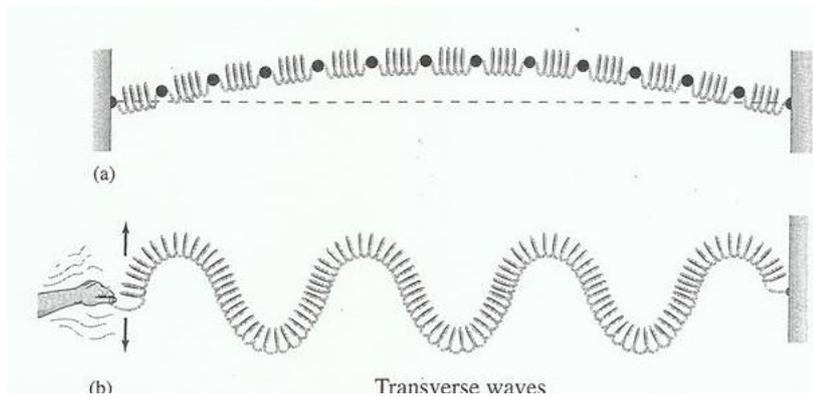
The medium of a mechanical wave is the substance through or along which the wave moves. For example, the medium of a water wave is the water; the medium of a sound wave is the air and the medium of a wave on a stretched string is the string. A medium must be elastic. That is a restoring force of some sort brings the medium back to equilibrium after it has been displaced or disturbed.

As a wave passes through a medium, the atoms that make up the medium are displaced from equilibrium. This is a disturbance of the medium. The disturbance of a wave is an organized motion of the particles in the medium, in contrast with the random molecular motions of the thermal energy.

### **I.2. Types of wave motions:** <sup>(84)</sup>

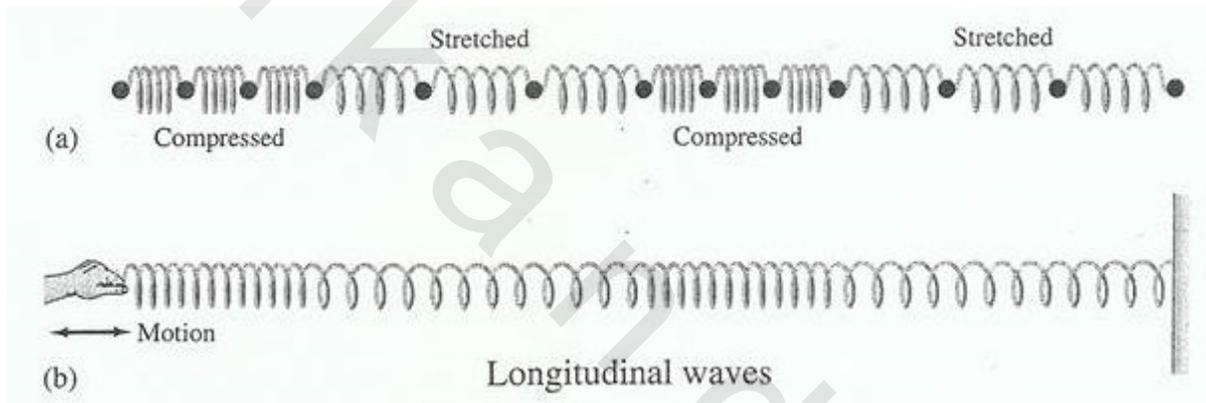
There are 2 distinct types of wave motions: transverse and longitudinal:

**I.2.1. Transverse wave:** is a wave in which the particle in the medium moves perpendicular to the direction in which the wave travels (energy transfer), Fig.1.



**Fig.1: Transverse waves.**

**I.2.2. Longitudinal wave:** is a wave in which the particle in the medium moves parallel to the direction in which wave travels, Fig.2.



**Fig.2: Longitudinal waves.**

**I.3. Particle motion:** <sup>(85)</sup>

Particles of medium propagating a wave do not move far from their undisplaced positions, as shown in Fig. 3. The disturbance travels on, but the propagating particles move only in localized regions. The velocity of a particle is maximum at its equilibrium position, and zero at the point of maximum displacement.

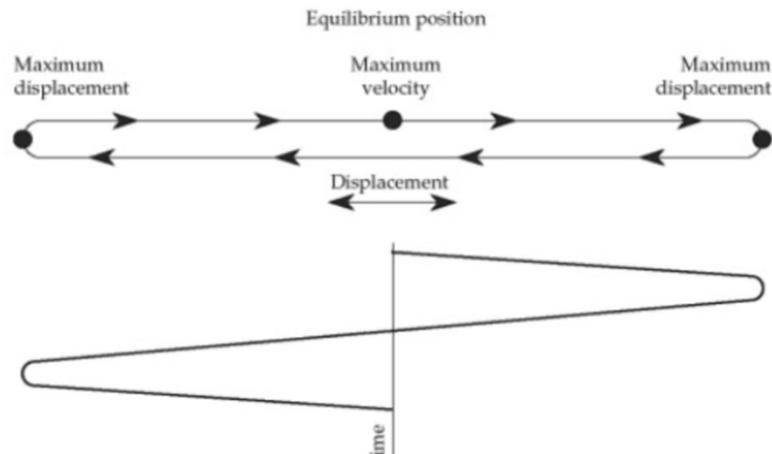


Fig.3: Vibration of air particles about its equilibrium position.

## II. Sound waves: <sup>(86)</sup>

What we hear as sound is a class of physical kinetic energy called acoustical energy. Sound waves are changes in air pressure occur at frequencies in the audible range. Sound is the propagation of pressure waves radiating from a vibrating body through an elastic medium. A *vibrating body* is essential to cause particle displacement in the propagating medium. An *elastic medium* is any substance whose particles return to their point of origin as soon as possible after they have been displaced. Propagation occurs because displaced particles in the medium displace neighboring particles. Without a medium, sound can't be propagated.

Sound requires energy. Energy is used to set a body into vibration. The energy is important to particles in the propagating medium and then is distributed over the surface of the receiver (eardrum or microphone) in the form of sound pressure. Energy is equal to the square of pressure ( $E = P^2$ ).

### II.1. Characteristics of sound waves: <sup>(87)</sup>

Sound waves travels in straight lines in all directions from the source, decreasing in intensity at a rate inversely proportional to the square of the distance from their source. This is called the **inverse-square law**. This mean that if a person shortens his distance from the source of sound and moves from position 4 m away to only 2 m from the source, the sound will be four times as intense rather than merely twice as intense.

Sound waves travel through different media at different speeds; the speed also varies when the medium is not uniform. Sound is readily conducted in gases, liquids, and solids which are all elastic media. If a rock is stroked the railroad rail, two sounds will be hear one sound coming through the rail and one through the air. The sound through the rail arrives first because the speed of sound in the dense steel is faster than in air. However, sound waves are not transmitted through a vacuum.

The bone of the head also conduct sounds, but ordinarily the ear is much more sensitive to sounds that are airborne. Under certain conditions, as in cases of conductive hearing loss, a patient may hear better by bone conduction than by air conduction.

## II.2. Sound Propagation: <sup>(88)</sup>

As was mentioned, the generation of a sound wave requires not only vibration, but also an elastic medium in which the disturbance created by that vibration can be transmitted. To say that air is an elastic medium means that air, like all other matter, tends to return to its original shape after it is deformed through the application of a force.

To understand the mechanism underlying sound propagation, it is useful to think of air as consisting of collection of particles that are connected to one another by springs, with the springs representing the restoring forces associated with the elasticity of the medium.

Air pressure is related to particle density. When a volume of air is undisturbed, and the elastic forces are at their resting state. A volume of air that is in this undisturbed state it is said to be at atmospheric pressure.

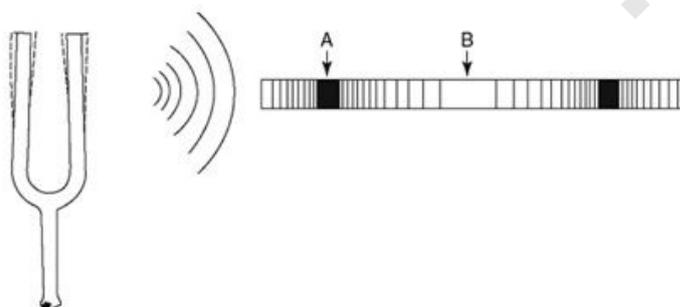
For our purposes, atmospheric pressure can be defined in terms of two interrelated conditions:

- The air molecules are approximately evenly spaced.
- The elastic forces, represented by the interconnecting springs

Both are neither compressed nor stretched beyond their resting state.

When a vibratory disturbance causes the air particles to crowd together (i.e., producing an increase in particle density), air pressure is higher than atmospheric, and the elastic forces are in a compressed state. Conversely, when particle spacing is relatively large, air pressure is lower than atmospheric pressure.

When a vibrating object is placed in an elastic medium, an air pressure disturbance is created through a chain reaction. As the vibrating object (a tuning fork in this case), similar to that illustrated in Fig. 4.



**Fig.4: Areas of compression (A) and rarefaction (B) produced by a vibrating tuning fork.**

A single complete cycle of an acoustical pressure wave consists of one half-cycle of compression and it is characterized by dense particle spacing and, consequently, air pressure that is slightly higher than atmospheric pressure, followed by one half-cycle of rarefaction, and it is characterized by relatively wide particle spacing and, consequently, air pressure that is slightly lower than atmospheric pressure.

The dots of Fig. 5 a&b, represent air molecules with different density variations. In reality, there are more than a million molecules in a cubic inch of air. The molecules crowded together represent areas of compression (crests). The sparse areas represent rarefaction (troughs). Any given molecules, because of elasticity, after initial displacement, will return toward its original position. It will move a certain distance to the right and then the same distance to the left of its undisplaced position as the sound waves progresses uniformly to the right. Sound exists because of the transfer of momentum from one particle to another. The compression wave, along with the rarefaction wave that immediately follows it, will be propagated outward at the speed of sound.

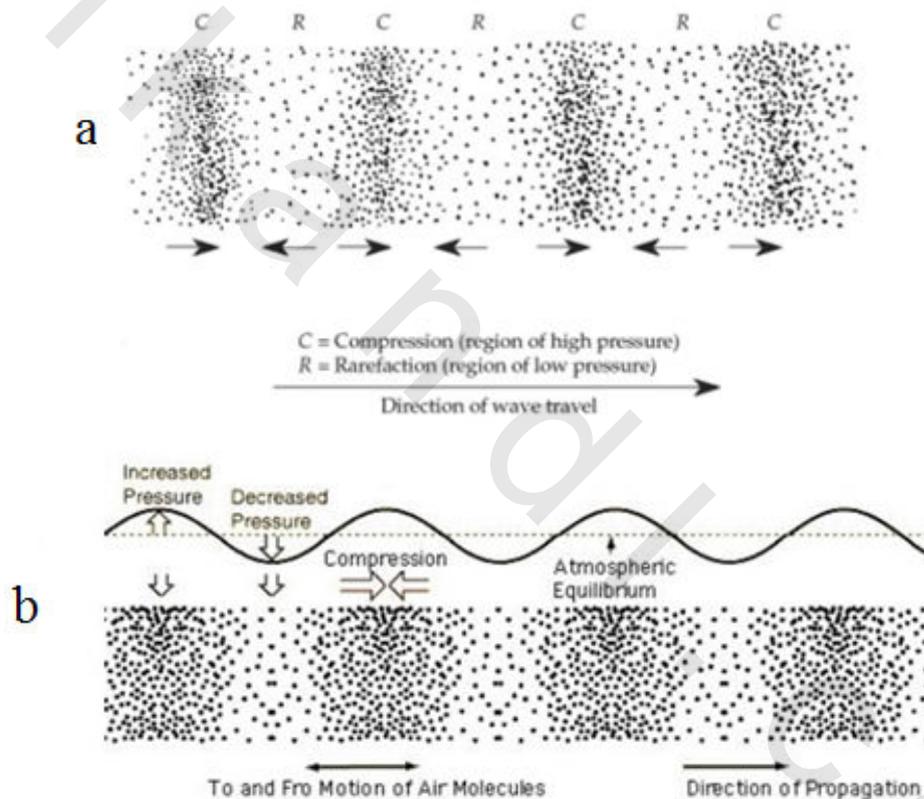


Fig. 5 a&b: Sound waves traveling through a medium change localized air particle density.

### II. 3. Sine wave:

A simple type of sound waves, called a *pure tone* (sine wave). Figure. 6 is a graphic representation pure tone (sine wave), the zero line represents atmospheric pressure, with the area of compression represented by the top curve and the area of rarefaction by the bottom curve. Although pure tones don't occur in nature, the more complicated sounds that we actually encounter are composed of combinations of pure tones.<sup>(89)</sup>

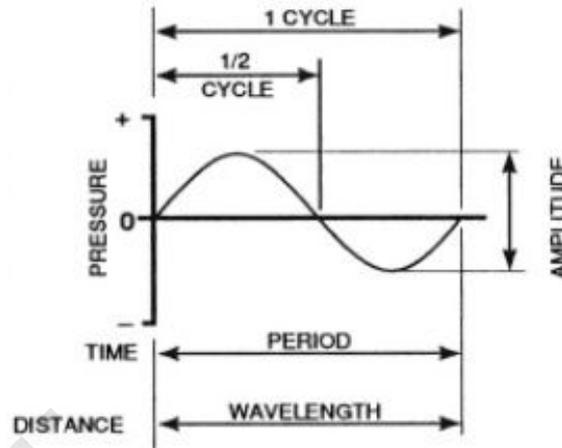


Fig.6: Typical sine wave.

**II.3.1. Main characteristic of sine wave:** <sup>(90)</sup>

A sine wave can be characterized or described completely by three numbers:

- Frequency.
- The maximum amplitude.
- The phase.

**II.3.2. Sine wave terminology:** <sup>(91)</sup>

**II. 3.2.1. Cycle:**

It refers to one repetition of the pattern, Fig.6.

**II.3.2.2. Frequency:**

The frequency of a wave is the number of cycles of motion of a particle which occur in one second. The units of frequency may be cycle per sec (cps) or hertz (Hz; 1 cps = 1 Hz). A wave's frequency depends on the frequency of the source. The frequency of a wave remains constant even when it travels through different materials.

The formula for frequency is :

$$f = \frac{1}{t} \quad (1)$$

**Where:**

f = frequency in Hz

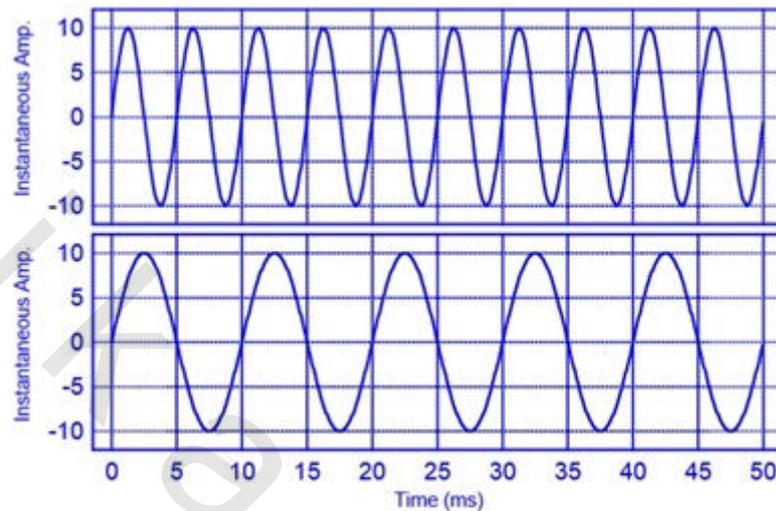
t = time in sec.

It is important to note that time must be represented in sec in order to get the answer to come out in cps, or Hz.

### II.3.2.3. Pitch:

Pitch is the frequency of the fundamental component in the sound, that is, the frequency with which the waveform repeats itself.

Different frequencies sound different to the ear. High frequencies said to be of high pitch; low frequencies said to be of low pitch. Hearing for humans is less sensitive to lower frequency (low pitch) and more to higher frequency (high pitch) sounds, Fig. 7.



**Fig. 7:** Two vibratory patterns that differ in frequency the panel on top is higher in frequency (higher pitch) than the panel on bottom.

### II.3.2.4. Period (T):

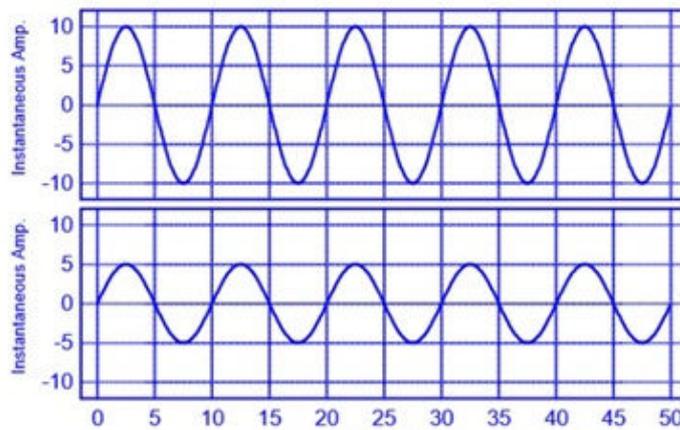
The period of a wave is the time taken by a particle to complete a single complete cycle of motion. A wave's period is expressed in seconds per cycle.

$$T = \frac{1}{f} \quad (2)$$

The higher the frequency of the wave, the shorter its period, and the higher its pitch.

### II.3.2.5. Amplitude:

The amplitude of a wave is the maximum displacement on either side of equilibrium position, Fig. 8. In the sine wave diagram of a pure tone, a more intense sound will have a higher peak and lower valley than a softer sound. Greater intensity also means that the particles in the propagating medium are more compressed. Amplitude is measured in dB. It reflects the amounts of pressure (or energy) existing in the sound waves. Sounds of higher amplitude (louder) compress and rarefy the air molecules to greater extent than do lower amplitude (softer) sounds.



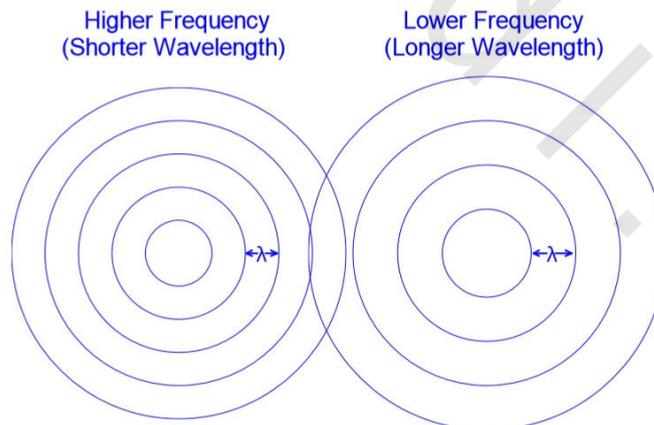
**Fig.8:** Two vibratory patterns that differ in amplitude. The panel on top is higher in amplitude than the panel on bottom.

### II.3.2.6. Wavelength:

Is the linear distance between any point in one cycle and the same point on the next cycle (peak-to-peak, for examples), Fig. 9. It may be calculated as the speed of sound divided by the frequency.

$$\text{Wavelength } (\lambda) = \frac{\text{Speed of sound } (c)}{\text{Frequency } (f)} \quad (3)$$

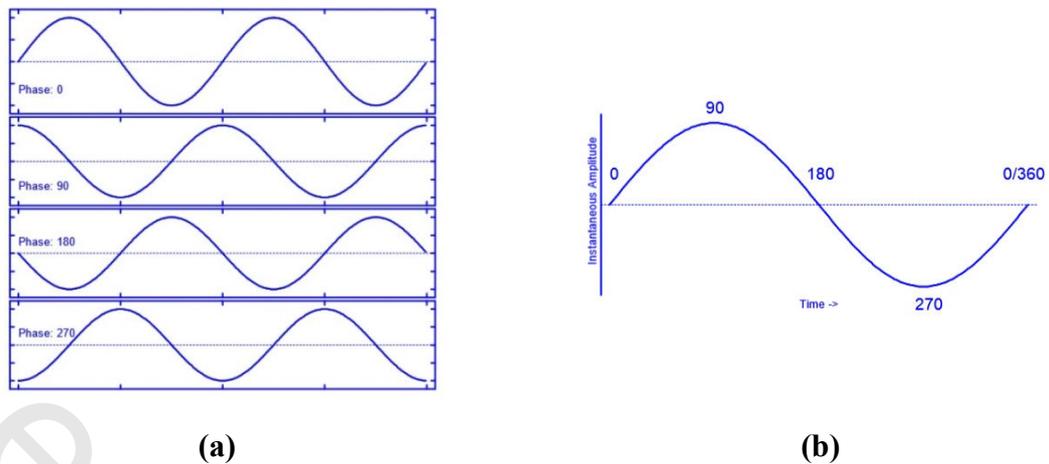
Wavelength is symbolized by the Greek letter lambda ( $\lambda$ ) and is inversely proportional to the frequency. Low- frequency sounds have long wavelength and vice versa.



**Fig.9:** Relation between frequency and wavelength.

### II.3.2.7. Phase:

Any point along the cycle of the wave is its phase, Fig. 10 a&b. Because a sine wave is a cyclical event, it can be described in degrees like a circle. The halfway point of the sine wave is the  $180^\circ$  phase point. The first peak occurs at  $90^\circ$ , etc.



**Fig. 10: (a) Vibratory patterns that differ in phase. (b) The system for representation phase.**

#### II.4. Speed of sound: <sup>(92)</sup>

Sound waves travel through air at the speed (velocity) = 334 m/sec at sea level on a standard temperature day (which is 59 degrees Fahrenheit or 15 degrees Celsius).

Velocity of sound = wavelength x frequency. written in symbols as

$$c = f \lambda \quad (4)$$

Where  $c$  is the velocity of sound,  $\lambda$  the wavelength and  $f$  the frequency.

The speed of sound is dramatically slower than the speed of light. The speed of sound in the audible range is not appreciably affected by intensity of the sound, or by changes in atmospheric pressure.

Sound will propagate at a certain speed that depends on the medium, and other factors:

- The denser the molecules structure, the easier it is for the molecules to transfer sound energy; compared to air, sound travels faster in denser media such as liquids and solids. For example, sound travels at about 4900 ft/sec in freshwater and about 16700 ft/sec in steel.
- Sound also travels faster in air as temperature increases (an increase of about 1.1 ft/sec for every degree Fahrenheit).
- Humidity affects the velocity of sound in air; the more humid the air, the faster speed.

It should be noted that the speed (velocity) of sound is different from the particle velocity in:

- The velocity of sound determines how fast sound energy moves across a medium.
- Particle velocity is determined by the loudness of the sound.

Table (2) gives the speed of sound in various media. Notice that sound travels considerably faster in solids and liquids than in gases. Unlike gas molecules, the molecules of solids and liquids are in constant contact with their neighbors. Consequently these

molecules respond more quickly to a wave pulse than do gas molecules which interact only through occasional collisions.

**Table 2: Speed of sound in different media**

Medium	Speed (m/s)
Air (0°C)	332
Air (20°C)	334
Hydrogen (0°C)	1270
Water (20°C)	1480
copper	3560
Aluminum	5100
Iron	5130

**II.5. Superposition and interference:** <sup>(93)</sup>

The superposition principle tells us that when two or more waves move in the same linear medium, the net displacement of the medium at any time equals the algebraic sum of the displacements caused by all the waves. The shape of resultant waves is given by the sum of amplitude.

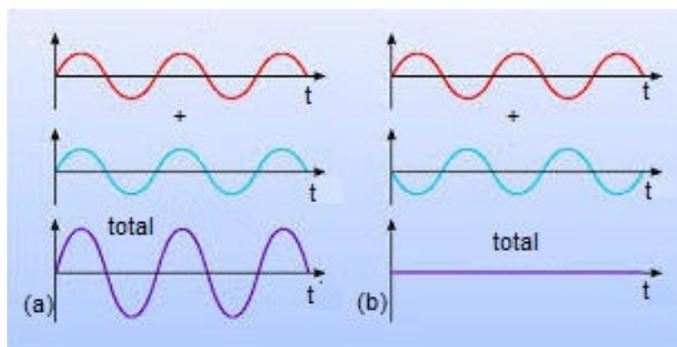
When two waves meet, there can be two kinds of interference patterns; constructive and destructive, Fig.11 a &b.

**II.5.1. Constructive interference:**

When two waveforms are added together. The peaks add with the peaks, and the troughs add with the troughs, creating a louder sound.

**II.5.2. Destructive interference:**

Occurs when two waves are out of phase (the peaks on one line up with troughs on the other). In this, the peaks cancel out the troughs, creating a diminished waveform. For example, if two waveforms that are exactly the same are added, the amplitude doubles, but when two opposite waveforms are added, they cancel out, leaving silence.



**Fig.11: Two kinds of interference (a) constructive interference (b) destructive interference.**

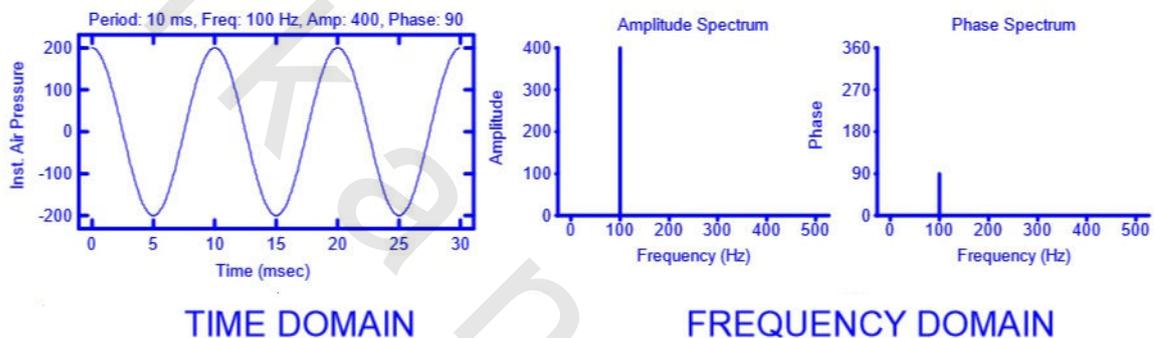
## II.6. Periodic and aperiodic Sounds: <sup>(94)</sup>

### II.6.1. Periodic Sounds:

#### II.6.1.1. Simple periodic signals (Sinusoidal signal):

Sinusoids are sometimes referred to as simple periodic signals. The term "periodic" means that there is a pattern that repeats itself, and the term "simple" means that there is only one frequency component present.

This is confirmed in the frequency domain representations in Fig.12, which shows a single frequency component in both the amplitude and phase spectra. Time and frequency domain representations of sinusoid. The frequency domain consists of two graphs: an amplitude spectrum and a phase spectrum. An amplitude spectrum is a graph showing what frequencies are present with what amplitudes, and a phase spectrum is a graph showing the phases of each frequency component.



**Fig.12: Time and frequency domain representations of sinusoid.**

#### II.6.1.2. Complex periodic signals:

Complex periodic signals involve the repetition of a nonsinusoidal pattern, and in all cases, complex periodic signals consist of more than a single frequency component. All nonsinusoidal periodic signals are considered complex periodic.

Figure 13 shows example of complex periodic signals, along with the amplitude spectra for this signal. The time required to complete one cycle of the complex pattern as a whole is called the **fundamental period**. The only reason for using the term "fundamental period" instead of the simpler term "period" for complex periodic signals is to differentiate the fundamental period from other periods that may be present in the signal (e.g., more rapid oscillations that might be observed within each cycle). The symbol for fundamental period is  $t_0$ . Fundamental frequency ( $f_0$ ) is calculated from fundamental period using the same kind of formula that we used earlier for sinusoids:

$$f_0 = 1/t_0 \quad (5)$$

Examination of the amplitude spectra of the signal confirms that it consists of more than a single frequency. In fact, complex periodic signals show a very particular kind of amplitude spectrum.

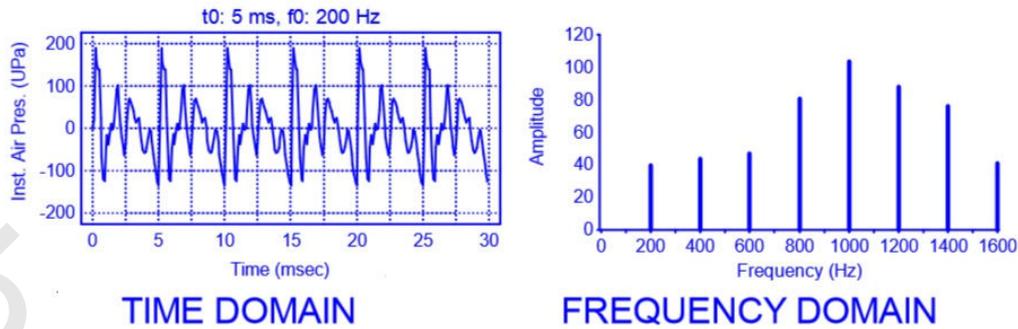


Fig.13: Time and frequency domain representations of complex periodic signals.

**II.6.2. Aperiodic Sounds:**

An aperiodic sound is any sound that does not show a repeating pattern in its time domain representation. There are many aperiodic sounds in speech.

There are two types of aperiodic sounds:

**II.6.2.1. Continuous aperiodic sounds (noise):**

The lack of periodicity in the time domain is quite evident.

Unlike complex periodic signals, complex aperiodic signals show energy that is spread across the spectrum. This type of spectrum is called dense or continuous, Fig.14.

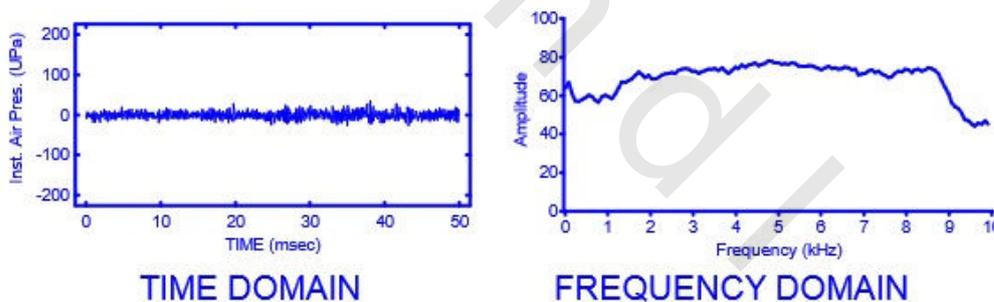
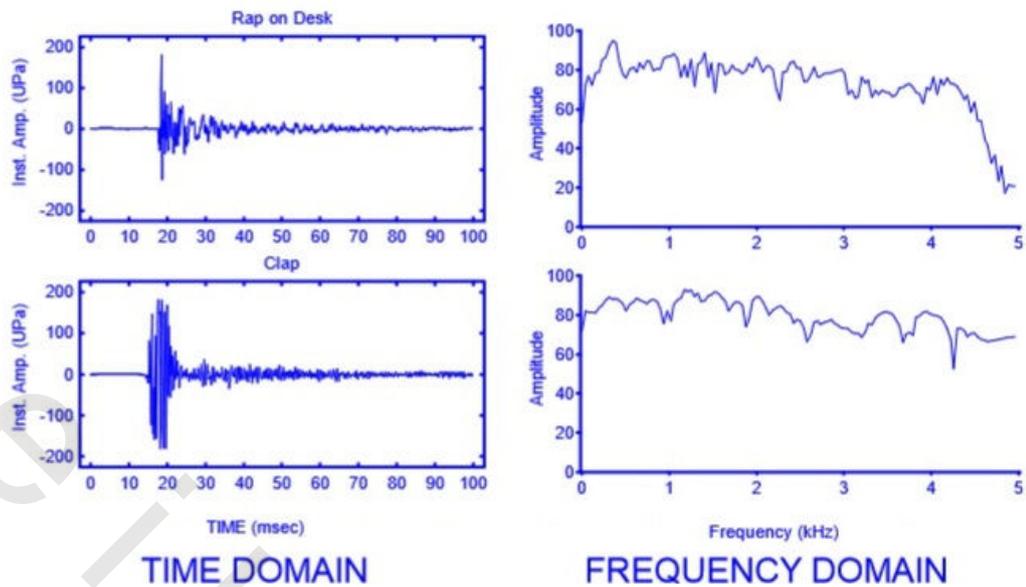


Fig. 14: Time and frequency domain representations of continuous aperiodic sounds.

**II.6.2.2. Transients aperiodic sounds:**

Although there is no sharp cutoff, the distinction between continuous aperiodic sounds and transients is based on duration. Transients are defined by their very brief duration, and continuous aperiodic sounds are of longer duration.

Transients aperiodic sounds can be produced by several ways like rapping on a wooden desk, sound gun fire, or single clap of the hands, Fig.15.



**Fig. 15: Time domain representations and amplitude spectra for transients aperiodic sounds.**

## II.7. Spectrum Envelope: <sup>(95)</sup>

Spectrum envelope is an imaginary smooth line drawn to enclose an amplitude spectrum. This is a rather simple concept that will play a very important role in understanding certain aspects of auditory perception. For example, we will see that our perception of a perceptual attribute called **timbre** (also called sound quality) is controlled primarily by the shape of the spectrum envelope, and not by the fine details of the amplitude spectrum.

The examples in Fig. 16 show how differences in spectrum envelope play a role in signaling differences in one specific example of timbre called vowel quality (a, i, e, u, o)

Spectrum envelope shows:

- The spectra of two signals (the vowel, å) with different  $f_0$  but very similar spectrum envelopes.
- Two signals with different spectrum envelopes but the same  $f_0$ .

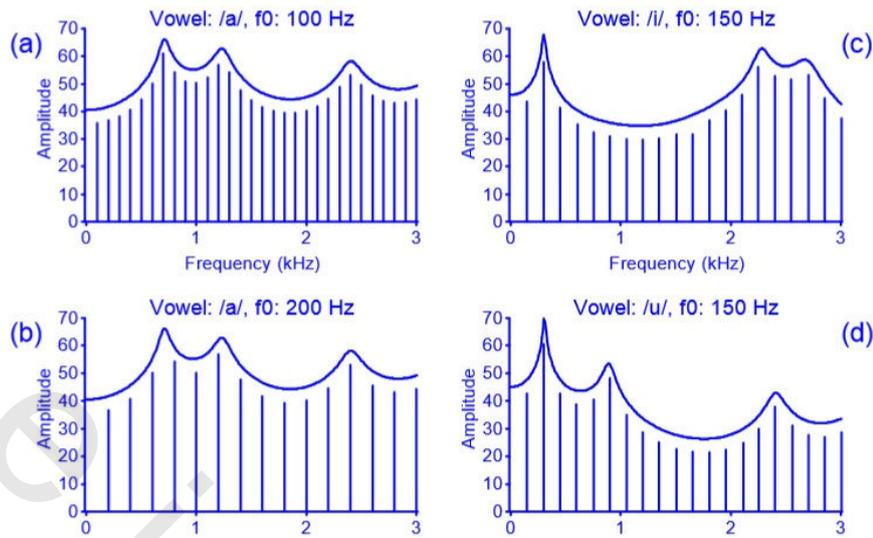


Fig. 16: Spectrum envelope.

### III. Intensity level and loudness: <sup>(96)</sup>

An essential aspect of wave propagation of all sorts is transfer of energy. The intensity ( $I$ ) of a travelling wave is defined as the time average rate at which energy is transported by the wave per unit area.

$$I = \frac{P}{A} \quad (6)$$

$P$ : is energy transferred (the power) of sound wave, measured in watt (W).

$A$ : the area of the surface interception the sound, measured in  $m^2$ .

Therefore the intensity of sound wave is measured in  $W \cdot m^{-2}$  and is proportional to the square of the pressure fluctuation, which is measured in Pascals (Pa).

The human ear normally detects sounds ranging from  $10^{-12} Wm^{-2}$  (the threshold of hearing) to  $10^0$  or  $1 Wm^{-2}$  (the threshold of pain).

Intensity level is a measure of intensity sound relative to reference intensity  $I_0$

$$\beta = 10 \cdot \log \frac{I}{I_0} \quad (7)$$

Where  $I_0$  is arbitrary reference intensity, taken as  $10^{-12} Wm^{-2}$  which corresponds roughly to the faintest sound that can be heard.

Number  $\beta$  is expressed as dB.

### III.1. Decibel (dB): <sup>(97-98)</sup>

Sound is perceived and recognized by its loudness (pressure) and pitch (frequency). The indicator of loudness is the dB, which is a logarithmic ratio of sound intensity level to a reference level.

Decibel is used to measure sound level, but it is also widely used in electronics, signals and communication. The dB is a logarithmic way of describing a ratio. The ratio may be power, sound pressure, voltage or intensity or several other things. Also, logarithmic dB values related to how we hear better than do absolute numbers or simple ratios. Thus, the dB was intended to simplify things, not to complicate them

**Bel:** is defined as the logarithm of an electrical, acoustic, or other power ratio.

$$\text{Bel} = \log \frac{I}{I_0} \quad (8)$$

In practice, a bel is a bit too large to use for measuring sound, so a one-tenth unit called the dB is used instead.

The dB is actual 1/10 of a Bel (a unit named after Alexander Graham Bell).

The dB is more convenient to use in sound systems, because the number scaling is more natural. Since a dB is 1/10 of a Bel, it can be mathematically expressed by equation:

$$\text{dB} = 10 \cdot \log \frac{I}{I_0} \quad (9)$$

If the intensity of sound wave equals  $I_0$  or  $10^{-12} \text{ W.m}^{-2}$ , so its intensity level equal 0 dB.

$$\text{dB} = 10 \cdot \log \frac{I_0}{I_0} = 10 \log 1 = 0 \quad (10)$$

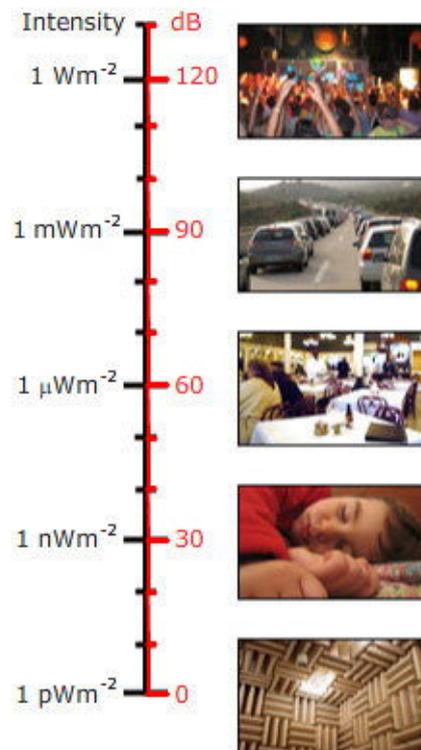
So 0 dB does not mean no sound, but it mean that I equal to the lowest audible sound  $I_0$

The maximum intensity that the ear can tolerate, about  $1 \text{ Wm}^{-2}$ , corresponding to an intensity level of 120 dB (Table 3 and Fig.17).

$$\begin{aligned} \text{dB} &= 10 \cdot \log \frac{I}{I_0} & (11) \\ &= \log \frac{1 \text{ Wm}^{-2}}{10^{-12} \text{ Wm}^{-2}} \\ &= 10 \log 10^{12} = 120 \text{ dB} \end{aligned}$$

**Table (3): Noise levels due to various sources (representative values)**

Source of noise	dB	Intensity $W.m^{-2}$
Threshold of pain	120	1
Elevated train	90	$10^{-3}$
Busy street traffic	70	$10^{-5}$
Ordinary conversation	65	$3.2 \times 10^{-6}$
Quiet automobile	50	$10^{-7}$
Quiet radio in home	40	$10^{-8}$
Average whisper	20	$10^{-10}$
Rustle of leaves	10	$10^{-11}$
Threshold of hearing	0	$10^{-12}$



**Fig. 17: Approximate sound intensity levels for assortment of familiar sound sources.**

### III. 2. Sound level: <sup>(99)</sup>

There are two parameters of sound that are used to express sound level; sound pressure level and sound power level.

#### III.2.1. Sound pressure:

Is what is heard and measured with a sound meter (Pa) at some location relative to the device being measured.

#### III.2.2. Sound power:

Is the acoustical power (W) emitted by the device. An analogy for understanding these parameters is the light bulb.

It is very important to understand the difference between sound pressure and sound power. Sound pressure levels describe the “effect” of the sound. The sound pressure depends on both the sound source and the environment of the sound source and the receiver. All of the criteria or ratings used to describe the “effect” of the sound are based on sound pressure level. As an incandescent light bulb or lamp is rated in watts but emits light (lumens). If you are very close to the light it is very bright and far away it is very dim. So, distance from the lamp affects its brightness but regardless its wattage is the same.

Sound behaves the same way, the farther away from a device the lower the SPL but the sound power level is the same.

Humans hear sound as a result of the pressure that sound waves exert on the eardrums. This SPL is expressed in dB. One limitation of the dB SPL is that it does not take account of the subjective changes in loudness of different-frequency tones whose intensity is the same. Such changes in apparent loudness with frequency arise from the variation of the threshold of hearing and human sensitivity with frequency.

The loudness level (LL) or phon scale does take this variation into account. The unit of loudness level is phon. One phon is the loudness level of a pure tone of 1000 Hz whose sound intensity level is 1 dB;

1 phon is equal to 1 dB at 1000 Hz.

### III.3. Audibility curve:

In the 1930s, researchers Fletcher and Munson conducted experiments on the response of the human ear and the relationship between sound frequency and pressure (Fletcher H. and Munson WA. 1933). Fletcher and Munson developed curves to approximate this relationship which were then revised by the International Organization for Standardization (ISO) and are now referred to as Normal Equal-Loudness Level Contours (Fig.18).<sup>(100)</sup>

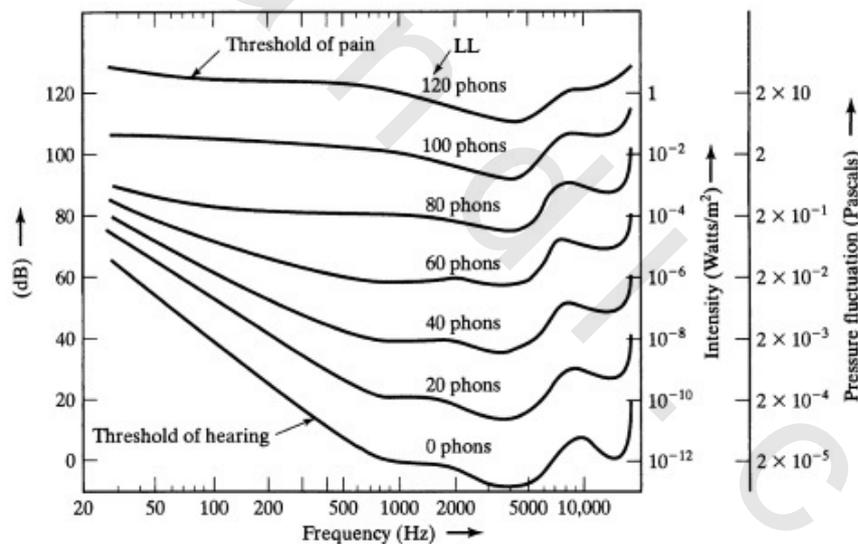
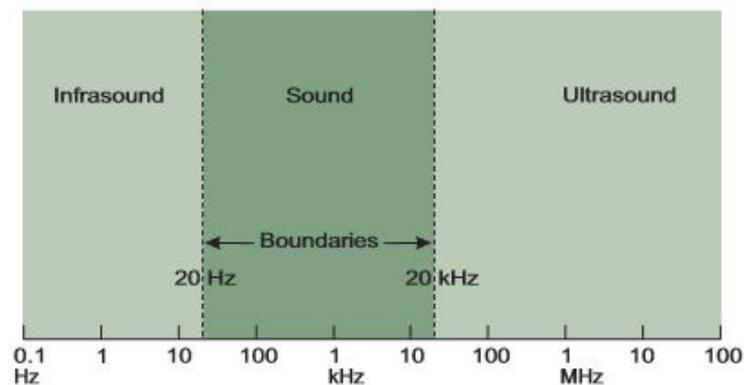


Fig.18: Fletcher-Munson curves (audibility curve).

#### III.3.1. Frequency bands for acoustic waves:<sup>(101)</sup>

Within the range of audibility the sensitivity of ear varies with frequency. The threshold of audibility at any frequency that can be detected for a young adult with normal hearing; the range of human hearing is generally considered to be 20 Hz to 20 kHz, but it is far more sensitive to sounds between 1 kHz and 4 kHz, with a declining upper frequency range correlating with increasing age, Fig.19.



**Fig.19: Frequency bands for acoustic waves.**

## IV. Analysis of sound waves:

### IV.1. Fourier theory: <sup>(102)</sup>

By the superposition of harmonic waves of different amplitude and frequencies, we can construct some rather complicated wave shapes. In fact, it can be shown that any arbitrary periodic wave can be constructed by the superposition of sufficiently large number of sinusoidal harmonic waves.

Analysis of complex wave in term of its harmonic components is called Fourier analysis, after the French mathematician Joseph Fourier (1768-1830), Fourier showed that any periodic wave can be decomposed into a sum of simple harmonic waves. Fourier analysis has many applications ranging from music to structural engineering and communications because it helps us understand how a complex wave behaves if we know how its simple harmonic components behave.

This analysis called Fourier Transform (FT), which based on two principles:

1. Any function of time can be represented as a sum of sine waves differing in frequency.
2. Each component has a distinct frequency, amplitude and phase.

### IV.2. Sound Spectrum: <sup>(103)</sup>

A sound spectrum displays the different frequencies present in a sound. Most sounds are made up of a complicated mixture of vibrations.

A sound spectrum is a representation of a sound – usually a short sample of a sound – in terms of the amount of vibration at each individual frequency. It is usually presented as a graph of either power or pressure as a function of frequency. The power or pressure is usually measured in dB and the frequency is measured in Hz or kHz.

### IV.3. Related functions used to elucidate graphically noise analysis:

- Spectrogram.
- Autocorrelation.
- Cepstrum.

**IV.3.1. Spectrogram (sonogram):** <sup>(103)</sup>

It's a visual representation of the spectrum of frequencies in a sound or other signal as they vary with time or some other variable.

Spectrograms can be used to identify spoken words or noise around us phonetically, and to analyze the various calls of animals. They are used extensively in the development of the fields of music, radar, and speech processing, etc.

**IV.3.2. Autocorrelation:** <sup>(104)</sup>

It's a mathematical tool for finding repeating patterns, such as the presence of periodic signal obscured by noise. It provides a measure of similarity between a signal and itself at a given lag. In other words, you step through the signal sample-by-sample and perform a correlation between your reference window and the lagged window.

**IV.3.3. Cepstrum:** <sup>(105)</sup>

It is an analysis function with many applications in signal processing. Cepstrum analysis is generally used as a complementary tool to spectral analysis, it helps identifying items which not readily identified by spectral analysis.

Cepstrum was defined to be the inverse FT (IFT) of log magnitude spectrum of signal, Fig. 20. Its name was derived by reversing the first four letters of "spectrum".



**Fig.20: Block diagram showing how a signal x(n) would be converted to the cepstral domain.**

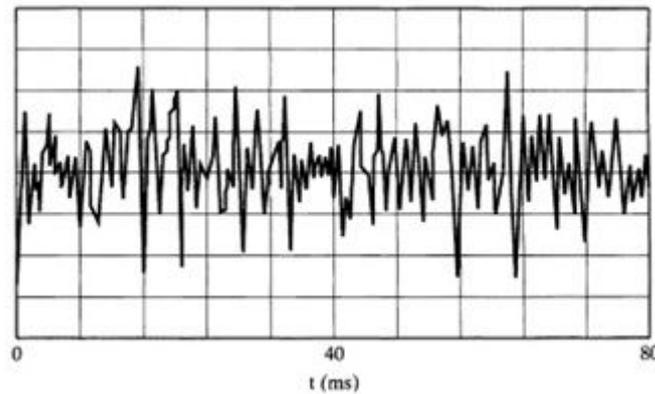
**IV. 3.3.1. Cepstrum applications:**

Cepstrum has several applications in noise. It can be used for the identification of any periodic structure. It is ideally suited to detection of periodic effects such as detecting harmonic patterns in machine vibration spectra.

**V. Noise:** <sup>(106)</sup>

The word “sound” and “noise” are terms that can be used interchangeably. “Noise” often implies an unwanted sound. The use of “noise” also depends on the intensity of the sound or the complex temporal pattern. The classification of a “sound” or “noise” may also depend of cultural factors, the individual, or the time and circumstance.

Waveform of noise (Fig.21) is characteristic by non-periodic waveform. This is the different between musical sounds, which are periodic, and nonmusical sounds, or noise, which are non-periodic.



**Fig.21: The wave shape of noise.**

A partial list of noise requirements shown in Table 4

**Table 4: Average normal noise levels for several acoustical environments**

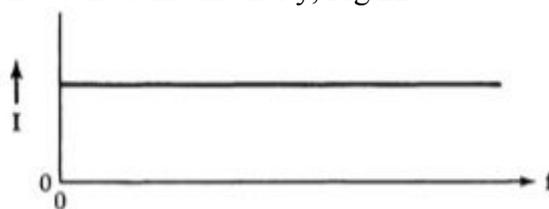
Studios (recording, radio, TV)	25 dB
Auditoriums and theaters	30 dB
Classrooms or lecture hall	30 dB
Hospitals	30 dB
Homes	40 dB
Offices	45 dB
Restaurants	50 dB

## V.1. Types of noise: <sup>(99)</sup>

### V.1.1. White noise:

An elementary optics experiment is to pass a beam of white light through a prism and observe that the white light is separated into its component colors. The reverse process can also be demonstrated: superposition of all the colors in the visible region results in white light. The audio analog to white light is white noise, which consists of all frequencies of the audible spectrum superimposed with equal intensities.

White noise is a type of continuous aperiodic sound, it has a flat amplitude spectrum; that is, approximately equal amplitude at all frequencies, or it a random signal in which all frequencies in all bands have the same intensity, Fig.22.



**Fig.22: Spectrum of white noise.**

### V.1.2. Colored noise:

A variation on white noise is called colored noise or filtered noise. Term colored noise applied to non-musical sound that contain a continuum of frequencies with unequal intensities, Fig.23.

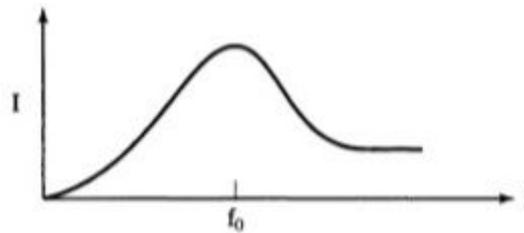


Fig.23: Spectrum of a type of colored noise.

### V.2. Adverse effects of noise:

The World Health Organization (WHO) definition of the adverse effects of noise is as follows: Change in the morphology and physiology of an organism that result in impairment of functional capacity to compensate for additional stress, or increases in the susceptibility of an organism to the harmful effects of other environmental influences. Includes any temporary or long-term lowering of the physical, psychological or social functioning of humans or human organs. <sup>(107)</sup>

#### V.2.1. Annoyance:

An earlier definition of annoyance was "a feeling of displeasure, anger, depression and helplessness. Associated with any agent or condition, known or believed by an individual or group to adversely affect them. The WHO considers annoyance an adverse health effect of noise in addition to sleep disturbance, performance effects, and psychological effects such as irritability (WHO 2001). Annoyance was also defined as a feeling of displeasure with varying tolerance levels. WHO also characterized annoyance as a feeling that increases with noise impulses as opposed to a steady noise (WHO 2001). <sup>(108)</sup>

#### V.2.2. Auditory effect of noise:

NIHL is caused by exposure to sound levels or durations that damage the hair cells of the cochlea. Initially, the noise exposure may cause a temporary threshold shift-that is, a decrease in hearing sensitivity that typically returns to its former level within a few min to a few hours. Repeated exposures lead to a permanent threshold shift, which is an irreversible hearing loss. <sup>(109)</sup>

#### V.2.3. Non-auditory effect of noise:

Non-auditory effects of noise can be defined as 'all those effects on health and well-being which are caused by exposure to noise, with the exclusion of effects on the hearing organ and the effects which are due to the masking of auditory information (i.e. communication problems). <sup>(110)</sup>

### **V.3. Instrumentation for Noise Measurement:** <sup>(111)</sup>

#### **V.3.1. Purposes of measurements:**

There are many reasons to make noise measurements. Noise data contains amplitude, frequency, time or phase information, which allows us to:

- Identify and locate dominant noise sources.
- Optimize selection of noise control devices, methods, materials.
- Evaluate and compare noise control measures.
- Determine compliance with noise criteria and regulations.
- Quantify the strength (power) of a sound source.
- Determine the acoustic qualities of a room and its suitability for various uses and many, many more....

#### **V.3.2. Measuring systems:**

Many types of measuring systems can be used for the measurement of sound depending on the purpose of the study, the characteristics of sound and the extent of information that is desired about the sound.

- Microphones.
- Sound level meters (SLM).
- Frequency analyzers.
- Noise dosimeters.

##### **V.3.2.1. The microphone:**

Microphones are the interface between the acoustic field and the measuring system. It responds to sound pressure and transforms it into an electric signal which can be interpreted by the measuring instrument (e.g. SLM). The best instrument cannot give a result better than the output from the microphone. Therefore, its selection and use must be carefully carried out to avoid errors.

##### **V.3.2.2. Sound Level Meter:**

The primary tool for noise measurement is the SLM. The most basic SLM will have an analog or digital output of sound pressure.

The electrical signal from the transducer is fed to the pre-amplifier of the SLM. Further amplification prepares the signal either for output to other instruments such as a tape recorder or for rectification and direct reading on the meter.

##### **V.3.2.3. Frequency analyzers:**

The objective of frequency analysis is to determine how the overall level is distributed over a range of frequencies.

##### **V.3.2.4. Noise dosimeters:**

Dosimeters are actually SLM having a DC output signal converted into a series of impulses which are counted to provide the dose. The noise dosimeter is clipped

to the workers' clothes with the microphone close to the ear, and can be worn without hampering work.

## VI. Auditory system: <sup>(112-113)</sup>

### VI.1. Parts of auditory system:

The peripheral auditory system can be divided both functionally and anatomically into three distinct parts, the external ear, the middle ear, and the inner ear.

The outer ear or pinna leads to the middle ear's auditory canal or meatus. The auditory canal terminates at the eardrum, or tympanic membrane. Beyond the eardrum is the inner ear which contains the hidden parts of the ear, encased in bone. The complicated structure is hard to see or to understand in photomicrographs of actual dissected specimens. We will rely on schematized drawings that depict the shapes and relation of various parts of the ear Fig. 24.

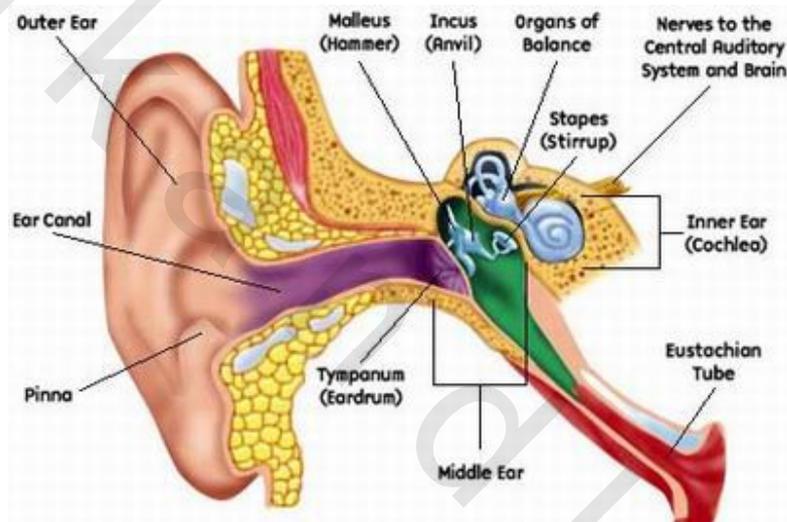


Fig. 24: Schematic diagram of the auditory system.

#### VI.1.1. The external ear:

The external ear consists of two parts, the cartilaginous auricle or pinna, which acts as a collector, gathering sound waves and concentrating them into the auditory canal to a limited extent, a tube about 0.5 cm in diameter extending about 3 cm into the head which lead to the lateral surface of the tympanic membrane or ear drum. In addition, the length of the auditory canal helps to protect the very sensitive eardrum against some shocks and intrusion by external objects.

It serves as a passive acoustic resonator that increases the sound pressure of certain frequencies at the tympanic membrane, and as a passive acoustic filter that aids in detecting the direction of sounds.

**The eardrum:**

The very important function of the eardrum is to separate the outer and middle ears physically, so that the air pressure will not rapidly equalize between the two. This would reduce the amplitude of the vibration of the drum caused by the pressure changes of the impinging sound wave.

Even a very small hole in the eardrum will reduce the pressure difference, particularly at low frequencies. The slower changes in air pressure caused by changes in weather are equalized by air flow from the throat to the middle ear through the Eustachian tube.

**VI.1.2. The middle ear:**

The middle ear consists of tympanic cavity, the bone chain of the three ossicles (the hammer, the anvil, and the stirrup), and the middle ears muscles and couples sounds energy from the external ear to the inner ear.

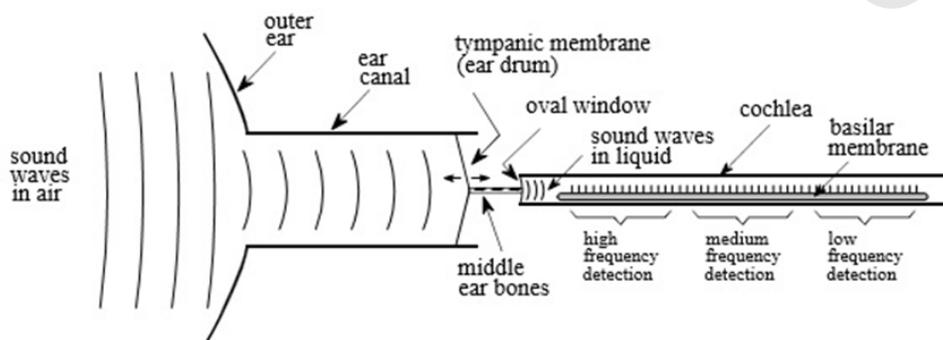
Sound waves striking the tympanic membrane cause it to vibrate. The small bones convert the small-amplitude vibrations of eardrum into the larger-amplitude pressure oscillations required to set up waves in the fluid of the inner ear (cochlea) where it is converted to neural impulses. Ear muscles help to limit the vibration of these bones for very-large-amplitude continuous sounds, and thus prevent damage to the middle ear. Unfortunately, sharp noise such as gunshots or loud music may occur too quickly for the protective mechanism to prevent damage to the middle ear.

It functions as an acoustic transformer which matches the acoustic impedance of the external canal to much higher impedance at cochlear fluids, i.e. middle ear is impedance matching network.

**VI.1.3. The inner ear:**

The principal hearing organ of the inner ear is the cochlea, which is actually coiled on itself, like a snail, the cochlea contains the nerves that convert the physical vibrations into electrical signals. The width of the coiled cochlea decreases along its length from base to apex.

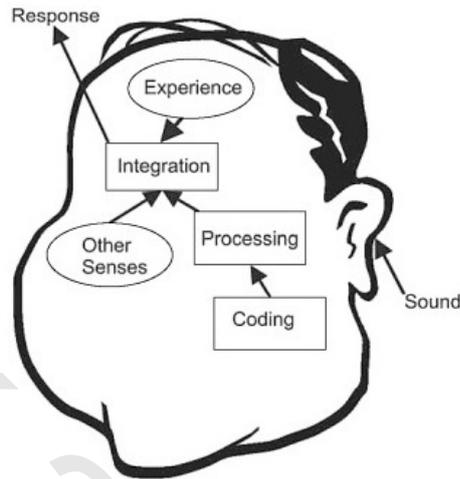
The inner ear serves as an electromechanical transducer, converting acoustic energy into neural impulses (Fig.25). Additionally, it serves as an accelerometer, generating neural signals including head position and acceleration.



**Fig.25: Functional diagram of the human ear.**

## VI.2. The stages of processing that lead to hearing: <sup>(114)</sup>

The physical attributes of sound (f, I, and t) are first coded by the peripheral auditory nervous system. The neural code is then processed by higher neural centers to help the listener determine the sources of sound. This neural information is integrated with other sensory information and that based on experience, and all of this neural processing leads to behavioral responses (Fig. 26).



**Fig.26: The stages of processing that lead to hearing.**

## VI.3. Disorders of auditory systems: <sup>(115)</sup>

The signs and symptoms of disorders of the auditory system are decreased function and abnormal function.

Decreased function includes elevated threshold and decreased speech discrimination, generally known as impairment of hearing. The most common abnormal function is tinnitus, which is sign of hyperactivity. Other examples of abnormal function are recruitment of loudness, hyperacusis, distortion of sound, and phonophobia, such symptoms are mostly caused by changes in the function of auditory nervous systems.

## VII. Oxidative stress:

An imbalance between oxidants and antioxidants in favour of the oxidants, potentially leading to damage, is termed 'oxidative stress'. Oxidants are formed as a normal product of aerobic metabolism but can be produced at elevated rates under pathophysiological conditions. Antioxidant defense involves several strategies, both enzymatic and non-enzymatic

Disturbances in the normal redox state of cells can cause toxic effects through the production of peroxides and free radicals that damage all components of the cell, including proteins, lipids, and DNA. <sup>(116)</sup>

In humans, oxidative stress is thought to be involved in the development of cancer, <sup>(117)</sup> Parkinson's disease, Alzheimer's disease, <sup>(118)</sup> atherosclerosis, heart failure, <sup>(119)</sup> myocardial infarction, <sup>(120)</sup> fragile X syndrome, <sup>(121)</sup> Sickle Cell Disease, <sup>(122)</sup> and chronic fatigue syndrome <sup>(123)</sup> other effects are shown in Fig.27.

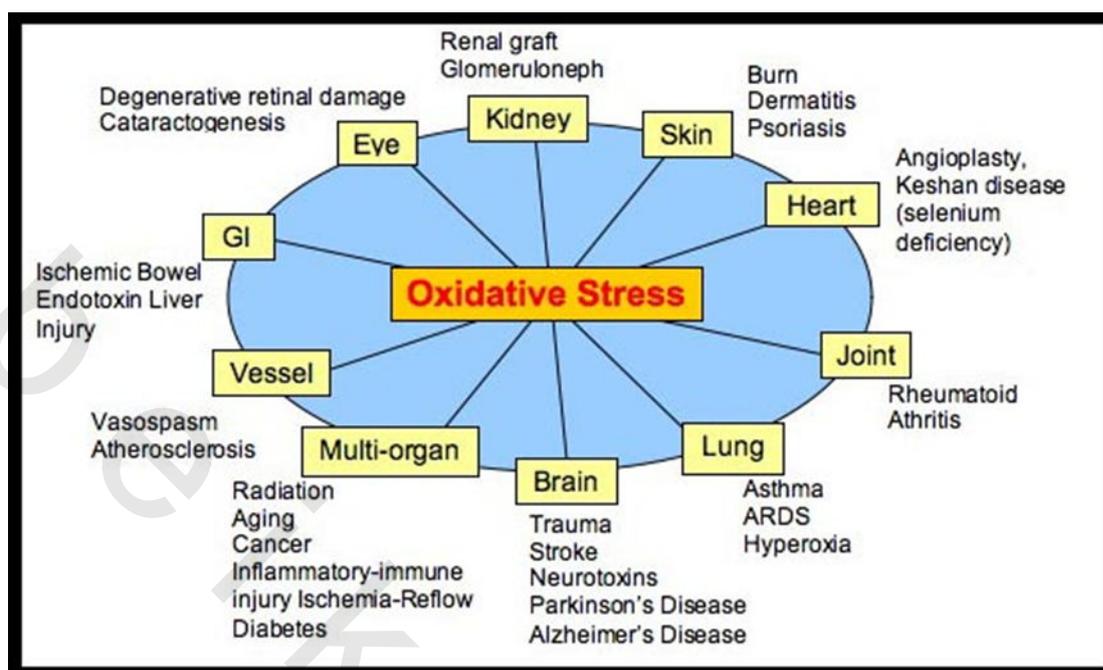


Fig.27: Effects of oxidative stress on human.

## VII.1. Oxidation:

"Oxidation" is the chemist's term for the process of removing electrons from an atom or molecule. The result of this change can be destructive.

Free radicals defined as molecules or molecular fragments containing one or more unpaired electrons in atomic or molecular orbits. This unpaired electron(s) usually gives a considerable degree of reactivity to the free radical. Radicals derived from oxygen represent the most important class of radical species generated in living system. <sup>(124)</sup>

### VII.1.1. Reactive species (RS):

RS of various types are formed in vivo and many are powerful oxidizing agents, capable of damaging DNA and other biomolecules. Increased formation of RS can promote the development of malignancy, and the 'normal' rates of RS generation may account for the increased risk of cancer development in the aged. <sup>(125)</sup>

### VII.1.2. Reactive oxygen species & reactive nitrogen species:

Oxygen free radicals or, more generally, Reactive oxygen species (ROS) & reactive nitrogen species (RNS) are product of normal cellular metabolism. Both are well recognized for playing a dual role as both deleterious and beneficial species, since they can be either harmful or beneficial to living systems. <sup>(126)</sup>

Beneficial effects of ROS occur at low/moderate concentration and involve physiological roles in cellular response to noxia, in defense against infectious agent and in the function of number of cellular signaling system, as they are used by the immune system as a way to attack and kill pathogens. <sup>(127)</sup>

The harmful effect of free radicals causing potential biological damage (oxidative stress). This occurs in biological systems when there is overproduction of ROS/RNS on one side and deficiency of enzymatic and non-enzymatic antioxidant. <sup>(128)</sup>

At high concentrations, ROS can be important mediators of damage to cell structures, nucleic acids, lipids, and protein. The ROS is known to react with all components of the DNA molecules, damaging both the purine and pyrimidine bases and also the deoxyribose backbone. ROS not only attack DNA, but also on other cellular components involving polyunsaturated fatty acid residues of phospholipids, which are extremely sensitive to oxidation. The major endproduct of lipid peroxidation (LPO) is malondialdehyde (MDA). <sup>(129-130)</sup>

#### VII.1.2.1. Malondialdehyde:

Malondialdehyde is one of the most frequently used indicators of LPO. MDA is found in human and animal tissue as an end-product of LPO. It is also a side-product of prostaglandin and thromboxane biosynthesis. MDA is present in blood platelets and in serum. MDA is the organic compound with the formula  $\text{CH}_2(\text{CHO})_2$ , Fig.28. <sup>(131)</sup>



**Fig.28: Chemical structure of MDA.**

Clinical research in the area of LPO has been hampered by the lack of a valid biomarker. One of the most frequently used biomarkers providing an indication of the overall LPO level is the plasma concentration of MDA, one of several byproducts of LPO processes. <sup>(132)</sup>

#### VII.2. Antioxidant: <sup>(133-134)</sup>

Is a molecule that inhibits the oxidation of other molecules. Oxidation is a chemical reaction that transfers electrons or hydrogen from a substance to an oxidizing agent. Oxidation reactions can produce free radicals. In turn, these radicals can start chain reactions. When the chain reaction occurs in a cell, it can cause damage or death to the cell. Antioxidants terminate these chain reactions by removing free radical intermediates, and inhibit other oxidation reactions.

Antioxidant defense involves several strategies, both enzymatic and non-enzymatic. Non-enzymatic antioxidants like such as glutathione, ascorbic acid (vitamin C), vitamin A,  $\alpha$ -tocopherol (vitamin E), and flavonoids. Overall, these low molecular mass antioxidant molecules add significantly to the defense provided by the enzymes SOD, CAT and GPx, under normal condition, there is a balance between both the activities and the intracellular levels of these antioxidants. This balance is essential for the survival of the organism and their health.

The balance between oxidative species production and antioxidant production species is the redox state of the cell. Oxidative stress generally describes a condition in

which cellular antioxidant defenses are inadequate to completely detoxify free radicals that have been generated due to excessive production of ROS, loss of antioxidant defense or typically both.

### VII.2.1. Superoxide dismutase:

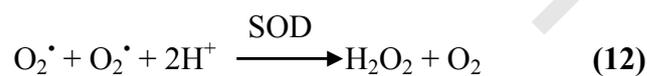
We can't live without oxygen. Our cells rely on oxygen as the final acceptor of electrons in respiration, allowing us to extract far more energy from food than would be possible without oxygen. But oxygen is also a dangerous compound. Reactive forms of oxygen, such as superoxide, (oxygen with an extra electron,  $O_2^-$ ). This superoxide can then cause mutations in DNA or attack enzymes that make amino acids and other essential molecules. To combat this potential danger, most cells make SOD, an enzyme that detoxifies superoxide into oxygen and hydrogen peroxide, consequently, SOD serves a key antioxidant role. <sup>(135)</sup>

SOD is an important copper–zinc enzyme that catalyzes the removal of superoxide radicals generated during normal metabolic processes, as well as during the phagocytosis of infecting viruses and bacteria in white cells. SOD enzymes are present in almost all aerobic cells and in extracellular fluids. <sup>(136)</sup>

Three forms of SOD are present in humans, in all other mammals, and most chordates. SOD1 is located in the cytoplasm, SOD2 in the mitochondria, and SOD3 is extracellular. <sup>(137)</sup>

#### VII.2.1.1. Dismutation:

Dismutation is a term that refers to a special type of reaction, where two equal but opposite reactions occur on two separate molecules. SOD takes two molecules of superoxide, strips the extra electron off of one, and places it on the other. So, one ends up with an electron less, forming normal oxygen, and the other ends up with an extra electron. The one with the extra electron then rapidly picks up two hydrogen ions to form hydrogen peroxide ( $H_2O_2$ ), which then must be removed by GPx or CAT. <sup>(138)</sup>



## VIII. Chemical Signals & neurotransmitters:

Electrical signals are the simplest of all communication devices. In the human brain they cross the space that separates nerve cells from one another. These spaces are known as gap junctions, or electrical synapses, where the cytoplasmic membranes on either side are closely enough to allow signals to propagate directly from cell to cell. The rapid transmission of electrical signals within and among neuronal networks may contribute to the large-scale synchronization of cerebral activity. <sup>(139)</sup>

Although electrical communication does indeed occur in the brain, in many synapses chemistry takes the place of electricity. Simple chemical substances called neurotransmitter (NT) are capable, like electrical impulses, of crossing the synaptic cleft.

The brain therefore operates as both an electrical and a chemical signaling machine. In the 1930s only a few NT were known. The chief one of these, acetylcholine, had first been discovered in connection with the action of the vagus nerve on the heart and also at the junction between motor nerves and skeletal muscle; its action in the rest of the nervous system was detected soon afterward.<sup>(140)</sup>

Several dozen additional NT have been identified since, along with an even greater number of peptides serving as chemical messengers. It is now known, too, that an individual nerve cell is capable of synthesizing and releasing more than one NT. NT are synthesized and stored in nerve endings. Released into the space between two neurons, they rapidly diffuse and reach the neighboring cell in a fraction of a millisecond.<sup>(141)</sup>

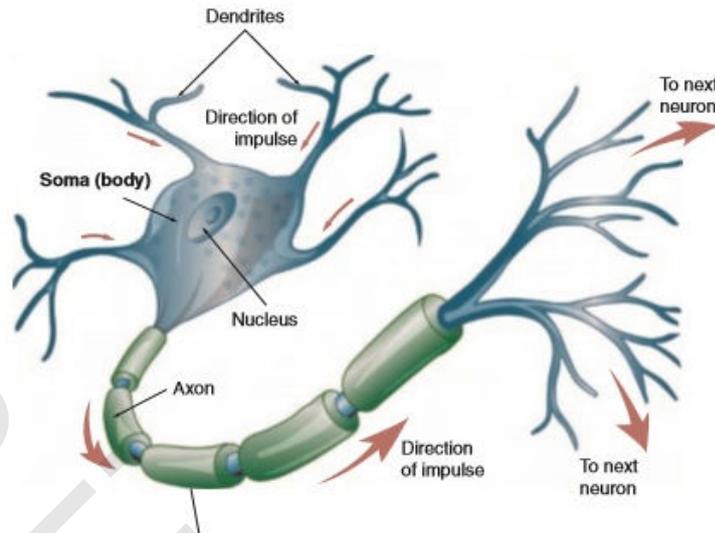
On reaching their target cells, NT are recognized by specialized molecules. In 1905 the English pharmacologist John Newport Langley named these molecules “receptive substances”. Despite the evident power of their physiological and pharmacological action, they long escaped biochemical identification, chiefly because they are found in very small quantities in neuromuscular junctions. Today it is known that 5% of our genes are dedicated to the production of receptors, now understood to be large proteins located in the postsynaptic cell membrane that function as molecular switches, assuring the recognition and transduction of chemical signals.<sup>(142)</sup>

These membrane proteins are capable of recognizing not only NT but also medicinal substances and drugs that likewise lodge themselves at specialized binding sites. Receptors also convert the NT’s signal into biological activity: either the opening of an ion channel or the activation of an enzyme reaction.<sup>(142)</sup>

### **VIII.1. Neurons:**<sup>(143)</sup>

Is the term for a nerve ending that senses pain. From the neuron, the pain signal travels through a complex of peripheral nerves distributed throughout the body and through the central nervous system, including the brain and the spinal cord.

The neurons from which NTs are released number more than 7 billion in the human brain. Each neuron consists of cell body, with one major cytoplasmic process termed the axon, which projects variable distances to other neurons (Fig.29). All neurons, except primary sensory neurons, have number of other, generally shorter distance among neighboring neurons like the branches of tree, called dendrites. The axon terminals of one neuron synapse with other neurons .



**Fig.29: Typical neurons.**

## VIII.2. Neurotransmitters:

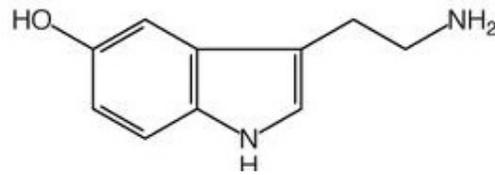
The chemical signal, a NT (such as acetylcholine, dopamine, norepinephrine, or serotonin), is released from the nerve ending of the interneuron (sending neuron) into the synaptic gap and then combines with its receptor on the dendrite of the receiving neuron. The balance of ions on the outer and inner surfaces of a neuron is altered when a chemical contacts the surface of the membrane and reaches a threshold level, coursing across the membrane to the axon. Upon reaching the axon, this alteration produces an action potential. The action potential is a brief electrical pulse that travels along the axon. When the action potential reaches the nerve ending (axon terminal), it triggers the release of a NT. <sup>(144)</sup>

NT can be divided into two main groups: classical transmitters and neuropeptides. Classical NT are small, low molecular weight compounds. Acetylcholine, monamines (dopamine, serotonin, norepinephrine, epinephrine, and histamine) and some amino acids (gamma-aminobutyric acid, glycine and glutamate) all belong to the group of classical NT. <sup>(145)</sup>

The neuropeptides are larger molecules. Every peptide molecule is built of several amino acid units, or residues. Neuropeptides are responsible for mediating sensory and emotional responses including hunger, thirst, sex drive, pleasure and pain. <sup>(146)</sup>

### VIII.2.1. Serotonin: <sup>(147)</sup>

Serotonin or 5-hydroxytryptamine (5-HT) (Fig.30) is a monoamine NT. Biochemically derived from tryptophan, serotonin is primarily found in the gastrointestinal (GI) tract, platelets, and in the central nervous system (CNS) of animals and humans.

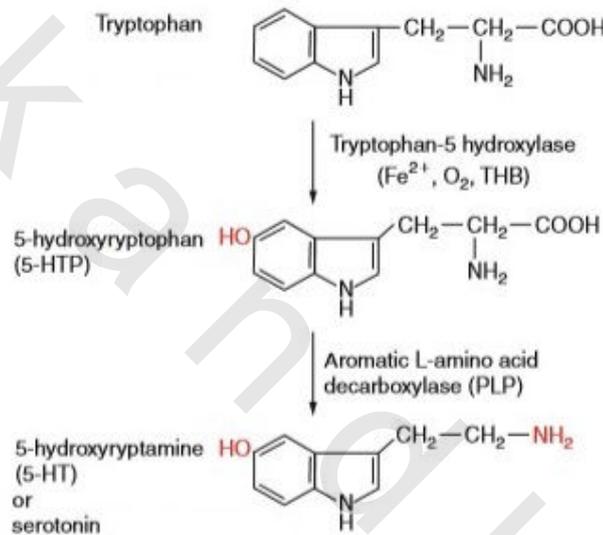


**Fig.30: Chemical structure of serotonin.**

Serotonin, like other NT found in both the periphery and the brain. In cardiovascular system, it causes marked vasoconstriction and it is from this action called "serotonin"

#### VIII.2.1.1. Synthesis of serotonin: <sup>(148)</sup>

Serotonin is synthesized from tryptophan by the action of tryptophan hydroxylase and aromatic amino acid decarboxylase, as shown in Fig. 31.

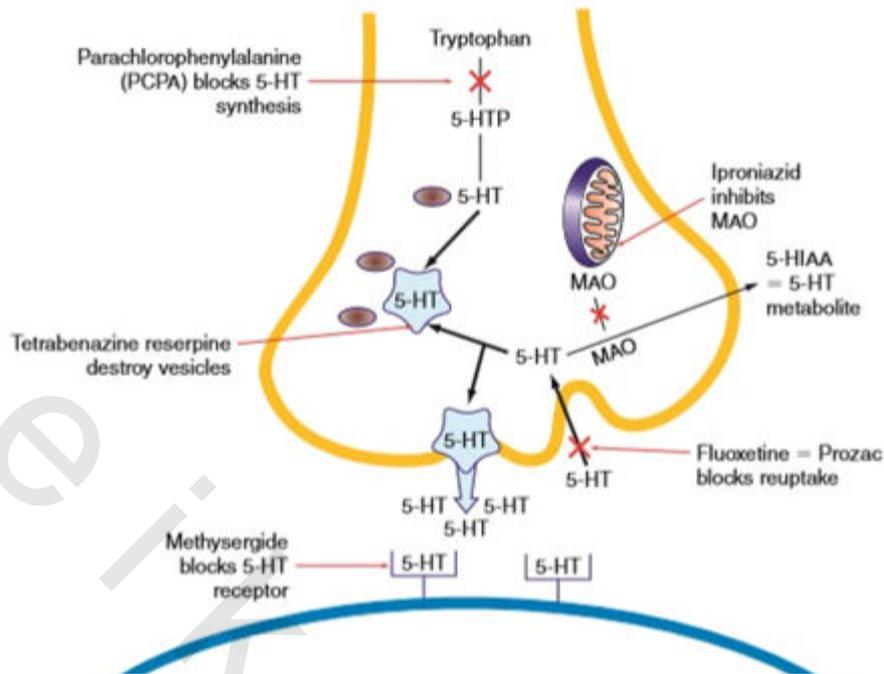


**Fig.31: Synthesis of serotonin (5-hydroxytryptamine).**

#### VIII.2.1.2. Storage and release of serotonin: <sup>(149)</sup>

Serotonin is found primarily in storage vesicles (30-35 nm diameter) where 'serotonin-binding proteins' (SBPs) have also been identified. These seem to form a macromolecular complex with 5-HT.

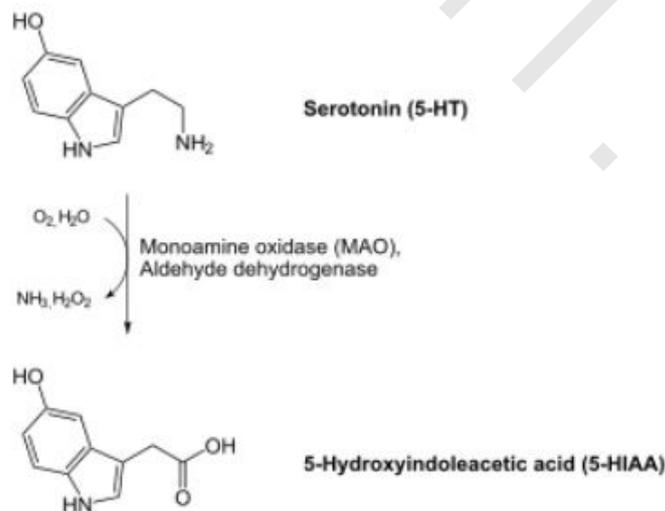
Serotonin is secreted from vesicles into the synaptic space from the axonal nerve ending, and it crosses the synapse to bind to serotonin receptors on the membrane of the postsynaptic cell (Fig. 32). There is a reuptake mechanism for serotonin in the synaptic space so that it can be stored again in the presynaptic vesicles and reused. Nearly all tryptophan in the brain is converted to serotonin.



**Fig.32:** Synthesis of serotonin from tryptophan and incorporation of serotonin (5-HT) into vesicles. Serotonin is released in response to a signal into the synaptic space and binds to serotonin receptors on the membrane of the postsynaptic cell.

### VIII.2.1.3. Metabolism of serotonin: <sup>(150)</sup>

5-HT is metabolized primarily by MAO to 5-hydroxyindoleacetic (5-HIAA) in liver, Fig: 33.



**Fig.33:** Metabolism of serotonin.

**VIII.2.1.4. Serotonin functions:** <sup>(151-152)</sup>

1. Serotonin participate in hypothalamic control of pituitary secretion, particularly in the regulation of adrenocoticotropin hormone (ACTH)
2. Serotonin is a neurotransmitter essential for a large number of physiological process including the regulation of vascular and non-vascular smooth muscle contraction, memory, modulation of platelet aggregation, appetite, mood, anxiety, depression, temperature, sexual behavior and pain sensation.
3. Serotonin and its receptors and involved in the control of gastrointestinal function.
4. Serotonin affects neural regulation of bone and skeletal tissue.
5. Serotonin plays a role in pulmonary arterial hypertension.
6. Serotonin acts as precursor for melatonin.

**IX. Cognition functions:** <sup>(153)</sup>

Cognition function is the set of all mental abilities and processes related to knowledge: attention, judgment, evaluation, reasoning, computation, problem solving, decision making, comprehension, production of language, etc. Cognitive functions must be accessed through different kind of behaviors in many specific, experimental models of memory and learning. Among them, the novel object recognition (NOR) test which can be evaluated by the differences in the exploration time of novel and familiar objects.

The way how performance of animals is evaluated in the NOR test may vary. It can be calculated through different indexes, as recognition index. The NOR task is particularly attractive because it requires no external motivation, reward, or punishment but a little training or habituation is required, and it can be completed in a relatively short time. Principally it depends on the concept that when animals are exposed to a familiar and a novel object, they approach frequently and spend more time exploring the novel than the familiar one.