5 SOUND

Most of the information about our physical surroundings comes to us through our senses of hearing and sight.

Sound is a mechanical wave produced by vibrating bodies. For example, when an object set into vibrational motion, the surrounding air molecules are disturbed and are forced to follow the motion of the vibrating body. When the air vibrations reach the ear, they cause the eardrum to vibrate; this produces nerve impulses that are interpreted by the brain.

5.1 HEARING AND THE EAR

The sensation of hearing is produced by the response of the nerves in the ear to pressure variations in the sound wave. The ear is much more sensitive to pressure variations than any other part of the body.

The ear is usually divided into three main sections: **the outer ear, the middle ear, and the inner ear**. The sensory cells that convert sound to nerve impulses are located in the liquid-filled inner ear. The main purpose of the outer and middle ears is to conduct the sound into the inner ear.

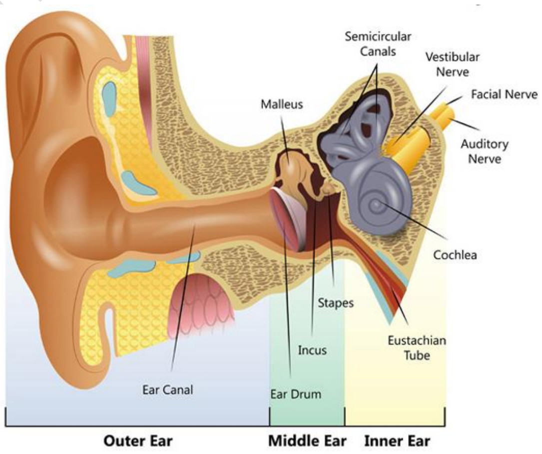

Figure 5: Outer, middle and inner ears.

The human ear is capable of detecting sound at frequencies between about 20 and 20,000 Hz. Within this frequency range, however, the response of the ear is not uniform. There are wide variations in the frequency response of individuals. Furthermore, the hearing of most people deteriorates with age. The sensation of pitch (tone) is related to the frequency of the sound. The pitch increases with frequency.

The ear responds to an enormous range of intensities. The lowest intensity that the human ear can detect is about 10^{-16} W/cm^2. The loudest tolerable sound has an intensity of about 10^{-4} W/cm^2. These two extremes of the intensity range are called the **threshold of hearing** and the **threshold of pain**, respectively. Sound intensities above the threshold of pain may cause permanent damage to the eardrum and the ossicles.

The **intensity** I of a wave is the rate at which the energy transported by the wave transfers through a unit area A perpendicular to the direction of travel of the wave,

$$I = \frac{Pressure}{Area} = \frac{\Delta P^2}{2\rho v}$$

where ΔP is the maximum pressure change due to the sound wave. ρ is the density of the medium, and v is the speed of sound propagation.

The ear does not respond linearly to sound intensity. The response of the ear to intensity is closer to being logarithmic than linear, so the **sound level** (β) is measured by

$$\beta = 10 \log\left(\frac{I}{I_0}\right)$$

where I_0 is the reference intensity, taken to be at the threshold of hearing and I is the intensity in watts per square meter to which the sound level β corresponds, where β is measured in decibels (dB).

Table 2: Sound Levels Due to Various Sources.

Source of sound	Sound level (dB)	Sound level (W/cm^2)
Threshold of pain	120	10^{-4}
Riveter	90	10^{-7}
Busy street traffic	70	10^{-9}
Ordinary conversation	60	10^{-10}
Quiet automobile	50	10^{-11}
Quiet radio at home	40	10^{-12}
Average whisper	20	10^{-14}
Rustle of leaves	10	10^{-15}
Threshold of hearing	0	10^{-16}

The sensitivity of the ear is remarkable due to random pressure variations in the air as shown above and to the mechanical construction of the ear.

The process of hearing cannot be fully explained by the mechanical construction of the ear. The brain itself plays an important role in our perception of sound. The brain can effectively filter out ambient noise and allow us to separate meaningful sounds from a relatively loud background din.

5.2 CLINICAL USE OF SOUND: STETHOSCOPE

The most familiar clinical use of sound is in the analysis of body sounds with a **acoustic stethoscope**. This instrument consists of a small bell-shaped cavity attached to a hollow flexible tube. The bell is placed on the skin over the source of the body sound (such as the heart or lungs). The sound is then conducted by the pipe to the ears of the examiner who evaluates the functioning of the organ.

If the **diaphragm** is placed on the patient, **body sounds vibrate** the diaphragm, creating acoustic pressure waves which travel up the tubing to the listener's ears. If the **bell** is placed on the patient, the **vibrations of the skin** directly produce acoustic pressure waves travelling up to the listener's ears. The bell transmits **low** frequency sounds, while the diaphragm transmits **higher** frequency sounds (Breath sounds and heart sounds).

Electronic stethoscope overcomes the low sound levels by electronically amplifying body sounds by placement of a piezoelectric crystal with contact to the diaphragm, then be amplified and processed for optimal listening.

The electronic stethoscope can be a wireless device, can be a recording device, and can provide noise reduction, signal enhancement, and both visual and audio output for analysing the recorded heart sounds.

Figure 6: Acoustic stethoscope.

Figure 7: Electronic stethoscope.

5.3 SONIC WAVES

Sound waves are divided into three categories that cover different frequency ranges:

(1) **Audible waves** lie within the range of sensitivity of the human ear. They can be generated in a variety of ways, such as by musical instruments, human voices, or loudspeakers.

(2) **Infrasonic waves** have frequencies below the audible range. Elephants can use infrasonic waves to communicate with one another, even when separated by many kilometres.

(3) **Ultrasonic waves** have frequencies above the audible range. You may have used a "silent" whistle to retrieve your dog. Dogs easily hear the ultrasonic sound this whistle emits, although humans cannot detect it at all. Ultrasonic waves are also used in medical imaging.

The limit of hearing varies from person to person and is approximately 20 kilohertz in healthy, young adults. Ultrasound devices operate with frequencies from 20 kHz up to several gigahertz.

5.4 USES OF ULTRASONIC WAVES

5.4.1 Ultrasonic imaging

Ultrasonic waves penetrate tissue and are scattered and absorbed within it. By **ultrasound imaging**, it is possible to form visible images of ultrasonic reflections and absorptions. Therefore, structures within living organisms can be examined with ultrasound, as with X-rays.

Ultrasonic examinations are **safer** than X-rays and often can provide as much information. In some cases, such as in the examination of a fetus and the heart, ultrasonic methods can **show motion**, which is very useful in such displays.

5.4.2 Ultrasonic flow meter

Using the Doppler effect, it is possible to measure motions within a body. One device for obtaining such measurements is the **ultrasonic flow meter**, which produces ultrasonic waves that are scattered by blood cells flowing in the blood vessels. The frequency of the scattered sound is altered by the Doppler effect. The velocity of blood flow is obtained by comparing the incident frequency with the frequency of the scattered ultrasound.

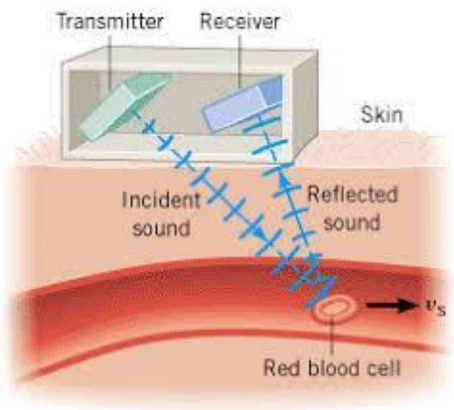

Figure 8: Ultrasonic blood flow meter.

5.4.3 Diathermy and lithotripsy

Within the tissue, the mechanical energy in the ultrasonic wave is converted to heat. With a sufficient amount of ultrasonic energy, it is possible to heat selected parts of a patient's body more efficiently and evenly than can be done with conventional heat lamps. This type of treatment, called **diathermy**, is used to relieve pain and promote the healing of injuries. It is actually possible to destroy tissue with very high-intensity ultrasound. Ultrasound is now routinely used to destroy kidney and gall stones (**lithotripsy**).

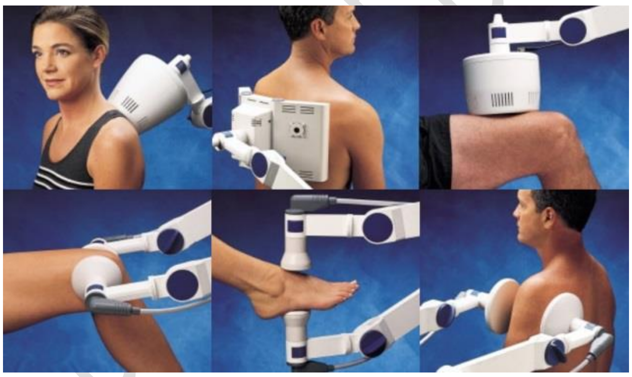

Figure 9: Diathermy.

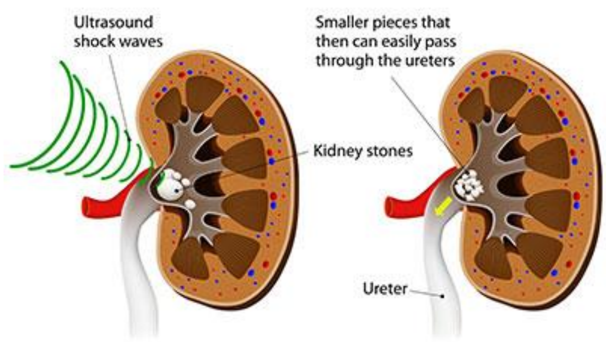

Figure 10: Lithotripsy.