# ME413 HW 10

Benjamin Masters

TOTAL POINTS

**145 / 150**

QUESTION 1

1 Q1 **100 / 100**

- **- 0 pts** Correct
- **+ 1 Point adjustment**

QUESTION 2

2 Q2 **20 / 20**

- **- 0 pts** Correct
- **+ 1 Point adjustment**

QUESTION 3

3 Q3 **25 / 30**

- **- 0 pts** Correct
- **- 5 Point adjustment**

1 Q1 **100 / 100**

- **- 0 pts** Correct

**+ 1 Point adjustment**

2 Q2 **20 / 20**

- **- 0 pts** Correct

**+ 1 Point adjustment**

3 Q3 **25 / 30**

- **- 0 pts** Correct

**- 5 Point adjustment**

Hw-10

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ME 413

Hearing and it's Supporting Mechanisms

Hearing is an amazing and complex process that takes place in most life forms on Earth. The general mechanism is understood, however there are also many complexities related to the perception and processing of the sound by the brain that are not as well understood. In this essay I will explain the process of human hearing, and how the outer, middle, and inner parts of the ear play a role in the process. To explain the process of hearing, I will describe the events as they occur when a sound wave travels from the outside into the ear.

The process begins with what is called the outer ear. Hearing starts with the Pinna, which is the outermost part of the ear and serves to effectively direct the sound waves towards the inner ear. The sound then travels through a sort of tube, called the Auditory Canal. Worth mentioning is that the sound pressure level within the ear is much greater than the free field level due to the reduction in area between the free field and the ear canal. This canal carries the sound waves to the middle ear.

The middle ear converts the sound waves to mechanical energy through a piece of anatomy called the Tympanic Membrane or Ear Drum. The sound waves cause vibrations in the membrane, which then results in motion of a series of three bones, called Ossicles, which are connected to the other side of the membrane. The three bones that make up the ossicles are called the Malleus (hammer), Incus (anvil), and Stapes (stirrup). The generic names describe well what the act of each bone is. The hammer is moved by the movement of the eardrum and strikes the anvil causing it's motion. The Stapes translates this motion into the inner ear. In the same area as the ossicles, there is another important feature that is responsible for equalization of the middle ear pressure to the outside atmospheric pressure, which is called the Eustachian tube and connects the middle ear to the nose. The last part of the middle ear is called the Oval Window, which vibrates as a result of the movement of the ossicles. The oval window serves as the link between the middle and inner parts of the ear. A diagram of the middle ear can be seen in Figure 1.

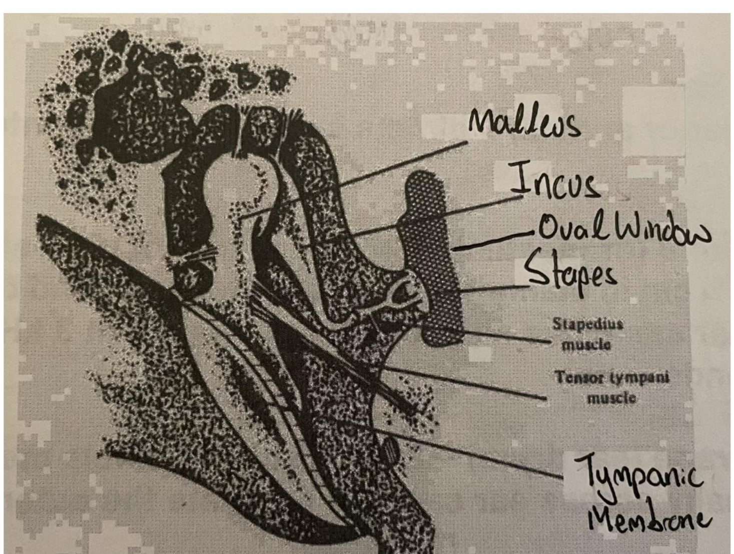


*Figure 1 - The middle ear*

The inner ear is arguably the most interesting and complex part of the ear. The oval window is connected to an organ which is called the Cochlea. The cochlea is snail-like in shape and is filled with fluid, and is also very small at only about 3.5cm in length and having a volume of 0.05 cubic centimeters. There are 4 main parts of the cochlea. The Upper Gallery, or Scala Vestibuli, the Lower Gallery, or Scala Tympani, the Helicotrema, and the Basilar Membrane. The upper and lower galleries contain the perilymph fluid, which vibrates as a result of the motion of the oval window and the helicotrema connects the two galleries. The basilar membrane separates the two galleries throughout the spiral of the cochlea, and also contains what are known as hair cells, or cilia. These hair cells react to the motion of the fluid and generate a nerve impulse which gets sent to the brain to be processed. The signal is sent to the brain via an auditory nerve. The motion of the fluid is stopped at what is known as the round window, which dissipates the leftover energy. A diagram of the entirety of the ear can be seen below in Figure 2.

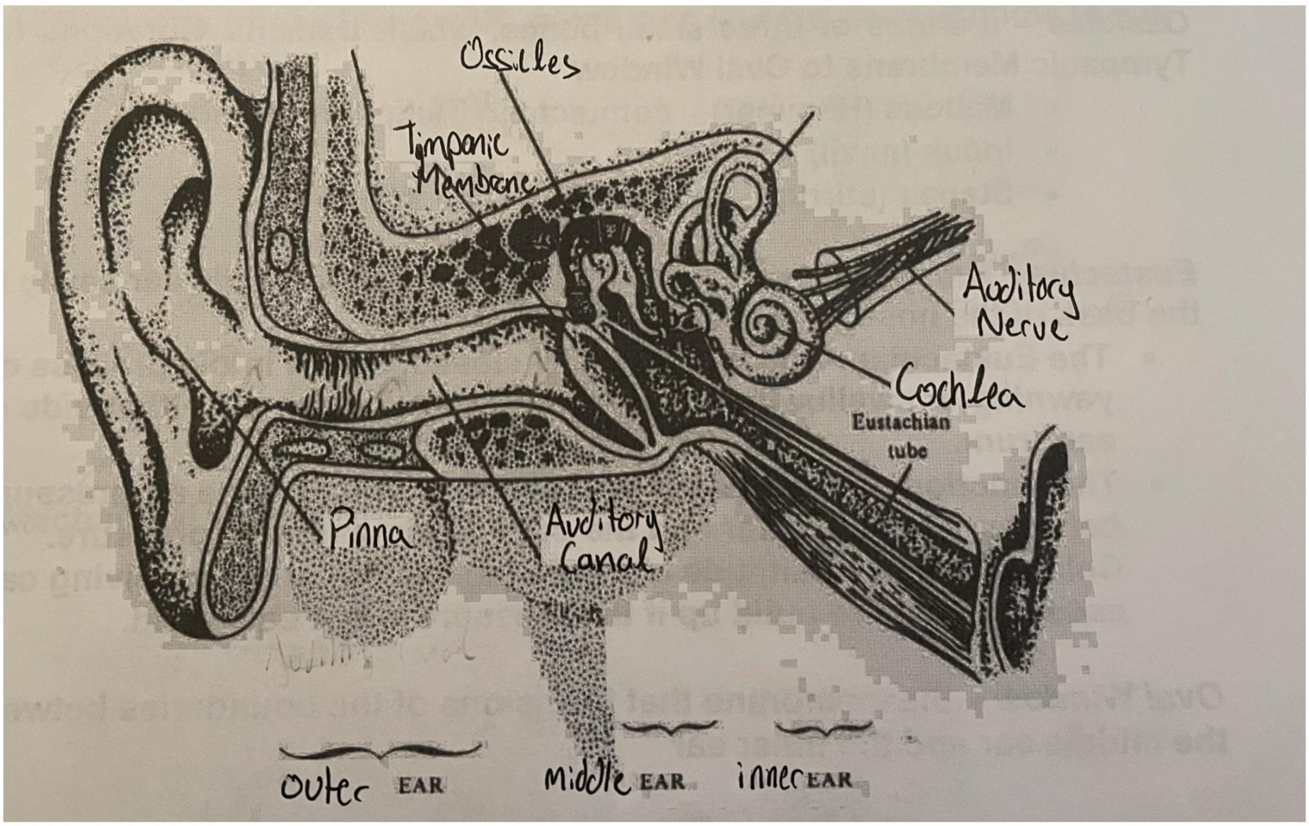


*Figure 2 - A diagram of the ear*

There are some other nuances to hearing that are worth mentioning beyond how it fundamentally operates. One quality of the hearing process is the loss of hearing. The ossicles have a lack of protection from loud impulses of sounds which can result in a rupturing of the eardrum and permanent hearing loss. Another form of hearing loss can be explained by the basilar membrane processing the higher frequencies closer to the oval window, therefore the cilia that are responsible for processing higher frequencies are subjected to more motion of fluid than those further along the basilar membrane. This is the reason that people tend to lose their hearing of higher frequencies first as they age.

Another point worth mentioning is that many of the operations of the middle and inner ear are non-linear, and therefore there are differences between the perception of sound and the measurable levels of sound pressure and loudness. Partially due to the way in which the basilar membrane processes sounds based on frequency. However, frequency is not the sole determining factor in perception of sound. The processing of sound is actually based on the pitch, which is defined as the perceived frequency, which is not identical to frequency. Pitch has other contributing factors such as sound pressure level and the existence of other frequencies in the content of the tone. Overall this can be summarized by stating that the sensitivity of hearing is related to the frequency and level of the incoming sound waves.

To summarize and conclude, the process of hearing takes place as a sound wave travels from free space into the inner ear. First the sound wave is directed into the auditory canal by the pinna. The sound wave then travels down the auditory canal and causes a vibration of the tympanic membrane, or eardrum. The movement of the eardrum causes motion in a series of three bones, called the ossicles, which in turn vibrate another membrane called the oval window. The oval window is connected to an organ called the cochlea, and its movement causes the movement of fluid within the cochlea. This movement of fluid causes motion of hair cells, or cilia, that generate nerve signals and send them to the brain via the auditory nerve. There are also some other points worth mentioning, such as hearing loss, the non-linear perception of sound, and the concept of pitch. This was written in an attempt to explain, in general, the process of hearing, the anatomy of the ear, and how the two are related.

**Question 2** (20 points)
Explain in your own words the difference between
(a) White noise
(b) Pink Noise
(c) Brown Noise
(d) Blue Noise
(e) Black Noise

(You should be able to get this information in a good internet site)

a) White noise has equal power through all bands, it is flat with respect to frequency.

b) Pink noise has decreasing power with frequency on a logarithmic scale it decreases by 3dB for each octave band as frequency increases.

c) Brown noise decreases by 6dB per octave as frequency increases. Similar to Pink noise but a greater decrease in power.

d) blue noise is opposite of pink noise, it's power increases by 3dB as frequency increases.

e) Black noise is silence.

**Question 3** (30 points)
Explain the following terms

(a) What is the percentage bandwidth for a one-fifth octave band?
(b) Low pass, high pass and band pass filters
(c) Aliasing Effects
(d) Nyquist frequency
(e) Dynamic range
(f) What is the dynamic range for a 24-bit A/D converter?

a) $f_{c_1} = f_c / 2^{1/5}$ , $f_{c_2} = f_c \cdot 2^{1/5}$ $\Rightarrow$ $\%BW = \dfrac{2^{1/5} - 1/2^{1/5}}{1}$

$\boxed{\%BW = 27.8\%}$

b) Low Pass filters remove all components of a signal above a threshold frequency.
High Pass removes components below a threshold frequency.
Band Pass passes signal components between two frequencies.

c) Aliasing is the loss of signal definition due to sampling. Can be seen as false frequencies.

d) Nyquist states that the sampling frequency must be greater than twice the highest occurring frequency.

e) Dynamic Range is the maximum level that can be accurately represented at a given bit rate.

f $S/N = 20 \log(2^{24}) = 144.5 dB$