# Neural Science for Engineers
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## Lecture - 41
## Human auditory system - II

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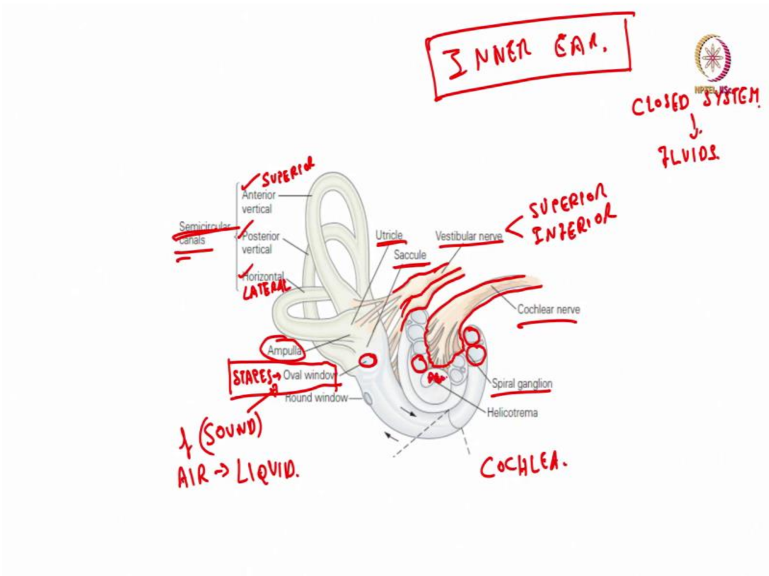


So, we start back with diagram of the inner ear where I had explained to you the various parts, the cut section showing the cochlea. Now, each spiral of the cochlea has got a circular part which is what is actually going around up to the apex of the cochlea. So, this is the apex.

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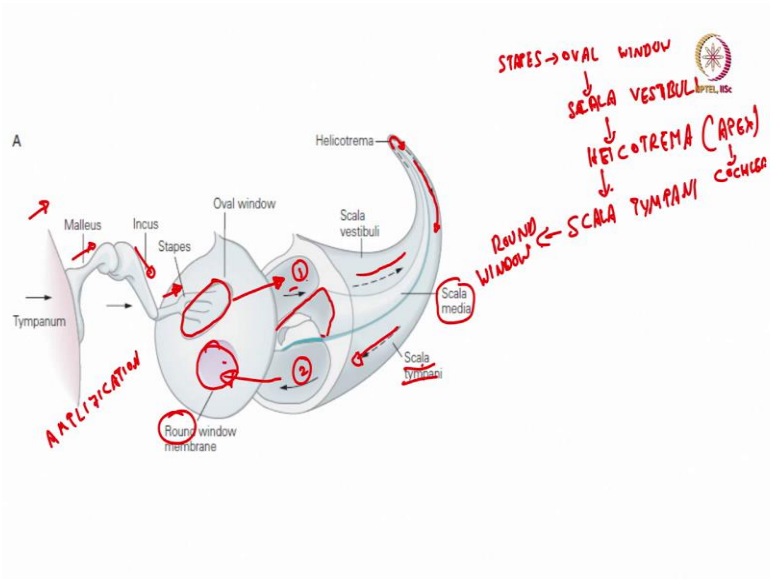


Now, if you look at a different diagram, there are several important things which need to be made out. So, one is this is the helical part, which is the cochlear, this one unwound actually. So, then that is unwound to have a sense that it is the same membrane and cavity.

Now, the cochlea is divided into three sort of cavities in the sense that it is called we will change the nomenclature subsequently. So, there is something called as scalar vestibuli, then there is something called scalar tympani. Now, the logic is that the oval window opens into this part of the cavity and then there is this round window which opens into this part of the cavity, I put the directions like this.

Now, I have spoken about the direction in which sound is transmitted. So, it is through the tympanic membrane through the malleus through the incus and through the stapes. Now, when sound is transmitted, I told you about amplification here. So, amplification is between the oval window and the sound is transmitted through this thing called as the scala vestibuli.

So, it is a 3D cut section. So, please do note that this is a 3D cut section. So, scala vestibuli and it goes through the scala vestibuli up to the apex, where it continues on the other side. So, that is what I meant by it being one single cavity, but it is called different scala tympani. So, through there it goes way back over here and impinges on to the round window.

So, if we map the pathway, it is steps oval window to scala vestibuli goes across the helicotrema which is the apex, apex of the cochlea; from there it is actually a continuous cavity. So, that is what is important to be remembered. So, scala tympani and finally, it gets dissipated into the round window.

So, that is the sort of pathway, it is a very complex structure. If you recollect the imaging which I showed you, I showed how big the size of the ear is and how small these structures are, and it is within these structures these smaller microstructures exist. Now, this is from the point of view of the sound wave, how the sound wave actually traverses through the inner ear.

And so, far I have not spoken anything about the sensor mechanisms. So, the entire sensor mechanism is present within the central center of this structure called as the scala media which is this part over here. So, the scala media is this area and that is the important place where things happen. So, we progress on to the next video.

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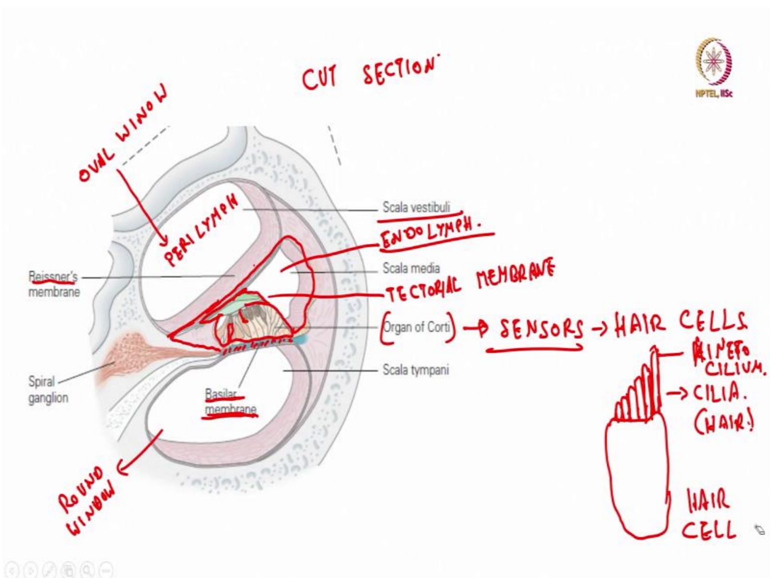


So, next picture and we will look at in greater detail of the cut section. So, scala vestibuli; so, we know that this is in terms of the oval window, and this goes how the sound is going out through the round window. It’s not going out, it is just that there is a membrane and the sound which is transmitted across this fluid filled cavity, it’s just it gets dissipated sort of over here.

Now, the central part is sort of sealed out excepting for this blue stuff which is seen over here. So, you have a very fairly rigid membrane over here which is called Reissner's membrane and then there is bone over here, bone over here excepting for this membrane over here which is sort of acting like a diaphragm.

So, the basilar membrane is a membranous structure, this is the cut section remember. So, this is part of the helix of the cochlea, within the helix of the cochlea is this set of structures. So, there is there are other features which are there. So, this the fluid which is over here is called perilymph and this area would be the endolymph.

So, endo lymph perilymph, perilymph is in the outside endolymph has endo is inside. So, endo is within these structures and that is what is seen. There is also this funny structure called tectorial membrane whereas, the treasonous membrane is this. This is called tectorial membrane. Now, all these are parts of the structure, but the important thing is called as organ of corti which is these things over here, you will see it in the next in greater detail.

So, this whole thing over here from here onwards up to this part is the organ of corti, I think it even includes the tectorial membrane. So, that whole thing is the organ of corti and that is where the sensors are actually present, now they are called hair cells, they are called hair cells because they have hair. The tallest one is called kineto cilium. So, this is the hair.

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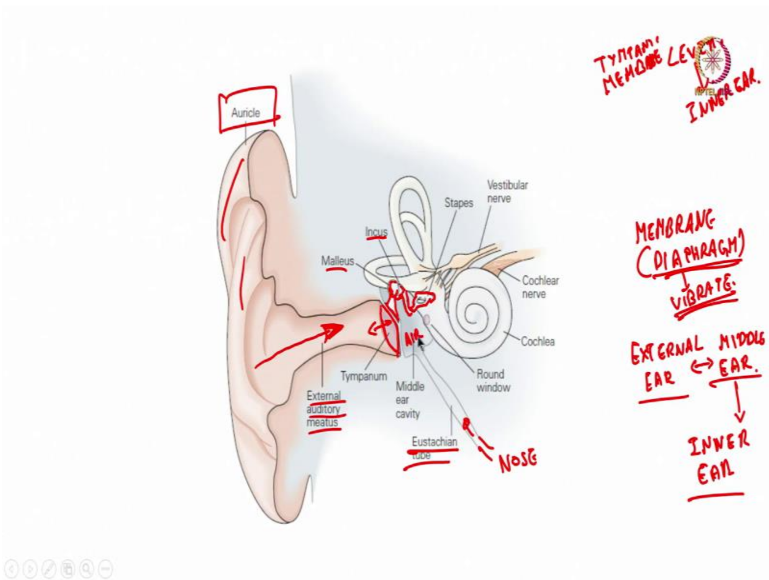

So, we started with the external ear which is this oracle which is over here and then you have the tympanic membrane, tympanic membrane on air on both sides goes through a set of bones, impinges on something called as the oval window, goes through the cochlear. So, cochlea, it's a two-channel system actually. So, there is a central channel and then there is a peripheral channel.

So, the peripheral channel goes all the way up to the apex where it meets with the other channel which is in continuity and then that channel comes back over here as the round window. The round window is actually not connected to anything, it is just connected to air over here in the eustachian tube, closer part of the closest section of the inner ear. Oval window, round window sound comes through the oval window, goes all over here from here and comes up to the base.

Then takes another turn over there and then goes back over here and back to the base and comes back into the round window. So, the fluid through which it goes is the perilymph, the fluid through which it does not go through is the endolymph. Now, cut section of that showing the arrangement of the structure.

So, the central thing, central chambers contains something called as the organ of corti and then there is this blue line which is continuing all the way separating this chamber from the below chamber here which is the scala tympani and that is extending all the way from the base up to the apex.

So, that is what is shown here. So, another cut section in which you can clearly see the basilar membrane, we can notice that the cells are situated on this basilar membrane. So, the hair cells which is written over here, this is the hair cell; several other kinds of supporting cells which are which serve several purposes. One is to stabilize the cells, literally in the sense that it mechanically stabilizes the cells. They also provide synapses, the synapses which go specifically to the spiral ganglion, and this is the spiral ganglion.

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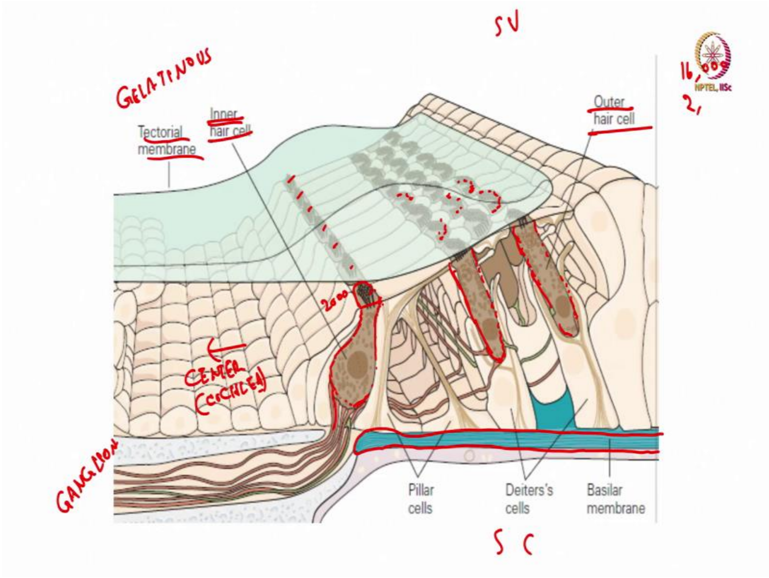


So, we go look into the organ of corti and the structure how it is arranged. So, to give context though this is the scala vestibuli and then this is the scala tympani. So, we are in the middle part of the cochlea. So, this is to give context again this is basilar membrane, on top of the basilar membrane is the cells.

So, we start with the most important cell, this is something called as the inner hair cell. The inner hair cell as you can make out here several synaptic connections and these synaptic connections go on to the ganglion. Now, this is inner hair cell because it is towards the center of the cochlea. So, inner hair cell then you got corresponding outer hair cell.

So, outer hair cells are these brown things and there are several of them. So, this is one single row. So, this one, this one, this one, this one, this one, this one is inner hair cell. There are multitudes of outer hair cells. A total of I think 16000, 16000 of which about 2000 are inner hair cells.

The remaining 13, 14000 is all outer hair cells. So, the there are so, many of them. So, these U-shaped stuff which you see over here are the cilia. Now, this cilia in turn are embedded within the sort of embedded within the tectorial membrane. So, tectorial membrane is gelatinous. So, these are the players. So, we have introduced the players where the players are situated, where the players stay, how the players are connected with the various parts with the cochlear ganglion and that is how the arrangement is made.

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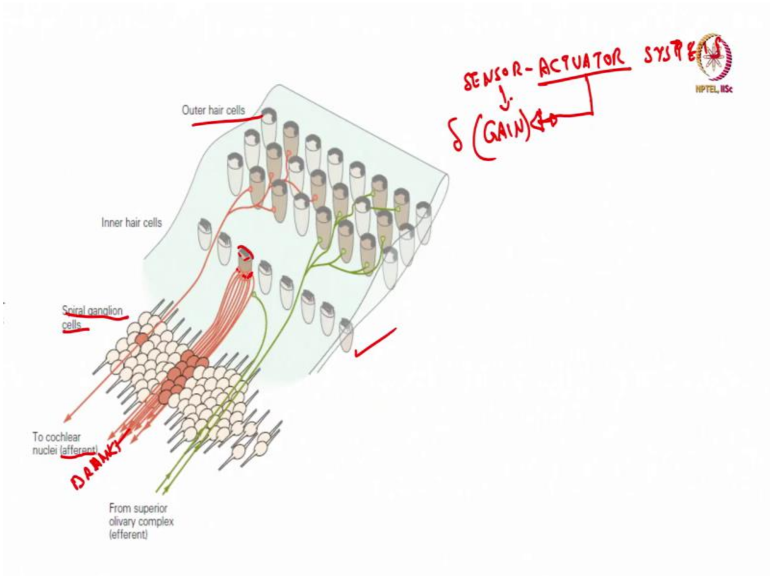


A little bit more about this diagram, I think I will be using this diagram later on also. So, you got outer hair cells which are on the outside, you have got inner hair cells which are over here. Now, each inner hair cell you can make out as making multiple synapses. So, multiple synapses go to multiple cells within the ganglion and from there the information goes back into the brain. I use the term brain, which is the cochlear nucleus, the olivary nucleus, the vestibular nucleus to the inferior colliculus to the primary auditory area.

So, all these afferents towards the brain. So, these are the signals which come, incidentally these are again sensor actuator systems is a common theme. So, we had looked at this in our class on muscle cells and muscle architecture and muscle reflexes, where I use these concepts.

So, these are again examples of sensor actuator systems in which the sensors are not just dumb systems of acquiring data, the sensors themselves are modulable; in the sense that you can change your gain of the sensor. So, the gain can be changed based upon whatever the requirement is and then we see how the gain is changed by the mechanism.

So, that is the actuator part of it. So, actuators can change gain. So, gain can be changed.

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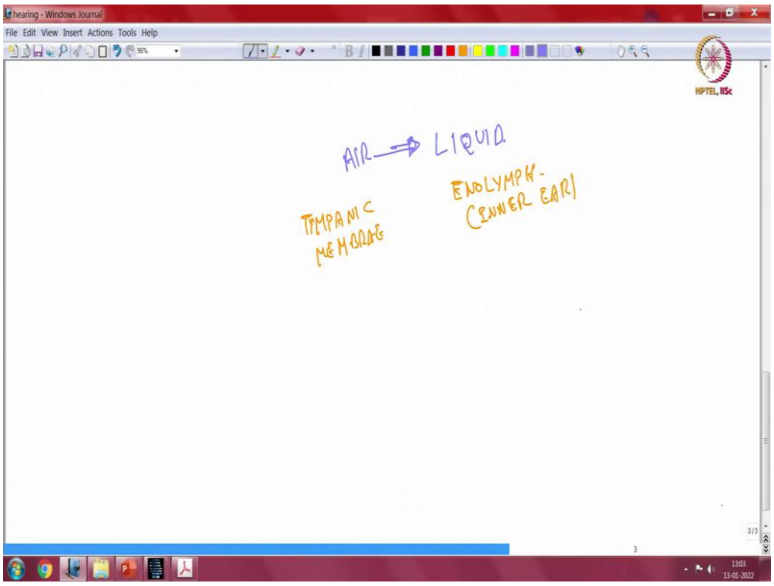


Now so, we now understand certain things and we understand fluid dynamics to some extent.

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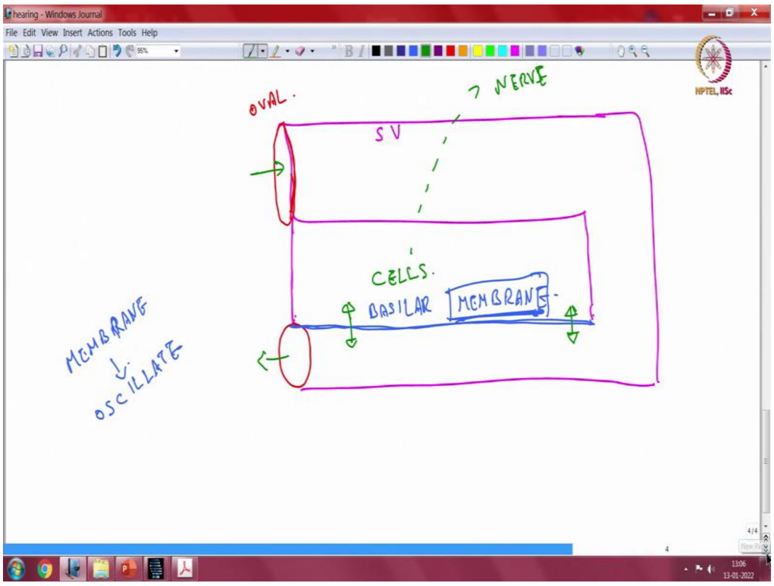


So, now I can go to the box notation for the fluid dynamics. So, we look at how things are, we have the scala vestibuli and then this is the round window, oval window. So, this thing continues up there. So, this is sealed. Now, what actually separates these two things is the basilar membrane and that is a membrane. So, that is the key thing.

So, what membrane can do is oscillate. So, we have started at very gross anatomical structures and then we come down to this idea that it is basically a sealed cavity. So, sound comes from here, goes out sort of from here. And, in the bargain what happens is the basilar membrane does this vibration and this vibration is what is getting transmitted onto the cells here and that sort of is going on to the nucleus.

So, that is where the nerve signals are coming and you have got electrical signals. So, there are lots of membranes here. So, reiterating what I have earlier told.

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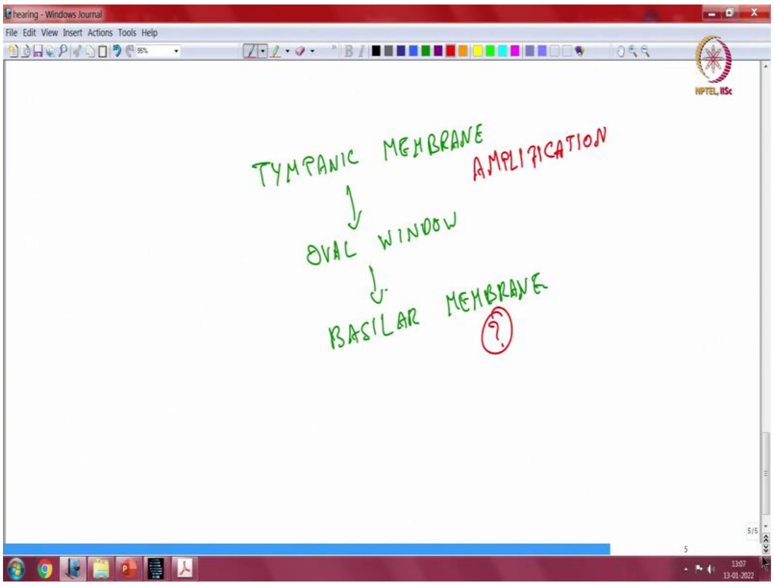


So, if we look at mechanism; so, tympanic membrane to oval window to basilar membrane. So, if you look at what is done over here it is amplification. So, then whole window to basilar membrane is also there is something else which is happening over here. So, what is exactly the basilar membrane doing. So, some properties of the basilar membrane are interesting.

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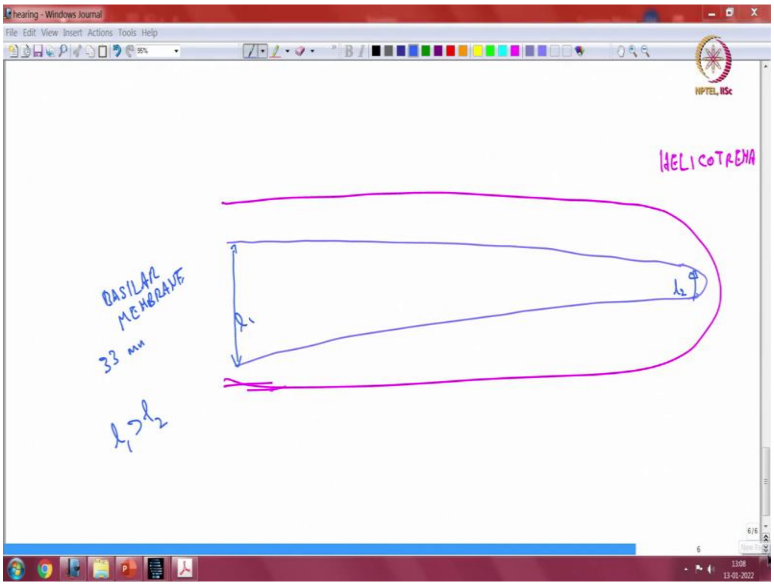


So, again we draw the whole, this unfolded; so, that to give a better idea of the basilar membrane. So, basilar membrane basically tapers, I have exaggerated the taper. So, this is something called as the helicotrema, now this whole thing is the basilar membrane. I think its 33 millimeter in length, 33 millimeter is about 3 centimeters. So, 33 millimeter in length, it has a length which is varying. So, you have l 1, then you have got l 2; so, l 1 greater than l 2.

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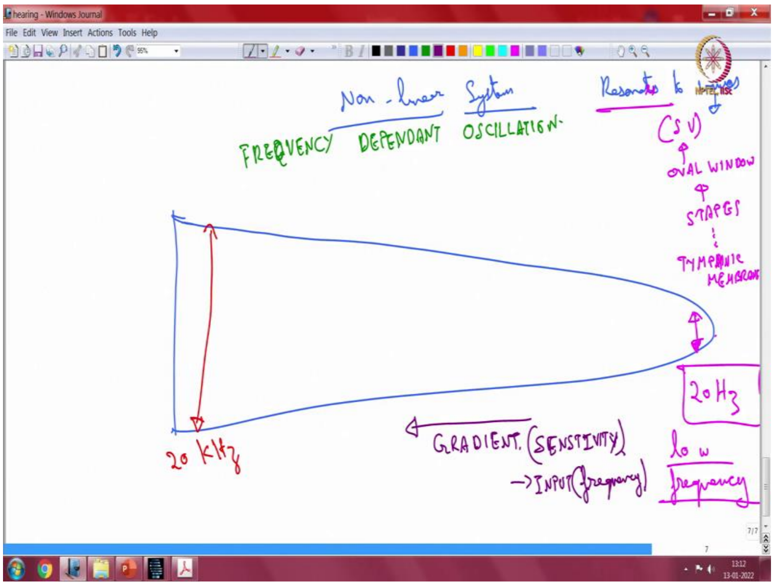

Now, apart from this difference in length, what is important is its response to, it is a non-linear system, I have to explain both the non-linear and the system part of it. So, what actually it does is it is like this, and it sort of resonates to two waves. Now, where did this wave come from? The wave came from the scala vestibuli which is coming from the oval window which is coming from the stapes and then from the tympanic membrane. So, non-linear system; so, it just it sort of resonates.

Now, I use the term resonates instead of something else for a specific reason. So, the entire membrane has a differential response to differential frequencies. So, frequency change, frequency dependent oscillation. So, how is it? So, something like 20 hertz and 20 kilohertz. So, 20 hertz there is maximum oscillation in this part of the membrane.

So, this is the basilar membrane. So, the apex of the basilar membrane vibrates with low frequency, then I need colors and high frequency that is 20 kilohertz, the base vibrates. So, there is a gradient of sensitivity to frequency input frequencies, sorry I think I should not use the confusing terminologies. So, the membrane is essentially split into various components. So, I have just shown it as 20 hertz.

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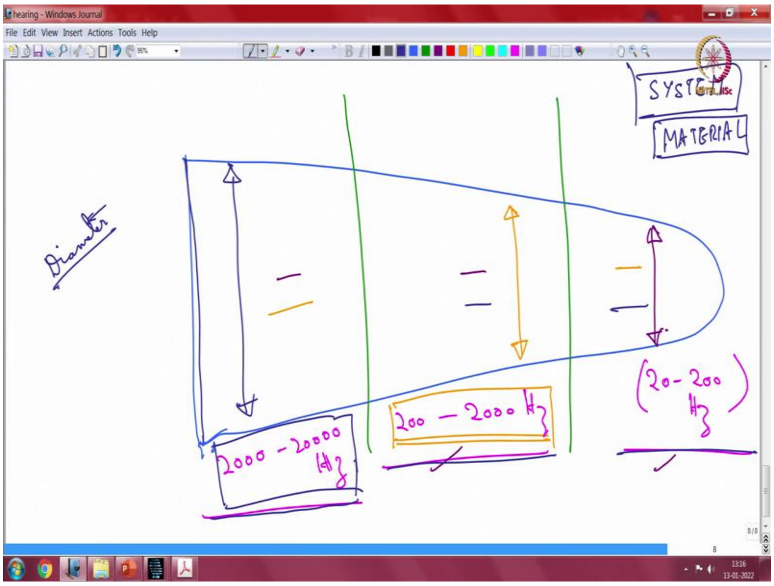


And so, big basilar membrane, the basilar membrane deserves respect, and I will shortly tell you why it is so. So, it is experimentally found that you have you can divide this into three components. So, 200 hertz, 200 to 2000 hertz, 2000 to 20000 hertz. So, that is how it is graded. So, what I mean is when you have frequency in the range of 20 to 200 hertz, there is a maximal displacement over here.

And no displacement over here when it is 2200 and when it is 200 to 2000 hertz, you have 200 I think I should have marked it with a different color. So, you have maximum displacement over here, minimum displacement over here. And, if we look at the more colors, if you look at the 2000 to 20000 kilohertz maximum displacement over here, no displacement in the rest. So, the basilar membrane is selective to frequency and different frequencies you know causes amplitude changes only in selected parts of the membrane. So, that is the idea of saying system.

So, it is just not a membrane, it is a system. So, the system has got material properties which ensure that it is material property. So, it mentions material properties based upon one maybe diameter and of course, I do not know the protein structure of this stuff. But the diameter you know it is this thing and that causes this membrane to oscillate at different frequencies.

So, this is the concept which I need to explain in lot more detail and so, I will take lots more time to explain this very important concept. And, interestingly there are I think at least some people in the audience by now there is an aha moment, once I spoke that this selective stimulation.

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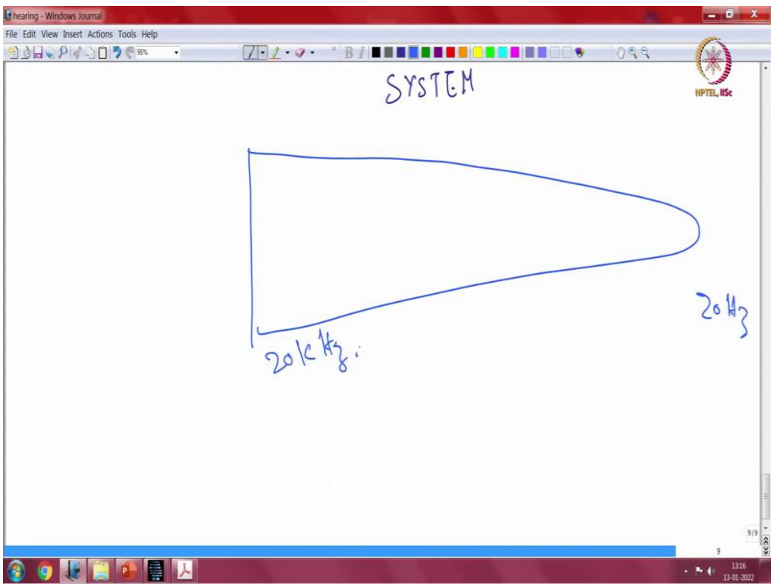

That is one part of the system. So, one part of the system story. So, system story of the basilar membrane. So, basilar membrane again 20 hertz, 20 kilohertz.

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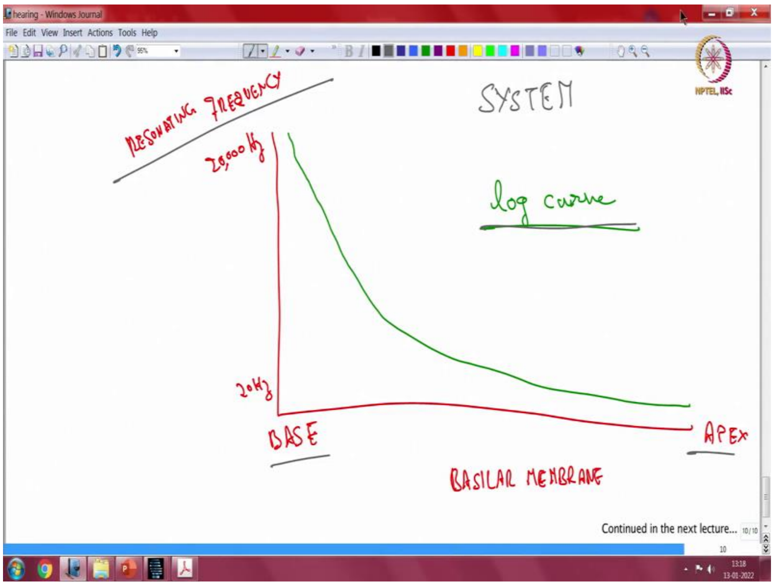


So, we plot frequency I should call it resonating frequency. So, the part of the membrane resonates to a particular frequency that is the idea. So, resonating frequency and then you have got the basilar membrane; so, apex base. So, we start at 20 hertz to 20000 hertz. So, if you would plot that, you would notice that it is a I think the curvature is a log. So, that is a log curve.

So, that is one more reason why I call it as a system instead of just a membrane. So, the membrane what you call gets excited by very different frequencies at very different parts of the membrane. So, that is the part of the story to which we have come down, couple more people would have the aha moment at this time because there is a lock and then there is a resonating frequency and then there is a base in the apex. So, we go to the next part of the story.