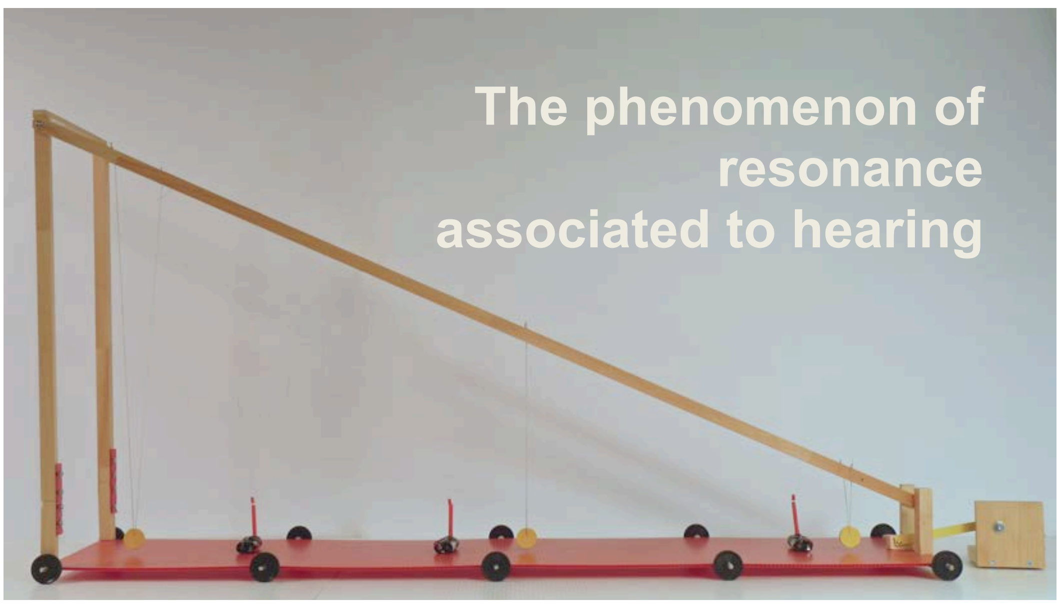
centre de développement pédagogique
pour la formation générale en science et technologie

Working document

Theoretical capsule about the model of the basilar membrane of the cochlea
(Intended for personnel)



October 2014

Pedagogical intentions

The model of the basilar membrane was developed by the Centre de Développement Pédagogique (CDP) following a request from the Commission scolaire des Draveurs. This model illustrates the mechanism for detecting different tonalities of sound by the inner ear.

The stereocilia of the cochlea transform the sound waves into nerve impulses, but are not directly responsible for the differentiation of sounds of different frequencies. Indeed to affirm that "the difference in the length of the hairs allows low sounds to be distinguished from high sounds" is an erroneous concept. Rather, it is the basilar membrane, by its morphology, that effects this distinction. The model enables the phenomenon of resonance, which is at the base of the sound perception mechanism by the inner ear, to be demonstrated.

Among other things, the model answers these questions:

- How can the inner ear distinguish between low and high sounds?
- Why do the stereocilia not vibrate all at once?
- What role do the stereocilia play?
- What role does the basilar membrane play?
- How does a guitar string produce the desired sound?

The present document allows personnel to understand the phenomenon and suggests tools for a potential presentation in class. Some of the videos are in French. In this case, narration by the teacher[1] would be desirable.

Propagation of a sound to the cochlea

When a sound is propagated through matter, it moves in the form of a compression wave. The particles of matter get closer and further from one another. In the case of solids, the particles are closer together. To make things easier, you can then say that the particles hit one another. Hence, the idea of using marbles to illustrate the phenomenon. To this end, a video from the CDP allows you to illustrate several sound phenomena using marbles:

Video produced by: "CDP"
https://www.youtube.com/watch?v=Pf6GBr6Kik8

Watching this video will allow you to better grasp the concept of a compression wave hitting the ear drum and moving the ossicles, which transmit their movement to the cochlea. Among other structures, the stereocilia and the basilar membrane are inside the cochlea. The basilar membrane is seldom dealt with in a task designed for high school. It is this structure, however, that disseminates the sounds of various frequencies to certain stereocilia. In fact, the basilar membrane is narrow and rigid at the beginning of the cochlea and wide and flexible at its furthest end. These morphological differences allow us to distinguish the different notes on the scale.

[1] In this document, the masculine is used to make the text more readable.

Resonance frequency of a system

The resonance frequency at first glance seems to be a very complex or difficult notion. Don't worry, it's not. As a child, you probably experienced it while swinging at the local park. How much fun was it to swing like mad?

At first, it wasn't easy. An adult had to push you, because the movement required coordination. Indeed, the torso and legs have to swing at a certain rhythm, otherwise nothing happens and it's frustrating...you need to adapt to the swing and follow its natural oscillation frequency. In physics, this is called resonance frequency of a system or an object. Each object has its own resonance frequency: wine glasses, guitar cords, pendulums, swings, bridges, etc. The phenomenon of resonance is also possible in the presence of electromagnetic waves: tuning into a radio station, heating water in the microwave, etc.

Resonance frequency and the basilar membrane

Sound waves that get to the cochlea resonate with certain sections of the basilar membrane. When this membrane vibrates, it excites nearby stereocilia. As we said earlier, the make-up of the basilar membrane is not uniform. At the beginning of the cochlea, it is rigid and narrow and has a relatively high resonance frequency. This section starts to vibrate when high frequency sounds reach the inner ear. The stereocilia associated to it then also vibrate and send a nerve impulse associated to a high sound to the brain.

A low frequency sound has no effect on this rigid, narrow section of the basilar membrane. It continues on its path, plunging deeper into the cochlea. The basilar membrane progressively becomes more flexible and reacts better to low frequencies. At a certain point, the membrane begins to vibrate, exciting the stereocilia, which send a nerve impulse associated to a low sound to the brain.

A wonderful video shows the path travelled by sound from the auricle (external part of the ear) to the basilar membrane. Since there is no narration, this video can be shown to the students directly:

Video produced by: ″Hughes Medical Institute″
https://www.youtube.com/watch?v=dyenMluFaUw

This same video, narrated in English, is also shown here:

Video produced by: ″Hughes Medical Institute″
https://www.youtube.com/watch?v=shStw2PIS5k

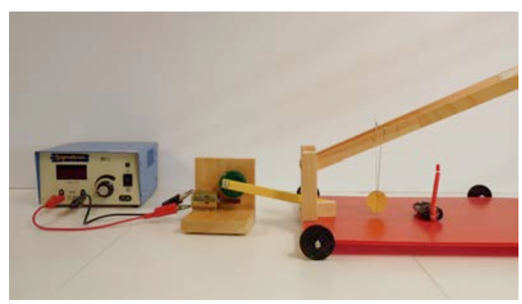
There is another good video in English, showing the path travelled by sound from the auricle to the stereocilia:

Video produced by: "Javitz 3D"
https://www.youtube.com/watch?v=qgdqp-oPb1Q

Model of the basilar membrane

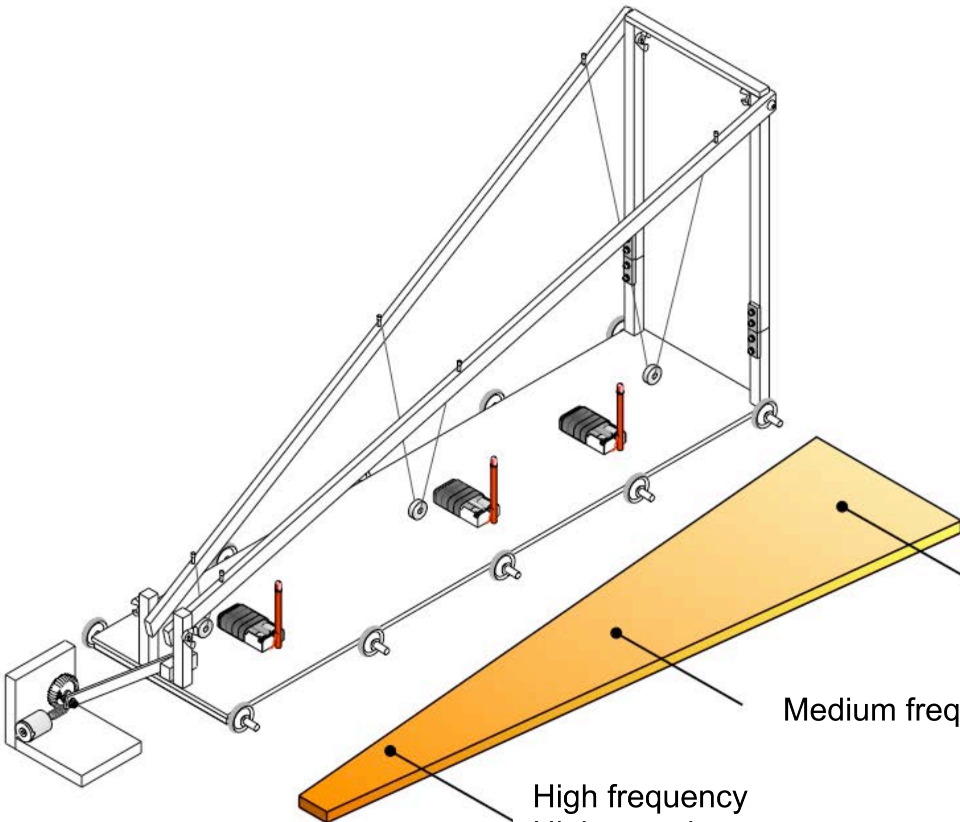
One last point remains to be cleared up. How to use the model to understand the phenomenon of resonance observed with the basilar membrane? In other words, what analogies are possible between the two phenomena?
The following video presents the model of the basilar membrane:

Video produced by: "CDP"
https://www.youtube.com/watch?v=7Jijp5GKLL4



Like the basilar membrane, the model does not react the same way to oscillations of different frequencies. When one section of the membrane vibrates, other sections are completely at rest. In the case of the model, when one pendulum starts to oscillate strongly, the other pendulums stay practically motionless.

Here are the parallels to be drawn between the basilar membrane and the model:



Model of the membrane		Basilar membrane	
Oscillation frequency	**Excited pendulum**	**Sound frequency**	**Excited zone**
High frequency (rapid oscillation)	The short pendulum	High frequency (high sound)	Narrow, rigid zone
Medium frequency	The medium pendulum	Medium frequency	Adjoining zone
Low frequency	The long pendulum	Low frequency (low sound)	Wide, flexible zone

Glossary and definitions that will be useful to the students

- **Pendulum:** Mass suspended at the end of a string
- **Oscillation:** one back and forth motion (a complete cycle)
- **Frequency:** the number of cycles per second (expressed in Hertz)
- **Resonance frequency:** natural frequency specific to a system

References

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5. Lesion of inner stereocilia
http://en.wikipedia.org/wiki/Organ_of_Corti
6. Toxicity of hyper-frequencies (microwave resonance vs. DNA) (in French)
http://www.cem-expert.fr/facteurs-toxicite-hyperfrequences-rayonnement-micro-onde-toxique-solutions-expertise,fr,8,71.cfm