INTRODUCTION
An introductory physics laboratory experiment guides students through several computer simulations investigating the properties of waves and wave interference. After the simulations, students are prompted to determine the minimum and maximum frequencies they can hear using a basic function generator and headphones.

However, students with disabilities such as deafness would not be able to participate in all aspects of this investigation. Accommodations must be made in university educational settings to ensure all students have the proper tools to investigate scientific phenomena and learn.

OBJECTIVES
1) To create a physics lab accommodation allowing a deaf student to determine the hearing sensitivity of an electro-optical eardrum
2) To simulate playing tones of equal loudness to determine a person’s range of hearing by determining the eardrum’s range of hearing.

BIOPHYSICS OF HEARING
The purpose of the auditory system is to convert sound (pressure) waves into electrical signals the brain can interpret.

1) A sound wave travels down the auditory canal
2) The sound wave reaches the eardrum (tympanic membrane) at the end of the canal and oscillates it inward and outward
3) The eardrum oscillation vibrates the 3 inner ear bones (malleus, incus, stapes)
4) The vibration of the stapes strikes the stapes faceplate which rests against the cochlea, a fluid-filled tube with thousands of hair-like cells
5) This strike sends a compressional wave through the cochlea
6) If the frequency of this wave matches the resonant frequency of the hair cells, it will cause them to resonate and vibrate with larger amplitude
7) The large amplitude movement initiates nerve cells to emit electrical impulses to the brain

HEARING SENSITIVITY
An individual’s hearing sensitivity can be determined by a simple test—chose a reference tone at a specific frequency and loudness level—change the frequency from the reference but keep loudness level constant. The individual then relays if the new sound is perceived as of equal, higher, or lower loudness than the reference tone.

If the loudness at this new frequency is not perceived equal, the loudness level is changed until the individual perceives the new frequency tone as the same loudness level as the reference. From this collected data, an individual’s hearing sensitivity can be plotted on a graph of frequency vs. equal loudness. The graph displays the individual’s perceived equal loudness contours of different frequencies.

EXPERIMENTAL SET UP
A double open ended PVC pipe modeling the ear canal is suspended over a speaker via a hose clamp and ring stand. A membrane (exercise resistance band) is held in place by a separate hose clamp and stretched over one end of the pipe with constant tension. Delicately glued on the resistance band is a small circular mirror effectively making it a mass loaded membrane. The apparatus is placed equidistant between a screen and a laser pointer. The light ray from the laser is directed at the mirror and reflected on to a screen. The output of a function generator, which allows the user to control the amplitude and frequency of pressure waves originating from the speaker, is sent to an audio amplifier powering the speaker. The laser pattern seen on the screen is dependent on the mode that the speaker’s pressure wave produces on the mass loaded membrane.

PROCEDURE

- **Determine a “reference tone” – fixed membrane amplitude**
- **Use the membrane amplitude equations to determine the membrane amplitude utilizing the laser reflection pattern**
- **Determine lowest frequency the membrane responds to with this amplitude while at max power**
- **Increase frequency by 5 Hz increments, adjusting speaker power, aka “loudness level” each time so the membrane responds with the predetermined reference amplitude**
- **Re-normalize data and use to generate a hearing sensitivity plot**

MATHEMATICS FOR MODE (1,1) MEMBRANE AMPLITUDE

\[ \frac{1}{2} \pi = \frac{1}{2} \sqrt{\frac{E}{\rho}} \left( \frac{a}{b} \right) \]

**SOUND VISUALIZATION**

**EXPERIMENTAL SENSITIVITY PLOT**

**FUTURE WORK**

The system’s initial design attached the PVC pipe with twist resistance band directly to a speaker. The direct contact and subsequent direct transfer of energy from the speaker produced several more modes on the membrane than the final suspended PVC pipe position. Since the sheer weight of the mirror is the likely culprit for damping or preventing the formation of higher membrane modes, future inquiries are suggested to use a circular mirror of less mass to view more modes or possibly silver paint for reflection.

Also, it produced an interesting phenomenon, costed “periodic mode switching.” At fixed time intervals, the membrane spontaneously alternated between two modes of oscillation. It was hypothesized that thermal hysteresis effect was the cause; however, no further inquiry was made into this idea.

Other intriguing studies are the effects of different pipe diameters, mirror masses, and membrane tensions on the device’s frequency range.

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