A4_6 Music to my ears

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Abstract

In this paper we determine how much sound energy is transferred into the ear canal from headphones. After making assumptions, we found the sound energy to be a minute amount when you increase the sound level produced by the headphones. We found the sound energy difference between 80 and 90 dB to be 18.7 nJ.

Introduction

The invention of headphones has led to a revolution in listening to music on the go without disturbing anyone in the immediate area. However, due to the compact size and proximity to the ear drum, they can lead to serious hearing loss [1]. The aim of our investigation is to find out how much sound energy is transferred into the ear canal from headphones.

Sound Energy

The formula for finding the sound energy (W) of a given volume from [2] is:

$$W = \int_V \frac{p^2}{2\rho_0 c^2} dV + \int_V \frac{\rho v^2}{2} dV \qquad (1)$$

In Equation (1): V is the volume of the ear canal, p is the sound pressure, v is the velocity of the air molecules, ρ_0 is the density of the medium without the sound present, ρ is the local density of the medium of 1.5×10^{-6} m^2 [3], and c is the speed of sound [4]. We have included the values of sound level as it is a common way to measure sound. From here, we have converted sound level to sound pressure [5].

Finding the velocity of air molecules

A key factor in Equation (1) is the velocity of the air molecules. The equation for average kinetic energy of a gas which is given from [6] is:

$$E_{avg} = \frac{3}{2} kT \qquad (2)$$

Where k is the Boltzmann's constant and T is the average temperature.

This equation will allow us to calculate the kinetic energy for air molecules. However, we are going to model the atmosphere to be made completely out of nitrogen. This will help in calculating the velocity as we only need to model one type of molecule. The equation to find thermal velocity is given in [6]:

$$v = \sqrt{\frac{2E_{avg}}{m}} \qquad (3)$$

Where v is the thermal velocity of the nitrogen, E_{avg} is the kinetic energy of nitrogen and m is the mass of the nitrogen molecule at 4.65×10^{-26} kg [6].

For the maximum volume of sound, we have used 90 dB. This is considered the upper limit on what is safe for a human to listen to [1].

Assumptions

To find the velocity of the air molecules, we have assumed that air is an ideal gas. For this paper, we are using the assumptions that the temperature/pressure of air in the ear will be ($T = 301$ K, $p = 1$ atm). We believe this to be a reasonable assumption.

To find the sound energy, assumptions were also made. We assume that the ear canal walls do not cause any loss of energy due to oscillation or absorption of any incoming pressure wave. In future studies this could be investigated, but it is beyond the scope of this paper. Equation (1) has also assumed non-relativistic speed of the molecules. As headphones are made for humans, we can assume that the speed of the air molecules as a result from the pressure wave does not become relativistic. We have also used the range between 80 to 90 dB as it gives us a broader range of data for this investigation.

We have assumed that ρ_0 and ρ are the same due to the small volume we are using. We assume a constant volume for the human ear to be 1.5×10^{-6} m^2 [3]. We have also assumed that nitrogen is diatomic, as this is the most common form to find in the atmosphere.

Results

We calculated the average kinetic energy of air to be 6.2307×10^{-21} J by using Equation (2). From this value we calculated the velocity of air from Equation (3) to be 517.67 m/s. With this value, we can substitute into Equation (1), which allows us to attain a value for energy dependant to the sound pressure of the source. The results from this are shown in Table (1). There was an 18.7 nJ change in energy between 80 dB and 90 dB.

Sound level (dB)	Sound Pressure (Pa)	Change in Energy from 2.46×10^5 nJ
80.000	0.200	0
81.000	0.224	5.00×10^{-10}
82.000	0.251	1.20×10^{-9}
83.000	0.282	2.10×10^{-9}
84.000	0.316	3.10×10^{-9}
85.000	0.355	4.50×10^{-9}
86.000	0.399	6.20×10^{-9}
87.000	0.447	8.20×10^{-9}
88.000	0.502	1.10×10^{-8}
89.000	0.563	1.44×10^{-8}
90.000	0.632	1.87×10^{-8}

Table 1: The total energy of the sound wave in relation to the sound level in an adult ear canal.

Conclusion

In conclusion, the total sound energy produced by headphones is low, with a difference of 18.7 nJ between 80 to 90 dB. At 85 dB, prolonged listening at this level could affect your hearing permanently. Future work on the idea could be done to expand the concept of sound energy and apply to other situations.

References

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