Measurements of Sound Waves and Comparisons to Quantum Mechanics

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Abstract

In quantum mechanics, the wave equation can often be non intuitive. However, the nature of macroscopic waves can provide a useful analogy for understanding the wave nature of quantum objects. Sound was used here as a comparison. It was tested in an approximation of a 1 dimensional particle in a box through a hollow tube, and in a comparison to the hydrogen atom in a hollow sphere. The results show that the wave equation for sound and the wave equation in quantum mechanics produce similar behaviors in regard to resonance and spectra.

1 Introduction

In the time since the development of Schrodinger's wave equation, the wave nature of quantum particles[1] has been widely known. However, due to the scale of quantum mechanics this is something that is very hard to visualize or intuit. Sound is a convenient macroscopic wave, and since it shares this fundamental nature with quantum particles, there may be similarities worth exploring. This experiment tests these similarities in an approximation of a 1 dimensional particle in a box and a 3 dimensional sphere.

The particle in a box is also referred to as an infinite potential well. It consists of a single particle in a box with walls that would take infinite energy to break past. the possible states of this particle are dependent on the width of this box[2]. With sound, an analogous system could be a tube confining the sound as close to one dimension as is practical.

For the case of the hydrogen atom, a hollow spherical shell with a speaker in the lower hemisphere and a microphone in the upper hemisphere was used. This is analogous to the first electron orbital of the atom. Theoretically, both systems should produce harmonic frequencies that fall out of the spherical harmonic equations. Spherical harmonics are a convenient set of equations that explain the behavior of waves propagating through a sphere.

2 Method

For all parts of this experiment, an Agilent 33220A signal generator was used to determine the frequency of the sound produced by the speaker and a Tektronix TDS 2002C oscilloscope to measure the original signal and the sound received by the microphone.

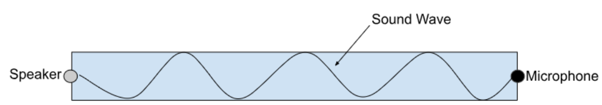

Figure 1: Diagram of part 1 instruments. note that sound waves are actually pressure waves not sinusoidal waves.

In part 1, the tube was set up as shown in figure 1. The length of the tube was 600 mm. The in put frequency was varied from 100Hz to 6100Hz and the resonant frequencies that were encountered were used to measure the speed of sound. When obtaining the spectra measurements, the oscilloscope was set to xy mode and the measurements were set to persist indefinitely. The frequency was then swept from 1000Hz to 10000Hz to obtain a spectrum curve. This was then repeated with a 450mm tube.

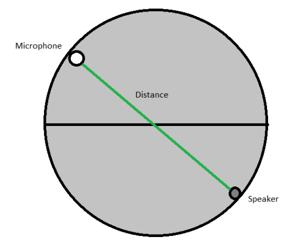

Figure 2: Diagram of part 2 instruments. The distance is not always equal to the radius. This experiment involved rotating the top hemisphere independently.

For part 2, the setup was switched to a hollow sphere as shown in figure 2. First, the frequency of sound was swept from 100Hz to 8000Hz to find resonances. Then the position of the top hemisphere was rotated at the first resonance found, and the angles that produced local maximum amplitudes were recorded. this was repeated for the first 4 resonance frequencies.

3 Results

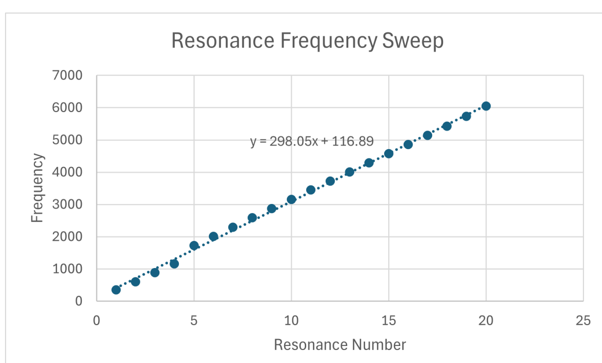

Figure 3: Data from first frequency sweep in tube.

Figure 3 is the result of the frequency sweep run in the 600mm tube. This data resulted in a measured speed of sound of 376 m/s. This was from the equation $S = \frac{2Ln}{f}$, were n is the frequency number, f is the frequency, L is the length of the tube, and S is the speed of sound.

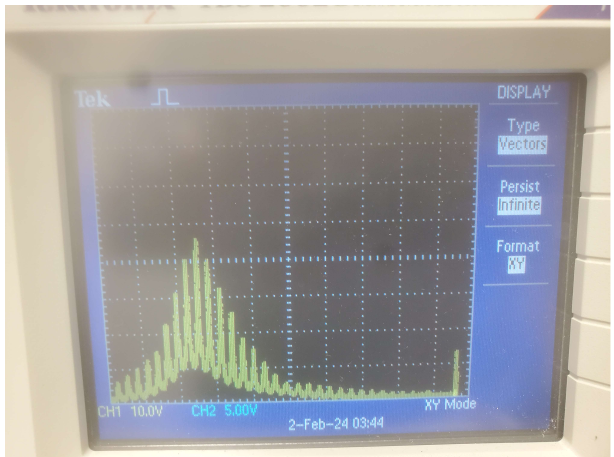

Figure 4: Spectrum measured on 600mm tube, disregard final spike.

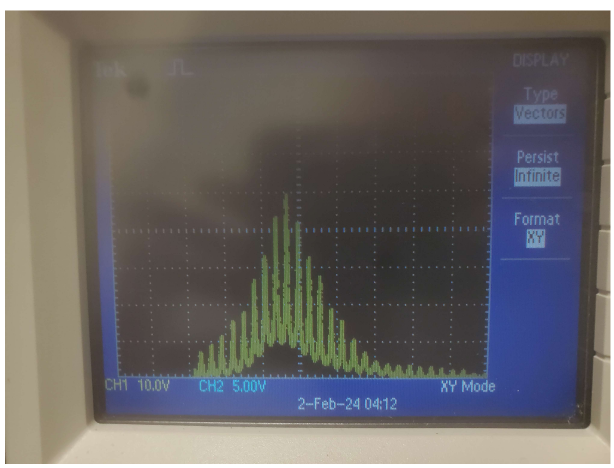

Figure 5: Spectrum measured on 450mm tube.

Figures 4 and 5 show the difference in spectra based on the length of the tube. Notice the shift to the left, showing the increase in resonance frequencies when the tube is shorter. In quantum mechanics, emission spectra do not have the curved spike shape they do here, instead the spikes are so steep that they appear as vertical lines. The locations of the peaks do still follow a similar trend.

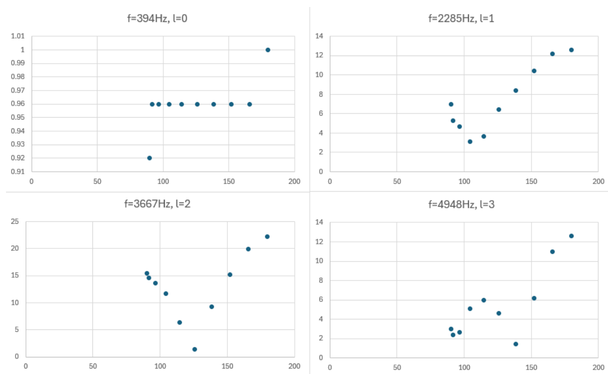

Figure 6: Y axis is amplitude, X axis is the polar angle between the microphone and speaker.

Figure 6 shows the results of the angle changes of the spherical shell. The theory to fit these to is the first 4 Legendre polynomials, which should look like figure 7. These come from spherical harmonics, which are also used to explain the behavior of the electron in the hydrogen atom. It is hard to be sure since there is only data from 90 to 180 degrees, but the shape of each data set is similar. Demonstrating a similarity between the behavior of sound waves and the wave nature of electrons.

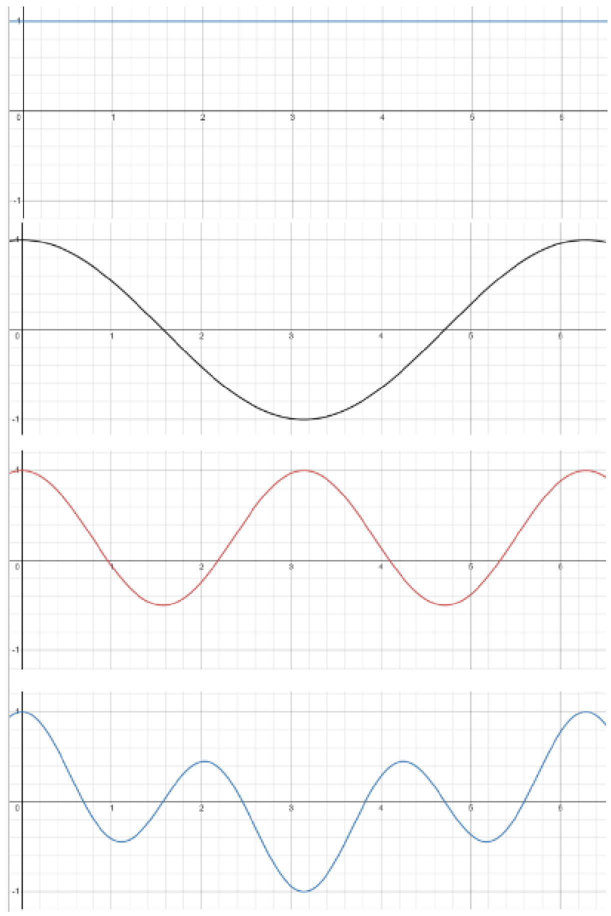

Figure 7: In descending order, Legendre polynomials of form $P_l^0(cos(\theta))$ for l=0,1,2,3

4 Conclusion

In this analogy between quantum mechanics and sound, a clear similarity has been demonstrated. This is due to their shared nature as a wave. Specifically, the properties of a particle in a box are shared with a sound wave in a hollow tube. The patterns of emission spectra can be demonstrated using the resonant frequencies of sound. Finally, the properties of the electron in a hydrogen atom expected from spherical harmonic equations are also shown from sound propagating in a sphere.

References

[1] Erwin Schrodinger, An Undulatory Theory of the Mechanics of Atoms, 1926

[2] David Griffiths, Introduction to Quantum Mechanics 2nd Edition, Prentice Hall, ISBN 9780131118928