

Quantum Mechanics Seen in Sound Wave Mechanics

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Quantum mechanics has been becoming more widely accepted, and for good reason – quantum theory can explain many previously unsolved problems, such as the photoelectric effect. There exist many systems that can behave like quantum systems, and one such system is acoustics. In this experiment we propagate sound waves through one-dimensional and three-dimensional systems and measure properties of acoustic resonance with these systems. Our experiment analyzes and compares the results of acoustic resonance to quantum resonance in both the “particle-in-a-box” situation and in the case of the hydrogen atom. Using our experimental setup, we report the speed of sound to be $c = 343.92 \pm 0.60$ m/s. The comparisons of this experiment align with quantum cases and support the hypothesis that quantum mechanics is a complete theory of modern physics.

I. INTRODUCTION

The Schrödinger equation,

$$i\hbar \frac{d}{dt}|\Psi\rangle = \hat{H}|\Psi\rangle, \quad (1)$$

describes the wave function of a quantum-mechanical system[1]. Wave equations can describe classical systems as well, such as sound waves. As quantum mechanics begins to be investigated more thoroughly, comparisons can be drawn between wave functions of classical systems versus wave functions of quantum systems. The wave function Ψ describes the propagation of motion of a wave, and can give the speed of propagation[2].

One similarity between quantum and classical systems is the idea of resonance, or when a system has matching temporal or spatial periods with another object. In the case of this experiment, we say that the material is at resonance when the sound waves incident are in matching in temporal phase with the metal tube or sphere. Resonance was discovered to be possible in atomic cases, such as the hydrogen atom, or some diatomic molecule[3]. This phenomenon is called nuclear magnetic resonance (NMR), and in the case of the hydrogen atom, can be adequately compared with a metal sphere with incident sound waves.

In the propagation of sound waves through a medium, we say that the acoustic resonant frequency observed through air is described by Equation 2,

$$f = \frac{nc}{2L}, \quad (2)$$

where f is the observed frequency, n is the resonance number, c is the speed of sound through air, and L is length of the material. Note that n must take discrete values $n = 1, 2, 3, \dots$. According to this equation, we

would expect that n and f are directly related, which will be further discussed in Section III.

In this experiment, we compare the quantum phenomena of NMR of a hydrogen atom to resonance of a metal sphere with sound waves, and we compare the “particle in a box” 1-D situation of quantum mechanics to sound waves in a 1-D metal tube. We will compare spectral lines of sound waves to those of light spectroscopy as well. If quantum mechanics is a complete theory of physics, then we expect to see the same phenomena in both sound waves and in quantum scenarios.

II. METHOD

A diagram of the apparatus used for the experiment can be seen in Figure 1. The experiments carried were of three different forms.

The first form was the simple 1-D case. The single generator pushed a sine wave to the controller, and the controller emitted the resulting sound wave from the speaker within the aluminum tube. The sound wave traveled down the 60 cm tube to the microphone, which then converted the incident sound wave into an alternating current to be read on the oscilloscope. The frequency was slowly increased until the sound wave from the microphone was at a local maximum amplitude, which meant that the aluminum tube was at resonance. This process was repeated for the first twenty resonances, and a generous uncertainty of 10 Hz on each frequency was claimed.

The second form used the 1-D tube but with the oscilloscope measuring driving frequency on the x-axis and resulting amplitude on the y-axis for a 15 cm aluminum tube. With the oscilloscope in this mode, spectra were taken by observing peaks of amplitude across a range of frequencies. No uncertainties were reported for this form, since no quantitative analysis took place.

The third form was identical to the first form, except instead of the sound wave passing through the aluminum tube, it was passed through the aluminum sphere. The sphere could be adjusted by its equatorial angle, and the

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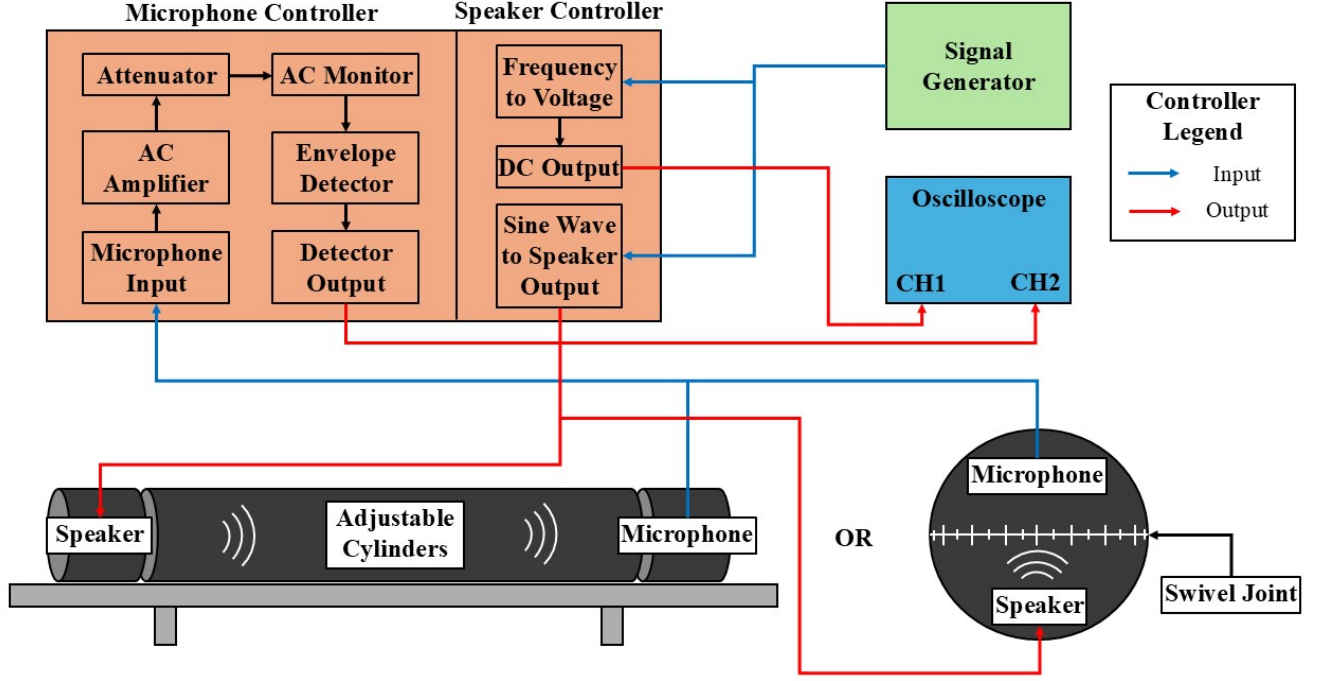


FIG. 1. The apparatus used for the experiment. The noise wave was generated as an oscillating sine wave with programmable frequency from the signal generator. This signal then traveled to the controller, which either pushed the wave to one of the speakers or to the frequency-to-voltage converter, which can then be monitored on the oscilloscope. The microphone recorded the amplitude and frequency of the incident sound waves and sent it back to the controller, which can adjust its output amplitude via the attenuator for easier viewing on the oscilloscope. The tube can be adjusted for different lengths, and the sphere can be rotated for different equatorial angles, which leads to different distances between the speaker and the microphone.

angle chosen for this experiment was 180° , which was chosen to be where the microphone and the speaker were a maximum of 10 cm apart. The resonant frequencies were identified in the same way as form 1. The first resonances within 0-8 kHz were measured, which resulted in measurements for the 8 first resonant frequencies. For this experiment, an uncertainty in frequency was claimed to be a generous 10 Hz.

III. RESULTS AND DISCUSSION

In Figure 2, we see the first twenty resonant frequencies of a 60 cm aluminum tube as a function of resonance number n . The data are fit with χ^2 to the direct relation seen in Equation 2, with a reduced form of $f = an$. The fit gives a χ^2 value of 5.4, which suggests that this is a good fit. The fit returns a value of $a = 286.60 \pm 0.14$ Hz, which corresponds to a value for the speed of sound in air of $c = 343.92 \pm 0.60$ m/s, which is a reasonable value. There is a slight decreasing trend in the residual values, which is likely to be an artifact of the increasing humidity and temperature of the room that held the apparatus, and does not negate our results.

The results of the 1-D tube align with the expectations

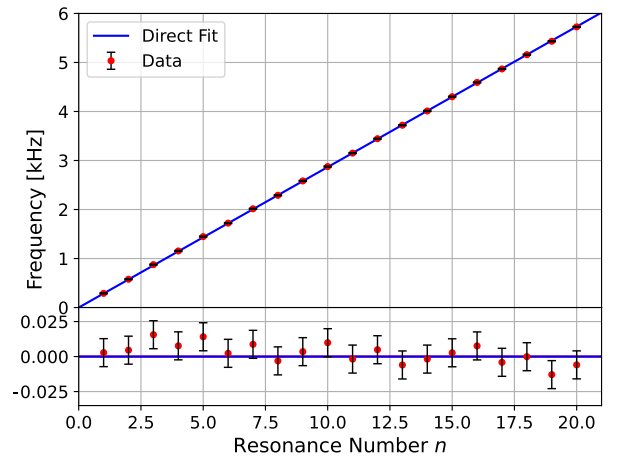


FIG. 2. The top portion of the plot shows resonant frequency values as a function of resonance number. The fit used is a direct fit with form $y = ax$, where $a = 286.60 \pm 0.14$ Hz. The bottom portion of the figure is the residual plot, and all error bars seen are ± 10 Hz.

of the “particle-in-a-box” quantum system – the energies of the system can only take discrete values, which

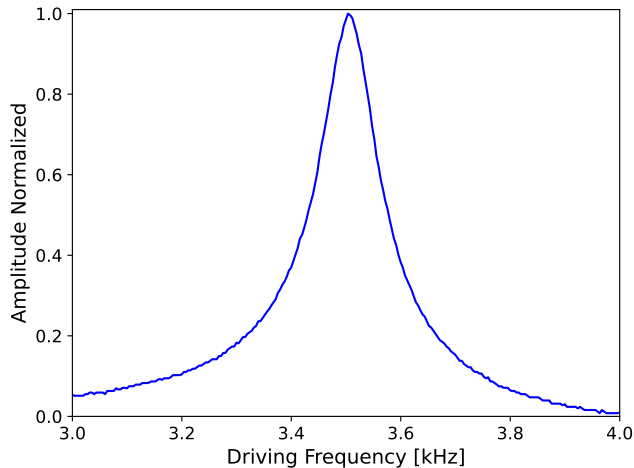


FIG. 3. A zoom of the resonant frequency of a 15 cm tube with the maximum amplitude frequency at the center. The data are taken from a still of the oscilloscope screen and scraped to take approximate data points. The y-axis is normalized to the maximum amplitude of the feature.

are integer multiples of the base-level energy. The wave function of this quantum system becomes like a standing wave at these discrete values, which is what we see during our validation of the resonant frequencies – as well as being at a maximum amplitude, the observed sound wave is in phase with the produced sound wave.

In Figure 3, we see the spectrum of sound amplitude versus driving frequency for a 15 cm tube. This distribution is not symmetric, and this is because of the other frequencies that are not seen in the plot. When one sound is heard from a source, what is actually heard is the combination of multiple different frequencies with one dominant frequency having the largest amplitude. In this case, we are viewing the dominant frequency, and the distributions of the other, lower amplitude resonant frequencies are seen in the differing minimum level to the far-left and far-right of the center peak.

This distribution appears to match that of a Lorentzian distribution, which is also the case for light spectroscopy. In light spectroscopy, we see line broadening occur because of Heisenberg’s uncertainty principle, which states that if the energy level (or frequency) is known precisely, then there must be some nonzero uncertainty in lifetime of the photon incident on the detector, resulting in broader spectral lines. The shape of lines due to the aforementioned broadening effect is described by a Lorentzian distribution, which looks near-identical to the distribution seen in Figure 3.

In Figure 4, we see the resonant frequency as a function of resonance number. This relation is clearly not linear, and more modeling work must be done in order

to determine the nature of the 3-dimensional case. Using the analysis of these data for the 3-dimensional case, we hope to compare results to the quantum system of the hydrogen atom.

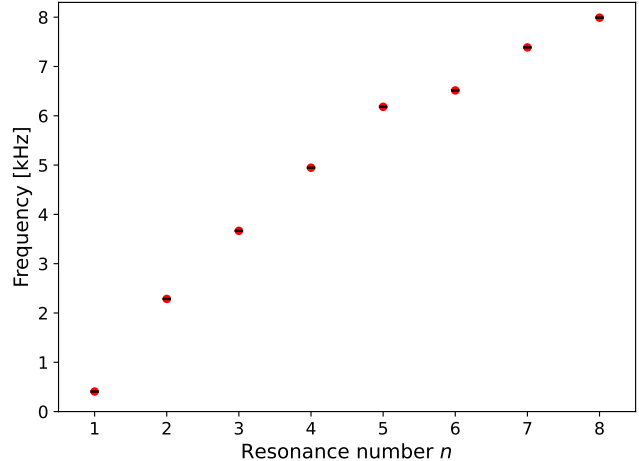


FIG. 4. A plot showing resonant frequency as a function of resonance number for the spherical shell with a diameter of 10 cm. All uncertainties are claimed to be 10 Hz.

IV. CONCLUSION

The purpose of this experiment was to compare acoustic resonance to quantum resonance in both one and three-dimensional cases. By applying the wave function, we were able to calculate the speed of sound through air, similar to the speed of light calculations. We showed that acoustic spectra have the same Lorentzian distribution as is seen in light spectroscopy, and we have seen that a sphere can have acoustic resonances, like atoms and molecules have been shown to have. We have seen that every application of acoustic wave physics aligns with some quantum physics phenomenon, which can only further confirm the validity of quantum theory over classical theory.

V. LOG

The data and logbook can be found here: <https://docs.google.com/document/d/1r3ryUkV3QHzzqj05Vwmxlcz-FgnTCLEgWYZKRplA75Q/edit?usp=sharing>

VI. IMPROVEMENTS

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