Speed of sound: tube resonance

FizziQ activity · High school · 30 min

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One smartphone sends white noise into a tube while a second runs the FizziQ spectrum analyzer; the resonance peaks yield the speed of sound. High school physics.

Learning objectives

- Excite the resonant modes of a cylindrical tube using white noise
- Identify the resonant frequency peaks in the spectrum analyzer output
- Verify that the resonant frequencies follow the pattern $f_n = n \times c / (2L_{eff})$
- Calculate the speed of sound from the measured resonant frequencies and tube dimensions
- Understand the physics of standing waves in open tubes and the role of end corrections

Instruments and sensors

Spectrum analyzer (FFT) · Synthesizer (white noise generator) · Microphone

Materials

- Two smartphones with the FizziQ application (one running the Synthesizer, one running the Spectrum Analyzer)
- A cylindrical tube (cardboard tube, such as a paper towel roll, or similar)
- A tape measure or ruler to measure the length and internal diameter of the tube
- FizziQ experiment notebook to record dimensions and resonant frequencies
- Note: the protocol remains adaptable to any comparable spectral analysis tool.

Protocol

1. Measure the length L and internal diameter D of your cylindrical tube using a ruler or tape measure.
2. On the first smartphone, open FizziQ and use the Synthesizer to generate white noise at moderate volume.
3. Place this smartphone at one end of the tube so the speaker emits directly into the tube opening.
4. On the second smartphone, open FizziQ and select the Spectrum Analyzer (FFT). Place the microphone near the other end of the tube.
5. Start the spectrum analysis. You should see several prominent peaks rising above the general noise level. These are the resonant frequencies.
6. Record the frequencies of the first 4-6 resonant peaks: f_1, f_2, f_3, f_4, etc.
7. Verify that the peaks are approximately equally spaced in frequency. For an open-open tube, $f_n = n \times f_1$.
8. Calculate the ratio between consecutive peaks: f_2/f_1, f_3/f_1, f_4/f_1. These should be approximately 2, 3, 4...
9. Calculate the speed of sound using the formula: $c = f_1 \times (2L + 1.24D)$, where the term 1.24D is the combined end correction for both open ends.
10. Average the speed calculated from each resonant frequency: $c = f_n \times (2L + 1.24D) / n$ for each n.
11. Compare your average with the accepted value of approximately 343 m/s at 20°C.
12. Try tubes of different lengths and verify that longer tubes have lower fundamental frequencies.

Expected results

For a cardboard tube 30 cm long with a 4 cm diameter, the fundamental resonant frequency should be approximately 543 Hz (using c = 343 m/s and the end correction). Higher resonances appear at approximately 1086, 1629, 2172 Hz, etc. The calculated speed of sound should fall within 320-370 m/s for careful measurements. The end correction (1.24D) is important: without it, the calculated speed of sound will be systematically too high by about 8-15% for typical tube dimensions. Students should observe that all resonant frequencies are integer multiples of the fundamental, confirming the standing wave pattern for an open-open tube.

Questions

- Why are only certain frequencies amplified by the tube while others are not?
- What is a standing wave, and how does it form inside the tube?
- Why does the end correction depend on the tube diameter?
- How would the resonant frequencies change for a tube closed at one end?
- What is the relationship between the tube length and the wavelength of the fundamental resonance?
- How do organ builders use these principles to design pipes of specific pitches?

Going further

- Compare open-open and open-closed tubes of the same length (cover one end with your hand) and observe the frequency shift
- Use tubes of different materials (cardboard, metal, plastic) and check whether the material affects the resonant frequencies
- Investigate the effect of temperature by repeating the experiment in warm and cool environments
- Use a longer tube (e.g., a PVC pipe of 1-2 meters) to obtain lower, more easily measurable frequencies
- Add holes along the tube (like a flute) and observe how opening them changes the resonant frequencies