Speed of sound: a test tube

FizziQ activity · High school · 35 min

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Blowing across a water-filled test tube excites resonance; the FizziQ spectrum analyzer on a smartphone measures each frequency to compute the speed of sound.

Learning objectives

- Produce resonant sounds by blowing across a test tube and measure the fundamental frequency with FizziQ
- Vary the air column length by adding water and record the resonant frequency for each length
- Verify the resonance formula for a closed tube: $f_1 = c / (4L + 2.48D)$
- Calculate the speed of sound from the measured data and compare with the accepted value
- Understand the physics of standing waves in tubes and the role of end correction

Instruments and sensors

Sound spectrum analyzer (FFT) · Microphone

Materials

- Smartphone with the FizziQ application (spectrum analyzer / frequency meter)
- A graduated cylinder or similar test tube, open at one end and closed at the other
- Water to adjust the length of the air column
- Ruler or measuring tape to measure the tube's internal diameter and length
- FizziQ experiment notebook to record the (L, f) data pairs
- Note: the protocol remains adaptable to any comparable spectral analysis tool.

Protocol

1. Select a test tube or cylindrical tube (open at one end, closed at the other). Measure its internal diameter D and total length using a ruler.
2. Open FizziQ and select the Frequency Meter or Spectrum Analyzer tool.
3. With the tube empty (maximum air column length L), blow steadily across the open end at an angle to excite the fundamental resonance.
4. Record the fundamental frequency displayed by FizziQ. Take three readings and average them.
5. Add water to the tube to reduce the air column length by about 1-2 cm. Measure the new air column length L.
6. Blow across the tube again and record the new resonant frequency.
7. Repeat this process for at least 8-10 different water levels, progressively shortening the air column.
8. Record all data pairs (L, f) in your FizziQ notebook.
9. Plot the graph of frequency versus 1/L. For a closed tube without end correction, this should be a straight line passing through the origin.
10. For each measurement, calculate the speed of sound using: $c = f \times (4L + 2.48D)$, where the term 2.48D is the end correction for an open tube end.
11. Average your calculated values of c and compare with the theoretical value (approximately 343 m/s at 20°C).
12. Plot the graph of frequency versus $1/(4L + 2.48D)$ and verify that the slope equals the speed of sound.

Expected results

The resonant frequency should increase as the air column shortens, ranging from approximately 200-400 Hz for a full test tube to 800-2000 Hz for a nearly full tube (with only 2-3 cm of air). The plot of f versus 1/L should be approximately linear, and the calculated speed of sound should fall between 330 and 360 m/s, depending on room temperature (c increases by about 0.6 m/s per degree Celsius above 0°C). The end correction factor (2.48D) is important for short columns: without it, the calculated speed of sound will be systematically too high, by 5-10% for typical test tube dimensions. Measurement variability of ±5-10 Hz in the frequency readings is typical, arising from difficulty in producing a consistent tone by blowing.

Questions

- Why does a shorter air column produce a higher-pitched sound?
- What is the physical meaning of the end correction, and why is it proportional to the tube diameter?
- Why can only odd harmonics exist in a tube closed at one end?
- How does temperature affect the speed of sound in air, and how would this affect your measurements?
- What is the difference between a Helmholtz resonator and a tube resonator?
- Could you use this method to measure the speed of sound in other gases (e.g., helium)?

Going further

- Repeat the experiment with tubes of different diameters to investigate the effect of the end correction
- Use different gases (if available safely, e.g., CO_2 from a fire extinguisher) to measure the speed of sound in a non-air medium
- Measure not only the fundamental frequency but also the third harmonic (the first overtone) and verify the 3:1 frequency ratio
- Compare the resonance of open-open versus open-closed tubes using tubes of the same length
- Investigate the effect of temperature by repeating the experiment in cold and warm environments