Helmholtz resonance: a bottle

FizziQ activity · High school · 30 min

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The pop of an uncorked bottle reveals Helmholtz resonance: students measure its frequency with the FizziQ smartphone app and derive the speed of sound. High school.

Learning objectives

- Record and analyze the sound produced when uncorking a bottle using FizziQ
- Measure the fundamental frequency of the resonant pop
- Apply the Helmholtz resonator formula to calculate the speed of sound from the measured frequency and bottle dimensions
- Compare the calculated speed of sound with the accepted value
- Understand the physics of Helmholtz resonance and acoustic cavities

Instruments and sensors

Fundamental frequency meter · Spectrum analyzer · Microphone

Materials

- Smartphone with the FizziQ application
- A bottle of wine (with an adult)
- Optional: a recorder to repeat the analysis
- Meter or ruler to measure the dimensions of the neck
- FizziQ experiment notebook
- Note: the protocol remains adaptable to any comparable frequency/spectral analysis tool.

Protocol

1. Measure the dimensions of the bottle neck: length L (depth of the neck) and internal diameter D of the opening. Also estimate the volume V of the air cavity inside the bottle.
2. Open FizziQ and select the Frequency Meter (fundamental frequency) tool.
3. Hold the smartphone close to the bottle opening (within 10-15 cm).
4. Start recording, then uncork the bottle with a quick, firm pull. (This must be done with adult supervision.)
5. The frequency meter should capture the resonant frequency of the pop. Record this value as f.
6. If the reading was too brief, try using the Spectrum Analyzer mode and replay the recording to identify the dominant frequency peak.
7. Repeat the measurement with 2-3 bottles of the same type for consistency.
8. Calculate the cross-sectional area of the neck: $A = \pi(D/2)^2$.
9. Apply the Helmholtz resonator formula: $f = (c / 2\pi) \times \sqrt{A / (V \times L_{eff})}$, where $L_{eff} = L + 0.6D$ is the effective neck length including end correction.
10. Rearrange to solve for the speed of sound: $c = 2\pi f \times \sqrt{V \times L_{eff} / A}$.
11. Calculate c and compare with the accepted value of approximately 343 m/s at 20°C.
12. Discuss the sources of uncertainty: volume estimation, neck dimension measurement, and frequency measurement precision.

Expected results

The pop frequency typically falls in the range of 300-600 Hz depending on the bottle shape and size. A standard 750 mL wine bottle with a neck length of about 8 cm and diameter of 2 cm produces a resonance around 400-500 Hz. The calculated speed of sound should fall within 300-380 m/s, with deviations from 343 m/s primarily due to the difficulty of accurately measuring the bottle's internal volume and neck dimensions. The end correction factor (0.6D) is important: without it, the calculated speed of sound will be systematically too high. Students should achieve agreement within 10-15% of the accepted value with careful measurements.

Questions

- What is a Helmholtz resonator, and how does it differ from a simple tube resonator?
- Why does the pop frequency depend on the volume of the bottle cavity?
- How would the resonant frequency change if you partially filled the bottle with water (reducing the air volume)?
- Why is the end correction (0.6D) necessary in the formula?
- What other everyday objects behave as Helmholtz resonators?
- How does temperature affect the speed of sound, and would this change your result?

Going further

- Compare the resonant frequencies of bottles with different shapes and volumes
- Partially fill a bottle with water and measure how the frequency changes as the air volume decreases
- Blow across the top of a bottle to produce a sustained tone and compare its frequency with the pop frequency
- Use the same method with a large jar or flask and verify the Helmholtz formula across different geometries
- Investigate how the speed of cork removal affects the clarity and frequency of the pop