Doppler effect: sound pendulum

FizziQ activity · High school · 40 min

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A tone from a swinging smartphone shifts in pitch; students follow it with FizziQ's frequency meter and derive the pendulum's maximum speed from the Doppler shift.

Learning objectives

- Analyze the frequency variations of a sound emitted by a pendulum using spectral analysis
- Identify the Doppler-shifted frequencies during approach and recession phases
- Determine the pendulum's oscillation period and maximum speed from the frequency data
- Apply the Doppler formula to relate frequency shift to pendulum velocity
- Understand how periodic motion creates a characteristic pattern of frequency modulation

Instruments and sensors

Spectrum analyzer (FFT) · Frequency meter · Synthesizer · Microphone

Materials

- Smartphone with the FizziQ application
- Wire or string for hanging a smartphone (option 1)
- Recording 'Doppler Pendulum Effect' from the sound library (option 2)
- FizziQ experience notebook
- Note: the protocol remains adaptable to any comparable spectral analysis tool.

Protocol

1. Option A: Suspend a smartphone emitting a pure tone (e.g., 1000 Hz from FizziQ's synthesizer) on a string to create a sound pendulum. Option B: Use the 'Doppler Pendulum Effect' recording from the FizziQ sound library.
2. If using Option A, set the pendulum length to at least 1 meter and place a second smartphone (for recording) at the same height as the pendulum's lowest point, about 1.5 meters away.
3. Open FizziQ on the recording phone and select the Frequency Meter or Spectrum Analyzer.
4. Start recording. Release the pendulum from an angle of about 20-30° and let it swing.
5. Record for at least 15-20 seconds to capture multiple complete oscillations.
6. Examine the frequency versus time graph. You should see periodic oscillations: the frequency rises above the emitted frequency during approach and drops below it during recession.
7. Identify the maximum frequency (f_{max}, during fastest approach) and the minimum frequency (f_{min}, during fastest recession).
8. Calculate the emitted frequency: $f_0 = (f_{max} + f_{min}) / 2$.
9. Calculate the maximum Doppler shift: $\Delta f = (f_{max} - f_{min}) / 2$.
10. Use the Doppler formula to calculate the maximum pendulum speed: $v_{max} = c \times \Delta f / f_0$, where $c = 343$ m/s.
11. Independently calculate v_{max} from the pendulum parameters: $v_{max} = \sqrt{2gL(1 - \cos\theta)}$, where L is the length and θ is the release angle.
12. Compare the two values of v_{max}. They should agree within 10-20%.
13. Measure the oscillation period from the frequency graph (time between consecutive maxima) and compare with $T = 2\pi\sqrt{L/g}$.

Expected results

For a 1-meter pendulum released at 30° and emitting at 1000 Hz, the maximum speed at the bottom is approximately 1.7 m/s. The Doppler shift should be about ±5 Hz ($f_{max} \approx 1005$ Hz, $f_{min} \approx 995$ Hz). This small shift requires good frequency resolution to detect. The frequency should oscillate sinusoidally at twice the pendulum frequency (because the maximum speed occurs twice per full oscillation: once approaching, once receding). The oscillation period should be about 2.0 seconds, matching the theoretical prediction. Measurement precision depends on the spectrum analyzer's frequency resolution and the background noise level.

Questions

- Why does the perceived frequency increase when the pendulum swings toward the microphone?
- At what point in the swing is the Doppler shift zero? Why?
- Why does the frequency oscillate at twice the pendulum frequency?
- How would increasing the pendulum length affect the maximum frequency shift?
- What is the relationship between the Doppler shift and the instantaneous velocity of the pendulum?
- How is this experiment related to the Doppler effect used in medical ultrasound?

Going further

- Vary the pendulum length and verify that the maximum Doppler shift changes as predicted
- Use different emitted frequencies (500 Hz, 1000 Hz, 2000 Hz) and check whether the Doppler shift is proportional to f_0
- Analyze the full time-frequency pattern and verify the sinusoidal variation of frequency
- Position the microphone at different angles relative to the swing plane and observe how the Doppler pattern changes
- Compare the Doppler analysis result for v_{max} with a kinematic video analysis of the same pendulum