Pendulum period: isochronism

FizziQ activity · Middle and high school · 35 min

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Timing ten oscillations at several amplitudes, students test Galileo's isochronism with FizziQ on smartphone or tablet and compare readings with $T = 2\pi\sqrt{L/g}$.

Learning objectives

- Measure the period of a pendulum at several different amplitudes with high precision
- Verify Galileo's isochronism principle for small oscillations
- Detect the deviation from isochronism at large amplitudes
- Apply the formula $T = 2\pi\sqrt{L/g}$ and compare theoretical and measured periods
- Develop precision measurement techniques using timing over multiple oscillations

Instruments and sensors

Acoustic stopwatch · Absolute acceleration · Microphone · Accelerometer

Materials

- Simple pendulum (string at least 1 meter long with a dense, compact bob)
- Rigid support for the pendulum
- Tape measure to determine the pendulum length and the horizontal displacement corresponding to each release angle
- Smartphone with the FizziQ app, using its acoustic stopwatch or accelerometer to time the oscillations
- FizziQ experiment notebook to record and plot period versus amplitude
- Note: the protocol remains adaptable to any comparable timing measurement tool.

Protocol

1. Construct a simple pendulum using a string at least 1 meter long with a dense, compact bob (a heavy ball or a bag of coins). Attach it to a rigid support point.
2. Measure the pendulum length L from the support point to the center of the bob. Record this value precisely.
3. Calculate the theoretical period: $T = 2\pi\sqrt{L/g}$, using $g = 9.81$ m/s².
4. Open FizziQ and prepare a timing method. You can use the accelerometer attached to the bob, an acoustic trigger, or a manual stopwatch.
5. Start with a small amplitude: pull the bob to an angle of approximately 5° (a horizontal displacement of about $L \times \sin(5°) \approx 0.09 \times L$).
6. Release the pendulum and time 10 complete oscillations. Divide the total time by 10 to get the period T_1. Repeat three times and average.
7. Increase the amplitude to 10° and repeat: time 10 oscillations, repeat three times, average.
8. Continue with amplitudes of 15°, 20°, 30°, 45°, and 60° (if safely achievable).
9. Record all data in a table: amplitude (degrees), measured period (averaged), and theoretical prediction.
10. Plot the measured period versus amplitude graph. For small angles (< 15°), the period should be nearly constant.
11. At larger amplitudes (> 30°), the period should increase noticeably. Calculate the percentage increase relative to the small-angle period.
12. Compare your small-angle period with the theoretical value $T = 2\pi\sqrt{L/g}$. Calculate the percentage error

and discuss sources of uncertainty.

Expected results

For a 1-meter pendulum, the theoretical period is approximately 2.006 seconds. At amplitudes below 15°, the measured period should agree with this value within ±1-2% (about ±0.02 seconds). At 30°, the period increases by about 1.7%; at 45°, by about 4%; at 60°, by about 7%. These small increases may be difficult to detect without precise timing. The key to precision is timing 10 or 20 oscillations and dividing, which reduces the uncertainty by a factor of 10 or 20. Students should find that the period is approximately independent of amplitude for small swings, confirming Galileo's isochronism, but shows detectable deviations for larger swings.

Questions

- What did Galileo observe about the chandelier in Pisa, and why was it significant?
- Why is the period independent of amplitude only for small oscillations? What changes for large angles?
- How does the period depend on the length of the pendulum? On the mass of the bob?
- Why is timing 10 oscillations and dividing by 10 more accurate than timing a single oscillation?
- How did pendulum clocks achieve such high accuracy for centuries?
- On the Moon ($g = 1.6\ m/s^2$), how would the period of the same pendulum change?

Going further

- Vary the pendulum length (0.25 m, 0.50 m, 1.0 m, 2.0 m) and verify that T is proportional to $\sqrt{L}$
- Test whether the period depends on the mass of the bob by using bobs of different masses
- Use FizziQ's accelerometer attached to the bob to automatically measure the period from the oscillation graph
- Compare a simple pendulum with a compound pendulum and investigate the effective length
- Investigate damping by measuring how the amplitude decreases over many oscillations