Mechanical energy of a pendulum

FizziQ activity · High school · 40 min

Scan to open in FizziQ

Frame-by-frame tracking of a pendulum in FizziQ's kinematics module lets high school students compute kinetic and potential energy and verify their constant sum.

Learning objectives

- Track the motion of a simple pendulum using video-based kinematic analysis in FizziQ
- Calculate the gravitational potential energy ($Ep = mgh$) and kinetic energy ($Ec = \frac{1}{2}mv^2$) at each tracked position
- Verify that the total mechanical energy ($Ep + Ec$) remains approximately constant during the swing
- Identify and quantify energy dissipation due to friction and air resistance
- Understand the continuous conversion between potential and kinetic energy in oscillatory motion

Instruments and sensors

Video (kinematics) analysis module · Camera

Materials

- Smartphone or tablet with the FizziQ application
- 'Pendulum' video from the FizziQ library or personal video of a simple pendulum
- Optional: spreadsheet for energy calculations
- FizziQ experience notebook
- Note: the protocol remains adaptable to any comparable video analysis tool.

Protocol

1. Open FizziQ and navigate to the Kinematics module. Load the 'Pendulum' video from the FizziQ resource library, or record your own pendulum video.
2. Set the scale using a known reference in the video (the length of the string, or a ruler visible in the frame).
3. Define the origin of the coordinate system at the lowest point of the pendulum's swing (the equilibrium position), with y-axis pointing upward.
4. Track the position of the pendulum bob frame by frame through at least one complete swing (from one extreme to the other and back).
5. Collect at least 15-20 data points across the full swing for smooth energy curves.
6. From the position data, calculate the height h above the lowest point for each tracked position: $h = y$ (since the origin is at the bottom).
7. Calculate the velocity v at each point from the position differences between consecutive frames divided by the time interval.
8. Compute the potential energy $Ep = mgh$ and the kinetic energy $Ec = \frac{1}{2}mv^2$ at each point. You may use $m = 1$ (arbitrary units) since we are verifying that the ratio Ec/Ep is consistent with conservation.
9. Calculate the total mechanical energy $E_{total} = Ep + Ec$ at each point.
10. Plot Ep, Ec, and E_{total} versus position (or versus time) on the same graph in the FizziQ notebook.
11. Verify that E_{total} remains approximately constant, while Ep and Ec oscillate in antiphase (when one is maximum, the other is minimum).
12. Calculate the percentage variation of E_{total} across the swing. For a well-tracked pendulum over one swing, the variation should be less than 10-15%.

Expected results

The potential energy should be maximum at the extremes of the swing (where the bob is highest and momentarily stationary) and zero at the lowest point. The kinetic energy should be zero at the extremes and maximum at the lowest point. These two curves should be mirror images of each other. The total mechanical energy should remain approximately constant, typically within 5-15% variation for careful tracking. The main sources of apparent energy non-conservation are velocity measurement noise (since velocity is derived from position differences, it amplifies errors) and scale calibration inaccuracies. Over multiple swings, a gradual decrease in total energy of 2-5% per swing reflects real energy dissipation from air resistance and pivot friction.

Questions

- At what point in the pendulum's swing is the kinetic energy maximum? The potential energy? Why?
- Why does the total mechanical energy remain constant in an ideal pendulum?
- What factors cause the total energy to decrease over time in a real pendulum?
- How does the period of a simple pendulum depend on its length? On the mass of the bob?
- What was Huygens' key insight that made the pendulum clock so accurate?
- How would the energy analysis change for a pendulum on the Moon (where $g = 1.6\ m/s^2$)?

Going further

- Track the pendulum over multiple swings and plot the decay of total energy to quantify energy dissipation
- Compare pendulums of different lengths and verify that the period depends on $\sqrt{(L/g)}$
- Analyze a pendulum with a large amplitude (>30°) and check whether the period depends on amplitude
- Use the accelerometer instead of video analysis: attach the smartphone to the pendulum and measure centripetal acceleration at the lowest point
- Compare the energy conservation of a pendulum swinging in air versus one swinging in water to quantify fluid resistance