Elastic shock: Newton's cradle

FizziQ activity · Middle and high school · 35 min

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Video kinematics of a Newton's cradle: track the balls frame by frame in FizziQ on smartphone or tablet to compare momentum and kinetic energy around impact.

Learning objectives

- Analyze the motion of Newton's pendulum balls before and after collision using video kinematic tracking
- Measure the velocities of balls before and after impact to calculate momentum and kinetic energy
- Verify that both momentum and kinetic energy are approximately conserved
- Determine the coefficient of restitution for the steel ball collision
- Understand why both conservation laws together determine the unique observed outcome

Instruments and sensors

Video (kinematics) analysis module

Materials

- Smartphone or tablet with the FizziQ app for video kinematic analysis
- Video 'Newton's Pendulum' (available from the FizziQ resource library)
- Note: the protocol remains adaptable to any comparable video analysis tool.

Protocol

1. Open FizziQ and navigate to the Kinematics module. Load the 'Newton's Pendulum' video from the FizziQ resource library.
2. Set the scale using a known dimension in the video (e.g., the diameter of one ball, typically 2-3 cm for a desk toy).
3. Set the coordinate origin at the equilibrium position of the first ball.
4. Track the incoming ball (Ball 1) frame by frame for at least 5 frames before impact. Record its position at each frame.
5. Track the outgoing ball (the ball at the opposite end) for at least 5 frames after impact.
6. Determine the velocity of Ball 1 before impact (v_1) from the slope of its position-time graph.
7. Determine the velocity of the outgoing ball after impact (v_2') from the slope of its position-time graph.
8. Check whether Ball 1 is stationary after impact ($v_1' \approx 0$), as expected for an elastic collision between identical masses.
9. Calculate the momentum before: $p\_before = m \times v_1$ (mass cancels since balls are identical).
10. Calculate the momentum after: $p\_after = m \times v_2'$. Compare with p_before.
11. Calculate the kinetic energy before: $Ec\_before = ½mv_1^2$. Calculate $Ec\_after = ½mv_2'^2$. Compare.
12. Calculate the coefficient of restitution: $e = v_2' / v_1$. For a perfectly elastic collision, $e = 1$.
13. If possible, repeat the analysis for the case of two balls released simultaneously, tracking both incoming and outgoing balls.

Expected results

For a well-made Newton's cradle with steel balls, the incoming ball should nearly stop after impact ($v_1' \approx 0$) and the outgoing ball should leave at approximately the same speed ($v_2' \approx v_1$). The coefficient of restitution should be between 0.90 and 0.98. Momentum conservation should hold within 5-10% (p_before ≈ p_after). Energy conservation should also hold within 5-15%, with small losses due to sound production, slight deformation, and energy transfer to the intermediate balls. For the two-ball case, both outgoing balls should have approximately the same speed as the incoming pair. Tracking precision is limited by the video frame rate and the fast motion of the balls near impact.

Questions

- Why does releasing one ball cause exactly one ball to swing out at the other end, rather than two balls at half speed?
- What would happen if the balls had different masses?
- Why is both momentum AND energy conservation necessary to predict the outcome?
- What fraction of energy is lost in each collision? Where does this energy go?
- Why do the oscillations eventually stop in a real Newton's cradle?
- How would the behavior change if the balls were made of clay instead of steel?

Going further

- Compare the behavior for 1, 2, and 3 balls released simultaneously
- Analyze the gradual decrease in amplitude over many cycles and quantify energy dissipation
- Replace one ball with a different material or mass and observe how the behavior changes
- Use the height of the outgoing ball to verify energy conservation independently of velocity measurements
- Compare a Newton's cradle with a simple two-ball collision on a flat surface