Atwood machine: Newton's 2nd law

FizziQ activity · High school · 30 min

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A cart carrying a smartphone is pulled by a hanging mass over a pulley; students measure acceleration with the FizziQ accelerometer and test F = ma by varying mass.

Learning objectives

- Measure the acceleration of a mechanical system with the smartphone accelerometer
- Experimentally verify Newton's second law (F = ma)
- Plot and interpret the acceleration versus hanging mass graph
- Identify the sources of discrepancy between theory and experiment
- Understand the role of total system mass in determining acceleration

Instruments and sensors

Linear acceleration · Accelerometer

Materials

- Smartphone or tablet with FizziQ
- A low-friction cart (or board with wheels)
- A pulley fixed at the edge of a table
- String and hanging masses (20-200 g)
- Adhesive tape to secure the phone
- Note: the protocol remains adaptable to any comparable acceleration measurement tool.

Protocol

1. Set up a horizontal track (air track, or simply a smooth table) with a pulley or guide fixed at the edge.
2. Place the smartphone on the cart (or directly on the table if smooth enough) and secure it with adhesive tape.
3. Attach a string to the cart. Run the string over the pulley and hang a mass m_1 from the free end.
4. Open FizziQ and select the Accelerometer instrument (linear acceleration in the direction of motion).
5. Hold the cart still, start the recording, then release the system.
6. Record the acceleration during the cart's displacement (a few seconds is enough).
7. Note the constant acceleration measured (ignoring the initial release spike and the final impact).
8. Calculate the theoretical acceleration: $a = m_1 g / (m_1 + m_2)$, where m_2 is the mass of the cart + smartphone.
9. Repeat the experiment by modifying the suspended mass m_1 (in increments of 20 to 50 g). Plot a versus m_1.
10. Verify that the graph $a = f(m_1)$ is a curve that approaches g when m_1 becomes much larger than m_2.

Expected results

The measured acceleration is constant during the motion (after the initial release transient). The measured value is slightly less than the theoretical prediction due to friction. The graph $a(m_1)$ is a curve that increases from near zero and asymptotically approaches g. Typical measured values range from 0.5 to 5 m/s² for reasonable mass ratios.

Questions

- Why is the measured acceleration always slightly less than the theoretical value?
- What happens when the suspended mass becomes very large compared to the cart mass?
- How does the pulley's mass affect the acceleration?
- Why is the string tension during motion less than the weight of the hanging mass?
- How could you use this experiment to measure g?
- What assumptions of the ideal model are not met in practice?

Going further

- Study the effect of pulley mass using pulleys of different sizes
- Use two suspended masses (classic Atwood machine) instead of a cart
- Measure the velocity during the motion and verify it increases linearly with time
- Add friction deliberately (rough surface) and measure its effect on acceleration
- Plot $1/a$ versus $1/m_1$ and extract g from the slope