Normal acceleration in rotation

FizziQ activity · High school · 25 min

Scan to open in FizziQ

Spinning with a smartphone at arm's length, students record centripetal acceleration with the FizziQ accelerometer and verify $a = \omega^2 r$. High school physics.

Learning objectives

- Measure centripetal acceleration during circular motion using the smartphone accelerometer
- Independently determine the angular velocity by timing the rotations
- Verify the relationship $a = \omega^2 r$ between centripetal acceleration, angular velocity, and radius
- Understand the direction and magnitude of centripetal acceleration in uniform circular motion
- Connect the experimental results to orbital mechanics and real-world applications

Instruments and sensors

Normal (centripetal) acceleration · Accelerometer

Materials

- Smartphone with the FizziQ application
- Clear space to turn safely
- Tape measure to measure arm length
- FizziQ experiment notebook
- Note: the protocol remains adaptable to any comparable acceleration measurement tool.

Protocol

1. Measure the radius of rotation: with your arm fully extended holding the smartphone, measure the distance from the center of your body to the phone. Record this as r (typically 0.6-0.9 m).
2. Find a clear, open space where you can safely turn around with arms extended without hitting anything.
3. Open FizziQ and select the Accelerometer sensor. Choose the component perpendicular to the phone screen (often labeled normal or Y-axis), which will measure the centripetal acceleration.
4. Hold the phone vertically at arm's length with the screen facing you. The centripetal acceleration will be directed along the axis pointing from the phone toward your body.
5. Start recording in FizziQ. Begin spinning slowly at a steady rate. Complete at least 5 full rotations at this speed.
6. Have a partner count your rotations and time them with a stopwatch, or count them yourself. Record the time for 5 rotations.
7. Stop spinning and stop recording. Note the average acceleration during the steady spinning phase from the graph.
8. Calculate the angular velocity: $\omega = 2\pi \times$ (number of rotations) / (total time in seconds).
9. Calculate the theoretical centripetal acceleration: $a_{theory} = \omega^2 \times r$.
10. Compare the measured and theoretical values. They should agree within 10-20%.
11. Repeat at a faster rotation speed and verify that the acceleration increases with ω^2.
12. Repeat at different arm lengths (bent arm vs. fully extended) to investigate the effect of radius on centripetal acceleration at the same angular velocity.

Expected results

For a typical arm length of 0.75 m and a comfortable rotation rate of about 1 revolution per second ($\omega \approx 6.28$ rad/s), the expected centripetal acceleration is approximately 30 m/s² (about 3g). Faster spinning (1.5 rev/s) would produce about 67 m/s² (7g). The measured acceleration should agree with the theoretical value within 10-20%, with discrepancies arising from non-uniform rotation speed, difficulty in maintaining a perfectly circular path, and the phone not being exactly perpendicular to the radius. Students should clearly observe that doubling the angular velocity quadruples the acceleration, confirming the ω^2 dependence. The effect of changing the radius should also be visible: a shorter arm (0.4 m) at the same angular velocity produces proportionally less acceleration.

Questions

- Why must an object moving in a circle experience an acceleration even if its speed is constant?
- In what direction does the centripetal acceleration point? What provides the centripetal force in this experiment?
- How does the centripetal acceleration of a satellite in orbit relate to the gravitational force?
- What would happen if the centripetal force suddenly disappeared while you were spinning?
- Why does a higher rotation speed produce a much larger acceleration (quadratic relationship)?
- How is centripetal acceleration used in the design of centrifuges and amusement park rides?

Going further

- Attach the phone to a string and swing it in a horizontal circle to create a more controlled circular motion
- Compare centripetal acceleration for different rotation speeds and create a graph of a versus ω^2 to verify proportionality
- Calculate the centripetal force required ($F = ma$) and compare with the tension you feel in your arm
- Use the experiment to calculate the orbital speed of the ISS from its known altitude and the value of g at that height
- Investigate whether the acceleration measured along the tangential direction is zero (as expected for uniform circular motion) or non-zero (indicating non-uniform speed)