Centrifuge: $a = \omega^2 r$

FizziQ activity · High school · 30 min

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With the FizziQ Web Centrifuge simulation in a browser, students vary rotation speed and arm radius, record centripetal acceleration and verify the relation $a = \omega^2 r$.

Learning objectives

- Measure centripetal acceleration for different rotation speeds and radii
- Verify the relationship $a = \omega^2 r$ experimentally
- Understand g-force as the ratio of acceleration to gravitational acceleration
- Plot a versus ω^2 and a versus r to confirm proportionality
- Calculate the rotation speed needed to simulate different gravity levels

Instruments and sensors

FizziQ Web Centrifuge simulation

Materials

- Computer, tablet, or smartphone with FizziQ Web
- Note: the protocol remains adaptable to any comparable circular-motion simulation tool.

Protocol

1. Open the Centrifuge simulation in FizziQ Web (Experiment → Simulations → Centrifuge).
2. Part 1 — Effect of speed: set the radius to 5 m. Set the rotation speed to 10 rpm and start the simulation.
3. Note the centripetal acceleration and g-factor displayed. Stop the recording.
4. Repeat for speeds 20, 30, 40, 50, and 60 rpm. Create a table: Speed (rpm), ω (rad/s), ω^2 (rad^2/s^2), Acceleration (m/s^2), g-factor.
5. To convert: ω (rad/s) = speed (rpm) × 2π / 60. Calculate ω and ω^2 for each speed.
6. Plot the graph of acceleration versus ω^2. Is it a straight line? The slope should equal r = 5 m.
7. Part 2 — Effect of radius: set the speed to 30 rpm. Vary the radius: 2, 4, 6, 8, 10 m.
8. Note the centripetal acceleration for each radius. Plot a versus r. The straight line confirms that a is proportional to r.
9. From your data, determine which speed-radius combination gives a g-factor of 3 (the threshold where untrained people may lose consciousness).
10. Conclusion: the relationship $a = \omega^2 r$ shows that acceleration depends on the square of speed but only linearly on radius. Doubling the speed quadruples the acceleration.

Expected results

For r = 5 m: at 10 rpm, ω = 1.05 rad/s, a = 5.5 m/s^2 (0.56 g). At 30 rpm, ω = 3.14 rad/s, a = 49.3 m/s^2 (5.0 g). At 60 rpm, ω = 6.28 rad/s, a = 197 m/s^2 (20.1 g). The graph $a(\omega^2)$ is a straight line with slope 5 m (equal to the radius). The graph a(r) at 30 rpm is a straight line with slope $\omega^2 \approx 9.87\ rad^2/s^2$. All results confirm $a = \omega^2 r$.

Questions

- Why does the acceleration depend on the square of angular velocity rather than simply on velocity?
- If you double the radius at constant angular velocity, the acceleration doubles. But if you double the tangential speed at constant radius, what happens?

- Why do car passengers feel pushed outward in a turn even though the acceleration is directed inward?
- What radius and rotation speed would be needed to simulate Earth's gravity in a 100 m diameter space station?
- Why are professional centrifuges built with long arms rather than short arms spinning very fast?
- What is the difference between centripetal acceleration and centrifugal force?

Going further

- Calculate the radius and rotation speed needed to simulate Earth's gravity (1 g) in a space station of 100 m diameter
- Estimate the g-factor experienced on a fairground ride given its radius and rotation period
- Plot the g-factor versus rotation speed for a fixed radius and identify the speed limit for human tolerance
- Compare the acceleration in the centrifuge with the acceleration during an airplane takeoff
- Investigate how the tangential velocity $v = \omega r$ changes with radius at constant ω