Variation of g with altitude

FizziQ activity · High school · 30 min

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During a flight, students record g at ground level and at cruising altitude with the FizziQ smartphone accelerometer and compare the drop with Newton's $g = GM/r^2$.

Learning objectives

- Measure the acceleration of gravity at ground level and at aircraft cruising altitude using the smartphone accelerometer
- Compare the two measurements and determine whether the difference is consistent with Newton's law of gravitation
- Calculate the theoretical variation of g with altitude using $g = GM/r^2$
- Understand the relationship between distance from Earth's center and gravitational acceleration
- Appreciate the sensitivity required to detect small variations in g

Instruments and sensors

Absolute acceleration · Accelerometer

Materials

- Smartphone with the FizziQ application
- A plane flight
- FizziQ experience notebook
- Calculator
- Note: the protocol remains adaptable to any comparable device with high-precision accelerometer access.

Protocol

1. Ground measurement: Place the smartphone on a flat, stable surface on the ground (ideally at a known elevation above sea level).
2. Open FizziQ and select the Accelerometer sensor with absolute acceleration.
3. Record data for at least 60 seconds while the phone is perfectly still. Calculate the mean and standard deviation.
4. Repeat the ground measurement three times, recording the mean each time. Calculate the overall average. This is your value of g_ground.
5. Note your altitude above sea level using a GPS app or known elevation data.
6. In-flight measurement: During a commercial flight, once the aircraft has reached cruising altitude and the seatbelt sign indicates stable flight, place the smartphone flat on the tray table.
7. Record data for at least 60 seconds during straight, level flight (avoid turbulence, turns, and altitude changes).
8. Calculate the mean acceleration. This is your value of g_flight.
9. Note the cruising altitude from the in-flight display or from a GPS/barometer reading.
10. Calculate the difference: $\Delta g = g_{ground} - g_{flight}$.
11. Calculate the theoretical difference using: $\Delta g = g_0 \times (1 - (R/(R+h))^2)$, where R = 6371 km and h is the cruising altitude.
12. Compare the measured and theoretical differences. Discuss whether the smartphone accelerometer has sufficient precision to detect the altitude effect.

13. Calculate how much lighter you are (in grams) at cruising altitude compared to on the ground.

Expected results

The theoretical decrease in g at 10 km altitude is approximately 0.031 m/s² (0.31%). This is at the very limit of smartphone accelerometer precision, which typically has a noise level of 0.02-0.10 m/s² and systematic calibration offsets of 0.05-0.20 m/s². In practice, students may or may not be able to detect the altitude effect, depending on their phone's sensor quality and the stability of the in-flight conditions. Aircraft vibrations, subtle accelerations from flight path adjustments, and the difference in the phone's orientation between ground and flight measurements all introduce errors comparable to the signal being measured. This makes the experiment as much a lesson in measurement limitations as in gravitational physics.

Questions

- How does Newton's law of gravitation explain the decrease of g with altitude?
- What percentage of your body weight do you lose at cruising altitude?
- Why is it difficult to detect the altitude effect on g with a smartphone accelerometer?
- At what altitude would g be reduced by half compared to its surface value?
- How do precision gravimeters used by geophysicists differ from smartphone accelerometers?
- What other factors (besides altitude) cause local variations in the acceleration of gravity?

Going further

- Compare the theoretical g variation for different altitudes (ground level, 100 m building, 2000 m mountain, 10000 m flight) and identify which changes are detectable with a smartphone
- Use the barometer instead of the accelerometer to verify the altitude during flight
- Measure g at different points during the flight (ascent, cruise, descent) and look for systematic trends
- Calculate the altitude at which an astronaut in the ISS (400 km) experiences g and compare with the surface value
- Investigate why astronauts float in the ISS despite g being about 90% of its surface value at that altitude