Damping: three regimes

FizziQ activity · High school · 35 min

Scan to open in FizziQ

Raising the damping coefficient in the FizziQ Web spring oscillator simulation, students compare underdamped, critical and overdamped returns in the browser.

Learning objectives

- Observe the effect of damping on oscillation amplitude and shape
- Identify the three regimes of a damped oscillator
- Determine the critical damping value experimentally
- Understand the exponential decay of amplitude in the underdamped regime
- Connect the three regimes to practical applications

Instruments and sensors

FizziQ Web Spring Oscillator simulation

Materials

- Computer, tablet, or smartphone with FizziQ Web
- Note: this simulation-based protocol needs no physical sensor and remains adaptable to any device able to run the FizziQ Web simulation.

Protocol

1. Open the Spring Oscillator simulation in FizziQ Web. Set the mass to 1.0 kg, stiffness to 20 N/m, and amplitude to 0.3 m.
2. Set the damping to 0 N·s/m. Start a recording (REC). Observe: the oscillations continue indefinitely with constant amplitude. This is the undamped reference.
3. Set the damping to 0.5 N·s/m. Start a recording. Observe: the oscillations continue but the amplitude gradually decreases. This is the underdamped regime.
4. Increase the damping to 1.0 N·s/m, then 2.0 N·s/m. Start a recording for each. Compare the curves: the amplitude decreases faster with higher damping.
5. Continue increasing the damping. Find the value at which the mass returns to equilibrium without oscillating (it does not overshoot). This is the critical damping value.
6. Increase the damping beyond the critical value. Observe: the mass returns to equilibrium even more slowly, without oscillating. This is the overdamped regime.
7. Superimpose the curves obtained for different damping values. Describe the differences.
8. For the underdamped regime (damping = 1.0 N·s/m), measure the amplitude of several successive oscillations. Does the amplitude decrease at a constant rate?
9. Calculate the ratio between two successive amplitudes. Is this ratio constant? If so, the decay is exponential.
10. Write a conclusion: describe the three regimes and give a concrete example of each (car shock absorber for critical, door closer for overdamped, guitar string for underdamped).

Expected results

For m = 1 kg and k = 20 N/m, the natural angular frequency is $\omega_0 = \sqrt{k/m} \approx 4.47$ rad/s. The theoretical critical damping is $b_c = 2\sqrt{km} = 2\sqrt{20} \approx 8.94$ N·s/m. For $b < b_c$: damped oscillations (underdamped) with exponentially decreasing amplitude. For b = b_c: fastest return to equilibrium without oscillation (critical damping). For b > b_c: slow return without oscillation (overdamped). The ratio of consecutive amplitudes is constant, confirming exponential decay.

Questions

- Why are car shock absorbers tuned to critical damping?
- In the underdamped regime, does the pseudo-period change compared to the undamped case?
- Why is the amplitude decay exponential rather than linear?
- What happens to the energy of the oscillator as the amplitude decreases?
- Could you determine the damping coefficient from the rate of amplitude decay?
- Why does overdamped motion take longer to reach equilibrium than critical damping?

Going further

- Plot velocity versus position (phase portrait) for the three regimes and observe the spiral, direct return, and slow return
- Measure the pseudo-period for different damping values and verify that it increases slightly compared to the undamped period
- Calculate the energy of the oscillator at each peak and plot energy versus time
- Determine the quality factor $Q = m\omega_0/b$ for each damping value
- Compare the simulation with a real damped spring experiment using the smartphone accelerometer