Pole vault: energy balance

FizziQ activity · High school · 40 min

Scan to open in FizziQ

Frame by frame, students track a vaulter's centre of gravity and compute kinetic, elastic and potential energy. FizziQ kinematics module, on smartphone or tablet.

Learning objectives

- Analyze the successive phases of a pole vault using video-based kinematic tracking
- Identify the key moments: plant, pole bend, pole straighten, release, and bar clearance
- Calculate the kinetic, elastic potential, and gravitational potential energy at key phases
- Verify the approximate conservation of mechanical energy throughout the vault
- Understand the role of the flexible pole as an energy storage and transfer device

Instruments and sensors

Video (kinematics) analysis module · Camera

Materials

- Smartphone or tablet with the FizziQ application
- 'Pole vault' video available in the FizziQ library
- FizziQ experience notebook
- Note: the protocol remains adaptable to any comparable video analysis tool.

Protocol

1. Open FizziQ and navigate to the Kinematics module. Load the 'Pole vault' video from the FizziQ resource library.
2. Set the scale using a known reference in the video (the bar height, which is usually displayed, or the athlete's height).
3. Define the origin of the coordinate system at ground level, at the position of the planting box.
4. Track the center of gravity of the athlete frame by frame through the entire vault sequence.
5. Identify and mark the five key phases: run-up, pole plant, pole bend (maximum), pole straighten, and flight over the bar.
6. From the run-up phase tracking, calculate the approach speed (v_0) of the athlete just before planting the pole.
7. Calculate the kinetic energy at the end of the run-up: $Ec = \frac{1}{2}mv^2$, using an estimated mass of 75-80 kg for the athlete.
8. At the highest point of the jump (bar clearance), measure the height h of the center of gravity above its initial position.
9. Calculate the gravitational potential energy gained: $Ep = mgh$.
10. Compare Ec and Ep. The potential energy at the top should be approximately equal to the kinetic energy at the bottom, confirming energy conservation.
11. Note that the vaulter's center of gravity at bar clearance is below the bar (due to the Fosbury-like arch), so the effective height gain is less than the bar height.
12. Discuss the energy losses (friction, imperfect elastic recovery of the pole, muscular energy added during the vault) and their effect on the energy balance.

Expected results

A competitive vaulter approaches at about 8-9 m/s, giving a kinetic energy of approximately 2400-3200 J for a 75 kg athlete. The center of gravity rises from about 1.0 m (standing) to about 5.5-6.0 m at bar clearance height of 5.5-6.0 m, giving a potential energy gain of approximately 3300-3700 J. The fact that the potential energy exceeds the kinetic energy by 10-20% reflects the muscular work the athlete adds during the vault (pulling and pushing on the pole). The kinematic tracking will show the characteristic velocity profile: high speed during approach, sharp deceleration at the plant, near-zero horizontal speed during the vertical phase, and moderate speed during bar clearance. Tracking precision is limited by video frame rate and the difficulty of locating the center of gravity during the complex body rotations.

Questions

- Why is a flexible pole so much more effective than a rigid pole for clearing high bars?
- How does the vaulter add energy to the system beyond the initial kinetic energy?
- Why is the center of gravity at bar clearance lower than the actual bar height?
- What is the theoretical maximum height a vaulter could clear based on approach speed alone?
- How has pole vault technology (pole materials, technique) evolved over the past century?
- What limits the current world record? Is it physics or human physiology?

Going further

- Compare the approach speeds and clearance heights of different vaulters to investigate the relationship between speed and performance
- Track the tip of the pole instead of the athlete and analyze the bending and straightening sequence
- Analyze the athlete's center of gravity trajectory after pole release and verify it follows a parabola
- Compare the pole vault with the high jump (Fosbury Flop) in terms of energy conversion strategy
- Calculate the spring constant of the pole from the maximum bend and the stored elastic energy