

Classical Mechanics

Newton's Laws and Energy Quiz – Answer Key

1. **(C) 10 N.** Using Newton's Second Law: $F = ma = 5 \text{ kg} \times 2 \text{ m/s}^2 = 10 \text{ N}$.
2. **(C) Centripetal acceleration toward the center.** Even at constant speed, direction changes continuously, requiring acceleration toward the center: $a_c = v^2/r$.
3. **(C) Quadruples.** Kinetic energy $KE = \frac{1}{2}mv^2$. If $v \rightarrow 2v$, then $KE \rightarrow \frac{1}{2}m(2v)^2 = 4 \times \frac{1}{2}mv^2$.
4. **(C) For every action, there is an equal and opposite reaction.** Newton's Third Law states forces always occur in pairs of equal magnitude and opposite direction acting on different objects.
5. **(B) Velocity is zero but acceleration is g downward.** At the apex, instantaneous velocity is zero, but gravitational acceleration ($g = 9.8 \text{ m/s}^2$) acts continuously throughout the motion.
6. **True.** Work $W = F \cdot d \cdot \cos \theta$. When $\theta = 90$, $\cos 90 = 0$, so $W = 0$. Example: centripetal force does no work on circular motion.
7. **False.** Momentum is conserved in all collisions (elastic and inelastic) when no external forces act. Kinetic energy is conserved only in elastic collisions.
8. **False.** In free fall (neglecting air resistance), an object experiences constant acceleration (g), not constant velocity. Velocity continuously increases.

9. Derivation:

Starting with Newton's Second Law: $F = ma$

For displacement d in the direction of force:

$$W = F \cdot d = ma \cdot d$$

Using kinematic equation $v^2 = v_0^2 + 2ad$:

$$ad = \frac{v^2 - v_0^2}{2}$$

Substituting:

$$W = m \cdot \frac{v^2 - v_0^2}{2} = \frac{1}{2}mv^2 - \frac{1}{2}mv_0^2 = \Delta KE$$

Work-Energy Theorem: $W_{net} = \Delta KE = KE_f - KE_i$

Physical significance:

- Net work done on an object equals change in kinetic energy
- Positive work increases kinetic energy (speeds up object)

- Negative work decreases kinetic energy (slows down object)
- Provides energy-based alternative to force analysis
- Useful when forces vary with position

10. Principle: In an isolated system with only conservative forces, the total mechanical energy (kinetic + potential) remains constant:

$$E_{total} = KE + PE = \text{constant}$$

Conditions for conservation:

- Only conservative forces do work (gravity, spring force)
- No non-conservative forces (friction, air resistance, applied forces)
- System is isolated (no external work)

Pendulum example:

- At maximum height: $KE = 0$, $PE = mgh_{max}$ (all potential)
- At lowest point: $KE = \frac{1}{2}mv_{max}^2$, $PE = 0$ (all kinetic)
- Energy transforms between KE and PE: $mgh = \frac{1}{2}mv^2$
- Maximum speed: $v_{max} = \sqrt{2gh}$

Roller coaster example:

- At top of first hill (height h_1): $E = mgh_1$ (starting from rest)
- At any other point (height h_2): $mgh_1 = \frac{1}{2}mv^2 + mgh_2$
- Speed at height h_2 : $v = \sqrt{2g(h_1 - h_2)}$
- Coaster cannot rise higher than starting height without external work