

PHYS11 CH:9 The Currency of the Universe

How Energy Powers Everything

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Outline

- 1 Introduction
- 2 Work, Power, and the Work-Energy Theorem
- 3 Mechanical Energy and Conservation of Energy
- 4 Summary

What if nothing ever stopped?

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Where does the motion go?

The Roller Coaster Experience



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Lifted to the top. Released. Speed builds. Climbs again. Slows down.
Same energy. Different forms.

Learning Objectives

By the end of this section, you will be able to:

- **9.1:** Describe and apply the work-energy theorem

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- **9.1:** Describe and calculate work and power

9.1 What Is Work?

Civilian View vs. Reality

Civilian: "Homework is work. Holding a heavy box is hard work."

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The Universal Law of Work

$$W = Fd$$

Work equals force times distance moved in the direction of the force.

9.1 Three Examples

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The Mental Model

Work requires TWO things: force AND motion in the direction of force.

9.1 Energy: The Ability to Do Work

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Stored energy. Gravitational PE is energy an object has due to its position above Earth's surface.

Both measured in joules (J), same unit as work.

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Work done equals force times distance:

Gravitational Potential Energy

$$PE = mgh$$

Potential energy equals mass times gravity times height.

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The Mental Model

Heavier objects and faster objects have more KE. Velocity matters more because it's squared.

9.1 The Work-Energy Theorem

Nature's Source Code

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Subscripts: ₁ is initial, ₂ is final.

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$$1.0 \text{ J} = 1.0 \text{ N} \cdot \text{m} = 1.0 \text{ kg} \cdot \text{m}^2/\text{s}^2$$

9.1 Power: Rate of Doing Work

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One watt equals one joule per second.

9.1 Work vs. Power

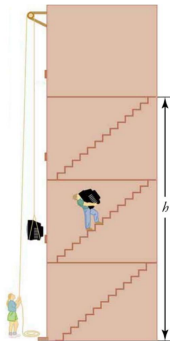


Figure: Two ways to move a TV to the fourth floor

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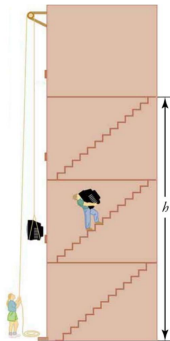


Figure: Two ways to move a TV to the fourth floor

Same work. Different power.

Pulley (2 min) generates more power than stairs (5 min).

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Watt improved the steam engine, converting reciprocal motion to circular motion.

This innovation powered the industrial revolution.

Attempt: The Skater's Push

The Challenge (3 min, silent)

An ice skater with mass 50 kg glides at 8 m/s. Her friend pushes, increasing speed to 12 m/s.

Given:

- $m = 50 \text{ kg}$
- $v_1 = 8 \text{ m/s}$
- $v_2 = 12 \text{ m/s}$

Find: How much work did the friend do on the skater?

Can you calculate the work? Try it silently.

Compare: The Skater's Push

Turn and talk (2 min):

- 1 What equation did you use?
- 2 Did you calculate KE initial and KE final?
- 3 What operation connects them to work?

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Reveal: The Skater's Push

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Equation: $W = \Delta KE = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2$

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Substitute: $W = \frac{1}{2}(50)(12^2 - 8^2)$

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Check: Energy increased because friend did work. Reasonable!

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- **9.2:** Explain the law of conservation of energy in terms of kinetic and potential energy
- **9.2:** Perform calculations related to kinetic and potential energy and apply conservation of energy

9.2 The Universe's Accounting System

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It only transforms.

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The Illusion

Civilian: "The ball lost energy when it stopped bouncing."

Physicist: "Energy transformed to heat from friction and sound."

9.2 Energy Transformations

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The Mental Model

Energy changes form constantly. The total amount stays the same.

9.2 The Roller Coaster

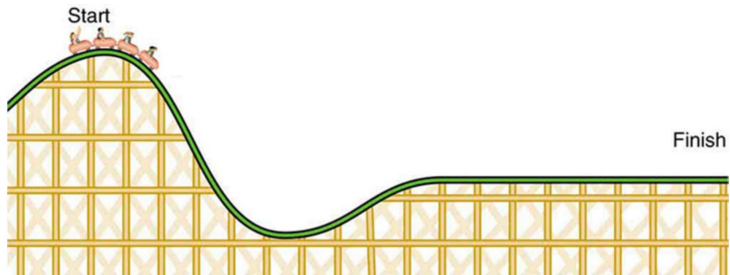


Figure: Energy transformations on a roller coaster

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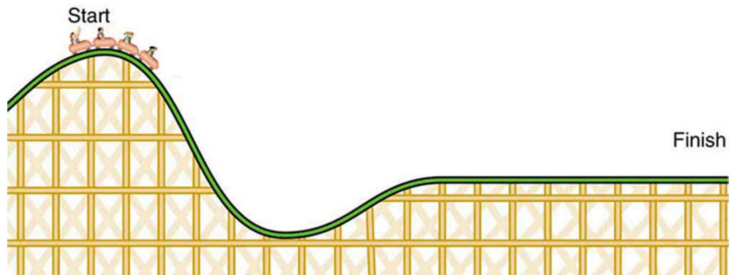


Figure: Energy transformations on a roller coaster

Top: High PE, low KE (slow)

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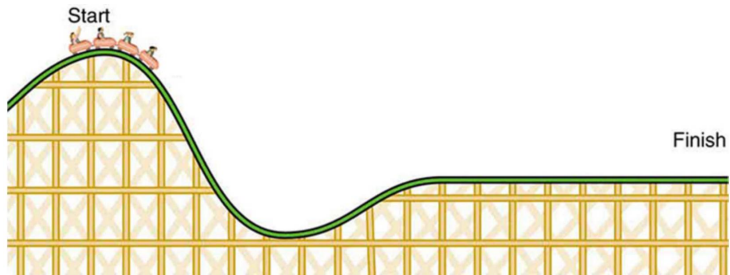


Figure: Energy transformations on a roller coaster

Top: High PE, low KE (slow)

Bottom: Low PE, high KE (fast)

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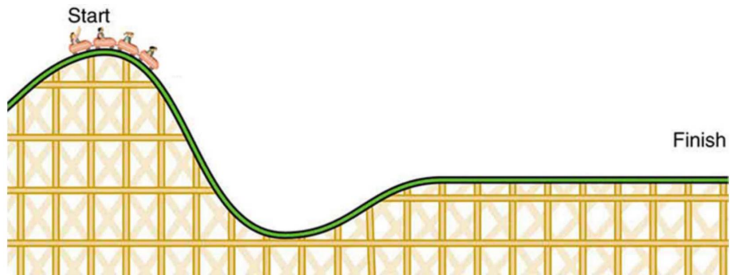


Figure: Energy transformations on a roller coaster

Top: High PE, low KE (slow)

Bottom: Low PE, high KE (fast)

Next hill: KE converts back to PE

9.2 Conservation Equation

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Conservation of Mechanical Energy

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Closed system: No energy lost to surroundings.

9.2 Equations Summary

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Pro tip: Mass often cancels out!

Attempt: The Falling Rock

The Challenge (3 min, silent)

A 10 kg rock falls from a 20 m cliff. When it has fallen 10 m, what are its KE and PE?

Given:

- $m = 10 \text{ kg}$
- $h_1 = 20 \text{ m}$ (initial height)
- $h_2 = 10 \text{ m}$ (after falling 10 m)
- $v_1 = 0$ (dropped from rest)
- $g = 9.8 \text{ m/s}^2$

Find: KE_2 and PE_2

Can you use conservation of energy? Work silently.

Compare: The Falling Rock

Turn and talk (2 min):

- 1 What is the initial KE? Why?
- 2 How did you calculate PE at 10 m height?
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Conservation: $KE_1 + PE_1 = KE_2 + PE_2$

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Check: Lost 980 J of PE, gained 980 J of KE. Energy conserved!

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At any point in between: $PE + KE = \text{constant}$

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The Paradox

Your brain says: "The roller coaster is slowing down, losing energy."

Reality: "KE converting to PE. Total energy unchanged."

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The Mental Model

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Engineers design to minimize friction losses.

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But many systems are approximately closed for short times.

The Approximation

Falling objects, roller coasters, pendulums: closed system is good approximation if friction is small.

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- 3 Energy has two forms: kinetic (motion) and potential (stored)
- 4 Power = rate of doing work
- 5 Energy is conserved: $KE + PE = \text{constant}$
- 6 Energy transforms but never vanishes

Key Equations

$$W = Fd$$

$$KE = \frac{1}{2}mv^2$$

$$PE = mgh$$

$$W = \Delta KE = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2$$

$$P = \frac{W}{t}$$

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Complete the assigned problems
posted on the LMS