PHYS11 CH:9 The Currency of the Universe

How Energy Powers Everything

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December 2025

Outline

The Mystery

What if nothing ever stopped?

What if motion could last forever?

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Balls bounce lower. Roller coasters slow down. Pendulums stop swinging.

The Mystery

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What if motion could last forever?

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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 apply the work-energy theorem
- **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."
Physicist: "Neither is work. No motion, no work."

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The Universal Law of Work

$$\boxed{W = Fd}$$

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

Consider these scenarios:

9.1 Three Examples

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1. Homework - objects not moving over distance

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2. Lifting a rock upward - force moves object upward
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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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Kinetic Energy (KE)

Energy of motion. A moving object has kinetic energy.

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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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The force equals the rock's weight: $F = w = mg$

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Work done equals force times distance:

Gravitational Potential Energy

$$\boxed{PE = mgh}$$

Potential energy equals mass times gravity times height.

9.1 Kinetic Energy

Drop the rock. Gravity does work on it. Rock speeds up.

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The Mental Model

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

Nature's Source Code

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

Net work equals change in kinetic energy.

9.1 The Work-Energy Theorem

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When you do work on an object, you change its kinetic energy.

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Subscripts: $_1$ is initial, $_2$ is final.

9.1 James Joule

Figure: James Joule (1818-1889)

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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

Work tells you how much. Power tells you how fast.

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Power equals work divided by time.

Unit: Watt (W)
One watt equals one joule per second.

9.1 Work vs. Power

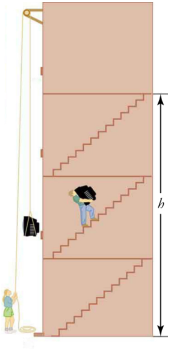

Figure: Two ways to move a TV to the fourth floor

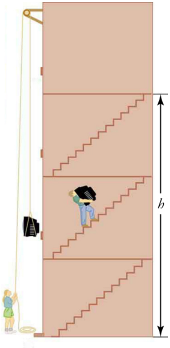

Figure: Two ways to move a TV to the fourth floor

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

9.1 James Watt and the Steam Engine

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Figure: James Watt (1736-1819) - The unit of power

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:

- $m = 50$ kg
- $v_1 = 8$ m/s
- $v_2 = 12$ 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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Name wheel: One pair share your approach (not your answer).

Reveal: The Skater's Push

Self-correct in a different color:

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

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Factor out: $W = \frac{1}{2}m(v_2^2 - v_1^2)$

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

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$W = 25(144 - 64) = 25(80)$

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$$\boxed{W = 2000 \text{ J}}$$

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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

Energy is never created or destroyed.

It only transforms.

9.2 The Universe's Accounting System

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The Law of Conservation of Energy

In a closed system, total energy remains constant.

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The Illusion

Civilian: "The ball lost energy when it stopped bouncing."
Physicist: "Energy transformed to heat from friction and sound."

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9.2 Energy Transformations

Lift a rock to the top. You do work. Rock gains PE.
Release the rock. PE converts to KE as it falls.

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The Mental Model

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

9.2 The Roller Coaster

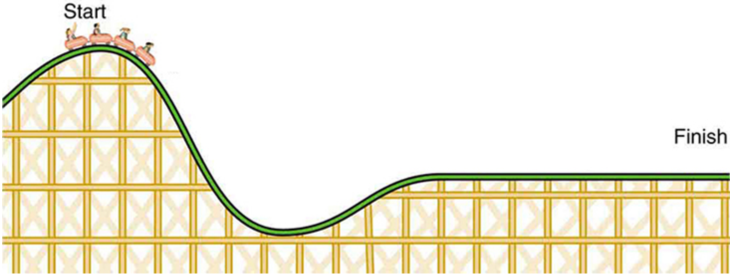

Figure: Energy transformations on a roller coaster

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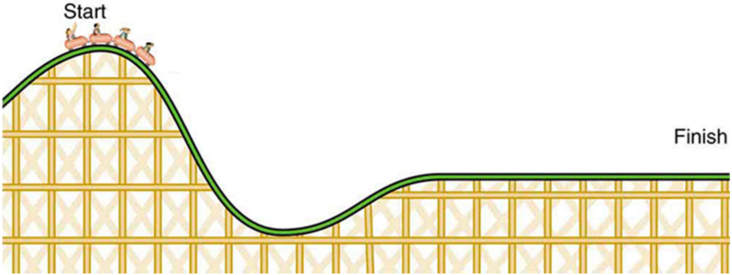

Figure: Energy transformations on a roller coaster

Top: High PE, low KE (slow)

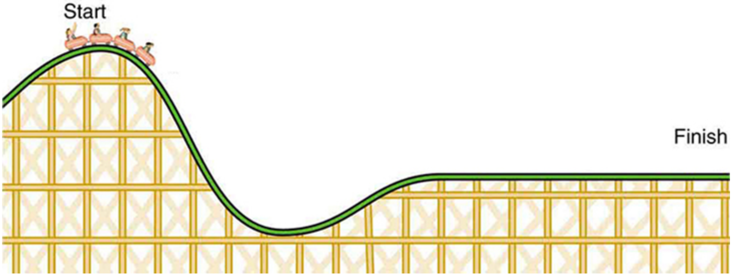

Figure: Energy transformations on a roller coaster

Top: High PE, low KE (slow)
Bottom: Low PE, high KE (fast)

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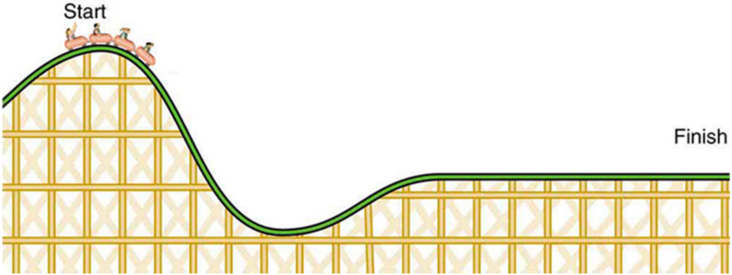

Figure: Energy transformations on a roller coaster

Top: High PE, low KE (slow)
Bottom: Low PE, high KE (fast)
Next hill: KE converts back to PE

9.2 Conservation Equation

Assume no energy lost to friction.

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Conservation of Mechanical Energy

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Either side equals total mechanical energy.
Closed system: No energy lost to surroundings.

9.2 Equations Summary

$$KE = \frac{1}{2}mv^2$$
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Combining them:

$$\frac{1}{2}mv_1^2 + mgh_1 = \frac{1}{2}mv_2^2 + mgh_2$$

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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:

- $m = 10$ kg
- $h_1 = 20$ m (initial height)
- $h_2 = 10$ m (after falling 10 m)
- $v_1 = 0$ (dropped from rest)
- $g = 9.8$ 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?
3. How did you find KE at 10 m height?

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Self-correct in a different color:

Initial energy: $KE_1 = 0$ (at rest), $PE_1 = mgh_1 = 10 \times 9.8 \times 20 = 1960$ J

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Conservation: $KE_1 + PE_1 = KE_2 + PE_2$

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$$\boxed{KE_2 = 980 \text{ J}}$$

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

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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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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.

What You Now Know

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1. Work = force times distance (only if motion happens)
2. Work changes energy (work-energy theorem)
3. Energy has two forms: kinetic (motion) and potential (stored)
4. Power = rate of doing work
5. Energy is conserved: KE + PE = constant
6. Energy transforms but never vanishes

Key Equations

$$
\begin{aligned}
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} \\
KE_1 + PE_1 &= KE_2 + PE_2
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Homework

Complete the assigned problems

posted on the LMS