PHYS11 CH:9 The Currency of the Universe

How Energy Powers Everything

Mr. Gullo

December 2025

Outline

The Mystery

What if nothing ever stopped?

What if motion could last forever?

What if nothing ever stopped?

What if motion could last forever?

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

What if nothing ever stopped?

What if motion could last forever?

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

Where does the motion go?

The Roller Coaster Experience

Figure: Roller coaster: energy transformation in action

The Roller Coaster Experience

Figure: Roller coaster: energy transformation in action

Lifted to the top. Released. Speed builds. Climbs again. Slows down.

The Roller Coaster Experience

Figure: Roller coaster: energy transformation in action

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

Learning Objectives

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

- **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."

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."

The Universal Law of Work

$$\boxed{W = Fd}$$

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

9.1 Three Examples

Consider these scenarios:

9.1 Three Examples

Consider these scenarios:

1. Homework - objects not moving over distance

Consider these scenarios:

1. Homework - objects not moving over distance
2. Lifting a rock upward - force moves object upward

9.1 Three Examples

Consider these scenarios:

1. Homework - objects not moving over distance
2. Lifting a rock upward - force moves object upward
3. Carrying a rock horizontally at constant speed

9.1 Three Examples

Consider these scenarios:

1. Homework - objects not moving over distance
2. Lifting a rock upward - force moves object upward
3. Carrying a rock horizontally at constant speed

The Mental Model

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

Two forms of mechanical energy:

Two forms of mechanical energy:

Kinetic Energy (KE)

Energy of motion. A moving object has kinetic energy.

9.1 Energy: The Ability to Do Work

Two forms of mechanical energy:

Kinetic Energy (KE)

Energy of motion. A moving object has kinetic energy.

Potential Energy (PE)

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

Two forms of mechanical energy:

Kinetic Energy (KE)

Energy of motion. A moving object has kinetic energy.

Potential Energy (PE)

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.

Lift a rock off the ground. You exert force upward over distance.

9.1 Gravitational Potential Energy

Lift a rock off the ground. You exert force upward over distance.

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

Lift a rock off the ground. You exert force upward over distance.

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

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

Kinetic Energy

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

Kinetic energy equals one-half mass times velocity squared.

9.1 Kinetic Energy

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

Kinetic Energy

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

Kinetic energy equals one-half mass times velocity squared.

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

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

Net work equals change in kinetic energy.

9.1 The Work-Energy Theorem

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.

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

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.

When you do work on an object, you change its kinetic energy.
Subscripts: $_1$ is initial, $_2$ is final.

9.1 James Joule

Figure: James Joule (1818-1889)

9.1 James Joule

Figure: James Joule (1818-1889)

The joule (J) is named after this physicist who proved the work-energy connection.

Figure: James Joule (1818-1889)

The joule (J) is named after this physicist who proved the work-energy connection.

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

9.1 Power: Rate of Doing Work

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

9.1 Power: Rate of Doing Work

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

Power

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

Power equals work divided by time.

9.1 Power: Rate of Doing Work

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

Power

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

Power equals work divided by time.

Unit: Watt (W)

9.1 Power: Rate of Doing Work

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

Power

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

Power equals work divided by time.

Unit: Watt (W)

One watt equals one joule per second.

9.1 Work vs. Power

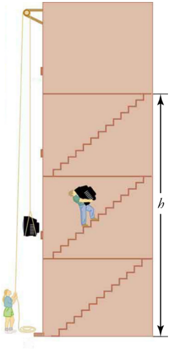

Figure: Two ways to move a TV to the fourth floor

9.1 Work vs. Power

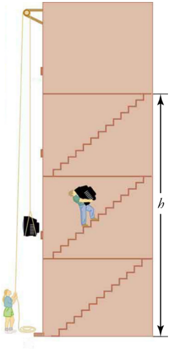

Figure: Two ways to move a TV to the fourth floor

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

9.1 James Watt and the Steam Engine

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

9.1 James Watt and the Steam Engine

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

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

9.1 James Watt and the Steam Engine

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?

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?

Name wheel: One pair share your approach (not your answer).

Reveal: The Skater's Push

Self-correct in a different color:

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

Reveal: The Skater's Push

Self-correct in a different color:

Equation: $W = \Delta KE = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2$
Factor out: $W = \frac{1}{2}m(v_2^2 - v_1^2)$

Reveal: The Skater's Push

Self-correct in a different color:

Equation: $W = \Delta KE = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2$
Factor out: $W = \frac{1}{2}m(v_2^2 - v_1^2)$
Substitute: $W = \frac{1}{2}(50)(12^2 - 8^2)$

Reveal: The Skater's Push

Self-correct in a different color:

Equation: $W = \Delta KE = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2$
Factor out: $W = \frac{1}{2}m(v_2^2 - v_1^2)$
Substitute: $W = \frac{1}{2}(50)(12^2 - 8^2)$
$W = 25(144 - 64) = 25(80)$

Reveal: The Skater's Push

Self-correct in a different color:

Equation: $W = \Delta KE = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2$
Factor out: $W = \frac{1}{2}m(v_2^2 - v_1^2)$
Substitute: $W = \frac{1}{2}(50)(12^2 - 8^2)$
$W = 25(144 - 64) = 25(80)$

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

Reveal: The Skater's Push

Self-correct in a different color:

Equation: $W = \Delta KE = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2$
Factor out: $W = \frac{1}{2}m(v_2^2 - v_1^2)$
Substitute: $W = \frac{1}{2}(50)(12^2 - 8^2)$
$W = 25(144 - 64) = 25(80)$

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

Check: Energy increased because friend did work. Reasonable!

Learning Objectives

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

- **9.2:** Explain the law of conservation of energy in terms of kinetic and potential energy

Learning Objectives

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

- **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.

Energy is never created or destroyed.

It only transforms.

The Law of Conservation of Energy

In a closed system, total energy remains constant.

Energy is never created or destroyed.

It only transforms.

The Law of Conservation of Energy

In a closed system, total energy remains constant.

The Illusion

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

9.2 Energy Transformations

Lift a rock to the top. You do work. Rock gains PE.

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

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.
Hit the ground. KE converts to heat and sound.

Lift a rock to the top. You do work. Rock gains PE.
Release the rock. PE converts to KE as it falls.
Hit the ground. KE converts to heat and sound.

The Mental Model

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

9.2 The Roller Coaster

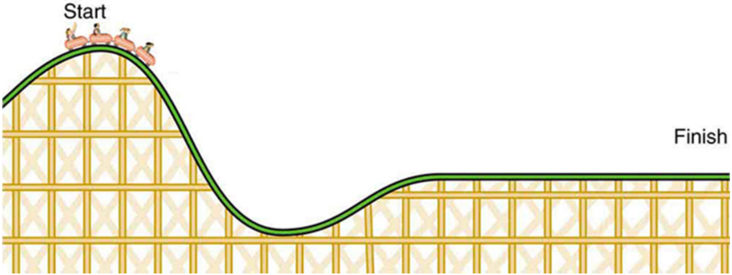

Figure: Energy transformations on a roller coaster

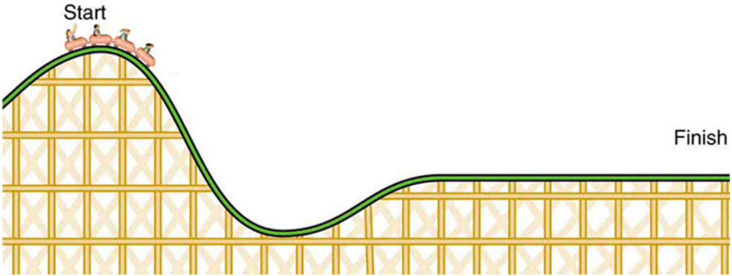

Figure: Energy transformations on a roller coaster

Top: High PE, low KE (slow)

9.2 The Roller Coaster

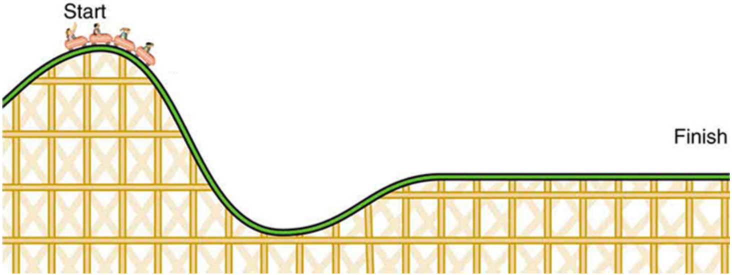

Figure: Energy transformations on a roller coaster

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

9.2 The Roller Coaster

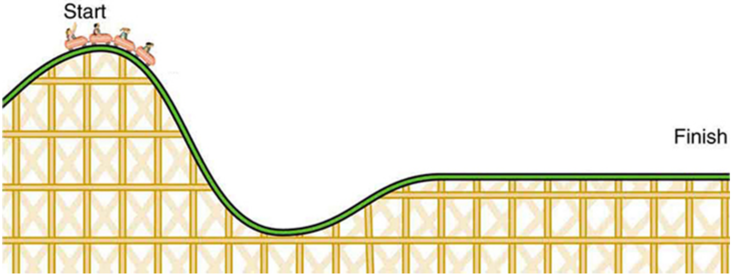

Figure: Energy transformations on a roller coaster

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.

9.2 Conservation Equation

Assume no energy lost to friction.

Conservation of Mechanical Energy

$$\boxed{KE_1 + PE_1 = KE_2 + PE_2}$$

Initial kinetic plus initial potential equals final kinetic plus final potential.

9.2 Conservation Equation

Assume no energy lost to friction.

Conservation of Mechanical Energy

$$\boxed{KE_1 + PE_1 = KE_2 + PE_2}$$

Initial kinetic plus initial potential equals final kinetic plus final potential.

Either side equals total mechanical energy.

Assume no energy lost to friction.

Conservation of Mechanical Energy

$$\boxed{KE_1 + PE_1 = KE_2 + PE_2}$$

Initial kinetic plus initial potential equals final kinetic plus final potential.

Either side equals total mechanical energy.

Closed system: No energy lost to surroundings.

9.2 Equations Summary

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

$$PE = mgh$$

$$KE_1 + PE_1 = KE_2 + PE_2$$

9.2 Equations Summary

$$KE = \frac{1}{2}mv^2$$
$$PE = mgh$$
$$KE_1 + PE_1 = KE_2 + PE_2$$

Combining them:

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

9.2 Equations Summary

$$KE = \frac{1}{2}mv^2$$
$$PE = mgh$$
$$KE_1 + PE_1 = KE_2 + PE_2$$

Combining them:

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

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?

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?

Name wheel: One pair share your approach (not your answer).

Reveal: The Falling Rock

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

Reveal: The Falling Rock

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
At 10 m height: $PE_2 = mgh_2 = 10 \times 9.8 \times 10 = 980$ J

Reveal: The Falling Rock

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
At 10 m height: $PE_2 = mgh_2 = 10 \times 9.8 \times 10 = 980$ J
Conservation: $KE_1 + PE_1 = KE_2 + PE_2$

Reveal: The Falling Rock

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
At 10 m height: $PE_2 = mgh_2 = 10 \times 9.8 \times 10 = 980$ J
Conservation: $KE_1 + PE_1 = KE_2 + PE_2$
$0 + 1960 = KE_2 + 980$

Reveal: The Falling Rock

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
At 10 m height: $PE_2 = mgh_2 = 10 \times 9.8 \times 10 = 980$ J
Conservation: $KE_1 + PE_1 = KE_2 + PE_2$
$0 + 1960 = KE_2 + 980$

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

Reveal: The Falling Rock

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
At 10 m height: $PE_2 = mgh_2 = 10 \times 9.8 \times 10 = 980$ J
Conservation: $KE_1 + PE_1 = KE_2 + PE_2$
$0 + 1960 = KE_2 + 980$

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

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

9.2 Why Conservation Works

Total mechanical energy at any point equals energy at start.

9.2 Why Conservation Works

Total mechanical energy at any point equals energy at start.

At the top of roller coaster: mostly PE, little KE

Total mechanical energy at any point equals energy at start.

At the top of roller coaster: mostly PE, little KE
At the bottom: mostly KE, little PE

9.2 Why Conservation Works

Total mechanical energy at any point equals energy at start.

At the top of roller coaster: mostly PE, little KE
At the bottom: mostly KE, little PE
At any point in between: PE + KE = constant

9.2 Why Conservation Works

Total mechanical energy at any point equals energy at start.

At the top of roller coaster: mostly PE, little KE
At the bottom: mostly KE, little PE
At any point in between: PE + KE = constant

The Paradox

Your brain says: "The roller coaster is slowing down, losing energy."
Reality: "KE converting to PE. Total energy unchanged."

9.2 Real Systems and Friction

Ideal system: No friction, energy perfectly conserved

9.2 Real Systems and Friction

Ideal system: No friction, energy perfectly conserved
Real system: Friction converts mechanical energy to heat

9.2 Real Systems and Friction

Ideal system: No friction, energy perfectly conserved
Real system: Friction converts mechanical energy to heat

The Mental Model

Friction is not a violation of conservation. Heat is still energy, just less useful.

Ideal system: No friction, energy perfectly conserved
Real system: Friction converts mechanical energy to heat

The Mental Model

Friction is not a violation of conservation. Heat is still energy, just less useful.

Engineers design to minimize friction losses.

Closed system: No energy enters or leaves

9.2 The Closed System

Closed system: No energy enters or leaves
In reality, perfectly closed systems don't exist.

9.2 The Closed System

Closed system: No energy enters or leaves

In reality, perfectly closed systems don't exist.

But many systems are approximately closed for short times.

9.2 The Closed System

Closed system: No energy enters or leaves
In reality, perfectly closed systems don't exist.
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

The Revelations

1. Work = force times distance (only if motion happens)

What You Now Know

The Revelations

1. Work = force times distance (only if motion happens)
2. Work changes energy (work-energy theorem)

What You Now Know

The Revelations

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)

What You Now Know

The Revelations

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

What You Now Know

The Revelations

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: $KE + PE = \text{constant}$

What You Now Know

The Revelations

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

$$W = Fd$$

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

$$PE = mgh$$

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

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

$$KE_1 + PE_1 = KE_2 + PE_2$$

Homework

Complete the assigned problems

posted on the LMS

Temporary page!

LaTeX was unable to guess the total number of pages correctly. A
was some unprocessed data that should have been added to the
this extra page has been added to receive it.
If you rerun the document (without altering it) this surplus page
away, because LaTeX now knows how many pages to expect for t
document.