Module 2 · Week 5 · Lesson

Work, Energy, and Power

PH11-9

ORIENTATION

Lesson goal: build accurate physics fluency for work, energy, and power and use that fluency to support clear HSC-style scientific writing.

This page is materialised into the MentorMind course shell from existing teaching, textbook, and eduKG material. Use it as the main lesson surface; use the tutor for targeted repair, worked examples, and concise writing feedback.

SYLLABUS INQUIRY QUESTION

- How is energy transferred and transformed in motion?

From The Feynman Lectures on Physics, Vol I, Chapter 4:

Energy accounting does not depend on the path taken. What matters is the initial and final states and the work done by non-conservative forces.

LEARNING OBJECTIVES

- Define work, kinetic energy, and gravitational potential energy.
- Apply the work-energy theorem.
- Calculate power and efficiency.
- Interpret energy changes in simple systems.

CONTENT

Work

Work is the energy transferred by a force acting through a displacement:

$$W = Fd\cos\theta$$

where:

- F = magnitude of force (N)
- d = displacement (m)
- θ = angle between force and displacement

SI unit: Joule (J), where 1 J = 1 N·m

- Force parallel to motion ($\theta = 0 degrees$): $W = Fd$ (positive work)
- Force opposite to motion ($\theta = 180 degrees$): $W = -Fd$ (negative work)
- Force perpendicular to motion ($\theta = 90 degrees$): $W = 0$ (no work done)

Kinetic Energy

Kinetic energy is the energy of motion:

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

- Always positive (mass and v^2 are positive)
- Doubles when speed doubles? No! **Quadruples** (because v^2)

Interactive: Energy Bar Chart - Motion

Visualise kinetic energy as an object speeds up:

Gravitational Potential Energy

Gravitational potential energy (GPE) is the energy stored due to height:

$$GPE = mgh$$

where:

- m = mass (kg)
- g = gravitational field strength (9.8 m/s^2 on Earth)
- h = height above reference point (m)

GPE depends on the chosen reference height. Usually, we set GPE = 0 at the lowest point in a problem.

Work-Energy Theorem

The **net work** done on an object equals its change in kinetic energy:

$$W_{net} = \Delta KE = KE_f - KE_i = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

This powerful theorem connects force, displacement, and speed change.

Interactive: Energy Conservation - Falling Object

As an object falls, GPE converts to KE:

Key observation: Total mechanical energy (KE + GPE) remains constant (in the absence of friction).

Conservation of Mechanical Energy

In the absence of friction and air resistance:

$$KE_i + GPE_i = KE_f + GPE_f$$

Or equivalently:

$$\frac{1}{2}mv_i^2 + mgh_i = \frac{1}{2}mv_f^2 + mgh_f$$

This is one of the most useful equations in physics!

Interactive: Pendulum Energy

A pendulum swings back and forth, continuously converting between KE and GPE:

At the highest points, all energy is GPE (momentarily stationary). At the lowest point, all energy is KE (maximum speed).

Power

Power is the rate of doing work or transferring energy:

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

For constant force and velocity:

$$P = Fv$$

SI unit: Watt (W), where 1 W = 1 J/s

Efficiency

Efficiency measures how much input energy becomes useful output:

$$\eta = \frac{E_{useful}}{E_{input}} \times 100$$

No machine is 100% efficient-some energy is always lost to friction, heat, sound, etc.

Interactive: Energy with Friction

When friction is present, some mechanical energy is lost:

Friction does negative work, removing mechanical energy and converting it to thermal energy.

WORKED EXAMPLES

Example 1: Work by a force

A 25 N force pulls a sled 8.0 m on level ground, parallel to motion.

Solution:

1. Force and displacement are parallel, so $\theta = 0 degrees$
2. Work: $W = Fd\cos\theta = 25 \times 8.0 \times \cos 0 degrees = 25 \times 8.0 \times 1 = 200$ J
3. Positive work-energy is transferred to the sled

Example 2: Speed from energy conservation

A 2.0 kg object falls 5.0 m from rest. Find its speed at the bottom (ignore air resistance).

Solution:

1. Use energy conservation: $GPE_i = KE_f$
2. $mgh = \frac{1}{2}mv^2$ (mass cancels!)
3. $v = \sqrt{2gh} = \sqrt{2 \times 9.8 \times 5.0} = \sqrt{98} = 9.9$ m/s

Example 3: Work-energy theorem

A 1.2 kg cart speeds up from 2.0 m/s to 6.0 m/s. Find the net work done.

Solution:

1. Initial KE: $KE_i = \frac{1}{2} \times 1.2 \times 2.0^2 = 2.4\,\text{J}$
2. Final KE: $KE_f = \frac{1}{2} \times 1.2 \times 6.0^2 = 21.6\,\text{J}$
3. Net work: $W_{net} = KE_f - KE_i = 21.6 - 2.4 = 19.2\,\text{J}$

Example 4: Power and efficiency

A motor lifts a 150 N load at 0.60 m/s using 200 W of electrical power.

Solution:

1. Mechanical power output: $P_{out} = Fv = 150 \times 0.60 = 90\,\text{W}$
2. Efficiency: $\eta = \frac{P_{out}}{P_{in}} \times 100$
3. The motor is 45% efficient-55% of input power is lost to friction and heat

Example 5: Roller coaster speed

A 500 kg roller coaster car starts from rest at 20 m high. Find its speed at 8 m high (ignore friction).

Solution:

1. Energy conservation: $KE_i + GPE_i = KE_f + GPE_f$
2. Initial: $KE_i = 0, GPE_i = mgh_i = 500 \times 9.8 \times 20 = 98000\,\text{J}$
3. Final: $GPE_f = mgh_f = 500 \times 9.8 \times 8 = 39200\,\text{J}$
4. $KE_f = 98000 - 39200 = 58800\,\text{J}$
5. Speed: $v = \sqrt{\frac{2 \times KE_f}{m}} = \sqrt{\frac{2 \times 58800}{500}} = \sqrt{235.2} = 15.3\,\text{m/s}$

Alternatively, using height difference:

$$v = \sqrt{2g\Delta h} = \sqrt{2 \times 9.8 \times 12} = 15.3 \text{ m/s}$$

COMMON MISCONCEPTIONS

- **Misconception:** Work is done whenever a force exists. **Correction:** Work requires displacement. No displacement = no work.
- **Misconception:** Power and energy are the same. **Correction:** Energy is a quantity (J); power is a rate (J/s = W).
- **Misconception:** Potential energy depends on path. **Correction:** GPE depends only on height. The path taken doesn't matter.
- **Misconception:** Friction destroys energy. **Correction:** Friction converts mechanical energy to thermal energy. Total energy is still conserved.
- **Misconception:** Doubling speed doubles kinetic energy. **Correction:** KE depends on v^2. Doubling speed **quadruples** KE.

PRACTICE QUESTIONS

Easy (2 marks)

A 10 N force moves an object 3.0 m in the direction of the force. Calculate the work done.

- Use $W = Fd$ (since force is parallel to displacement) (1)
- Correct value: $W = 10 \times 3.0 = 30$ J with units (1)

Answer: 30 J

Medium (4 marks)

A 1.2 kg cart speeds up from 2.0 m/s to 6.0 m/s. Find the net work done on the cart.

- Initial KE: $KE_i = \frac{1}{2} \times 1.2 \times 2.0^2 = 2.4$ J (1)
- Final KE: $KE_f = \frac{1}{2} \times 1.2 \times 6.0^2 = 21.6$ J (1)
- Work-energy theorem: $W = \Delta KE$ (1)
- Correct answer: $W = 21.6 - 2.4 = 19.2$ J (1)

Answer: 19.2 J

Hard (5 marks)

A pump raises 500 kg of water by 4.0 m in 60 s. Determine the output power and efficiency if the electrical input is 600 W.

- GPE gained: $E = mgh = 500 \times 9.8 \times 4.0 = 19600$ J (1)
- Work done equals energy gained (1)
- Output power: $P_{out} = W/t = 19600/60 = 327$ W (1)
- Efficiency formula applied correctly (1)
- Correct efficiency: $\eta = 327/600 \times 100$ (1)

Answer: Output power = 327 W; Efficiency = 54%

MULTIPLE CHOICE QUESTIONS

Test your understanding with these interactive questions:

SUMMARY

- Work: $W = Fd\cos\theta$ (units: J)
- Kinetic energy: $KE = \frac{1}{2}mv^2$
- Gravitational PE: $GPE = mgh$
- Work-energy theorem: $W_{net} = \Delta KE$
- Conservation: $KE_i + GPE_i = KE_f + GPE_f$ (no friction)
- Power: $P = W/t = Fv$ (units: W)
- Efficiency: $\eta = (E_{out}/E_{in}) \times 100$

SELF-ASSESSMENT

Check your understanding:

After studying this section, you should be able to:

- ☐ Calculate work using $W = Fd\cos\theta$
- ☐ Apply the work-energy theorem
- ☐ Use conservation of mechanical energy
- ☐ Calculate power and efficiency
- ☐ Explain energy transformations in everyday situations

MODULE 2 COMPLETE

Congratulations on completing Module 2: Dynamics!

- Forces and their effects on motion
- Newton's three laws of motion
- Friction and inclined plane analysis
- Momentum and impulse in collisions
- Work, energy, and power relationships

SCIENTIFIC WRITING AND EXAM SUPPORT

When answering questions from this lesson, separate:

- the physical quantity being discussed,
- the model or law being applied,
- the mathematical relationship, including units,
- the conclusion in words.

For explanation questions, write in the pattern: **claim -> physics reason -> consequence**. For calculation questions, state the formula, substitute with units, calculate, then interpret the answer.

MAINTENANCE LOOP

One-minute retrieval:

1. State the key law, model, or relationship used in this lesson.
2. Identify one common misconception that would lead to a wrong answer.
3. Write one sentence that links the calculation or evidence back to the physical meaning.

STUDENT WORKING