



EXPANDED STUDY MATERIAL

CHAPTER 7

Work, Energy, and Simple Machines

Understanding work, energy, power and mechanical advantage

INSIDE THIS BOOKLET

Detailed theory notes • Key definitions • Formula and concept boxes • Worked examples • One full page of practice questions • Answer key at the end

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Learn clearly. Practise consistently. Improve every rank.

Use these notes alongside your prescribed textbook and classroom teaching. Scientific terms and examples are explained in student-friendly language for revision and practice.

THEORY NOTES

1. Why do we study work and energy?

Everyday language uses the word **work** for many activities: reading, carrying a bag, pushing a wall or running. In physics, work has a precise meaning. A force does work on an object when it causes displacement and has a component along that displacement. This distinction helps us describe motion quantitatively.

Energy is a useful way to track changes in motion and position without analysing every force in detail. Food supplies chemical energy to our muscles; fuel supplies energy to engines; electricity operates appliances; and sunlight supports most ecosystems. Energy changes form, but the total amount in an isolated system is conserved.

Simple machines—such as levers, pulleys and inclined planes—help us apply forces more conveniently. They do not create energy. Ideally, they exchange a smaller force over a longer distance for a larger force over a shorter distance.

2. Work done by a force

For a constant force acting in the same direction as displacement, work is the product of force and displacement: $W = F \times s$. The SI unit is the joule (J); one joule is the work done when a force of one newton moves an object one metre in its direction.

If force and displacement are at an angle θ , only the component of force along the displacement contributes: $W = Fs \cos \theta$. When force and displacement point in the same direction, work is positive. If force acts opposite to displacement, work is negative. If force is perpendicular to displacement, the work done by that force is zero.

Work depends on force and displacement, not simply on how tired a person feels. A student holding a heavy bag still exerts an upward force, but if the bag does not move, the work done by that upward force on the bag is zero. During horizontal walking at constant height, the upward supporting force is perpendicular to horizontal displacement and therefore does no work on the bag in the idealised model.

Friction often does negative work because it acts opposite to the direction of sliding. The work-energy approach can include the effects of friction, though some mechanical energy is transformed into thermal energy.

Remember

Work is a transfer of energy. Energy is the capacity to do work. Power tells how quickly work is done.

3. Energy and its forms

Energy is the capacity to do work or cause change. Like work, energy is measured in joules. Energy appears as kinetic, potential, thermal, chemical, electrical, light, sound and nuclear energy. In real situations, more than one form may be present.

Kinetic energy is the energy an object has because it is moving. For an object of mass m moving at speed v , $KE = \frac{1}{2}mv^2$. Kinetic energy increases with mass and with the square of speed. If speed doubles, kinetic energy becomes four times as large; if speed triples, it becomes nine times as large.

Potential energy is stored energy associated with position or configuration. Near Earth's surface, gravitational potential energy relative to a chosen reference level is $GPE = mgh$, where m is mass, g is gravitational acceleration and h is height above the reference. Raising an object increases its gravitational potential energy.

Elastic potential energy can be stored when a spring or elastic object is stretched or compressed. Chemical energy is stored in fuels, food and batteries. The form of energy may change, but energy is not created from nothing.

4. Conservation and transformation of energy

The **law of conservation of energy** states that energy cannot be created or destroyed; it can only be transferred or transformed from one form to another. For a falling object, gravitational potential energy decreases while kinetic energy increases. If air resistance is negligible, the total mechanical energy ($KE + GPE$) remains constant.

In everyday systems, friction and air resistance transform some mechanical energy into thermal energy and sound. The mechanical energy may decrease, but total energy—including thermal energy—remains conserved. This is why a bouncing ball eventually stops bouncing: energy is transferred to the surroundings during each impact.

Power plants, vehicles and household appliances illustrate energy conversions. A hydroelectric plant converts gravitational potential energy of stored water into kinetic energy, then mechanical energy in a turbine, and finally electrical energy in a generator. A lamp converts electrical energy mainly into light and thermal energy.

5. Power and efficiency

Power is the rate at which work is done or energy is transferred. $P = W/t$ or energy transferred per unit time. The SI unit is the watt (W), where $1\text{ W} = 1\text{ J/s}$. A machine that performs the same work in less time has greater power.

Power is different from work: two people may do the same amount of work while taking different times. The person who finishes sooner produces greater average power. A kilowatt is 1000 watts; electrical energy used by households is commonly measured in kilowatt-hours (kWh). One kWh equals 3.6 million joules.

Efficiency compares useful output energy or work with input energy or work: $\text{efficiency} = (\text{useful output} \div \text{input}) \times 100\%$. Real machines are less than 100% efficient because friction, sound, deformation and heating transfer some input energy into forms that are not the intended useful output.

6. Simple machines: how they help

A **simple machine** changes the magnitude or direction of an applied force, or allows force to be applied more conveniently. Examples include levers, pulleys, wheels and axles, inclined planes, wedges and screws. A machine does not reduce the total work required in an ideal situation; it trades force for distance.

The **mechanical advantage (MA)** of a machine is the ratio of load to effort: $\text{MA} = \text{load} / \text{effort}$. A mechanical advantage greater than one means the machine allows a smaller effort to balance a larger load. The **velocity ratio (VR)** compares the distance moved by effort with the distance moved by load: $\text{VR} = \text{distance moved by effort} / \text{distance moved by load}$.

For an ideal machine, efficiency is 100% and $\text{MA} = \text{VR}$. In a real machine, friction means useful output work is less than input work; $\text{efficiency} = (\text{MA}/\text{VR}) \times 100\%$. Mechanical advantage is a ratio and has no unit.

7. Levers, pulleys and inclined planes

A **lever** is a rigid bar that turns around a fixed point called the fulcrum. The effort is the applied force and the load is the resistance being moved. In a first-class lever, the fulcrum lies between effort and load (seesaw, scissors). In a second-class lever, the load lies between fulcrum and effort (wheelbarrow, nutcracker). In a third-class lever, effort lies between fulcrum and load (tweezers, human forearm lifting an object).

A **pulley** is a grooved wheel with a rope or chain. A fixed pulley mainly changes the direction of effort; an ideal single fixed pulley has MA 1. A movable pulley can reduce the effort needed to lift a load. In an ideal block-and-tackle arrangement, the number of rope segments supporting the moving load gives the ideal mechanical advantage.

An **inclined plane** is a sloping surface that allows a load to be raised using a smaller force over a longer distance. A ramp is an everyday example. A longer, gentler ramp requires less effort but increases the distance over which the effort acts. Screws and wedges are related applications of inclined planes.

8. Solved examples

Example 1 — Work: A force of 20 N moves a box 3 m in the direction of the force. $\text{Work} = Fs = 20 \times 3 = \mathbf{60 \text{ J}}$.

Example 2 — Kinetic energy: A 2 kg ball moves at 4 m/s. $\text{KE} = \frac{1}{2} \times 2 \times 4^2 = \mathbf{16 \text{ J}}$.

Example 3 — Potential energy: A 5 kg object is raised 2 m. Taking $g = 9.8 \text{ m/s}^2$, $\text{GPE} = mgh = 5 \times 9.8 \times 2 = \mathbf{98 \text{ J}}$.

Example 4 — Power: A motor performs 600 J of work in 10 s. $P = W/t = 600/10 = \mathbf{60 \text{ W}}$.

Example 5 — Mechanical advantage: A machine lifts a 300 N load using 75 N effort. $\text{MA} = 300/75 = \mathbf{4}$.

QUICK REVISION SUMMARY

Key ideas to retain

$W = Fs$ (for force along displacement); $\text{KE} = \frac{1}{2}mv^2$; $\text{GPE} = mgh$; $P = W/t$; $\text{MA} = \text{load/effort}$; $\text{efficiency} = \text{useful output/input} \times 100\%$. Energy is conserved but can change form. Machines trade force for distance.

PRACTICE QUESTIONS

Attempt all questions before checking the answer key. Show working for numerical questions and write full sentences for explanation questions.

1. Define work in physics and state its SI unit.
2. A 25 N force moves an object 4 m in the same direction. Calculate the work done.
3. Explain why a person holding a stationary suitcase does zero mechanical work on it in the physics sense.
4. Distinguish between positive, negative and zero work, giving one example of each.
5. Calculate the kinetic energy of a 3 kg object moving at 5 m/s.
6. A 4 kg object is raised 3 m. Calculate its gain in gravitational potential energy using $g = 10 \text{ m/s}^2$.
7. State the law of conservation of energy and explain it using a falling object.
8. A machine performs 1500 J of work in 30 s. Find its average power.
9. A machine lifts a 500 N load with an effort of 125 N. Calculate its mechanical advantage.
10. Explain why the efficiency of a real machine is usually less than 100%.
11. Classify each lever: seesaw, wheelbarrow and tweezers.
12. Explain how a fixed pulley differs from a movable pulley.
13. A machine has $MA = 3$ and $VR = 4$. Calculate its efficiency.
14. Why does a longer ramp make it easier to raise a heavy object?
15. A 1000 W appliance operates for 2 hours. Calculate the energy used in kWh.

Before you submit

Check calculations, include units where appropriate, define important terms clearly and support explanations with examples.

ANSWER KEY

Use the answers to check your understanding. For explanation questions, equivalent scientifically correct wording is acceptable.

1. Work is done when a force causes displacement and has a component along it; SI unit: joule (J).
2. $W = Fs = 25 \times 4 = 100 \text{ J}$.
3. The suitcase has no displacement, so work done on it by the supporting force is zero.
4. Positive: force along displacement; negative: friction opposite sliding; zero: perpendicular force or no displacement.
5. $KE = \frac{1}{2}mv^2 = 0.5 \times 3 \times 25 = 37.5 \text{ J}$.
6. $GPE = mgh = 4 \times 10 \times 3 = 120 \text{ J}$.
7. Energy is transformed, not created or destroyed. During a fall, GPE decreases as KE increases; total mechanical energy is constant if resistance is negligible.
8. $P = W/t = 1500/30 = 50 \text{ W}$.
9. $MA = \text{load/effort} = 500/125 = 4$.
10. Friction and deformation transfer some input energy into heat, sound and other non-useful forms.
11. Seesaw: first class; wheelbarrow: second class; tweezers: third class.
12. A fixed pulley mainly changes force direction; a movable pulley moves with the load and can reduce the required effort.
13. $\text{Efficiency} = (MA/VR) \times 100 = (3/4) \times 100 = 75\%$.
14. It spreads the required work over a longer distance, reducing the force needed at any moment.
15. $\text{Energy} = 1 \text{ kW} \times 2 \text{ h} = 2 \text{ kWh}$.

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Revise the theory, practise without looking at the answers, and revisit any question you could not explain in your own words.

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