

Work done, energy conservation and power

Physics grades 11-12 (A Level · IB · Class 11-12) · Lesson

Quick answer: Work done is the energy a force transfers, $W = F s \cos \theta$, measured in joules. The work-energy theorem says the net work on an object equals its change in kinetic energy. Power is the rate of doing work, $P = W/t$ in watts, and efficiency is useful output divided by total input.

Level: Physics grades 11-12 (A Level · IB · Class 11-12) · **Curriculum:** IB A.3

What is work done by a force?

A force does work when it makes an object move. The force transfers energy to the object, or takes energy away from it. If you push a wall and nothing moves, you are tired but no work is done on the wall.

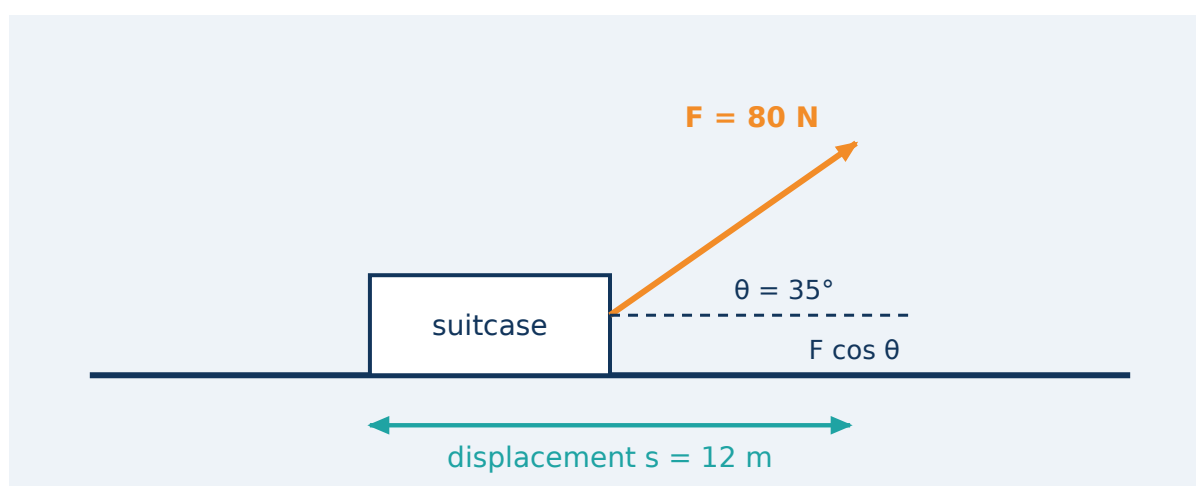
Definition

Work done is the energy transferred by a force. It equals the force multiplied by the displacement in the direction of the force. One joule (J) is the work done when a force of 1 N moves an object 1 m along the force.

Formula

$$W = F s \cos \theta$$

W = work done (J), F = force (N), s = displacement (m), θ = angle between the force and the displacement (degrees).



Only the part of the force along the displacement, $F \cos \theta$, does work.

Worked example 1

Aarav in Pune pulls a suitcase with a rope force of 80 N at 35° above the horizontal for 12 m.

$$W = F s \cos \theta = 80 \times 12 \times \cos 35^\circ = 960 \times 0.819 = \mathbf{786 \text{ J}}.$$

When the force is at 90° to the motion, $\cos 90^\circ = 0$ and no work is done. This is why gravity does no work on a bus on a level road, and why the tension in a string does no work on a stone swung in a horizontal circle. When the force points against the motion, $\cos 180^\circ = -1$ and the work is negative: the force removes energy, as friction does.

How does the work-energy theorem work?

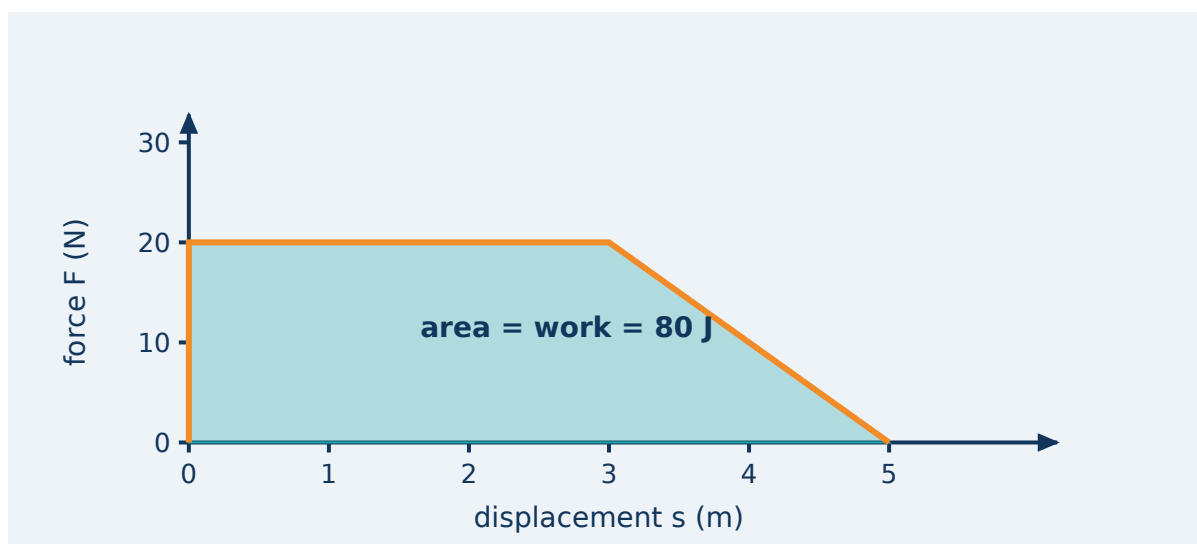
Key law

Work-energy theorem: the net work done on an object equals its change in kinetic energy.

$$W_{\text{net}} = \frac{1}{2} m v^2 - \frac{1}{2} m u^2$$

u = initial speed (m/s), v = final speed (m/s), m = mass (kg).

The theorem lets you skip the acceleration and the time. If the force changes with position, plot force against displacement. The area under the graph is the work done.



The area under a force-displacement graph is the work done. Here: $20 \times 3 + \frac{1}{2} \times 20 \times 2 = 80 \text{ J}$.

Worked example 2

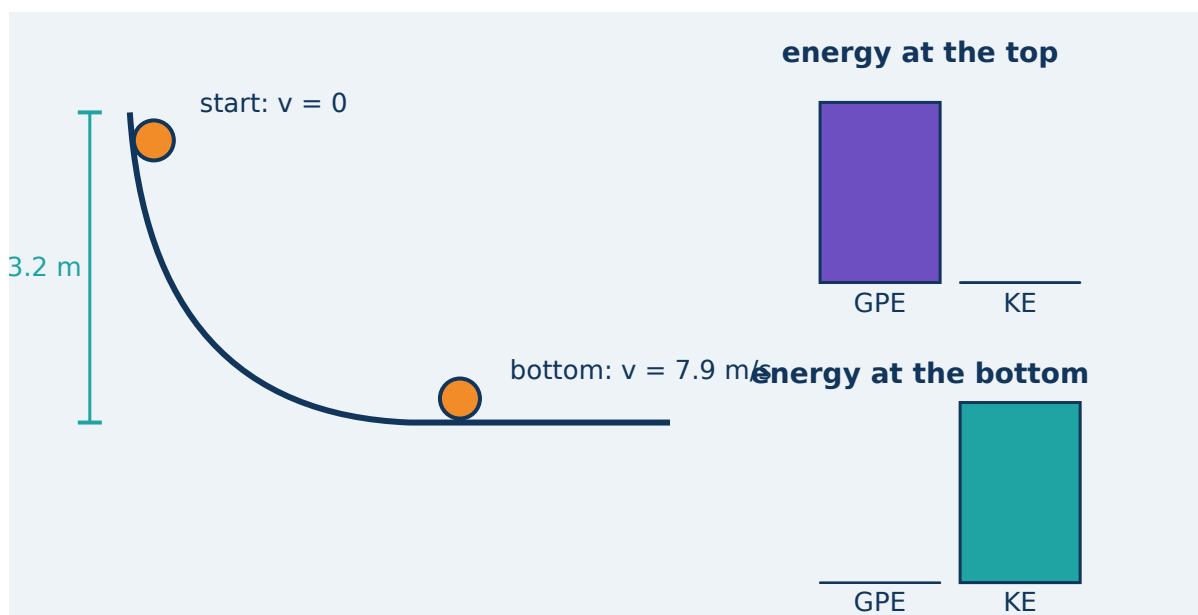
A car of mass 1100 kg speeds up from 12 m/s to 25 m/s over 150 m.

$$W_{\text{net}} = \frac{1}{2} \times 1100 \times (25^2 - 12^2) = 550 \times 481 = \mathbf{2.6 \times 10^5 \text{ J}}.$$

$$\text{Average net force} = W \div s = 264\,550 \div 150 = \mathbf{1.8 \times 10^3 \text{ N}}.$$

How is energy conserved when only gravity acts?

Energy is never created or destroyed. It moves between stores. Near Earth the gravitational potential energy gained when an object rises by Δh is $\Delta E_p = m g \Delta h$, with $g = 9.81 \text{ N/kg}$. If friction and drag are negligible, the total of kinetic and potential energy stays constant.



On a smooth ramp, gravitational potential energy converts completely to kinetic energy.

Worked example 3

A skateboarder starts from rest at the top of a smooth curved ramp 3.2 m high. At the bottom all the potential energy has become kinetic: $\frac{1}{2} m v^2 = m g h$, so m cancels.

$$v = \sqrt{2 g h} = \sqrt{2 \times 9.81 \times 3.2} = \sqrt{62.8} = \mathbf{7.9 \text{ m/s}}.$$

Because energy is a scalar, you do not need to know the shape of the ramp. Only the height difference matters. If a resistive force does work W_f on the way, subtract it: $KE_{\text{end}} = KE_{\text{start}} + \Delta E_p - W_f$.

How do you calculate power and efficiency?

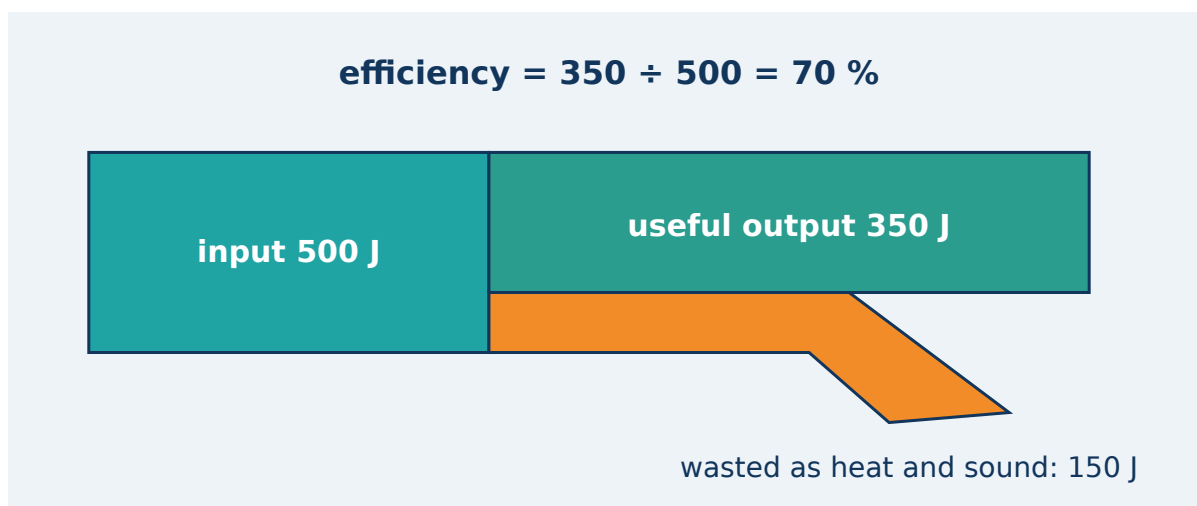
Power is the rate of doing work, or the rate of transferring energy. Its unit is the watt (W), which is 1 joule per second. For a force moving an object at constant speed in its own direction, power equals force times velocity.

Formulae

$$P = W \div t = F v$$

$$\text{efficiency} = \text{useful output} \div \text{total input} \times 100 \%$$

P = power (W), W = work or energy (J), t = time (s), F = force (N), v = speed (m/s).



A Sankey diagram shows how much of the input energy is useful. The widths are drawn to scale.

Worked example 4

Wanjiru in Nairobi tests an electric bicycle motor. It takes 320 W from the battery and drives the wheel with a useful power of 250 W.

Efficiency = $250 \div 320 \times 100 \%$ = **78 %**. The other 70 W warms the motor and the controller.

Quantity	Symbol	Unit	Link
Work done	W	joule (J)	$F s \cos \theta$
Kinetic energy	KE	joule (J)	$\frac{1}{2} m v^2$
Gravitational potential energy	ΔE_p	joule (J)	$m g \Delta h$
Power	P	watt (W)	$W \div t = F v$
Efficiency	none	% or ratio	useful $\div$ total

Common mistake

Students multiply any force by any distance. The force must be the one you are asked about, and the distance must be measured along its direction. Weight does no work when an object moves sideways. Also, the work-energy theorem uses the *net* work of all forces, not just the push you can see.

Lina's tip

Ask first: do I need the path or the time? If the question gives heights and speeds only, use energy and skip the forces. Write "energy at start = energy at end + work lost" and fill in each term.

Key points to remember

- Work done $W = F s \cos \theta$ (joules); zero if the force is perpendicular to the motion.
- Work-energy theorem: $W_{\text{net}} = \frac{1}{2} m v^2 - \frac{1}{2} m u^2$.
- Gravitational potential energy change: $\Delta E_p = m g \Delta h$, with $g = 9.81 \text{ N/kg}$.

- Power $P = W/t = F v$ in watts; efficiency = useful output ÷ total input.
- The area under a force-displacement graph equals the work done.

Work done, energy conservation and power: frequently asked questions

What is the difference between work and energy?

Work is the process of transferring energy by a force acting through a distance. Energy is the store that changes. Both are measured in joules, and the work done equals the energy transferred.

Can work be negative?

Yes. Work is negative when the force points opposite to the displacement, so the force removes energy. Friction on a sliding crate does negative work and reduces its kinetic energy.

Why does a satellite in a circular orbit have a constant speed?

Gravity acts at right angles to its velocity, so the work done by gravity is zero. With no net work, the kinetic energy and the speed stay constant.

How are power, force and velocity related?

When a force acts along the direction of motion at constant speed, $P = F v$. A motorbike with a thrust of 720 N at 25 m/s has a useful power of 18 kW.

Can efficiency ever be greater than 100 %?

No. Energy is conserved, so the useful output can never exceed the total input. Some energy is always transferred to the surroundings as thermal energy, which is why real machines have efficiencies below 100 %.