Work, Energy, and Power

AP Physics 1

Translational Kinetic Energy

Energy 能量 is the capacity to do work, measured in **joules** 焦耳 (J). A moving object has **kinetic energy** 动能:

$$K = \tfrac{1}{2}mv^2.$$

It depends on the **square** of the speed, so doubling the speed **quadruples** the kinetic energy. Kinetic energy is a scalar and is never negative.

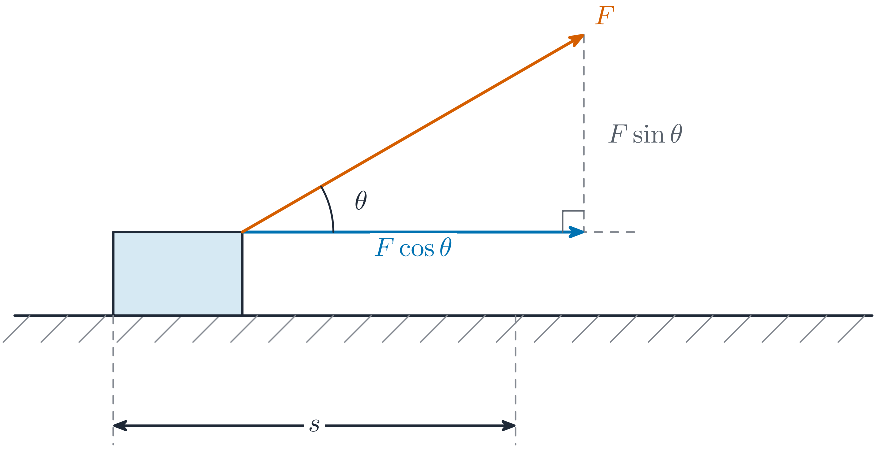
Worked example. A 1500 kg car travels at 20 m/s. Its kinetic energy is $K = \frac{1}{2} \times 1500 \times 20^2 = 3.0 \times 10^5$ J $= 300$ kJ. If it speeds up to 40 m/s (double), the kinetic energy becomes 4× larger, 1200 kJ –which is why stopping distance grows so fast with speed.

Work

Work 功 is energy transferred by a force acting over a displacement:

$$W = F\,d\cos\theta,$$

where θ is the angle between the force and the displacement. Work is **positive** when the force has a component along the motion (adds energy), **negative** when it opposes the motion (removes energy), and **zero** when the force is perpendicular. On a force–position graph, work is the **area** under the curve. The **work–energy theorem** 动能定理 states that the net work equals the change in kinetic energy: $W_{\text{net}} = \Delta K$.



Only the force component along the displacement does work

Worked example. A 2.0 kg block moving at 3.0 m/s on a frictionless floor is pushed by a 5.0 N force over 4.0 m in the direction of motion. Find its final speed. The net work is $W = Fd = 5.0 \times 4.0 = 20$ J, and by the work–energy theorem $W = \frac{1}{2}m(v^2 - v_0^2)$:

$$20 = \tfrac{1}{2} \times 2.0 \times (v^2 - 3.0^2) \;\Rightarrow\; v^2 = 29 \;\Rightarrow\; v = 5.4 \text{ m/s}.$$

Potential Energy

Potential energy 势能 is stored energy that depends on position or configuration:

- **Gravitational potential energy 重力势能** near the surface: $U_g = mgh$ (height h above a reference level).
- **Elastic potential energy 弹性势能** in a spring: $U_s = \frac{1}{2}kx^2$.

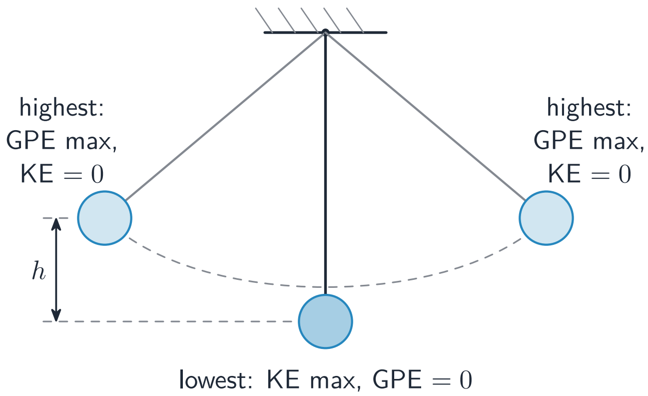
Potential energy is defined only for **conservative forces 保守力** (gravity, springs), for which the stored energy depends on position, not path. Only *changes* in potential energy matter, so you may put the zero level wherever is convenient.

Conservation of Energy

The **total mechanical energy 机械能** is $E = K + U$. When only conservative forces do work, mechanical energy is **conserved 守恒**:

$$K_1 + U_1 = K_2 + U_2.$$

When friction or other non-conservative forces act, they transfer mechanical energy to **thermal energy 热能**; then the general statement is that total energy (including thermal) is conserved. Energy bar charts are a good way to track where the energy goes.



A swinging pendulum trades gravitational potential energy for kinetic energy and back

Worked example. A ball is released from rest at the top of a frictionless ramp 5.0 m high. Find its speed at the bottom. All the gravitational potential energy becomes kinetic energy:

$$mgh = \frac{1}{2}mv^2 \;\Rightarrow\; v = \sqrt{2gh} = \sqrt{2 \times 9.8 \times 5.0} = 9.9 \text{ m/s}.$$

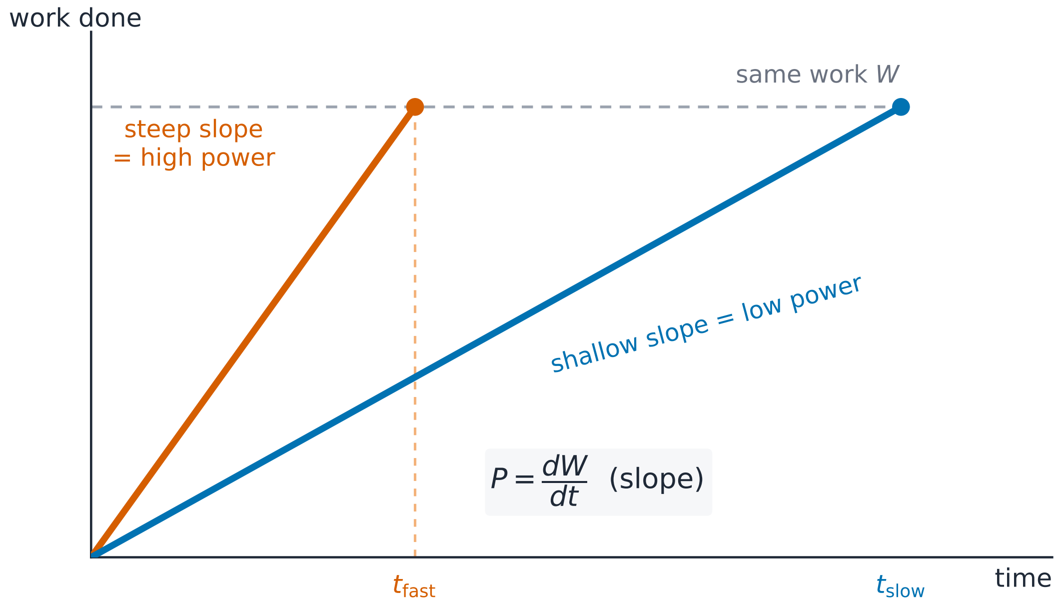
The mass cancels, so every object reaches the same speed –exactly the free-fall result, now got from energy. If instead 30 J were lost to friction, you would subtract it: $mgh - 30 = \frac{1}{2}mv^2$.

Power

Power 功率 is the **rate** of doing work or transferring energy, measured in **watts** 瓦特 (W):

$$P = \frac{W}{\Delta t} = \frac{\Delta E}{\Delta t}, \qquad \text{and instantaneously} \qquad P = Fv.$$

So the same job done faster requires more power. On an energy–time graph, power is the slope.



Power is the slope of the work-time graph: the same work in less time means more power

Worked example. A motor lifts a 50 kg load at a steady 2.0 m/s. Because it moves at constant speed, the lifting force equals the weight, so

$$P = Fv = mgv = 50 \times 9.8 \times 2.0 = 980 \text{ W}.$$

Real machines waste some energy, so we quote **efficiency** 效率–useful output power divided by total input power. If this motor draws 1400 W of electrical power to deliver 980 W of useful lifting, its efficiency is $980/1400 = 0.70$, or 70%; the other 30% becomes heat and sound.

Exam tips

- Use $W = Fd\cos\theta$: work is zero when the force is perpendicular to the motion, and negative when it opposes it.
- Reach for the **work–energy theorem** ($W_{net} = \Delta K$) or **energy conservation** ($K_1 + U_1 = K_2 + U_2$) instead of forces whenever the path is complicated.
- When friction acts, mechanical energy is **not** conserved —subtract the energy lost to heat.
- Remember $K \propto v^2$: doubling the speed **quadruples** the kinetic energy (and the stopping distance).

- Use $P = Fv$ for power at a steady speed; at constant velocity the net force is zero but the power is **not**.