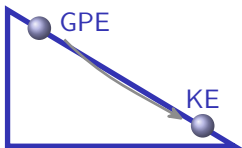


Work, Energy & Power

AS Physics ■ Topic 5

A-Level Physics



What we will cover

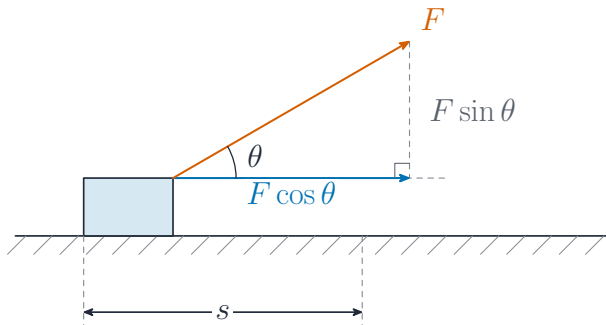
- 1 Work done by a force
- 2 Conservation of energy
- 3 Efficiency
- 4 Power
- 5 Potential & kinetic energy
- 6 Recap



1

Work

Work done by a force



Work 功 = force $\times$ distance **along the force**:

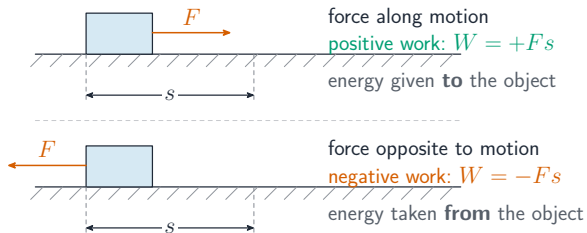
$$W = Fs \cos \theta, \quad [W] = \text{J} = \text{N m}.$$

Work is a **scalar** 标量.

Sledge: 20 N at 60° , 5.0 m

$$W = 20 \times 5.0 \times \cos 60^\circ = 50 \text{ J}$$

Positive, negative and zero work



- $\theta = 0^\circ$: $W = +Fs$ – energy in
- $\theta = 90^\circ$: $W = 0$ – no work
(normal force on a flat road)
- $\theta = 180^\circ$: $W = -Fs$ – energy out (friction 摩擦力)

2

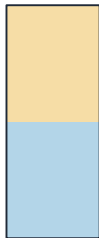
Conservation of energy

Conservation of energy

GPE
 KE
 total energy stays the same



top



middle



bottom

Energy is **never made or destroyed** – it only changes form, or moves between objects. In a **closed system** 封闭系统 the total is constant. On a frictionless **ramp** 斜坡:

$$mgh = \frac{1}{2}mv^2 \Rightarrow v = \sqrt{2gh}$$

With friction, some becomes **thermal energy** 热能. List every form at the start and the end: kinetic, gravitational potential, **elastic potential** 弹性势能, **electrical** 电能, thermal, sound, **chemical energy** 化学能.

Where $mg\Delta h$ comes from

In a **uniform** field, raising a **mass** 质量 m through a height Δh costs **gravitational**

potential energy 重力势能:

$$\Delta E_p = mg\Delta h$$

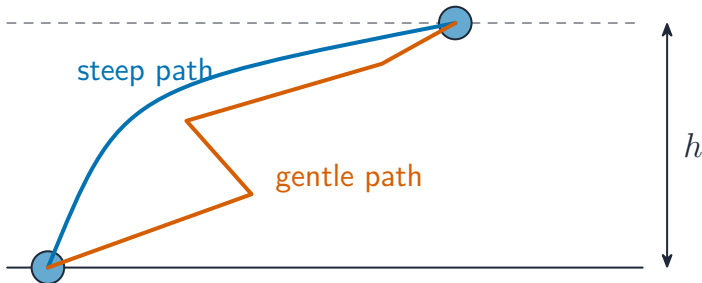
Lift it *slowly*, so no kinetic energy is gained:

- the gravitational force on the mass is mg downwards,
- the force needed to lift it slowly is mg upwards,
- the work done by this force is $W = F \cdot s = mg \cdot \Delta h$,
- this work becomes ΔE_p .

You need m , Δh and g – **never** speed or time.

Only the height matters, not the path

same $\Delta E_P = mgh$ – only the height h matters



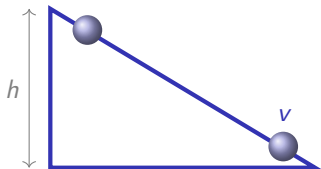
Steep or zig-zag, the gain is mgh either way: gravitational PE counts only the height risen.

Worked example – speed down a ramp

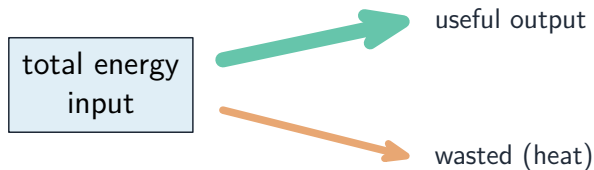
Released from rest, smooth ramp $h = 1.2$ m

All GPE becomes KE, so $v = \sqrt{2gh}$ (mass cancels):

$$v = \sqrt{2 \times 9.81 \times 1.2} \approx 4.9 \text{ m s}^{-1}.$$



Efficiency



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

$$\eta = \frac{\text{useful output}}{\text{total input}} \times 100\%.$$

Motor lifts 50 kg at 0.40 m s^{-1} , draws 250 W

$$\text{useful } P = mgv = 50 \times 9.81 \times 0.40 = 196 \text{ W}$$

$$\eta = \frac{196}{250} \times 100\% \approx 78\%.$$

Always $< 100\%$ – the rest is wasted as heat.

Efficiency: only part of the energy input leaves as useful output; the rest is wasted, usually as heat

3

Power

Power – the rate of energy transfer

$$P = \frac{W}{t} = \frac{\Delta E}{\Delta t}, \quad [P] = W = \text{J s}^{-1}.$$

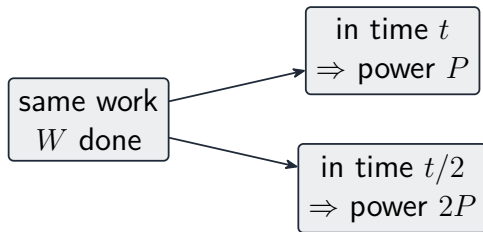
Power is a **scalar** 标量.

same work
in less time



more power

Same work, different power



$$P = \frac{W}{t} \text{ — less time, more power}$$

Power is **work per second**: climbing the stairs twice as fast does the *same* work against gravity, at **twice** the power.

4

Potential and kinetic energy

Kinetic energy: where $\frac{1}{2}mv^2$ comes from

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

Push a mass m from rest up to speed v
over a displacement s .

- from $v^2 = u^2 + 2as$ with $u = 0$: $s = \frac{v^2}{2a}$
- the work done is $W = Fs = ma \cdot \frac{v^2}{2a}$
- the a cancels: $W = \frac{1}{2}mv^2$

All of that work becomes kinetic energy, so
 $E_K = \frac{1}{2}mv^2$.

When you know the momentum, not the speed

$$p = mv \quad \text{and} \quad E_K = \frac{1}{2}mv^2$$


$$E_K = \frac{p^2}{2m}$$

A momentum change from p_1 to p_2 at constant mass changes the kinetic energy by $\frac{p_2^2 - p_1^2}{2m}$.

Reach for this whenever a question gives you **momentum** 动量 and asks for energy – there is no need to find v first.

Power at a steady speed is force times velocity

$$P = Fv$$

In a time Δt the force moves through $v\Delta t$, doing $Fv\Delta t$ of work. Divide by Δt .

Car at 25 m s^{-1} against 600 N

At constant speed the driving force equals the resistive force, so $P = 600 \times 25 = 15 \text{ kW}$.

- a car on a flat road: the engine balances the total resistive force, $P = F_{\text{resist}} v$
- **drag** 阻力 grows like v^2 , so doubling the speed roughly quadruples the power
- lifting a **weight** 重力 mg at steady v : useful $P = mgv$ – the same $P = Fv$ with $F = mg$
- a hovering aircraft needs large power – air must be pushed down all the time

Three quantities a power equation can give you

A force

At a steady speed the useful power is $P = Fv$, so a measured power and speed give the force opposing motion.

A lifting speed

For an electric motor lifting a load at **voltage** 电压 V and **current** 电流 I with efficiency η , the useful output power is ηVI – and $\eta VI = mgv$ gives the speed.

A tension

Same equation, read the other way: the **tension** 张力 in the cable is the useful power divided by the speed.

Which forces do no work

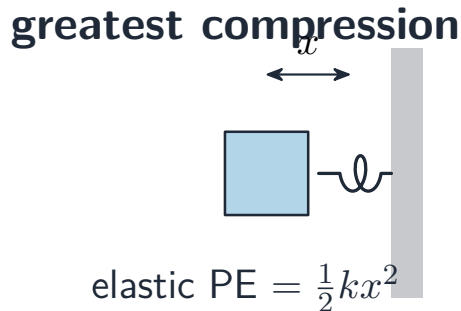
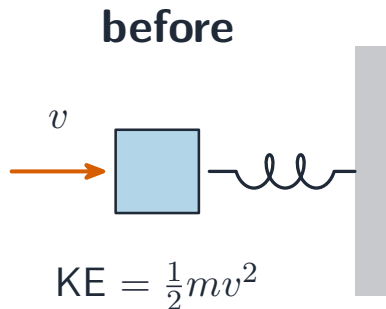
A force perpendicular to the motion does none – the **normal contact force** 法向接触力 on a car on a flat road, or any centripetal force.

Work is $F \cos \theta$ with θ measured from the **horizontal** 水平 displacement – so a force at 90° transfers no energy at all.

Using energy methods

- 1 write energies at the **start** and **end**
- 2 add work by outside forces (push in, friction out)
- 3 set $E_{\text{start}} + W_{\text{in}} = E_{\text{end}} + W_{\text{lost}}$
 - into a **spring** 弹簧: $\frac{1}{2}mv^2 = \frac{1}{2}kx^2$ at greatest **compression** 压缩, where k is the **spring constant** 劲度系数
 - box pushed up a ramp at **constant velocity**: E_K is unchanged, so the push pays for ΔE_P and the friction
 - a ball bouncing from h_1 to h_2 : the fraction of energy kept is $h_2/h_1 = (v_{\text{up}}/v_{\text{down}})^2$
 - a **projectile** 抛体 thrown to the same height at any angle lands at the **same speed** – only the height counts; use **components** 分量 for the direction

Using energy methods, in detail



A block's kinetic energy becomes elastic potential energy as it compresses the spring

Exam tips

- **Work** = **force** $\times$ **distance moved in the direction of the force** – use $Fs \cos \theta$ when they are at an angle.
- Use **conservation of energy**: loss in GPE = gain in KE (+ work done against resistance).
- **Power** = **work** / **time** = Fv ; efficiency = useful output $\div$ total input.
- GPE uses the **vertical** height gained, not the distance along a slope.

5

Recap

Topic 5 – key takeaways

1

Work

$$W = Fs \cos \theta; \text{ energy in or out}$$

2

Energy

conserved; only changes form

3

Power

$$P = W/t = Fv; \text{ efficiency} < 100\%$$

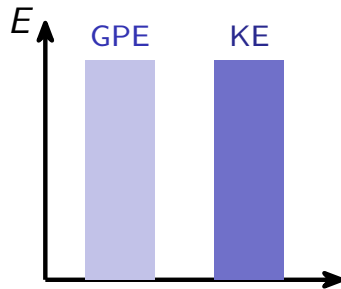
4

Stores

$$E_P = mg\Delta h, E_K = \frac{1}{2}mv^2$$

Check yourself

- 1 Work done by a force at 90° to the motion?
- 2 Speed at the foot of a smooth 5.0 m drop?
- 3 Power to move at 20 m s^{-1} against 400 N?
- 4 Why is a real machine never 100% efficient?



Answers 1. zero 2. $\sqrt{2g \cdot 5} \approx 9.9 \text{ m s}^{-1}$ 3. $Fv = 8 \text{ kW}$ 4. some energy always wasted as heat