5.1 Energy conservation

Name: ____________ Class: __________ Date: ____________ **Total: 26 marks**

KEY WORDS power 功率 • work 功 • efficiency 效率 • energy 能量 • conservation of energy 能量守恒

Objective

Build the skills to answer exam questions on **energy conservation** — work, the conservation principle, efficiency and power.

You must be able to:

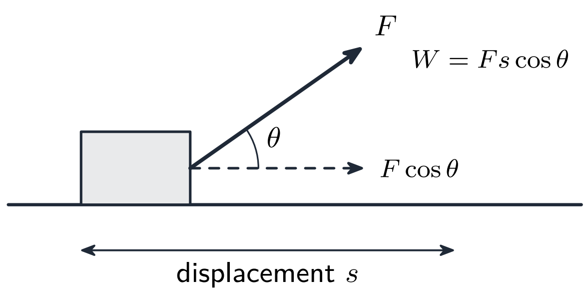
- use **work done** $= Fs\cos\theta$
- apply **conservation of energy** (e.g. GPE → KE)
- use **efficiency** and **power** ($P = W/t$ and $P = Fv$)

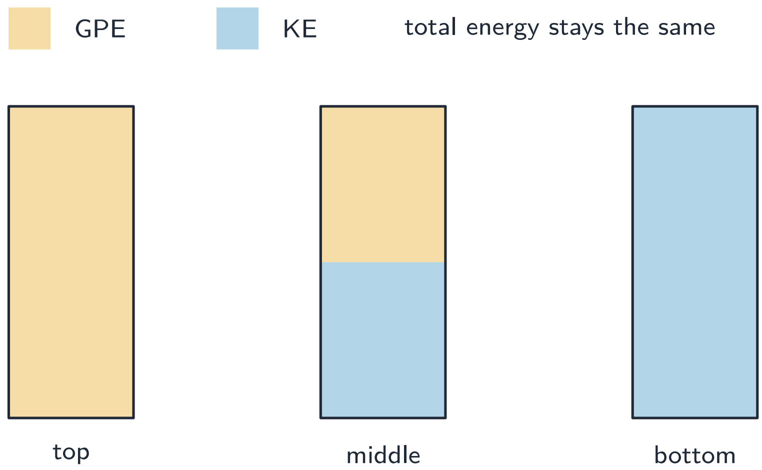
1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ Work done

Work is done when a force moves along its own line: $W = Fs\cos\theta$. Only the component **along** the displacement does work:





Energy is conserved as it transfers

- $\theta = 0$: $W = Fs$ (max); $\theta = 90°$: $W = 0$ (e.g. the normal force on a flat road); $\theta = 180°$: $W = -Fs$ (e.g. friction).

Conservation of energy

Energy is never made or destroyed. On a **smooth** ramp, GPE → KE:

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

Efficiency and power

$$\text{efficiency} = \frac{\text{useful energy out}}{\text{total energy in}}, \qquad P = \frac{W}{t}, \qquad P = Fv.$$

$P = Fv$ comes from $P = W/t = Fs/t = F(s/t) = Fv$.

Efficiency, and where the wasted energy goes

Efficiency compares what you **want** with what you **paid for**, as energies or as powers:

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{total energy input}} = \frac{\text{useful power output}}{\text{total power input}}$$

It has **no unit**, and it can be written as a decimal or a percentage — but never above 1. Two habits win the marks:

- **Work out the useful output first**, from what the machine actually achieves (mgh for a lift, Fs for a drag, $\tfrac{1}{2}mv^2$ for a launch).
- **The wasted energy is input minus useful output**, and the exam wants to know *where it went*: thermal energy in the motor windings and bearings, sound, and in a lift the kinetic energy left over if it does not stop.

Worked example. A pump raises 600 kg of water through 12 m in 30 s, drawing 3.0 kW.

$$P_{\text{useful}} = \frac{mgh}{t} = \frac{600 \times 9.81 \times 12}{30} = 2354 \text{ W}, \qquad \text{efficiency} = \frac{2354}{3000} = 0.78$$

2 Practice

Now apply the methods above.

2.1 Define the **work done** by a force. [1]

2.2 A child pulls a sledge 5.0 m with a 20 N force at 60° to the ground. Find the **work done**. [2]

2.3 Define **power** and give its unit. [1]

2.4 State the **principle of conservation of energy**. [1]

3 Exam-style questions

3.1 A force acts at 90° to the direction of motion. The work it does is: [1]

- **A** maximum
- **B** Fs
- **C** zero
- **D** negative

3.2 A ball is released from rest at the top of a **smooth** ramp 1.2 m high. Calculate its speed at the bottom. ($g = 9.81$ m s^{-2}.) [3]

3.3 A motor lifts a 50 kg load through 8.0 m in 10 s.

(a) Calculate the **useful power** output. [2]

(b) If the input power is 500 W, calculate the **efficiency**. [2]

3.4 Derive $P = Fv$ from $P = W/t$. [2]

3.5 A crane is used on a building site.

(a) **Define** the **work done** by a force. [1]

(b) A block of mass m is raised vertically at constant speed through a height Δh. **Derive** an expression, in terms of m and Δh, for the change in gravitational potential energy ΔE_P of the block. State the meaning of any other symbol you use. [2]

(c) The crane raises a steel beam of mass 450 kg at constant speed through a vertical height of 24 m, taking 40 s.

(i) **Calculate** the work done on the beam. [2]

(ii) **Calculate** the useful output power of the crane. [2]

(iii) The input power to the crane is 3.6 kW. **Calculate** its efficiency. [2]

(iv) **Determine** the energy wasted during the 40 s, and **state** one form it takes. [2]

Solutions

2.1 Work = force × displacement **in the direction of the force** ($W = Fs\cos\theta$).

2.2 $W = Fs\cos\theta = 20 \times 5.0 \times \cos 60° = 50$ J.

2.3 Power is the **work done (energy transferred) per unit time**, unit **watt** (W = J s^{-1}).

2.4 Energy cannot be **created or destroyed**, only **transferred** from one form to another; the total energy of a closed system is constant.

3.1 **C** — zero.

3.2 $mgh = \frac{1}{2}mv^2$; $v = \sqrt{2gh} = \sqrt{2 \times 9.81 \times 1.2} = \sqrt{23.5} = 4.9$ m s^{-1}.

3.3 (a) useful work = $mgh = 50 \times 9.81 \times 8.0 = 3924$ J; $P = W/t = 3924/10 = 392$ W.
(b) efficiency = 392/500 = 0.78 = 78%.

3.4 $P = W/t = Fs/t$; since $s/t = v$, $P = Fv$.

3.5 (a) The product of the force and the **displacement in the direction of the force**.
(b) Raising the block at constant speed needs an upward force equal to its weight, mg, where g is the acceleration of free fall; the gain in potential energy is the work done by that force, so $\Delta E_{\mathrm{P}} = mg\Delta h$.
(c)(i) $W = mg\Delta h = 450 \times 9.81 \times 24 = 1.1 \times 10^5$ J.
(c)(ii) $P = \dfrac{W}{t} = \dfrac{1.06 \times 10^5}{40} = 2.6 \times 10^3$ W.
(c)(iii) efficiency $= \dfrac{P_{\text{useful}}}{P_{\text{input}}} = \dfrac{2650}{3600} = 0.74$, i.e. 74%.
(c)(iv) input energy $= 3600 \times 40 = 1.44 \times 10^5$ J, so wasted $= 1.44 \times 10^5 - 1.06 \times 10^5 = 3.8 \times 10^4$ J; it becomes **thermal energy** in the motor windings, gearbox and cable (also some sound).