1.7 Energy, work and power

Name: ______________ Class: __________ Date: ____________ **Total: 41 marks**

KEY WORDS kinetic 动能 • energy resources 能量资源 • power 功率 • gravitational potential 重力势能 • efficiency 效率 • efficiency 效率 • power 功率 • kinetic 动能 • energy 能量 • work done 做功

Objective

Build the skills to answer exam questions on **energy, work and power 能量、功与功率**: the energy stores and the transfers between them, E_k and ΔE_p, the **principle of conservation of energy 能量守恒定律**, **energy resources 能量资源**, $W = Fd$, $P = \dfrac{W}{t}$ and **efficiency 效率**.

You must be able to:

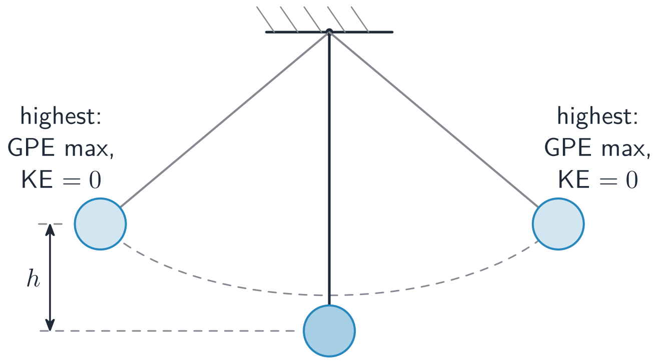
- name the energy stores and describe the transfers in an event
- use $E_k = \frac{1}{2}mv^2$ and $\Delta E_p = mg\,\Delta h$
- apply conservation of energy, including to a falling object
- describe how electricity is generated from each resource and compare them
- use $W = Fd$, $P = \dfrac{W}{t}$ and both efficiency formulas

1 Worked examples

■ Stores and transfers

Energy is **stored** as kinetic, gravitational potential, chemical, elastic (strain), nuclear, electrostatic and internal (thermal). It is **transferred** between stores by forces doing mechanical work, by electric currents, by heating, and by waves.

To describe an event, name the store it starts in, the store it ends in, and any store in between. For a ball dropped onto the ground and not bouncing: gravitational potential energy before it falls, transferred to kinetic energy as it falls, then transferred to internal (thermal) energy of the ball and the ground when it lands.



A swinging pendulum moves energy between the gravitational potential store (highest points) and the kinetic store (lowest point)

The **principle of conservation of energy** says energy is never created or destroyed, only transferred between stores. The total stays the same.

The two energy equations

$$E_k = \tfrac{1}{2}mv^2 \qquad \Delta E_p = mg\,\Delta h$$

Worked example 1. A ball of mass 0.50 kg is dropped from 1.8 m. Find its speed just before it lands ($g = 10$ m/s^2), ignoring air resistance.

1. All the gravitational potential energy becomes kinetic energy: $\frac{1}{2}mv^2 = mg\,\Delta h$.
2. The mass cancels: $v^2 = 2g\,\Delta h = 2 \times 10 \times 1.8 = 36$.
3. $v = \sqrt{36} = 6.0$ m/s.

Worked example 2 (mass from kinetic energy). Wind carries 11 000 J of kinetic energy each second at a speed of 6.3 m/s. Show that about 550 kg of air passes each second.

Rearrange $E_k = \frac{1}{2}mv^2$ to $m = \dfrac{2E_k}{v^2} = \dfrac{2 \times 11\,000}{6.3^2} = \dfrac{22\,000}{39.7} = 554$ kg, which is about 550 kg.

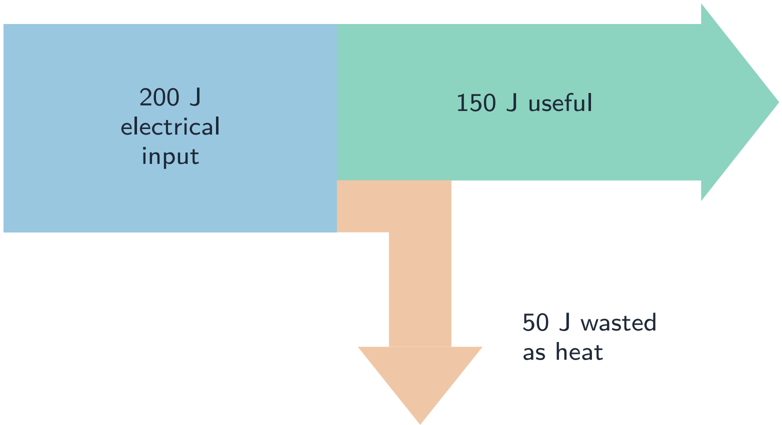
Work, power and efficiency

$$W = Fd = \Delta E \qquad P = \frac{W}{t} = \frac{\Delta E}{t}$$

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

Worked example 3. A wind turbine receives 11 000 J each second and produces 6000 J of electrical energy each second. Efficiency $= \dfrac{6000}{11\,000} \times 100\% = 55\%$.

Efficiency is always below 100%: some energy is always transferred to the surroundings, usually as heat.



A Sankey diagram: the band widths are proportional to the energy, so the wasted branch shows what is lost

Energy resources

Most power stations spin a **turbine** 涡轮机 that drives a **generator** 发电机. Fossil fuels, nuclear fuel, geothermal energy and biofuels do it by boiling water to make steam; hydroelectric, wave, tidal and wind power turn the turbine directly with moving water or air. **Solar cells** make electricity from sunlight directly, and solar panels heat water.

Compare resources with five ideas: **renewability** 可再生性, **availability** 可用性, **reliability** 可靠性, **scale** 规模 and **environmental impact** 环境影响.

Most resources trace back to the Sun: fossil fuels are ancient stored sunlight, and wind and waves come from solar heating. The exceptions are **geothermal**, **nuclear** and **tidal**. Research continues into using **nuclear fusion** 核聚变 to generate electricity on a large scale, but no fusion reactor yet gives out more electrical energy than it uses.

2 Practice

2.1 A 2.0 kg object moves at 3.0 m/s. Find its kinetic energy. [2]

2.2 A force of 25 N moves a box 4.0 m in the direction of the force. Find the work done. [2]

2.3 Name three energy stores, and state one way energy can be transferred between stores. [2]

2.4 A lift raises a 60 kg person through 9.0 m. Take $g = 10$ N/kg. Find the gain in gravitational potential energy. [2]

2.5 State two energy resources for which radiation from the Sun is the main source of energy, and two for which it is not. [2]

2.6 A kite of mass 0.80 kg falls 5.0 m from rest. Ignoring air resistance and taking $g = 10\ \text{m/s}^2$, calculate its speed just before it lands. [3]

2.7 Suggest one reason why tidal energy is more useful than wind energy, ignoring the cost of building the station. [1]

3 Exam-style questions

3.1 A motor lifts a load. It is supplied with 500 J of electrical energy and gives the load 300 J of gravitational potential energy. What is the efficiency of the motor, and what happens to the rest of the energy? [1]

- **A** 60%; the rest is destroyed
- **B** 60%; the rest is transferred to the surroundings, mostly as heat
- **C** 167%; the rest is created by the motor
- **D** 40%; the rest is stored in the load

3.2 A student drops a heavy ball from a height of 1.8 m above the ground. It does not bounce.

(a) Describe the energy transfers from the moment the ball begins to fall to the moment it stops on the ground. [3]

(b) The mass of the ball is 0.40 kg and $g = 10$ N/kg. Calculate the gravitational potential energy it loses. [2]

(c) Calculate the speed of the ball just before it hits the ground, assuming no air resistance. [3]

(d) In practice the ball lands slightly more slowly than your answer to (c). Explain why. [1]

3.3 A wind turbine has blades that sweep a circle of air. The kinetic energy of the air arriving each second is 11 000 J and the wind speed is 6.3 m/s.

(a) Show that the mass of air arriving each second is approximately 550 kg. [2]

(b) The turbine generates 6.0 kW of electrical power. Calculate its efficiency. [2]

(c) Explain, in terms of energy transfer, why the efficiency cannot be 100%. [2]

(d) Compare wind with a coal-fired power station using two of: renewability, reliability and environmental impact. [3]

3.4 A crane lifts a 2400 N load through a height of 15 m in 12 s.

(a) Calculate the work done on the load. [2]

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

(c) The crane's motor takes 5.0 kW of electrical power. Calculate its efficiency. [2]

(d) The crane then lifts the same load through the same height in 6.0 s. State and explain what happens to the work done and to the power. [2]

Solutions

2.1 $E_k = \frac{1}{2}mv^2 = \frac{1}{2} \times 2.0 \times 3.0^2 = 9.0$ J.

2.2 $W = Fd = 25 \times 4.0 = 100$ J.

2.3 Any three of: kinetic, gravitational potential, chemical, elastic (strain), nuclear, electrostatic, internal (thermal). Any one of: by a force doing mechanical work; by an electric current; by heating; by waves.

2.4 $\Delta E_p = mg\,\Delta h = 60 \times 10 \times 9.0 = 5400$ J.

2.5 From the Sun, any two of: fossil fuels, biofuels, wind, waves, hydroelectric, solar. Not from the Sun, any two of: geothermal, nuclear, tidal.

2.6 $\frac{1}{2}mv^2 = mg\,\Delta h$, so $v^2 = 2g\,\Delta h = 2 \times 10 \times 5.0 = 100$; $v = 10$ m/s.

2.7 The tides follow a regular, predictable pattern, so tidal power is reliable, while the wind may drop.

3.1 **B**. Efficiency $= \dfrac{300}{500} \times 100\% = 60\%$, and the missing 200 J is transferred to the surroundings as heat (and sound). A breaks conservation of energy, C inverts the fraction, and D subtracts the wrong way round.

3.2 (a) The ball starts with energy in the gravitational potential store; as it falls this is transferred to the kinetic store, which increases; when it lands the kinetic energy is transferred to the internal (thermal) store of the ball and the ground.
(b) $\Delta E_p = mg\,\Delta h = 0.40 \times 10 \times 1.8 = 7.2$ J.
(c) $\frac{1}{2}mv^2 = 7.2$ J, so $v^2 = \dfrac{2 \times 7.2}{0.40} = 36$; $v = 6.0$ m/s.
(d) Some energy is transferred to the air by air resistance, so less becomes kinetic energy.

3.3 (a) $E_k = \frac{1}{2}mv^2$, so $m = \dfrac{2E_k}{v^2}$; $m = \dfrac{2 \times 11\,000}{6.3^2} = \dfrac{22\,000}{39.7} = 554$ kg ≈ 550 kg.
(b) Efficiency $= \dfrac{6000}{11\,000} \times 100\% = 55\%$.
(c) Not all the energy of the air is transferred to the blades: the air still moves after passing them, and energy is also transferred to the surroundings by friction and heating in the generator.
(d) Any two comparisons, each developed: wind is renewable while coal will run out; wind is unreliable because it needs the wind to blow, while a coal station runs whenever it is needed; wind releases no carbon dioxide during use while coal releases carbon dioxide and other pollution.

3.4 (a) $W = Fd = 2400 \times 15 = 36\,000$ J.
(b) $P = \dfrac{W}{t} = \dfrac{36\,000}{12} = 3000$ W.
(c) Efficiency $= \dfrac{3000}{5000} \times 100\% = 60\%$.
(d) The work done is unchanged at 36 000 J, because the force and the distance are the same; the power doubles to 6000 W, because the same energy is transferred in half the time.