1.6 Work, energy, power and efficiency

Name: _____ Class: _____ Date: _____ **Total: 21 marks**

KEY WORDS work • kinetic energy • gravitational potential energy • power • efficiency

Objective

Build the skills to answer WPH11 questions on **work, energy and power** 、 : calculate work, kinetic and gravitational potential energy, apply conservation of energy with losses, and compute power and efficiency. This sheet covers Unit 1 statements 17–22.

You must be able to:

- use $\Delta W = F\Delta s$, including when the force is not along the motion
- use $E_k = \frac{1}{2}mv^2$ and $\Delta E_{\text{grav}} = mg\Delta h$
- apply conservation of energy, naming every transfer – including work done against drag
- use $P = \dfrac{E}{t} = \dfrac{W}{t}$ and efficiency $= \dfrac{\text{useful output}}{\text{total input}}$
- identify the correct input when a system both speeds down and climbs

1 Key knowledge and worked examples

Work and the three energies

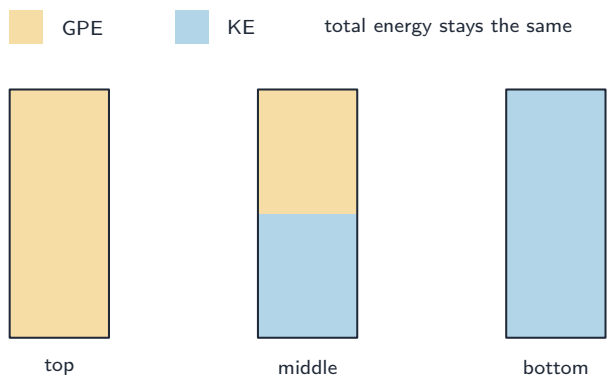
- **Work** : $\Delta W = F\Delta s$ when the force acts along the motion. If the force is at angle θ to the motion, only the component along the motion does work: $\Delta W = F\Delta s\cos\theta$.
- **Kinetic energy** : $E_k = \frac{1}{2}mv^2$ – speed is squared, so doubling the speed quadruples the energy.
- **Gravitational potential energy** : $\Delta E_{\text{grav}} = mg\Delta h$ near the Earth's surface.

Conservation of energy

Energy is transferred or transformed, never created or destroyed. In any fall with drag:

$$\Delta E_{\text{grav}} = \Delta E_k + \text{work done against drag}$$

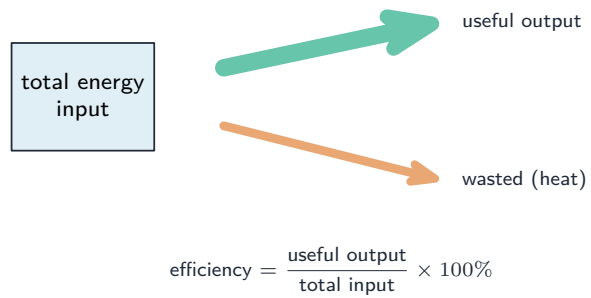
At terminal velocity $\Delta E_k = 0$, so **all** of the gravitational loss becomes work against drag. Without drag, all of it becomes kinetic energy.



Power and efficiency

Power is energy transferred per unit time: $P = \dfrac{E}{t} = \dfrac{W}{t}$, unit watt (1 W = 1 J s^{-1}). **Efficiency** compares useful output with total input:

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



Worked example (the two-direction trap, June 2025 Q14 style). A 1500 kg car brakes from 20 m s^{-1} to rest while **climbing** 2.0 m. The battery recovers 2.6 ×

10^5 J. Find the efficiency of the recovery.

- Known: m, v, Δh, recovered energy. Why: the brakes' input is the kinetic energy lost **minus** the potential energy the car keeps by ending higher.

$$E_k = \tfrac{1}{2}mv^2 = \tfrac{1}{2} \times 1500 \text{ kg} \times (20 \text{ m s}^{-1})^2 = 3.0 \times 10^5 \text{ J}$$

$$\Delta E_{\text{grav}} = mg\Delta h = 1500 \text{ kg} \times 9.81 \text{ N kg}^{-1} \times 2.0 \text{ m} = 2.9 \times 10^4 \text{ J}$$

$$\text{efficiency} = \frac{\text{useful output}}{\text{total input}} = \frac{2.6 \times 10^5 \text{ J}}{3.0 \times 10^5 \text{ J} - 2.9 \times 10^4 \text{ J}} = 0.96$$

- Check: under 1, as required; dividing by E_k alone (0.87) is the trap this question sets.

2 Practice

2.1 A crane lifts a 250 kg load by 12 m. Calculate the gravitational potential energy gained. [2]

2.2 A 0.40 kg ball moves at 15 m s^{-1}. Calculate its kinetic energy. [2]

2.3 A motor transfers 800 J in 4.0 s. Calculate its power. [1]

2.4 A 60 kg runner speeds up from 3.0 m s^{-1} to 6.0 m s^{-1}. Calculate the work done on the runner by her muscles. *(Hint: work = change in kinetic energy here.)* [3]

3 Exam-style questions

3.1 A braking force dissipates an average power of 40 kW over 3.0 s while a car moves 45 m. Which expression gives the braking force? [1]

☐ **A** $\dfrac{40 \times 10^3 \times 45}{3.0}$

B $\dfrac{40 \times 10^3 \times 3.0}{45}$

C $\dfrac{45}{40 \times 10^3 \times 3.0}$

D $\dfrac{40 \times 10^3}{45 \times 3.0}$

3.2 A ball is dropped and falls with air resistance. Which statement describes the fall at terminal velocity? [1]

☐ **A** gravitational energy becomes kinetic energy only

B gravitational energy becomes work done against air resistance only

C no energy is transferred

D kinetic energy becomes gravitational energy

3.3 A pump lifts 200 kg of water through 4.5 m every minute.

(a) Show that the useful power output of the pump is about 150 W. [3]

(b) The pump's electrical input power is 550 W. Calculate its efficiency. [2]

3.4 A cyclist of total mass 85 kg freewheels down a hill, dropping 25 m vertically. Her speed rises from 4.0 m s^{-1} to 18 m s^{-1}.

(a) Calculate the loss of gravitational potential energy. [2]

(b) Calculate the gain in kinetic energy. [2]

(c) Account for the difference between your two answers. [2]

Solutions

2.1 $\Delta E_{\text{grav}} = mg\Delta h = 250\ \text{kg} \times 9.81\ \text{N kg}^{-1} \times 12\ \text{m} = 2.9 \times 10^4\ \text{J}$.

2.2 $E_k = \frac{1}{2}mv^2 = \frac{1}{2} \times 0.40\ \text{kg} \times (15\ \text{m s}^{-1})^2 = 45\ \text{J}$.

2.3 $P = \dfrac{E}{t} = \dfrac{800\ \text{J}}{4.0\ \text{s}} = 200\ \text{W}$.

2.4 $W = \Delta E_k$: E_k change $= \frac{1}{2}m(v^2 - u^2) = \frac{1}{2} \times 60\ \text{kg} \times (36 - 9.0)\ \text{m}^2\text{s}^{-2} = 810\ \text{J}$.

3.1 B. Work dissipated = power × time, and force = work ÷ distance. A multiplies by the distance; C and D invert the ratio.

3.2 B. At terminal velocity the kinetic energy is constant, so the whole gravitational loss does work against air resistance. A forgets the drag; C violates conservation; D reverses the fall.

3.3 (a) $\Delta E_{\text{grav}} = mg\Delta h = 200\ \text{kg} \times 9.81\ \text{N kg}^{-1} \times 4.5\ \text{m} = 8.8 \times 10^3\ \text{J}$ per minute; $P = \dfrac{E}{t} = \dfrac{8.8 \times 10^3\ \text{J}}{60\ \text{s}} = 147\ \text{W} \approx 150\ \text{W}$. (b) efficiency $= \dfrac{\text{useful power output}}{\text{total power input}} = \dfrac{147\ \text{W}}{550\ \text{W}} = 0.27$.

3.4 (a) $\Delta E_{\text{grav}} = mg\Delta h = 85\ \text{kg} \times 9.81\ \text{N kg}^{-1} \times 25\ \text{m} = 2.1 \times 10^4\ \text{J}$. (b) $\Delta E_k = \frac{1}{2}m(v^2 - u^2) = \frac{1}{2} \times 85\ \text{kg} \times (18^2 - 4.0^2)\ \text{m}^2\text{s}^{-2} = 1.3 \times 10^4\ \text{J}$. (c) The remaining 8×10^3 J is work done against air resistance and friction – energy is conserved once every transfer is counted.