1.2 Changes in energy

Name: _____ Class: _____ Date: _____ **Total: 29 marks**

KEY WORDS kinetic energy • gravitational potential energy • gravitational field strength • elastic potential energy • spring constant • limit of proportionality • extension

Objective

Calculate $E_k = \frac{1}{2}mv^2$, $E_e = \frac{1}{2}ke^2$ and $E_p = mgh$ in any direction, convert units first, and chain two equations together in a transfer. These are original teaching questions for spec statement 4.1.1.2.

1 Key knowledge and worked examples

All three equations are printed on your Physics Equations Sheet. The marks are for choosing, converting and rearranging.

Quantity	Symbol	Unit	Convert first
mass	m	kg	g ÷ 1000; tonnes × 1000
speed	v	m/s	km/h ÷ 3.6
spring constant	k	N/m	–
extension	e	m	cm ÷ 100
height	h	m	cm ÷ 100
field strength	g	N/kg	value given (usually 9.8)

$$E_k = \frac{1}{2}mv^2 \qquad E_e = \frac{1}{2}ke^2 \qquad E_p = mgh$$

Extension is the stretch beyond the natural length: e = stretched length − original length. $E_e = \frac{1}{2}ke^2$ is valid only below the **limit of proportionality** – double the extension, four times the energy.

Worked example. A 58 g tennis ball moves at 25 m/s. Find E_k.

- Known: mass and speed. Convert the mass first: 58 g = 0.058 kg.

$$E_k = \frac{1}{2}mv^2 = \frac{1}{2} \times 0.058 \text{ kg} \times (25 \text{ m/s})^2 = 18 \text{ J}$$

- Check: J = kg m^2/s^2, so the units agree.

Worked example. A spring of $k = 64$ N/m is compressed by 0.075 m and launches a 0.052 kg toy car. Find the maximum possible speed.

- Known: spring data and mass. The elastic store empties into the kinetic store; "maximum possible" means assume all of it arrives.

$$E_e = \tfrac{1}{2}ke^2 = \tfrac{1}{2} \times 64 \text{ N/m} \times (0.075 \text{ m})^2 = 0.18 \text{ J}$$

- Why $E_k = E_e$: energy conservation at the moment of release, before any dissipation.

$$E_k = \tfrac{1}{2}mv^2 \quad \Rightarrow \quad v = \sqrt{\frac{2E_k}{m}} = \sqrt{\frac{2 \times 0.18 \text{ J}}{0.052 \text{ kg}}} = 2.6 \text{ m/s (2 s.f.)}$$

Worked example. Water of mass 2.5×10^6 kg drops through a mean height of 15 m ($g = 9.8$ N/kg). Find the loss of gravitational potential energy.

- Known: mass, height, g. The unit is already kg.

$$E_p = mgh = 2.5 \times 10^6 \text{ kg} \times 9.8 \text{ N/kg} \times 15 \text{ m} = 3.7 \times 10^8 \text{ J}$$

- Check: this is a mean height, so the answer is a mean loss – the same wording appears in real papers ("mean change in vertical height").

Chains the exam uses: $E_e \to E_p$ (two cords: add the energies), $E_e \to E_k$, $E_p \to E_k$ (falling objects), $E_k \to E_p$ (projected upwards). Write one equation per line and keep every stage – each earns a mark.

2 Practice

2.1 Calculate the kinetic energy of a 1200 kg car travelling at 30 m/s. [2]

2.2 A spring has spring constant 250 N/m. Calculate the elastic potential energy stored when its extension is 4.0 cm. [3]

2.3 A 65 kg climber gains 8.4 kJ of gravitational potential energy climbing a wall ($g = 9.8$ N/kg). Calculate the height gained. [3]

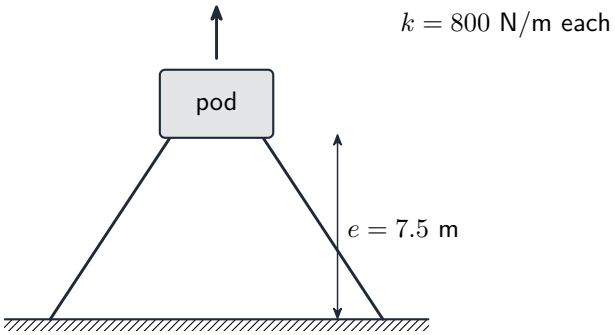
2.4 A toy train of mass 0.90 kg has kinetic energy 5.0 J. Calculate its speed. [2]

3 Exam-style questions

3.1 A ride at a theme park holds a 240 kg pod on two stretched bungee cords. Each cord behaves like a spring of spring constant 800 N/m. Before release each cord is stretched by 7.5 m.

(a) Calculate the elastic potential energy stored in one cord. [3]

(b) Calculate the total elastic potential energy stored in the two cords. [1]



3.2 The pod in question 3.1 is released and rises. At its highest point it has 24 000 J of gravitational potential energy ($g = 9.8$ N/kg).

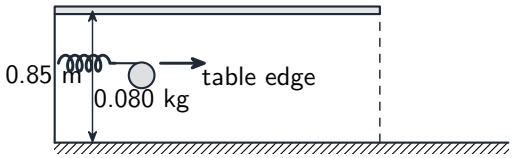
(a) Calculate the maximum height the pod reaches above its release point. [3]

(b) The actual height reached is lower than this value. Explain why. [2]

3.3 A pinball machine fires a 0.080 kg ball with a compressed spring. The spring constant is 320 N/m and the compression is 6.0 cm. The ball leaves horizontally along the table, which is 0.85 m high. Air resistance is negligible until the ball leaves the table edge.

(a) Show that the elastic potential energy stored in the spring is about 0.58 J. [2]

(b) Calculate the speed of the ball as it leaves the spring. [3]

(c) The ball then falls from the table edge to the floor. Its kinetic energy just before landing is 0.63 J. Calculate the speed just before landing. [3]

(d) Explain why the speed in (c) is greater than the speed in (b), using energy stores. [2]