

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 specification 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	$\text{g} \div 1000$; tonnes $\times 1000$
speed	v	m/s	$\text{km/h} \div 3.6$
spring constant	k	N/m	–
extension	e	m	$\text{cm} \div 100$
height	h	m	$\text{cm} \div 100$
field strength	g	N/kg	value given (usually 9.8)

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

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 m²/s², so the units agree.

Worked example. A spring of $k = 64 \text{ N/m}$ 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.

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

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

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

Worked example. Water of mass $2.5 \times 10^6 \text{ kg}$ drops through a mean height of 15 m ($g = 9.8 \text{ N/kg}$). 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: $E_e \rightarrow E_p$ (two cords: add the energies), $E_e \rightarrow E_k$, $E_p \rightarrow E_k$ (falling objects), $E_k \rightarrow E_p$ (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 ($g = 9.8 \text{ N/kg}$). Calculate the height gained. [3]

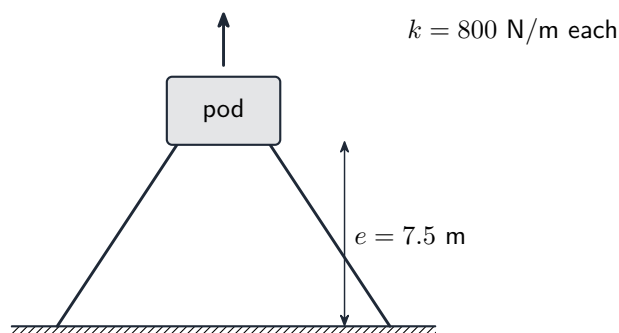
2.4 A toy train of mass 0.90 kg has kinetic energy 5.0 J. Calculate its speed. [2]

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 ($g = 9.8 \text{ N/kg}$).

(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]

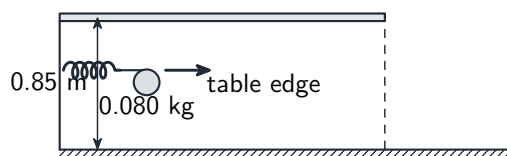
3.3 A pinball machine fires a 0.080 kg ball with a compressed spring. The spring constant is 320 N/m and the compression is 6.0 cm. The ball leaves horizontally along the table, which is 0.85 m high. Air resistance is negligible until the ball leaves the table edge.

(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]



Solutions

2.1 Known: mass and speed.

$$E_k = \frac{1}{2}mv^2 = \frac{1}{2} \times 1200 \text{ kg} \times (30 \text{ m/s})^2 = \mathbf{5.4 \times 10^5 \text{ J}}$$

(1 mark substitution, 1 mark answer with unit.)

2.2 Convert first: 4.0 cm = 0.040 m (C1).

$$E_e = \frac{1}{2}ke^2 = \frac{1}{2} \times 250 \text{ N/m} \times (0.040 \text{ m})^2 = \mathbf{0.20 \text{ J}}$$

(substitution 1, answer with unit 1.)

2.3 Convert: 8.4 kJ = 8400 J (C1). Rearrange then substitute.

$$E_p = mgh \quad \Rightarrow \quad h = \frac{E_p}{mg} = \frac{8400 \text{ J}}{65 \text{ kg} \times 9.8 \text{ N/kg}} = \mathbf{13 \text{ m}} \text{ (2 s.f.)}$$

(rearrangement 1, answer with unit 1.)

2.4 Known: mass and E_k ; v is wanted, so rearrange before substituting.

$$E_k = \frac{1}{2}mv^2 \quad \Rightarrow \quad v = \sqrt{\frac{2E_k}{m}} = \sqrt{\frac{2 \times 5.0 \text{ J}}{0.90 \text{ kg}}} = \mathbf{3.3 \text{ m/s}}$$

(1 mark method, 1 mark answer with unit.)

3.1 (a) Known: $k = 800 \text{ N/m}$, $e = 7.5 \text{ m}$ (already base units).

$$E_e = \frac{1}{2}ke^2 = \frac{1}{2} \times 800 \text{ N/m} \times (7.5 \text{ m})^2$$

$$E_e = \mathbf{22\,500 \text{ J}}$$

(substitution C1, square of 7.5 evaluated A1, answer with unit A1.) (b) The two identical cords store the same energy each.

$$E_{total} = 2 \times 22\,500 = \mathbf{45\,000 \text{ J}}$$

3.2 (a) Known: E_p , m , g ; rearrange for h .

$$E_p = mgh \quad \Rightarrow \quad h = \frac{E_p}{mg} = \frac{24\,000 \text{ J}}{240 \text{ kg} \times 9.8 \text{ N/kg}} = \mathbf{10 \text{ m}}$$

(rearrangement C1, substitution C1, answer with unit A1.) (b) As the pod rises it does work against air resistance, so some elastic potential energy is transferred to thermal stores of the air and the pod rather than to the gravitational potential store.

3.3 (a) Convert: 6.0 cm = 0.060 m (C1).

$$E_e = \frac{1}{2}ke^2 = \frac{1}{2} \times 320 \times (0.060)^2 = 0.576 \text{ J} \approx 0.58 \text{ J} \checkmark$$

(shown statement A1.) (b) All E_e becomes E_k at launch.

$$E_k = \frac{1}{2}mv^2 \quad \Rightarrow \quad v = \sqrt{2E_k/m} = \sqrt{2 \times 0.576/0.080} = \mathbf{3.8 \text{ m/s}} \text{ (2 s.f.)}$$

(equating C1, rearrangement C1, answer A1.) (c) Just before landing the ball's kinetic energy is given (0.63 J), not re-derived.

$$v = \sqrt{2E_k/m} = \sqrt{2 \times 0.63/0.080} = \mathbf{4.0} \text{ m/s (2 s.f.)}$$

(method C1, answer A1, 2 s.f. A1.) (d) On the way down the gravitational potential store empties as well: the ball has both the launch energy and the energy from falling 0.85 m, so the kinetic store (and the speed) at the floor is larger than at launch. Mentioning "energy gained = $mg \times 0.85 = 0.67 \text{ J}$, so E_k grows from 0.58 J to about 0.63 J once a little is dissipated" is a full-credit comparison.