

Exercise walk-through

5.1

Energy conservation

A-Level Physics

Sheet 5.2.1 – what you need to know

You must be able to:

- use the work done by the resultant force as the change in E_K
- compare kinetic energies, including with the same momentum
- find a speed from energy whatever the direction of motion
- find the work done against air resistance, and the average force

What the exam asks

“Calculate the maximum kinetic energy of the car.” [2]

“Determine the ratio of the kinetic energy of the child at Y with the resistive force to that without it.” [1]

“Explain why the work done by the upthrust is not equal to the gain in elastic potential energy of the spring.” [1]

Practise on exercise sheet 5.2.1, then try the real exam questions on past-paper sheet 5.2.1.

When you know the momentum, not the speed

$$p = mv \quad \text{and} \quad E_K = \frac{1}{2}mv^2$$


$$E_K = \frac{p^2}{2m}$$

A momentum change from p_1 to p_2 at constant mass changes the kinetic energy by $\frac{p_2^2 - p_1^2}{2m}$.

Reach for this whenever a question gives you **momentum** and asks for energy – there is no need to find v first.

Same momentum, different kinetic energy

$$E_K = \frac{1}{2}mv^2 = \frac{p^2}{2m}$$

The same momentum with four times the mass: **one quarter** of the kinetic energy.

A 1000 kg car at 20 m s^{-1} ; a 4000 kg truck, same p

$$\text{car: } p = mv = (1000 \text{ kg})(20 \text{ m s}^{-1}) = 2.0 \times 10^4 \text{ kg m s}^{-1}$$

$$E_K = \frac{1}{2}mv^2 = \frac{1}{2}(1000 \text{ kg})(20 \text{ m s}^{-1})^2 = 2.0 \times 10^5 \text{ J}$$

$$\text{truck: } v = \frac{p}{m} = \frac{2.0 \times 10^4 \text{ kg m s}^{-1}}{4000 \text{ kg}} = 5.0 \text{ m s}^{-1}$$

$$E_K = \frac{1}{2}mv^2 = \frac{1}{2}(4000 \text{ kg})(5.0 \text{ m s}^{-1})^2 = 5.0 \times 10^4 \text{ J}$$

A speed from energy, whatever the direction

A stone is thrown horizontally at 8.0 m s^{-1} from a cliff 20 m high; no air resistance.

Energy gives the **speed**, not the direction or the time: use the equations of motion for those.

Conservation of energy; the mass cancels

$$\frac{1}{2}mv^2 = \frac{1}{2}mu^2 + mg\Delta h$$

$$v = \sqrt{u^2 + 2g\Delta h} =$$

$$\sqrt{(8.0 \text{ m s}^{-1})^2 + 2(9.81 \text{ m s}^{-2})(20 \text{ m})}$$
$$= 21.4 \text{ m s}^{-1}$$

Air resistance takes its share

A 0.20 kg ball is dropped from 5.0 m and lands with 8.0 J of kinetic energy.

With air resistance the total energy is **not** constant: the lower the ball, the less it has left.

The missing energy is the work done against air resistance

$$E_P = mgh = (0.20 \text{ kg})(9.81 \text{ m s}^{-2})(5.0 \text{ m}) = 9.81 \text{ J}$$

$$W = E_P - E_K = 9.81 \text{ J} - 8.0 \text{ J} = 1.8 \text{ J}$$

$$F = \frac{W}{s} = \frac{1.81 \text{ J}}{5.0 \text{ m}} = 0.36 \text{ N, on average}$$

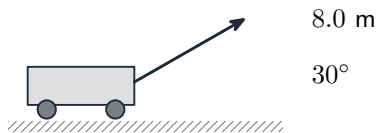
Exercises 2.1·2.2

2.1 Define the **work done** by a force.

[1]

work done

2.2 A trolley is pulled 8.0 m along a level floor by a rope at 30° to the horizontal. The tension in the rope is 25 N. Calculate the work done by the tension. [2]



Exercises 2.1·2.2

2.1 Define the **work done** by a force.

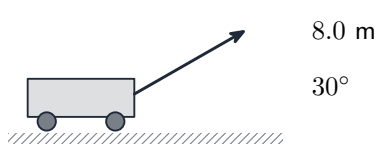
[1]

work done

2.1

- the force multiplied by the displacement in the direction of the force
-

2.2 A trolley is pulled 8.0 m along a level floor by a rope at 30° to the horizontal. The tension in the rope is 25 N. Calculate the work done by the tension. [2]



2.2

- work done, $W = F s \cos \theta$

$$W = F s \cos \theta = 25 \text{ N} \times 8.0 \text{ m} \times \cos 30^\circ = \mathbf{170 \text{ J}}$$

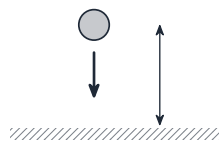
Exercises 2.3·2.4

2.3 State the **principle of conservation of energy**.

[1]

conservation of energy

2.4 A ball of mass 0.20 kg is dropped from a height of 5.0 m. Air resistance is negligible. Use conservation of energy to calculate its speed just before it reaches the ground. [2]



0.20 kg

5.0 m

Exercises 2.3·2.4

2.3 State the principle of conservation of energy.

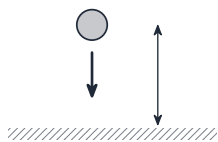
[1]

conservation of energy

2.3

- energy cannot be created or destroyed, only transferred from one store to another, so the total energy of a closed system is constant

2.4 A ball of mass 0.20 kg is dropped from a height of 5.0 m. Air resistance is negligible. Use conservation of energy to calculate its speed just before it reaches the ground. [2]



0.20 kg

5.0 m

2.4

- conservation of energy: $mg\Delta h = \frac{1}{2}mv^2$, so $v = \sqrt{2g\Delta h}$

$$v = \sqrt{2g\Delta h} = \sqrt{2 \times 9.81 \text{ m s}^{-2} \times 5.0 \text{ m}} = \mathbf{9.9 \frac{m}{s}}$$

Exercise 2.5 (a)

2.5 A car of mass 900 kg travelling at $20 \frac{\text{m}}{\text{s}}$ brakes to rest in 40 m on a level road.

(a) Calculate the kinetic energy of the car before it brakes.

[1]

Exercise 2.5 (a)

2.5 A car of mass 900 kg travelling at $20 \frac{\text{m}}{\text{s}}$ brakes to rest in 40 m on a level road.

(a) Calculate the kinetic energy of the car before it brakes. [1]

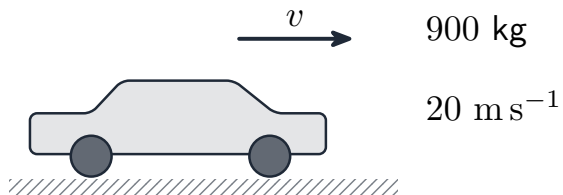
$$(a) E_K = \frac{1}{2}mv^2 = \frac{1}{2} \times 900 \times 20^2 = \mathbf{1.8 \times 10^5 \text{ J}}$$

Exercise 2.5 (b)

2.5 A car of mass 900 kg travelling at $20 \frac{\text{m}}{\text{s}}$ brakes to rest in 40 m on a level road.

(b) Calculate the average braking force.

[2]

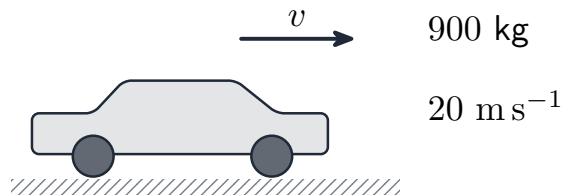


Exercise 2.5 (b)

2.5 A car of mass 900 kg travelling at $20 \frac{\text{m}}{\text{s}}$ brakes to rest in 40 m on a level road.

(b) Calculate the average braking force.

[2]



(b) all the kinetic energy is removed by the work done by the brakes: $Fs = E_K$

$$F = \frac{E_K}{s} = \frac{1.8 \times 10^5 \text{ J}}{40 \text{ m}} = \mathbf{4500 \text{ N}}$$

Exercise 2.5 (c)

2.5 A car of mass 900 kg travelling at $20 \frac{\text{m}}{\text{s}}$ brakes to rest in 40 m on a level road.

(c) State the energy transfer that takes place as the car stops.

[1]

Exercise 2.5 (c)

2.5 A car of mass 900 kg travelling at $20 \frac{\text{m}}{\text{s}}$ brakes to rest in 40 m on a level road.

(c) State the energy transfer that takes place as the car stops. [1]

(c) kinetic energy $\rightarrow$ thermal energy (of the brakes and the surroundings)

Exercise 3.1

3.1 A force acts on an object at 90° to the direction in which the object moves. What is the work done by the force? [1]

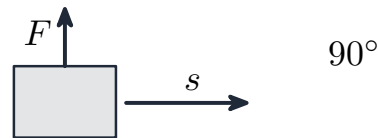
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A the product of the force and the distance moved

B negative

C zero

D a maximum



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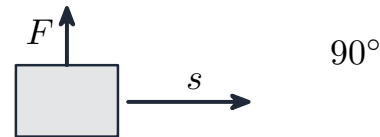
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A the product of the force and the distance moved

B negative

C zero

D a maximum



3.1 C

- the force has no component along the displacement, so $W = Fs \cos 90^\circ = 0$
- A** is a force along the motion; **B** is a force against it

Exercise 3.2

3.2 A force of 15 N moves a box 4.0 m along a floor. The force is at 30° to the floor. How much work does the force do? [1]

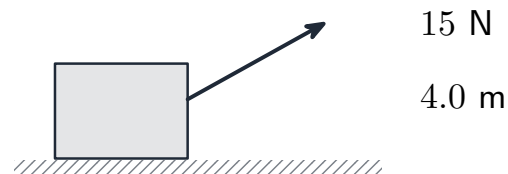
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A 30 J

B 52 J

C 60 J

D 69 J



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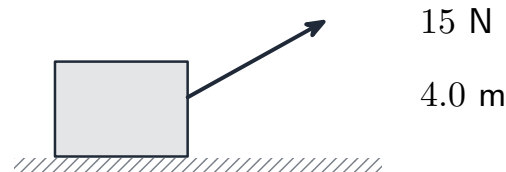
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A 30 J

B 52 J

C 60 J

D 69 J



3.2 B

- $W = Fs \cos \theta = 15 \times 4.0 \times \cos 30^\circ = 52 \text{ J}$
- **C** ignores the angle and **A** uses $\sin 30^\circ$

Exercise 3.3 (a)

3.3 A skier of mass 65 kg starts from rest at the top of a straight slope 120 m long. The bottom of the slope is 30 m lower than the top. The total resistive force on the skier is a constant 85 N.

(a) **Define** work done.

[1]

Exercise 3.3 (a)

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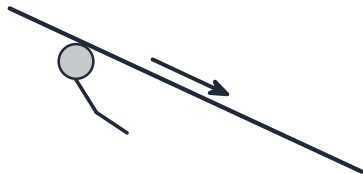
[1]

(a) the force multiplied by the displacement in the direction of the force

Exercise 3.3 (b)

3.3 A skier of mass 65 kg starts from rest at the top of a straight slope 120 m long. The bottom of the slope is 30 m lower than the top. The total resistive force on the skier is a constant 85 N.

(b) Calculate the gravitational potential energy lost by the skier on the slope. [2]



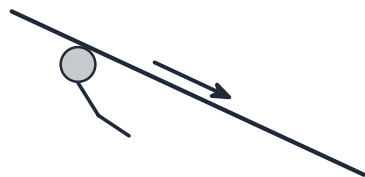
65 kg

120 m

Exercise 3.3 (b)

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65 kg

120 m

(b) gravitational potential energy, $\Delta E_P = mg\Delta h$

$$\Delta E_P = mg\Delta h = 65 \times 9.81 \times 30 = \mathbf{1.91 \times 10^4 \text{ J}}$$

Exercise 3.3 (c)

3.3 A skier of mass 65 kg starts from rest at the top of a straight slope 120 m long. The bottom of the slope is 30 m lower than the top. The total resistive force on the skier is a constant 85 N.

(c) Calculate the work done against the resistive force.

[1]

Exercise 3.3 (c)

3.3 A skier of mass 65 kg starts from rest at the top of a straight slope 120 m long. The bottom of the slope is 30 m lower than the top. The total resistive force on the skier is a constant 85 N.

(c) Calculate the work done against the resistive force. [1]

(c) $W = Fs = 85 \times 120 = \mathbf{1.02 \times 10^4 \text{ J}}$

Exercise 3.3 (d)

3.3 A skier of mass 65 kg starts from rest at the top of a straight slope 120 m long. The bottom of the slope is 30 m lower than the top. The total resistive force on the skier is a constant 85 N.

(d) Use conservation of energy to **determine** the speed of the skier at the bottom of the slope. [3]

Exercise 3.3 (d)

3.3 A skier of mass 65 kg starts from rest at the top of a straight slope 120 m long. The bottom of the slope is 30 m lower than the top. The total resistive force on the skier is a constant 85 N.

(d) Use conservation of energy to **determine** the speed of the skier at the bottom of the slope. [3]

(d) conservation of energy: the kinetic energy is the potential energy lost minus the work done against the resistance, $E_K = \Delta E_P - W = 1.91 \times 10^4 - 1.02 \times 10^4 = 8.9 \times 10^3 \text{ J}$

- from $E_K = \frac{1}{2}mv^2$: $v = \sqrt{\frac{2E_K}{m}}$

$$v = \sqrt{\frac{2E_K}{m}} = \sqrt{\frac{2 \times 8.9 \times 10^3}{65}} = \mathbf{17 \frac{m}{s}}$$

Exercise 3.3 (e)

3.3 A skier of mass 65 kg starts from rest at the top of a straight slope 120 m long. The bottom of the slope is 30 m lower than the top. The total resistive force on the skier is a constant 85 N.

(e) **Explain** why the speed at the bottom would be greater if the resistive force were smaller. [1]

Exercise 3.3 (e)

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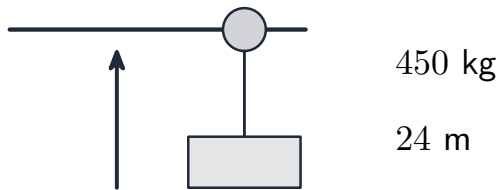
(e) less work is done against the resistive force, so more of the potential energy becomes kinetic energy

Exercise 3.4 (a)

3.4 A crane lifts a steel beam of mass 450 kg vertically at a constant speed through a height of 24 m.

(a) Calculate the work done by the crane on the beam.

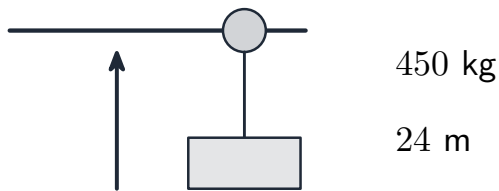
[2]



Exercise 3.4 (a)

3.4 A crane lifts a steel beam of mass 450 kg vertically at a constant speed through a height of 24 m.

(a) Calculate the work done by the crane on the beam. [2]



(a) the crane's force equals the weight at constant speed; work done, $W = Fs = mg\Delta h$

$$W = mg\Delta h = 450 \times 9.81 \times 24 = \mathbf{1.06 \times 10^5 \text{ J}}$$

Exercise 3.4 (b)

3.4 A crane lifts a steel beam of mass 450 kg vertically at a constant speed through a height of 24 m.

(b) **Explain** why this work equals the gain in gravitational potential energy of the beam. [2]

Exercise 3.4 (b)

3.4 A crane lifts a steel beam of mass 450 kg vertically at a constant speed through a height of 24 m.

(b) **Explain** why this work equals the gain in gravitational potential energy of the beam. [2]

(b) the speed is constant, so the kinetic energy of the beam does not change

- all the work done on the beam is stored as gravitational potential energy

Exercise 3.4 (c)

3.4 A crane lifts a steel beam of mass 450 kg vertically at a constant speed through a height of 24 m.

(c) The motor of the crane transfers 1.4×10^5 J of electrical energy during the lift. Calculate the energy that is not transferred to the beam, and state **one** form that it takes.

[2]

Exercise 3.4 (c)

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(c) The motor of the crane transfers 1.4×10^5 J of electrical energy during the lift. Calculate the energy that is not transferred to the beam, and state **one** form that it takes. [2]

(c) wasted energy = energy supplied – useful work = $1.4 \times 10^5 - 1.06 \times 10^5 = \mathbf{3.4 \times 10^4}$ J

- thermal energy in the motor and cables (or sound)