Chapter 1
Work and energy

Worksheet

Worked examples

Practical: Work done and kinetic energy

End-of-chapter test

Marking scheme: Worksheet

Marking scheme: End-of-chapter test

Worksheet

acceleration of free fall $g = 9.81\,\mathrm{m\,s^{-2}}$

Intermediate level

1 State the principle of conservation of energy. [1]

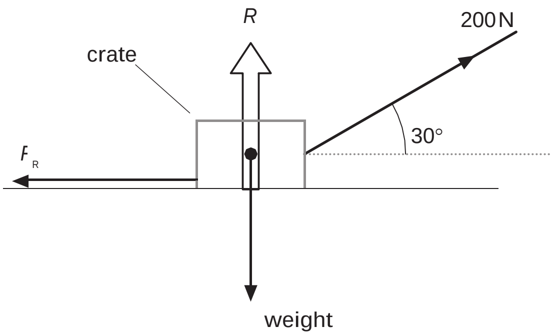
2 In each case below, discuss the energy changes taking place:

a an apple falling towards the ground; [1]

b a decelerating car when the brakes are applied; [1]

c a space probe falling towards the surface of a planet. [1]

3 A 120 kg crate is dragged along the horizontal ground by a 200 N force acting at an angle of 30° to the horizontal. The crate moves along the surface with a constant velocity of $0.5\,\mathrm{m\,s^{-1}}$. The 200 N force is applied for a time of 16 s.



a Calculate the work done on the crate by:

i the 200 N force; [3]

ii the weight of the crate; [1]

iii the normal contact force *R*. [1]

b Calculate the rate of work done against the frictional force F_R [3]

4 Which of the following has greater kinetic energy?

- A 20 tonne truck travelling at a speed of $30\,\mathrm{m\,s^{-1}}$.
- A 1.2 g dust particle travelling at $150\,\mathrm{km\,s^{-1}}$ through space. [3]

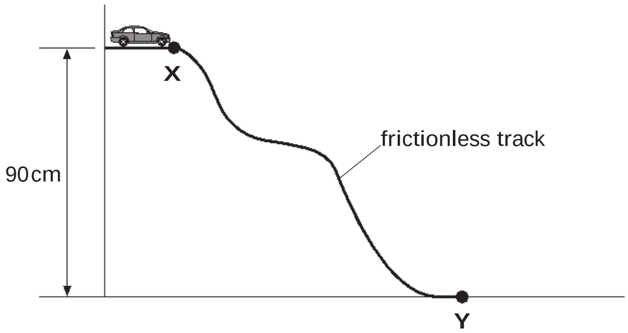
5 A 950 kg sack of cement is lifted to the top of a building 50 m high by an electric motor. The output power of the motor is 4.0 kW.

a Calculate the gain in the gravitational potential energy of the bag of cement. [2]

b The work done by the motor is 0.80 MJ. How much energy is wasted in the motor as heat? [1]

c Calculate how long it took to raise the sack to the top of the building. [2]

6 A 200 g toy car is released from point **X** on a frictionless track.



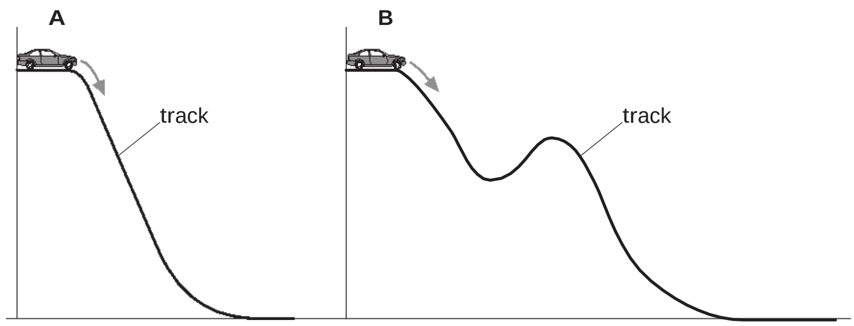
The car travels downhill from **X** to **Y**. Calculate:

a the loss of gravitational potential energy between **X** and **Y**; [2]

b the speed of the toy car at point **Y**. [3]

Higher level

7 The diagram shows two toy cars **A** and **B** at the top of frictionless tracks. The cars have different masses but they both drop through the same vertical height.



Which of the two cars will have a greater speed at the bottom of their track?

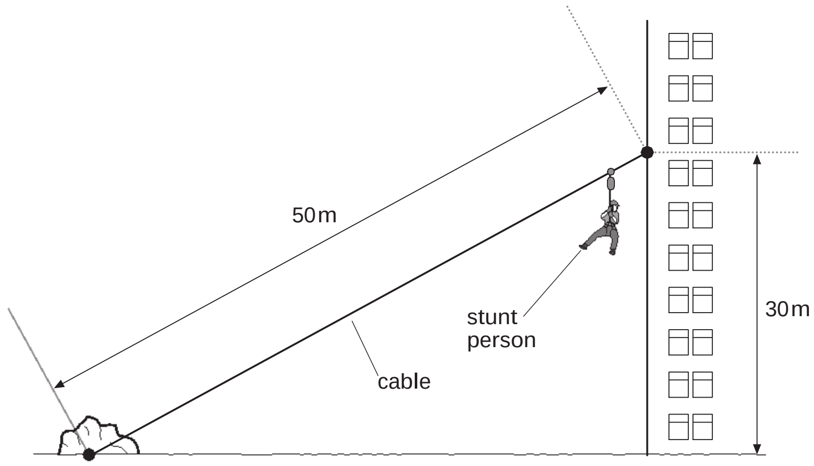
Explain your answer. [4]

8 The speed of a dart of mass 120 g is reduced from 180 m s^{-1} to 100 m s^{-1} when it passes through a book of thickness 3.0 cm. Calculate:

a the loss of kinetic energy of the dart; [3]

b the average frictional force exerted by the book on the dart. [3]

9 A stunt person slides down a cable that is attached between a tall building and the ground.



The stunt person has a mass of 85 kg. The speed of the person when reaching the ground is 20 m s^{-1}. Calculate:

a the loss in gravitational potential energy of the person; [2]

b the final kinetic energy of the person; [2]

c the work done against friction; [1]

d the average friction acting on the person. [2]

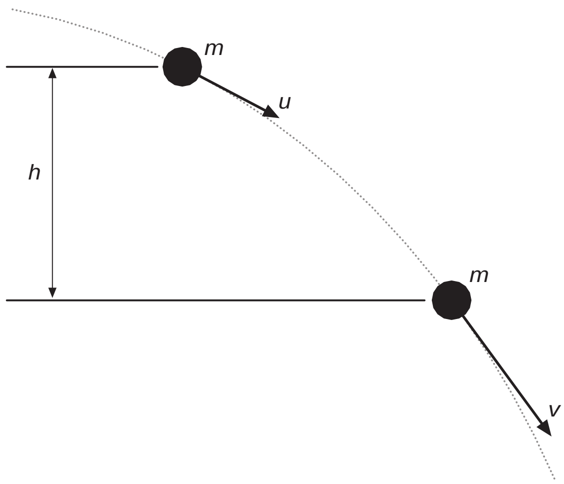
Extension

10 A constant force is applied to an object that is initially at rest. Show that the work done on the object, which is the same as its kinetic energy, is given by:

$\frac{1}{2}mv^2$

where m is the mass of the object and v is its speed. [4]

11 The diagram shows an object of mass m falling towards the surface of the Earth.



Assuming that there is negligible air resistance and using the principle of conservation of energy, show that:

$v^2 = u^2 + 2gh$

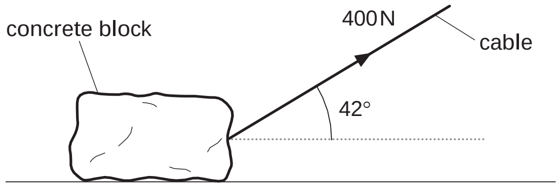
where u is the initial speed of the object and v is the speed of the object after falling through a vertical height h. [3]

Total: $\frac{}{49}$ Score: %

Worked examples

Example 1

A large concrete block is pulled along horizontal ground by a cable. The cable makes an angle of 42° to the horizontal and exerts a force of 400 N. Calculate the work done by the force when the block is dragged a horizontal distance of 30 m.



The force has a component of $F\cos$ in the direction of motion. When the block moves a horizontal distance x, the work done W by the force is given by:

$$W = F\cos \quad x$$

Work done = force distance moved in the direction of the force.

or

$$W = Fx\cos$$

$$W = 400 \quad 30 \quad \cos 42° \quad 8.9\,\text{kJ}$$

> **Tip**
>
> You can think of the work done by the force as the **product** of the force F and the displacement $x\cos$ in the direction of the force.

Example 2

A rugby player of mass 82 kg running at 7.5 m s^{-1} slides along the ground and comes to a halt in a distance of 5.6 m. What is the magnitude of the average friction acting on the player?

The work done by friction must be equal to the player's initial kinetic energy. Therefore:

$$Fx = \frac{1}{2}mv^2$$

It is important to understand that work done = energy transferred.

$$F = \frac{mv^2}{2x} = \frac{82 \;\; 7.5^{\;\;2}}{2 \;\; 5.6} \quad 410\,\text{N}$$

> **Tip**
>
> You can use an equation of motion and $F = ma$ to get the value for the force acting on the rugby player.
>
> $s = 5.6\,\text{m}$ $\quad u = 7.5\,\text{m s}^{-1}$ $\quad v = 0$ $\quad a = ?$
>
> $v^2 = u^2 + 2as$
>
> $a = \frac{v^2 - u^2}{2s} = \frac{0 - 7.5^2}{2 \;\; 5.6} = -5.02\,\text{m s}^{-2} \quad -5.0\,\text{m s}^{-2}$
>
> The magnitude of the friction F is given by:
>
> $F = ma = 82 \quad 5.02 \quad 410\,\text{N}$

Practical

Work done and kinetic energy

Safety

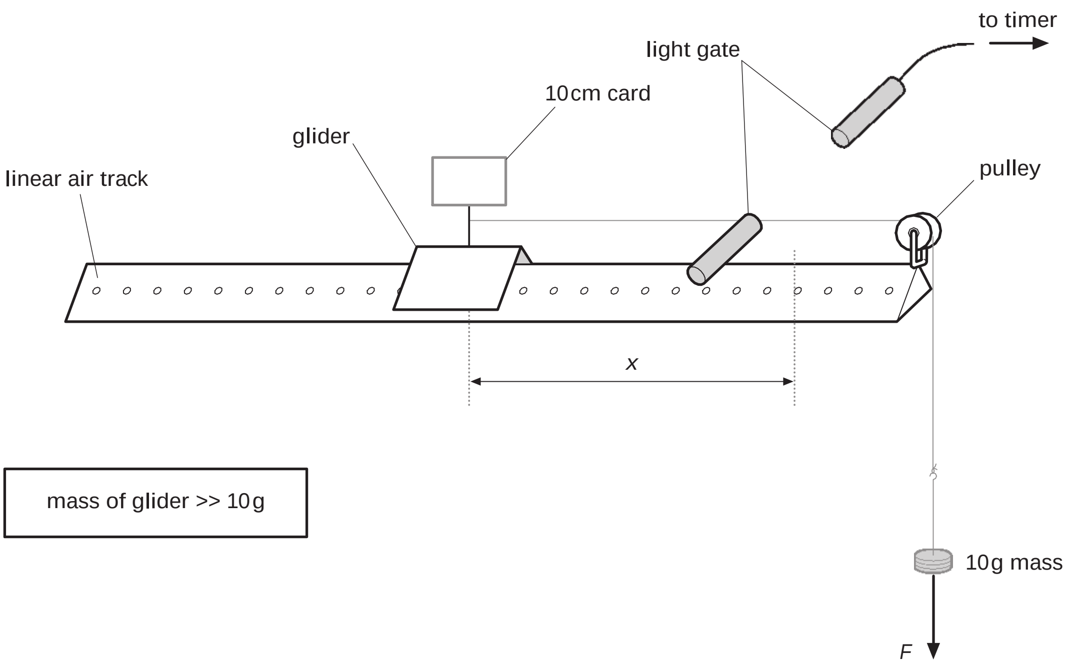
There are not likely to be any major hazards in carrying out this experiment. However, teachers and technicians should always refer to the departmental risk assessment before carrying out any practical work.

Apparatus

- linear air track
- air track glider
- 10 g masses used to accelerate the glider
- 10 cm card
- light gate
- timer

Introduction

The work done by a force is equal to the energy transferred (this is summarised on page 9 of *Physics 2*).



In this experiment, a constant force is applied to a glider on an air track. The kinetic energy of the glider is determined after it has travelled a given distance along the track. The work done by the force is equal to the change in the kinetic energy of the glider. For a glider starting from rest, we have:

$$Fx = \frac{1}{2}mv^2$$

where F is the force applied to the glider, x is the distance travelled by the glider, m is the mass of the glider, and v is the final speed of the glider after travelling the distance x.

Procedure

1 Tie one end of the string to the glider and the other end to the 10 g mass hanging over the pulley.

2 Release the glider from a distance of 0.80 m away from the light gate and record the time t taken by the 10 cm card on the glider to travel through the light gate.

3 Determine the speed v of the glider in m s^{-1} using:

$$v = \frac{0.1}{t}$$

4 Calculate the work done by the force on the glider and the kinetic energy of the glider.

Remember: work done = Fx where F is the weight of the 10 g mass and x is 0.80 m.

5 You should find that the work done on the glider is equal to the final kinetic energy of the glider. (This is only true if the mass of the glider ≫ 10 g.) How reliable is your experiment?

6 Now repeat the experiment for the same force F but for different distances x in the range 20 cm to 100 cm. Measure and record the distance x travelled by the glider and the time t taken for the 10 cm card to travel through the light gate.

x (10^{-2} m)	t (s)	v (m s^{-1})	v^2 ($m^2 s^{-2}$)

7 For each distance x, determine the speed², v^2.

8 Plot a graph of distance x against v^2 and draw a straight line of best fit.

9 Can you explain why the graph is a straight line? What is the gradient of the line?

(The gradient is equal to $\frac{m}{2F}$, where m is the mass of the glider and F is the weight of the 10 g mass accelerating the glider. Remember that this is only true as long as the kinetic energy of the falling 10 g mass is negligible compared with the kinetic energy of the glider.)

End-of-chapter test

Answer all questions.

acceleration of free fall $g = 9.81\,\mathrm{m\,s^{-2}}$

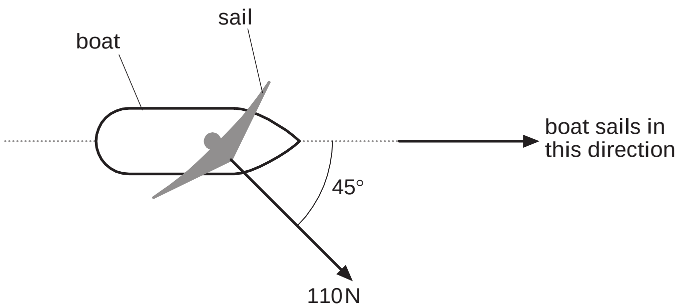
1 An apple of mass 80 g falls off a tree. It drops through a vertical height of 2.3 m.

a Discuss the energy changes of the apple as it falls from the tree and hits the soft ground below. [2]

b Calculate the loss of gravitational energy of the apple as it falls from the tree to the ground. [2]

c Assuming negligible air resistance, calculate the speed of the apple just before it hits the ground. [3]

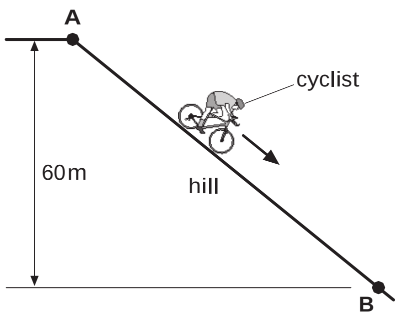
2 The diagram below shows the force of the wind acting on the sail of a boat.



a Define work done by a force. [1]

b Calculate the total work done by the wind when the boat moves a distance of 1.2 km. [3]

3 The diagram below shows a cyclist freewheeling down a hill from **A** to **B**.



The total mass of the cyclist and the bicycle is 95 kg. The total distance between **A** and **B** is 320 m and the cyclist drops through a vertical height of 60 m. At point **A**, the speed of the cyclist is zero. The average friction on the cyclist and his bicycle is 140 N.

a Calculate the work done against friction between points **A** and **B**. [2]

b Determine the kinetic energy of the cyclist and his bicycle at point **B**. [3]

c Use your answer to **b** to determine the speed of the cyclist at point **B**. [3]

Total: $\frac{\quad}{19}$ Score: %

Marking scheme

Worksheet

1 The total amount of energy in a closed system remains constant. [1]

2 **a** Loss of gravitational potential energy   gain in kinetic energy [1]

b Kinetic energy   heat (in the brakes) [1]

c Loss of gravitational potential energy   gain in kinetic energy [1]

3 **a** **i** Horizontal force = 200 cos 30° = 173 N   170 N [1]

Horizontal distance travelled = 0.5   16 = 8.0 m [1]

Work done = Fx = 173   8.0; work done = 1.39 10^3 N   1.4 kN [1]

ii Work done = 0 because the distance moved in the direction of the weight is zero. [1]

iii Work done = 0 because the distance moved in the direction of R is zero. [1]

b The net force on the crate is zero because the velocity is constant. Hence friction F_R is equal to the horizontal force. Therefore:

F_R = 173 N   170 N [1]

$P = Fv$; P = 173   0.5 [1]; P 87 W [1]

(Or from **a i** above, $P = \frac{W}{t} = \frac{1.39 \quad 10^3}{16}$ 87   W.)

4 Truck: $E_k = \frac{1}{2}mv^2 = \frac{1}{2}$ 20 000 30^2 = 9.0 10^6 J [1]

Dust particle: $E_k = \frac{1}{2}mv^2 = \frac{1}{2}$ 1.2 10^{-3} 150 000^2 1.4 10^7 J [1]

The dust particle has greater kinetic energy than the truck. [1]

5 **a** $E_p = mg \; h$; E_p = 950   9.81   50 [1]

E_p = 4.66 10^5 J   4.7 10^5 J [1]

b The total energy is conserved, therefore:

energy wasted as heat = 8.0 10^5 – 4.66 10^5

energy wasted as heat   3.3 10^5 J [1]

c Power = $\frac{\text{work done}}{\text{time}}$

time = $\frac{4.66 \quad 10^5}{4.0 \quad 10^3}$ [1];   time = 116.5 s ≈ 117 s [1]

6 **a** $E_p = mg \; h$

E_p = 0.200   9.81   0.90 [1]; E_p = 1.77 J   1.8 J [1]

b There is no loss of energy as heat since the track is frictionless.

Kinetic energy = loss in GPE

$\frac{1}{2}mv^2$ = 1.77 [1]

$v = \sqrt{\frac{2 \quad 1.77}{0.200}}$ [1]; v = 4.2 m s^{-1} [1]

7 Both cars **A** and **B** have the same speed at the bottom of the tracks. [1]

There are no losses as heat because the tracks are frictionless. [1]

The final speed v of each car dropping through the same vertical height h is independent of the mass m of the car. [1]

$\frac{1}{2}mv^2 = mgh$ or $v = \sqrt{2gh}$ [1]

8 **a** Loss in KE = $[\frac{1}{2}\quad 0.120\quad 180^2] - [\frac{1}{2}\quad 0.120\quad 100^2]$ [2]

Loss in KE = $1.34\quad 10^3\,\text{J}\quad 1.3\,\text{kJ}$ [1]

b Work done by friction = loss in KE of dart

$F\quad 0.03 = 1.34\quad 10^3$ [1]

$F = \frac{1.34\quad 10^3}{0.03}$ [1]; $F\quad 4.5\quad 10^4\,\text{N}$ [1]

9 **a** $E_p = mg\ \ h$; $E_p = 85\quad 9.81\quad 30$ [1]; $E_p\quad 2.5\quad 10^4\,\text{J}$ [1]

b $E_k = \frac{1}{2}mv^2 = \frac{1}{2}\quad 85\quad 20^2$ [1]; $E_k = 1.7\quad 10^4\,\text{J}$ [1]

c The total energy is conserved. Therefore:

work done against friction = $2.5\quad 10^4 - 1.7\quad 10^4$

work done against friction = $8.0\quad 10^3\,\text{J}$ [1]

d $W = Fx$

$F = \frac{W}{x} = \frac{8000}{50}$ [1]; $F = 160\,\text{N}$ [1]

10 Work done = Fx [1] (F is the applied force and x is the distance moved in the direction of the force.)

However, $F = ma$. Hence:

work done = $(ma)x$ [1]

Since a is constant, $v^2 = u^2 + 2as$ or $v^2 = 2ax$ (since $u = 0$) [1]

Work done = $m\left(\frac{v^2}{2x}\right)x$ [1]; work done = $\frac{1}{2}mv^2$

The work done on the object is equivalent to the KE of the object.

11 Loss in GPE = gain in KE of the mass [1]

$mgh = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$ [1]

The mass m 'cancels', therefore:

$gh = \frac{v^2 - u^2}{2}$ [1]

Hence: $v^2 = u^2 + 2gh$

Marking scheme

End-of-chapter test

1 **a** The apple loses gravitational potential energy and gains kinetic energy as it travels towards the ground. [1]

When it hits the ground, the kinetic energy of the apple is transferred into heat. [1]

b $E_p = mg \quad h$; $E_p = 0.080 \quad 9.81 \quad 2.3$ [1]

$E_p = 1.81\,\text{J} \quad 1.8\,\text{J}$ [1]

c There is no loss of energy as heat since air resistance is negligible:

kinetic energy = loss in GPE

$\frac{1}{2}mv^2 = 1.81$ [1]

$v = \sqrt{\frac{2 \quad 1.81}{0.08}}$ [1]; $v = 6.7\,\text{m}\,\text{s}^{-1}$ [1]

2 **a** Work done = force   distance moved in direction of the force. [1]

b $W = Fx\cos$⟨ [1]; $W = 110 \quad 1200 \quad \cos 45°$ [1]

$W \quad 9.3 \quad 10^4\,\text{N}$ [1]

3 **a** $W = Fx$, $W = 140 \quad 320$ [1]; $W = 4.48 \quad 10^4\,\text{J} \quad 4.5 \quad 10^4\,\text{J}$ [1]

b The total energy is conserved. Therefore, the kinetic energy E_k at **B** is:

E_k = loss of gravitational potential energy – work done against friction [1]

$E_k = mg \quad h - 4.48 \quad 10^4$

$E_k = (95 \quad 9.81 \quad 60) - 4.48 \quad 10^4$ [1]

$E_k = 1.11 \quad 10^4\,\text{J}$ [1]

c $\frac{1}{2}mv^2 = 1.11 \quad 10^4$ [1]

$v = \sqrt{\frac{2 \quad 1.11 \quad 10^4}{95}}$ [1]

$v = 15.3\,\text{m}\,\text{s}^{-1} \quad 15\,\text{m}\,\text{s}^{-1}$ [1]