Page 168 Test yourself on prior knowledge

1 The force needed to lift the mass is: 24 kg × 9.8 N kg^{-1} = 235 N

W = F × d

= 235 N × 1.3 m

= 306 J

2 E = P × t

= 2 000 W × 3.5 × 3600 s

= 25.2 MJ

3 Work is done only in **b)** and **f)**. Work = force × distance; work is only done when something moves in the direction of an applied force.

Explanations:

a) The weightlifter may get tired lifting the weight, but it is not moving, so no work is done.

b) Work is done against frictional forces.

c) There are no frictional forces acting, no work is done.

d) Although the spacecraft is moving, and gravity acts to deflect it, no work is done as the force is always at right angles to the motion. The spacecraft stays in orbit without work being done; so it does not have to use its engines.

e) The magnet is not moving; no work is done.

f) When you walk down stairs, energy is transferred from GPE in the body to thermal energy in the leg muscles; here the body does work on the legs – whereas when you climb the stairs, the legs do work on the body. When you walk down stairs, you are stretching muscles, thus descending and ascending stairs both tire you out and are good exercise; but it is more tiring going up than down.

4 a)

- Chemical energy in your muscles is transferred to kinetic energy (and heat) in the ball.
- Kinetic energy in the ball is transferred in potential energy (and a little heat in the air).
- The ball falls converting potential energy back into kinetic energy (and a little more heat in the air).
- The ball's kinetic energy is transferred to heat and sound. Both the ball and the ground will warm up slightly.

b) Chemical energy is transferred to heat in the engine and kinetic energy in the car. The car works against drag and frictional forces, which transfers energy to heat.

c)

- Chemical energy in your muscles does work to stretch the band.
- Elastic potential energy (strain energy) is stored in the band.
- When the band is released, the elastic potential energy is transferred to the paper's kinetic energy and gravitational potential energy as it rises. Some energy will be transferred to vibrational energy in the band and sound energy.
- Once again, some energy will be transferred to the surroundings as heat at each step.

Page 170 Test yourself

1 a) $W = F s \cos \theta$

$= 60\text{ N} \times 400\text{ m} \times \cos 50^0$

$= 15\text{ kJ}$

b) When the case wheel meets a small step or bump in the ground, the vertical component of the force helps to lift the case. If you push the case, you push it down into a step.

2 Work done $= (300\text{ N} + 400\text{ N} \cos 25° + 250\text{ N} \cos 25°) \times 60\text{ m}$

$= 53\text{ kJ}$

3 No work is done, as the force is at right angles to the direction of motion.

4 Work done $= (40\text{ N} \times 50\text{ m}) + (23\text{ kg} \times 9.8\text{ N/kg} \times 0.9\text{ m})$

$= 2\ 200\text{ N}$

Page 172 Test yourself

5 a) i) $\Delta PE = mg\Delta h$

$= 25\ 000\text{ kg} \times 9.8\text{ N kg}^{-1} \times 12\text{ m}$

$= 3.0\text{ MJ}$

ii) $W = Fs$

$= 150\text{ N} \times 20\text{ m}$

$= 3\text{ kJ}$

iii) $\Delta PE = mg\Delta h$

$= 25\ 000\text{ kg} \times 9.8\text{ N kg}^{-1} \times -8\text{ m}$

$= -2.0\text{ MJ}$

The container's GPE is 2.0 MJ less than it was on the dockside. We do not define a zero point of GPE, we talk in terms of differences.

b) g = ΔPE/mΔh

= 5×10^{18} J/(18000 kg × 100 m)

= 2.8×10^{12} N kg^{-1}

6 a) ΔKE $= \frac{1}{2} m v_2^2 - \frac{1}{2} m v_1^2$

$= \frac{1}{2} \times 720 \text{ kg} \times (88 \text{ ms}^{-1})^2 - \frac{1}{2} \times 720 \text{ kg} \times (42 \text{ ms}^{-1})^2$

= 2.2 MJ

b) KE $= \frac{1}{2} m v^2$

$= \frac{1}{2} \times 0.05 \text{ kg} \times (300 \text{ m s}^{-1})^2$

= 2.3 kJ

7 a) ΔEPE = average force × distance

= 4.0 N × 0.12 m

= 0.48 J

b) Work done = 0.48 J = F × (0.96 + 0.12) m

⇒ F $= \frac{0.48}{1.08}$ N

= 0.44 N

Note: the frictional force also acts over the distance Δx (0.12 m) in the diagram.

Page 174 Test yourself

8 ΔPE = mgΔh

= 2.3 kg × 9.8 N kg^{-1} × 3.5 m

= 79 J

Efficiency $= \frac{\text{useful energy}}{\text{energy supplied}}$

$= \frac{79 \text{ J}}{280 \text{ J}}$

= 0.28 or 28% (2 sf)

9 a) Useful energy available = 0.27 × 30 MJ

= 8.1 MJ

b) Work done = 8.1 MJ = F × s

⇒ F = 8.1×10^6 J / 7000 m = 1.2 kN (2 sf)

Pages 175–176 Activities

How high can you climb using a chocolate bar?

A range of values are possible – depending on resources used and assumptions made, but this example demonstrates method.

Energy content of 100g plain chocolate = 2426 kJ
Efficiency of the human body estimated at 25%
Mass of a person = 70 kg

Assuming all available energy is transferred into gravitational PE:
$0.25 \times 2426 \times 10^3$ J = 70 kg × 9.8 N/kg × Δ h
$\Longrightarrow$ **Δ**h = 606500 J ÷ 686 N = 884 m
i.e. you could climb a mountain about the height of Pen y Fan, going from sea level.

In practice, the height is likely to be much less for a variety of reasons including: the efficiency figure is likely to apply to fit people; clothing and kit would increase mass; forward motion isn't entirely work-free because of overcoming friction; few ascents are continuous and gravitational PE 'gained' on descending sections of the climb is not available for use when we go up again (as a lot of it might in, for example, a roller coaster); and there's the effect of pushing against wind and rain …

Elastic potential energy transferred to kinetic energy

First trial

Elastic potential energy = ½ × 4.6 N × 0.1 m = 0.23 J

Kinetic energy = ½ × 0.85 kg × $(0.69\ \text{m s}^{-1})^2$ = 0.20 J

Second trial

Elastic potential energy = ½ × 9.3 N × 0.2 m = 0.93 J

Kinetic energy = ½ × 0.85 kg × $(1.31\ \text{m s}^{-1})^2$ = 0.73 J

In both trials, as expected, not all the elastic potential energy stored in the springs is transferred to kinetic energy of the trolley. Elastic potential energy will be transferred to heat energy as a result of drag and frictional forces and this transfer continues as the trolley travels/oscillates until it stops moving.

The efficiency of the transfer is greater in the first trial, but more results are needed to determine if this reduction is related to the initial displacement.

Gravitational potential energy to kinetic energy

Ball falling vertically:

$\Delta PE = 0.0157 \text{ kg} \times 9.8 \text{ N kg}^{-1} \times 0.35 \text{ m} = 54 \text{ mJ}$

$\Delta KE = \frac{1}{2} m v_B^2 - \frac{1}{2} m v_A^2$

$= \frac{1}{2} \times 0.0157 \times 3.04^2 - \frac{1}{2} \times 0.0157 \times 1.56^2 = 53 \text{ mJ}$

The loss of PE is close to the gain of KE, because the frictional forces acting on the ball are small in comparison with its weight.

Ball rolling down the slope:

$\Delta PE = 54$ mJ as before

$\Delta KE = (⅕+ ½)\ m v_B^2 - (⅕+ ½)\ m v_A^2$

$0.7\ m v_A^2 = 0.7 \times 0.0157 \text{ kg} \times (0.91 \text{ m s}^{-1})^2 = 9 \text{ mJ}$

So $0.7\ m v_B^2 = 54 \text{ mJ} - 9 \text{ mJ} = 45 \text{ mJ}$ (ignoring friction and drag)

$\Longrightarrow V_B = 2.02 \text{ m s}^{-1}$

You might measure a speed less than this, as there may be drag forces against which the ball has to do work (energy lost heating the air/tube), and some energy may be transferred to sound energy as the ball rolls or/and hits the sides of the tube.

Pages 176–177 Test yourself

10 a) $\mathrm{mg}\,\Delta\mathrm{h} = \frac{1}{2}\,\mathrm{m}\,\mathrm{v}^2$

$\Rightarrow v^2 = 2g\Delta h$

$v = (2\,g\,\Delta h)^{\frac{1}{2}}$

$= (2 \times 9.8 \text{ N kg}^{-1} \times 15)^{\frac{1}{2}}$

$= 17 \text{ m s}^{-1}$ (2 sig figs)

b) $\mathrm{m\,g}\,\Delta\mathrm{h} = \frac{1}{2}\mathrm{m\,v}^2 - \frac{1}{2}\mathrm{m\,u}^2$

$\Rightarrow v^2 = u^2 + 2g\Delta h$

NOTE: you have met this equation before as an equation of motion.

$\Rightarrow v^2 = (10^2 + 2 \times 9.8 \times 15) \text{ m}^2 \text{ s}^{-2}$

$= 100 + 294$

$= 394 \text{ m}^2 \text{ s}^{-2}$

$v = 20 \text{ m s}^{-1}$

11 a) KE = $\frac{1}{2}$ m v^2

= $\frac{1}{2} \times 0.1\text{ kg} \times (10\text{ m s}^{-1})^2$

= 5.0 J

b) mgΔh = 0.1 kg × 9.8 N kg^{-1} × 20

= 20 J (2 s.f.)

c) 25 J – this is the sum of the energies calculated in parts a) and b).

d) 25 J = $\frac{1}{2}$ m v^2

$v^2 = \frac{50}{0.1}$

$v^2 = 500\ (\text{m s}^{-1})^2$

v = 22 m s^{-1}

12 $F \times s = \frac{1}{2} m v^2 - \frac{1}{2} m u^2$

$F \times 200\text{ m} = \frac{1}{2} \times 1\,800 \times 20^2\text{ J} - \frac{1}{2} \times 1\,800 \times 15^2\text{ J}$

$F = \frac{157\,500\text{ J}}{200\text{ m}}$

F = 790 N (2 s.f.)

13 They both have the same kinetic energy as the same work (F × s) is done in accelerating them both.

14 a) P = F v

$F = \frac{P}{v}$

$= \frac{2.0\text{ MW}}{55\text{ m s}^{-1}}$

= 36 kN

b) Work done against resistive forces over a 200 km journey.

W = 36 kN × 200 km

= 7.2×10^9 J (7 200 MJ)

efficiency = $\frac{\text{useful work done against resistive forces}}{\text{energy from fuel}}$

⇒ Energy from fuel $= \frac{7\,200\text{ MJ}}{0.32}$

= 22 500 MJ

⇒ no of litres × 40 MJ = 22 500 MJ

no of litres = 560 l (2 sf)

15 a) The area under the graph is about 35.5 squares.

Each square has a value of:

1 mN × 2 mm = 2 μJ

So the stored elastic PE 35.5 × 2 μJ = 71 μJ

b) Assuming all the fly's kinetic energy is transferred to elastic potential energy:

½ mv^2 = 71 μJ

v^2 = (2 × 71 × 10^{-6} J)/(16 × 10^{-6} kg)

So v = 3.0 m s^{-1}

16 a) $a = \frac{v-u}{t}$

$= \frac{3\ \mathrm{m\ s^{-1}}}{25 \times 10^{-3}\ \mathrm{s}}$

= 120 m s^{-2}

b) F = m a

= 2.5 × 10^{-3} kg × 120 m s^{-2}

= 0.3 N

c) W = F × d

= 0.3 N × 0.05 m

= 0.015 J

d) $P = \frac{W}{t}$

$= \frac{0.015\ \mathrm{J}}{(25 \times 10^{-3}\ \mathrm{s})}$

= 0.6 W

e) Locust power kg^{-1} = $\frac{0.6\ \mathrm{W}}{2.5 \times 10^{-3}\ \mathrm{kg}}$ = 240 J kg^{-1}

Athlete power = $\frac{m\,g\,\Delta h}{t}$

Power kg^{-1} = $\frac{g\,\Delta h}{t}$

$= \frac{9.8\ \mathrm{N\ kg^{-1}} \times 1.3\ \mathrm{m}}{0.2\ \mathrm{s}}$

= 64 J kg^{-1}

The power : mass ratio for the locust is about 4 times greater.

17 Efficiency = 0.36 × 0.25 = 0.09 or 9%

The remaining energy heats up the surroundings.

18 ΔPE for 1 kg = 1 kg × 9.8 N kg^{-1} × 160 m

= 1568 J

ΔPE for 700 m^3 = 1568 J × 700 m^3 × 1000 kg m^{-3}

= 1.1 GJ

Power of electricity generation = 0.8 × 1.1 GJ s^{-1}

= 0.9 GW

19 a) mass of water = volume × density

= 200 × 10^6 m^2 × (13 – 6) m × 1020 kg m^{-3}

= 1.43 × 10^{12} kg

The centre of mass of this body of water is 6 m + ½(13 – 6) m = 9.5 m above low-tide level.

So GPE relative to sea level at low tide = mgh = 1.43 × 10^{12} kg × 9.81 N kg^{-1} × 9.5 m

= 133 × 10^{12} J = 133 TJ

b) Power = (0.78 × 133 TJ)/ (5.5 × 3600 s) = 5 240 MW or 5 GW to 1 sf

c) Annual energy output = 133 TJ × 0.78 × 2 × 365 = 76 000 TJ or 80 000 TJ to 1 sf

Pages 178–182 Practice questions

1 B

2 B

3 C

4 C

5 D

6 A

7 B

8 A

9 B

10 B

11 a) Potential energy is transferred into heat energy as work is done to drive it into the wood.

m g h = F s

h = height from which the driver is dropped, s = distance the nail travels in the wood [1]

$F = \frac{m\,g\,h}{s}$ [1]

$= \frac{0.31\text{ kg} \times 9.8\text{ N kg}^{-1} \times 0.25}{6 \times 10^{-3}\text{ m}}$ [1]

= 130 N (2 sf) [1]

b) On subsequent drops, the nail does not travel so far into the wood.

Once the nail is knocked into the wood there is a longer length of it in contact with the wood, so the frictional force, F, on it is larger. [1]

Since the pile driver falls with the same energy, F × s is constant so, as F increases, s becomes less. [1]

12 a) $\Delta E_p/s = mg\Delta h/t$ [1]

$= \frac{9\,600\text{ kg}}{60\text{ s}} \times 9.8\text{ N kg}^{-1} \times 36\text{ m}$ [1]

$= 56\text{ kJ s}^{-1}$ (2 sf) [1]

b) Efficiency $= \frac{\text{useful power}}{\text{power input}}$ [1]

$= \frac{56\text{ kW}}{80\text{ kW}}$

= 0.71 (2 sf) [1]

13 a) The total thrust is 4 × 23 kN = 92 kN, which is equal to the drag. [1]

The horizontal forces balance so there is no acceleration by Newton's first law of motion. [1]

b) Lift = weight = mg = 110 000 kg × 9.8 N kg^{-1} = 1.1 MN [1]

c) P = F v [1]

$= 23\text{ kN} \times 240\text{ m s}^{-1}$ [1]

= 5.5 MW (to 2 sf) [1]

14 a) Energy cannot be created or destroyed [1], but it can be transferred from one form of energy to another. [1]

b) Δh = 12 sin 30 = 6 m [1]

$\Delta PE = mg\Delta h = 32\text{ kg} \times 9.8\text{ N kg}^{-1} \times 6\text{ m}$ [1]

= 1.9 kJ (2 sf) [1]

c) $\Delta KE = \frac{1}{2} m v^2 = \frac{1}{2} \times 32\text{ kg} \times 9.3\ (\text{m s}^{-1})^2$ [1]

= 1.4 kJ (2 sf) [1]

d) Work is done against frictional forces [1] and thus potential energy is transferred to heat energy. [1]

e) Energy transferred to heat = 1.9 kJ – 1.4 kJ = 0.5 kJ [1]

Work = force × distance [1]

Force $= \frac{\text{work done}}{\text{distance}} = \frac{500\ \text{J}}{12\ \text{m}}$ = 42 N [1]

15 a) i) a $= \frac{v-u}{t} = \frac{41\ \text{m s}^{-1}}{0.49 \times 10^{-3}\ \text{s}}$ [1]

= 84 000 m s^{-2} [1]

ii) F = m a = 0.046 kg × 84 000 m s^{-2} [1]

= 3.8 kN [1]

b) KE $= \frac{1}{2} m v^2 = \frac{1}{2} \times$ 0.046 kg × (41 m $s^{-1})^2$ [1]

= 39 J [1]

c) $\frac{1}{2} m v^2 = F \times s$ [1]

39 J = 3.8 kN × s [1]

d = 0.01 m (1 cm) [1]

d) During the contact between the club and ball some energy will be dissipated as sound and heat [1]. The work done by the club, and thus the contact distance must therefore be a little greater [1].

16 a) ΔE_p = mgΔh = 1 300 kg × 9.8 N kg^{-1} × 17 m [1]

= 220 kJ (2 sf) [1]

b) i) PE lost = KE gained or 220 kJ $= \frac{1}{2} mv^2 = \frac{1}{2} \times$ 1 300 kg × v^2 [1]

$v^2 = \frac{440\ \text{kJ}}{1\ 300\ \text{kg}} \Longrightarrow v = 18\ \text{m s}^{-1}$ [1]

ii) Drag on the boat will slow it down. So, some potential energy is transferred to heat energy on the way down reducing the kinetic energy, and therefore the speed, of the boat. [1]

c) i) Either $mgh = \frac{1}{2} mv^2 \Rightarrow v^2 = 2\ g\ h$ [1]

So the speed is unaffected by mass. [1]

OR

The drag that acts on the boat is independent of mass so energy lost to heat will remain the same. [1]
As this is a smaller fraction of the larger total energy available, the speed might be a little more than before. [1]

ii) $\frac{1}{2}$ m v^2 = F × d [1]

Assuming the same drag force, a larger mass will require a larger stopping distance. [1]

17 a) When you drive a car, work is done against resistive (or drag) forces. Since W = F s; when the drag force is bigger (at a higher speed), more work is done [1] and so more energy must be transferred from the petrol. [1]

b) P = F v = 540 N × 30 m s^{-1} [1]

= 16.2 kW [1]

c) i) efficiency = $\frac{\text{useful power}}{\text{power input}}$ [1]

power input = $\frac{16.2 \text{ kW}}{0.27}$ = 60 kW [1]

ii) Energy is transferred to heat in the engine and some noise. [1]

d) Energy used = P × t [1]

= 60 kW × 3 600 s = 216 MJ [1]

Petrol used = $\frac{216 \text{ MJ}}{32 \text{ MJ l}^{-1}}$ = 6.8 l [1]

18 a) Mass = 350 × 10^6 m^3 × 3 000 kg m^{-3} [1]

= 1.05 × 10^{12} kg [1]

b) ΔPE = 1.05 × 10^{12} kg × 9.8 N kg^{-1} × 5 000 m [1]

= 5.1 × 10^{16} J [1]

c) The minimum KE of the meteor must have been 5.1 × 10^{16} J

⇒ 5.1 × 10^{16} = $\frac{1}{2}$ m v^2 [1]

⇒ m = $\frac{10.2 \times 10^{16}}{(1.4 \times 10^4)^2}$

= 5.2 × 10^8 kg [1]

d) The meteor is likely to have been much larger as not all of its energy would have been used to displace a volume of rock equal to the current volume of the crater: some would have been transferred as heat as rock from the earth (or/and some of the meteorite) was probably vaporised on impact; shock waves will have travelled around the Earth; the meteor itself may have been travelling more slowly than the given figure; and it will have been slowed to some extent by the time it had passed through the atmosphere. [Any one specific transfer or reason for velocity on impact being lower = 1]

19 a) work done = area under the graph [1]

= ½ × 2800 N × 0.3 m [1]

= 420 J [1]

b) Work done = $\frac{1}{2}$ m v^2 [1]

420 = ½ × 86 × v^2 [1]

v = 3.1 m s^{-1} [1]

Page 182 Stretch and challenge

20 KE = $\frac{1}{2}$ m v^2

So if v is double, the KE is four times as much.

E = P t

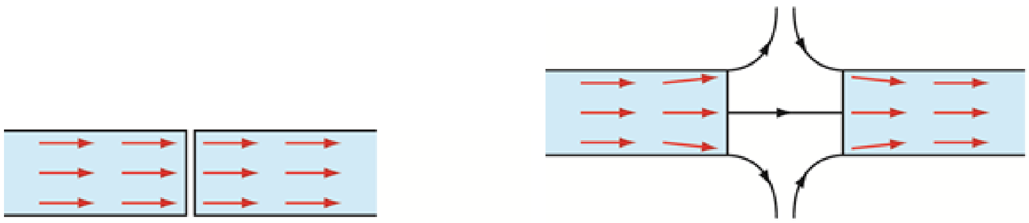
So if the power is constant, it will take four times the time to reach a kinetic energy four times greater / double the speed.

21 a) Work done = area under the graph

The area is about 10 squares = 10 × 1 N × 0.01 m

= 0.1 J

b) The magnetic potential energy of the magnets has been increased. When the magnets are in contact, the magnetic domains are in greater alignment. When they are pulled apart then the directions of some domains are tilted to the side. (Think of the diagrams of magnetic fields you drew during KS3/4 work.)



Magnets in contact: low magnetic potential energy **Magnets separated:** high magnetic potential energy

c) Newton's Third Law tells us that each magnet experiences equal and opposite magnetic forces, so they travel to the same distance.

Each magnet has 0.05 J of magnetic potential energy (MPE) transferred to it; each magnet moves 0.025 m.

So $\frac{1}{2}$ m v^2 = MPE – work done against frictional forces

$\frac{1}{2} \times 0.05 \times v^2 = 0.05 - 0.4 \times 0.025$

$v^2 = 2 - 0.4 = 1.6$

v = 1.3 m s^{-1}

d) This involves a little estimation work. If the graph is continued to ∞, the total area under the graph is corresponds to an energy of about 0.12 J.

So each magnet has 0.06 J of MPE transferred to it.

0.12 J = F s

⟹ 0.12 J = 0.4 N × s

s = 0.3 m or each magnet moves 0.15 m.

d) They will not move if the magnetic attraction is less than or is balanced by the frictional force of 0.4 N. Reading from the graph, this happens if the minimum distance between them is about 6 cm.

22 a) $N\ m^{-2} = Nm.m^{-3} = J\ m^{-3}$

b) Pressure = energy ÷ volume

Pressure × volume = m g Δh

$$P = \frac{m\ g\ \Delta h}{V}$$

$$= \frac{0.015\ \text{kg} \times 9.8\ \text{N kg}^{-1} \times 10\ \text{m}}{75 \times 10^{-2} \times 10^{-3}\ \text{m}^3}$$

$= 2000\ J\ m^{-3}$ or $2000\ N\ m^{-2}$

This is about 0.02 of an atmosphere pressure.