The answers to the practice questions below are as given to the IB examiners. The following notes may help you to interpret these and make full use of the guidance given.

- There are no half marks awarded. Each mark is shown by the number in brackets (1).
- Points worth single marks are separated from each other by a semicolon (;).
- Alternative possible answers are separated from each other by a dash (/).
- Any answer given in **bold** or underlined *must* be present to score the mark.
- Information in brackets ( ) is not needed to score the mark.
- Notes given in italics are to guide the examiner on what to accept/reject in their marking.
- *OWTTE* means 'or words to that effect', so alternative wording that conveys the same meaning can be equally rewarded.
- *ECF* means 'error carried forward', so examiners must award marks for an incorrect answer from an earlier part of a question used correctly in a subsequent step.
- MP1, MP2 etc. represent method marks to be awarded by an examiner for answers showing the appropriate steps of the working (method) necessary for answering the question.

You may notice occasional differences between the calculations or wordings given in the answers and those in the worked solutions. This is because the answers give
the final solution with the minimum of working, and the worked solutions provide the extra reasoning and working needed to understand how the answers are attained.

Skills

1 **(a)** 4.8×10^4 **(b)** 3.6×10^{-5}
(c) 1.45×10^4 **(d)** 4.8×10^{-7}

2 **(a)** 5.59×10^6 m **(b)** 1.75 m
(c) 2.54×10^{-5} m **(d)** 10^{26} m

3 **(a)** 2.68×10^9 s **(b)** 2.5×10^{-3} s
(c) 3.46×10^5 s **(d)** 1.04×10^4 s

4 **(a)** 2×10^{-1} kg **(b)** 1×10^{-8} kg
(c) 2×10^3 kg

5 150 m^3

6 **(a)** 1.0×10^{-10} m^3 **(b)** 1.09×10^{21} m^3

7 180 kg

8 86.85 kg

9 5.48×10^3 kg m^{-3}

10 **(a)** There is some variation in the mass of the apples, but the number of apples is proportional to the mass of the apples.
(b) There is a larger variation in the mass of the apples.
(c) The mass of the apples appears to be linearly related to the number of apples but there might be a large systematic error in the mass measurement, or the apples were counted incorrectly.

11 $A = 4B^2$

12 9056 ± 560 kg m^{-3}

13 1600 ± 4 m

14 1.12 ± 0.01 s

15 **(a)** 5.2 cm **(b)** 4.8 cm
(c) 3 cm **(d)** 8.8 cm

16 **(a)** 5 cm **(b)** 5.66 cm
(c) 6.32 cm **(d)** 3.61 cm

17 8.94 km, 63.4° north-west

18 112 km, 26.6° north-east

19 8.66 km

20 7.52 km

21 433 m

Challenge yourself

1 8 ± 4 m s^{-2}

A.1

Exercises

1 **(a)** 27.8 m s^{-1} **(b)** 5.6 m s^{-1}

2 **(a)** 4.2 m s^{-1} **(b)** 0 m s^{-1}
(c) –4.2 m s^{-1} (minus sign indicates traveling in opposite direction to initial direction)
(d) 90 m

3 22.4 m s^{-1}, 26.6°

4 4.1 m s^{-1}, direction is 14° W of S

5 31.6 m s^{-1}

6 49 m s^{-1}

7 –30 m s^{-1}

8 40 m

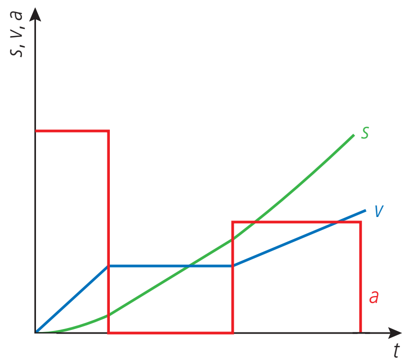
9 3.6 m s^{-1}

10 4 s

11 125 m, 2.5 m s^{-2}

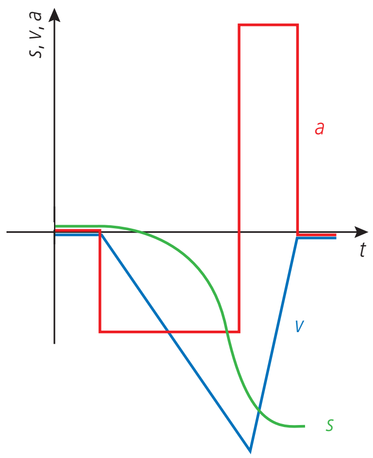
12 15 m

13



The displacement graph is quadratic in the first and last sections, and linear in between.

14



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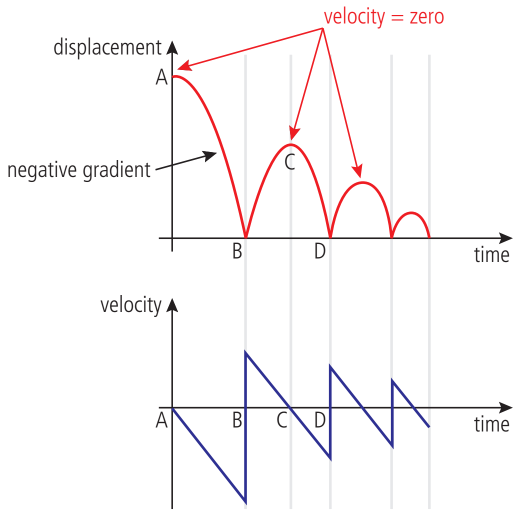

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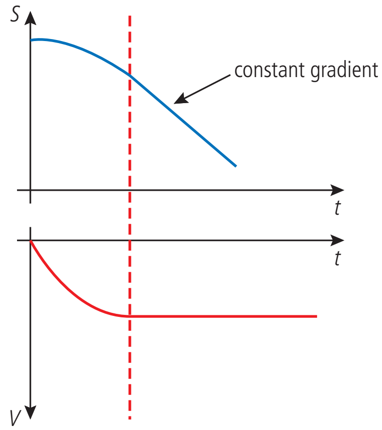


17 78 m

18 **(a)** 30° **(b)** 17.3 m

19 5 m

20 39.6 m

Challenge yourself

1 53 m

Practice questions

1 **(a)** $s_S = 18 \times t$ (1)

(b) 81 m (1)

(c) 27 m s^{-1} (1)

(d) $x = 27\,(t - 6.0)$ (1)

(e) $t = 9.0$ s (2)

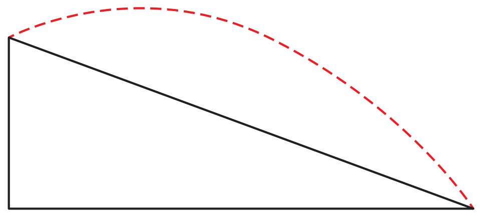
2 **(a)** **(i)** 4 m (1)

(ii) 2.1 s (3)

(iii) 15 m (2)

(**b**) On the way up, air resistance is in the same direction as weight. On the way down, air resistance is in the opposite direction to weight. The magnitude of acceleration is greater on the way up than down so the time to reach the highest point is smaller than the time back to the ground. (3)

3 (**a**) (2)



(**b**) The boy at the top of the hill will kick the ball with a smaller magnitude of velocity than the boy at the bottom. The direction of the shot from the boy at the top will be at an angle closer to the horizontal; the angle of the shot from the boy at the bottom will be closer to the vertical. (2)

4 C (1)

5 A (1)

6 (**a**) 0.19 s (2)

(**b**) Now we will use this time (to reach the net) in a vertical component calculation to find out the height of the ball when in line with the net. Listing the variables taking downwards to be positive: $u = 64 \sin 7.0°$ $a = 9.81$ $t = 0.19$;

$s = ut + \frac{1}{2}at^2$

$= 64 \sin 7.0 \times 0.19 + \frac{1}{2} \times 9.81 \times 0.19^2$

$= 1.66$ m;

This is vertical distance fallen. The height of the ball is 2.8 − 1.66 = 1.1 m, which means the ball passes over the net (height of 0.91 m). (3)

(**c**) 64.4 m s^{-1} (2)

7 5560 m (2)

8 (**a**) $t = \frac{l \cos\theta}{u \cos\theta} = \frac{l}{u}$ (2)

(**b**) $l = 4\frac{u^2 \sin\theta}{g}$ (3)

A.2

Exercises

1 (**a**) 10 N to the right

(**b**) 5.8 N, 31° above the horizontal, to the right

2 (**a**) 40 N (**b**) 69 N

3 (**a**) −74 N to the left

(**b**) 45 N, 63.4° above the horizontal, to the right

4 (**a**) 4N down slope (**b**) 4 N, 37.6° relative to the dashed line

5 (**a**) $F_1 = 8.49$ N (**b**) $F_2 = 17.3$ N, $F_3 = 50$ N

6 (**a**) $F = T \sin 30°$ (**b**) $10 = T \cos 30°$

(**c**) 11.5 N (**d**) 5.8 N

7 (**a**) $F = 50 \sin 30°$ (**b**) $50 \cos 30° = N$

(**c**) $F = 25$ N, $N = 43.3$ N

8 (**a**) $2T \cos 80° = 600$ N

(**b**) $T \sin 80° = T \sin 80°$

(**c**) 1728 N

9 −3 N s

10 −4.02 N s

11 6.7 m s^{-2}

12 997.5 N

13 (**a**) 3.3 m s^{-2} (**b**) 33 N

14 2 m s^{-2}

15 682.5 N

16 (**a**) 40 N (**b**) 150 m s^{-2}

17 (**a**) force on gas = −force on rocket

(**b**) force on water = −force on boat

(**c**) force on body = −force on board

(**d**) water exerts unbalanced force on ball, so ball exerts force on water; reading increases

18 (**a**) 31.4 m (**b**) 0 m

(**c**) 15.7 s (**d**) 6.4×10^{-2} Hz

(**e**) 0.4 rad s^{-1} (**f**) 0.8 m s^{-2}

19 1389 N

20 15.8 m s^{-1}

21 14 m s^{-1}

22 (**a**) 9 m s^{-1} (**b**) 30 N

Challenge yourself

1 72 km h^{-1}, 241 km h^{-1}

Practice questions

1 (**a**) the direction of the car is changing; hence the velocity of the car is changing

OR

since the direction of the car is changing; a force must be acting on it, hence it is accelerating (2)

(**b**) (**i**) arrow pointing vertically downwards (1)

(ii) weight

Do not penalize candidates if they state 'gravity'.

normal reaction; (2)

Do not penalize candidates if they state 'push of the track on the marble'.

(iii) loss in $E_P = 0.05 \times 10 \times (0.8 - 0.35)$; =

gain in $E_K = \frac{1}{2}mv^2$; to give $v = 3.0\ \text{m s}^{-1}$

OR

use of $v = 2gh$ to give $v = 4.0\ \text{m s}^{-1}$ at point B;

and then use of $v^2 - u^2 = \sqrt{2gh}$ with $v = 4.0\ \text{m s}^{-1}$

and $h = 0.35$ m; to get $u = 3.0\ \text{m s}^{-1}$ (3)

Do not penalize the candidate if $g = 9.8\ \text{m s}^{-2}$ is used.

(iv) recognize that resultant force $= \frac{mv^2}{r}$

$= \frac{(0.05 \times 9.0)}{0.175} = 2.6$ N

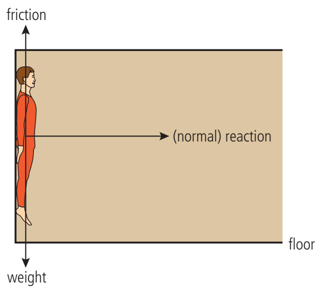
$N = \frac{mv^2}{r} - mg = 2.6 - 0.5 = 2.1$ N (4)

2 **(a)** ratio between (maximum) friction and normal reaction / OWTTE (1)

Don't accept equation without definitions of symbols.

(b) **(i)** static; (*Award this mark for bald statement even if the reason is wrong.*) since person is not moving vertically / OWTTE; (2)

(ii) *Award **[1]** for each force labeled to show understanding.* (3)



Use benefit of the doubt and accept, e.g, mg or W for weight etc.

*Note: 'centripetal force' is not a correct label for the reaction force. Award **[2]** for correct forces with no labels.*

(c) **(i)** friction, $F = mg = 800$ N;

$R = \frac{F}{\mu}$ ***OR*** $R = \frac{800}{0.4} = 2000$ N (2)

(ii) attempted use of $\frac{mv^2}{r}$ = answer to (c) (i) i.e. 2000

*Award **[0]** for $\frac{mv^2}{r} = 800$ or equivalent.*

Note: *Watch for ECF.*

Recall of $F = \frac{mv^2}{r}$ not sufficient without link to (c) (i).

$v^2 = \frac{2000 \times 6.0}{80} = 150$; to give correct answer:

$v = 12.247 \approx 12\ \text{m s}^{-1}$ (2)

Accept calculation of angular velocity = 2.0 radians s^{-1}.

3 **(a)** 31.6 kN (3)

(b) On sliding, $\mu_d F_N = 100 \sin 18.4°$ kN

Components perpendicular to slope:

$F_N = 100 \cos 18.4°$ kN

$\mu_d F_N \times 100 \cos 18.4° = 100 \sin 18.4°$

$\mu_d = \frac{100 \sin 18.4°}{100 \cos 18.4°} = \tan 18.4° \Rightarrow \mu_d = 0.33$ (3)

(c) **(i)** $1.26\ \text{m s}^{-2}$ (2)

(ii) $48.9\ \text{m s}^{-1}$ (2)

(d) **(i)** 20 kN (1)

(ii) 597.8 m (2)

4 **(a)** **(i)** 600 N (1)

(ii) 8 kg (2)

(iii) 300 N (2)

(b) If the rope jerks, the acceleration would be large. This means the tension would increase and, in turn, that the horizontal component of tension would increase. A greater frictional force would be needed to remain stationary. (2)

5 **(a)** **(i)** $4.5\ \text{m s}^{-1}$ (1)

(ii) $4.5\ \text{m s}^{-1}$ (1)

(iii) 31.8 N (3)

(b) **(i)** The horizontal component of velocity changes, so there is an unbalanced force on the sand. According to Newton's third law, an equal and opposite force is exerted on the truck. In turn, there must be a frictional force opposing this in order for the truck to remain stationary. (3)

(ii) 22.5 N (2)

6 C (1)

7 D (1)

8 D (1)

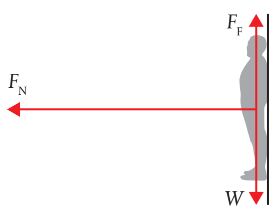
9 **(a)** 0 N (1)

(b) The blades exert a downward force on the air. The air exerts an equal and opposite force on the blades to form a Newton's third law pair. (2)

(c) $8.1\ \text{m s}^{-1}$ (3)

(d) $4.6\ \text{m s}^{-2}$ (2)

10 **(a)** (2)



(b) Horizontally, $F_N = mR\omega^2$. Vertically, $F_f = mg$

$F_f = \mu F_N = \mu mR\omega^2$

$\mu mR\omega^2 = mg$

$\omega = \sqrt{\frac{g}{\mu R}}$ (2)

(c) Using (b), the minimum required angular velocity $= \sqrt{\dfrac{9.81}{0.4 \times 3.5}} = 2.6\ \text{rad s}^{-1}$

The actual angular velocity $= 2\pi f = 2\pi \times \dfrac{28}{60} = 2.9\ \text{rad s}^{-1}$

The actual angular velocity is greater than the minimum, so the person does not slide. (3)

11 C (1)

12 D (1)

13 **(a)** $v = \sqrt{2\dfrac{(m_2 - m_1)g}{m_2 + m_1}h}$ (2)

(b) $s = \dfrac{2\dfrac{(m_2 - m_1)g}{m_2 + m_1}h}{2g} = \dfrac{(m_2 - m_1)}{m_2 + m_1}h$ (2)

A.3

Exercises

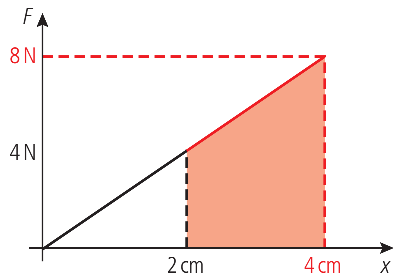
1 **(a)** −1300 J **(b)** dog

2 0 J

3 −300 J

4 **(a)** 2 cm **(b)** 4 N

(c)



(d) 4 J **(e)** 12 J

5 1950 J

6 $32\ \text{m s}^{-1}$

7 **(a)** 12.5 J **(b)** 12.5 J

(c) 1 cm

8 **(a)** 0.75 J **(b)** 0.75 m

9 **(a)** 0.2 m **(b)** 0.8 m

10 **(a)** 1.96 kJ **(b)** 4.36 kJ

11 **(a)** 3.86×10^5 J **(b)** 6.43×10^5 J

(c) 1.8×10^{-2} J

12 **(a)** 1.25×10^{-4} J **(b)** 6.25×10^{-5} J

(c) $0.1\ \text{m s}^{-1}$

13 **(a)** $-10.83\ \text{m s}^{-1}$ **(b)** 521.3 J

14 velocities swap

15 800 W

16 1000 W

17 20 kW

18 50%

19 42 kJ

20 **(a)** 6.67 kW **(b)** 11.1 kW

Challenge yourself

1 $1.7\ \text{m s}^{-1}$

Practice questions

1 **(a)** **(i)** 440 N s (2)

(ii) −440 N s (1)

(iii) 1740 J (1)

(b) To reach the other side, the initial kinetic energy must be equal to or greater than the change in potential energy. $\Delta E_p = mg\Delta h$
$= 180 \times 10 \times 1 = 1800$ J
The kinetic energy is slightly less than this, so the competitor will not reach the far end of the wire. (2)

2 **(a)** **(i)** 320 J (1)

(ii) 137 J (1)

(iii) The masses also gain kinetic energy and, due to conservation of energy, this subtracts from the total energy input.

(b) 34% (2)

3 **(a)** $14\ \text{m s}^{-1}$ (2)

(b) $2.3\ \text{m s}^{-1}$ (2)

(c) $794\ \text{N m}^{-1}$ (2)

4 B (1)

5 A (1)

6 C (1)

7 C (1)

8 D (1)

9 D (1)

10 C (1)

11 **(a)** Using conservation of energy, $\dfrac{\frac{1}{2}mv^2}{mgh} = 0.24$

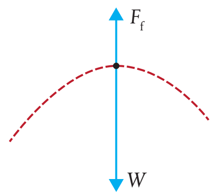
$v = 11.9\ \text{m s}^{-1}$ (2)

Award GPE lost = 65 × 9.81 × 30 = 19 130 J

Must see the 11.9 value for MP2, not simply 12.

Allow $g = 9.8\ \text{ms}^{-2}$.

(b) (2)



arrow vertically downwards from dot labeled weight/W/mg/gravitational force/F_g **AND** arrow vertically upwards from dot labeled reaction force/R/normal contact force/N/F_N;

$W > R$ (2)

Do not allow gravity.
Do not award MP1 if additional 'centripetal' force arrow is added.
Arrows must connect to dot.
Ignore any horizontal arrow labeled friction.
Judge by eye for MP2. Arrows do not have to be correctly labeled or connect to dot for MP2

(c) For the skier to remain in contact with the circular slope, a centripetal force is required (*allow centripetal acceleration*).

$\frac{mv^2}{r} = \frac{65 \times 12^2}{20} = 468$ N

The centripetal force is weight − normal reaction force. Since the weight is larger than the centripetal force, he skier does not lose contact with the ground. (3)

*There are several alternative ways of reaching the conclusion, but do **not** award a mark for the bald statement that the skier does not lose contact with the ground.*

(d) 0.14 (3)

(e) 730 N s (2)

(f) The change in momentum is the same with or without a flexible net, because the skier goes from having a speed to having zero speed. The net increases the stopping *time*.

Since $F = \frac{\Delta p}{\Delta t}$, F is smaller, which means that the body experiences less force (and harm). (2)

12 (a) (i) Using conservation of energy between the compressed spring and the top of the ramp,

$E_{p,\,elastic} = \frac{1}{2}mv^2 + mgh$

$E_{p,\,elastic} = \frac{1}{2} \times 55 \times 0.90^2 + 55 \times 9.81 \times 1.2$

$= 669$ J (2)

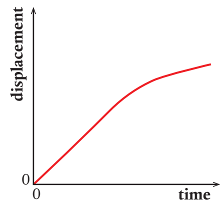
Award **[1 max.]** *for use of $g = 10$ N kg^{-1}, gives 682 J.*

(ii) 4.9 m s^{-1} (2)

(b) (i) no force/friction on the block, hence constant motion/velocity/speed. (1)

(ii) force acts on block **OR** gravity/component of weight pulls down slope;
velocity/speed decreases **OR** it is slowing down **OR** it decelerates (2)

(c) straight line through origin for at least one-third of the total length of time axis;
followed by curve with decreasing positive gradient (2)



(d) 640 N (2)

(e) 0.55 **OR** 0.547 **OR** 55% **OR** 54.7% (2)

13 (a) C (1)

(b) Although equal and opposite forces act between the car and the magnet, they are connected and cancel. Alternatively, no overall work is done and therefore no kinetic energy is produced. (1)

14 (a) $\frac{2}{3}$ (2)

(b) 89% (2)

(c) 10 (2)

A.4

Exercises

1 300 g

2 0.2 m

3 (a) 10 000 N
(b) 267 N
(c) 3000 N

4 210 N at one end and 690 N at the other end

5 0.1 m

6 (a) 509 N
(b) 360 N
(c) 240 N

7 (a) 933 N
(b) 660 N
(c) −60 N

8 75 N

9 0.375

10 (a) 16 rad s^{-1}
(b) 8.75 revolutions

11 (**a**) $-25\pi = -78.54$ rad s^{-2}
(**b**) 0.4 s

12 (**a**) 0.4 rad s^{-2}
(**b**) 1 m s^{-2}

13 (**a**) $0.5\pi = 1.57$ rad s^{-1}
(**b**) child at 2 m: $\pi = 3.14$ m s^{-1};
child at 0.5 m: $0.25\pi = 0.79$ m s^{-1}
(**c**) child at 2 m: 98.7 N, child at 0.5 m: 24.7 N

14 32 rad s^{-2}

15 7.85 N

16 15 rad s^{-2}

17 15 rad s^{-2}

18 (**a**) 500 rad s^{-2}
(**b**) 7.96 revolutions
(**c**) 224 rad s^{-1}

19 (**a**) -0.1 N m (anticlockwise)
(**b**) -250 rad s^{-2}
(**c**) 2.51 s

20 (**a**) 500 N m
(**b**) 3 rad s^{-2}

21 (**a**) 79 J
(**b**) 316 J
(**c**) 0.012 J

22 8 J

23 $v = \sqrt{\frac{6gh}{5}}$
the solid ball takes less time

24 (**a**) 0.25 J
(**b**) 0.85 m s^{-1}
(**c**) 0.29 m
(**d**) 0.68 s

25 3.14×10^{-2} kg m^2 s^{-1}

26 0.157 kg m^2 s^{-1}

27 (**a**) 4.675 kg m^2
(**b**) 0.925 kg m^2
(**c**) 5.1 revolution s^{-1}
(**d**) before: 92.3 J; after: 475 J
(**e**) work done pulling her arms in

28 (**a**) 1.125×10^{-2} kg m^2
(**b**) 1.225×10^{-2} kg m^2
(**c**) $0.92\pi = 2.9$ rad s^{-1}

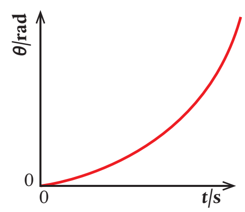
29 (**a**) 0.5 kg m^2 s^{-1}
(**b**) 5 m s^{-1}

Practice questions

1 (**a**) 245 kg m^2 (3)
(**b**) (**i**) 300 N m (1)
(**ii**) 2000 J (1)
(**iii**) 2000 J (1)
(**iv**) 4.0 rad s^{-1} (1)
(**v**) 980 kg m^2 s^{-1} (1)
(**c**) (**i**) the child accelerates, which means there is an unbalanced force; this is supplied by the roundabout; according to Newton's third law, the child exerts an equal and opposite force on the roundabout, so the roundabout slows down (3)
An answer in terms of energy is also acceptable, e.g. the child gains rotational kinetic energy, which subtracts from the roundabout's rotational kinetic energy due to conservation of energy.
(**ii**) 2.4 s^{-1} (2)
(**iii**) 461 N (2)
(**d**) (**i**) 0.98 rad s^{-2} (2)
(**ii**) invalid because angular acceleration is not constant; the answer obtained for time would be lower than in reality (2)

2 (**a**) 10 N (2)
(**b**) (**i**) There must be a horizontal frictional force at the bottom. (2)
(**ii**) 15 N. (3)

3 (**a**) Using $\omega_f^2 = \omega_i^2 + 2\alpha\Delta\theta$,
$\omega_f^2 = 0 + 2 \times 0.110 \times 6 \times 2\pi$
$\omega_f = 2.88$ rad s^{-1} (2)
At least 3 s.f.
Other methods are possible.
Answer 3 given so look for correct working.
(**b**)



concave up from origin (1)
(**c**) 2.38×10^{-3} N m (1)
(**d**) 130 s (2)
Various methods are possible.
Award **[2]** *marks for a bald correct answer.*

4 (**a**) the person rotates anticlockwise;
this is because of conservation of angular momentum; in order for the wheel to rotate clockwise, the person's angular momentum must be opposite to this (3)

(b) the rotational kinetic energy has increased; because the person has done work when flipping the wheel (2)

5 Using conservation of rotational and linear energy:

$mgh = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$

Now, $I = \frac{2}{5}mr^2$ **and** $\omega = \frac{v}{r}$

Correct manipulation to show that $v^2 = \frac{10gh}{7}$ (3)

6 **(a)** A torque requires a force and for there to be a distance between the force and the axis of rotation. (1)

(b) **(i)** Considering translational motion and components along the slope:

$Mg \sin\theta - F = Ma$

Considering rotational motion:

$F_f R = I\alpha$

Substituting $F_f = \frac{I\alpha}{R}$ gives $Mg \sin\theta = Ma + \frac{I\alpha}{R}$

Using $I = \frac{1}{2}MR^2$ and $\alpha = \frac{a}{R}$,

$Mg \sin\theta = Ma + \frac{\frac{1}{2}MR^2\frac{a}{R}}{R}$

$g \sin\theta = a + \frac{1}{2}a = \frac{3}{2}a$

$a = \frac{2}{3}g \sin\theta$ (4)

(ii) 0.96 s (2)

(c) The ice slides whereas the cylinder rotates. In terms of energies, the cylinder's potential becomes both kinetic and rotational kinetic. In terms of accelerations, the cylinder's is always less than that of the ice. Through either consideration we can see that the speed of the cylinder will be less at any given point. (1)

Allow answers in terms of energies, e.g. ice does not use energy to rotate and therefore will have a greater translational speed.

(d) the hollow cylinder has a greater moment of inertia; so the acceleration will be smaller for the same torque (2)

7 **(a)** B (1)

(b) The road exerts a forward force on the tires. The line of action of the force is along the roadway, which means the torque sees the front of the car rotate upward. (1)

8 **(a)** D (1)

(b) Linear momentum is always changing because the speed of the swing is always changing. Angular momentum is always changing because the angular speed of the swing is always changing.(1)

A.5

Exercises

1 **(a)** 8.5 m s^{-1}

(b) 10 m

(c) 170 m

2 **(a)** 1.34

(b) $t' = -2.44 \times 10^{-7}$ s, $x' = 123.4$ m

3 event 1 at 6.68×10^{-6} s, event 2 at 6.22×10^{-6} s

4 2.8 s

5 213 s

6 **(a)** rocket observer uses same clock so measures proper time = 2 years

(b) 3.3 years

7 1.43 m

8 **(a)** 5.94 m

(b) 1.42×10^{-7} s

(c) 42.2 m

(d) proper time is measured by nucleus frame of reference

(e) proper length measured by Earth observer

9 **(a)** 6.25 hours

(b) 3 light hours

(c) 3.75 hours

10 $-0.99\,c$

11 $0.85\,c$

12 $0.96\,c$

13 -9.86×10^3 m, -9.87×10^3 m

14 from graph: $t' = 5$ years, $x' = 1$ light year

from Lorentz transformation: $t' = 5.2$ years,

$x' = 0.86$ light years

$S = -26.3$ ly^2

$S' = -24$ ly^2

15 Both graph and Lorentz transformations agree, to give:

$t = 4$ years, $x = 6.3$ light years

$S = -23.7$ ly^2

$S' = -24$ ly^2

16 4 years

17 2.6 light years

18 7 years

19 Depart 2003, arrive 2000; if $2c$ then simultaneous, can't calculate y if $v > c$

Practice questions

1 (**a**) *proper time:* the time interval measured by an observer of an event that happens at the same place according to that observer;
proper length: the length of an object as measured by an observer who is at rest relative to the object (2)
Do not look for precise wording but look for the understanding of the quantities in the sense of the words.

(**b**) (**i**) no they will not appear to be simultaneous;
Look for a discussion along the following lines.
Carmen sees Miguel move away from the signal from A and since Miguel receives the two signals at the same time; and since the speed of light is independent of the motion of the source;
Carmen will see the light from A first / light from B will reach Carmen after light from A / OWTTE (4)

(**ii**) $\gamma = 2$; to give $u = 0.87\,c$ (2.6×10^8 m s^{-1}) (2)

(**iii**) both measure the correct distance; SR states that there is no preferred reference system / laws of physics are the same for all inertial observers / OWTTE (2)

2 (**a**) frame moving with constant velocity / frame in which Newton's first law is valid (1)

(**b**) $T_0 = \frac{2D}{c}$ (1)

(**c**) (**i**) light reflected off mirror when midway between F and R (1)

(**ii**) $F - R = vT$ (1)

(**iii**) $\left(\frac{1}{2}L\right)^2 = D^2 + \left(\frac{1}{2}vT\right)^2$

$L = 2\sqrt{\left(D^2 + \left(\frac{1}{2}vT\right)^2\right)}$ (2)

(**iv**) $T_0 = \dfrac{2\sqrt{\left(D^2 + \left(\frac{1}{2}vT\right)^2\right)}}{c}$;

$c^2T_0^2 = 4\left(D^2 + \left(\frac{1}{2}vT\right)^2\right)$;

use od $4D^2 = c^2T_0^2$;

hence $T = \dfrac{T_0}{\sqrt{\left(1 - \frac{v^2}{c^2}\right)}}$ (4)

3 (**a**) the speed of light in a vacuum is the same for all inertial observers; the laws of physics are the same in all inertial frames of reference (2)

(**b**) (**i**) this faster than light speed is not the speed of any physical object / inertial observer and so is not in violation of the theory of SR (1)

(**ii**) $u' = \dfrac{u - v}{1 = \frac{uv}{c^2}}$ with $v = -0.80c$ and $u = 0.80c$

so that $u' = \dfrac{0.80c + 0.80c}{1 + \frac{0.80c \times 0.80c}{c^2}}$;

$u' = \dfrac{1.60c}{1.64} = 0.98c$ (3)

4 (**a**) (**i**) The ct' axis is the same as a body traveling at the same velocity as the observer.
$\tan\theta = \frac{v}{c} = 0.5$
$v = 0.5c$ (2)

(**ii**) 1.16 (2)

(**iii**) $t = 4$ s and $x = 3$ light seconds (1)

(**iv**) $t' = 3$ s and $x' = 1$ light second (1)

(**v**) $x' = \gamma(x - vt) = 1.16(3c - 0.5c \times 4)$
$= 1.16$ light seconds ≈ 1 light second
$t' = \gamma\left(t - \frac{vx}{c^2}\right) = 1.16\left(4 - \frac{0.5c \times 3c}{c^2}\right)$
$= 2.9$ s ≈ 3 s (2)

(**b**) (**i**) $4c$ (1)

(**ii**) It would arrive before it left (2)

(**c**) (**i**) 4 s (1)

(**ii**) 4.6 s (1)

(**iii**) 4 s because the start and end are measured by same clock on spaceship. (1)

(**iv**) Time intervals are longer;
when measured by observers moving relative to events. (2)

5 It is possible to respond to this question in terms of time or distance.

Earth frame **transit time** $= \frac{2000}{0.98c} = 6.8$ μs

Earth frame dilation of proper half-life
$= 2.2 \times 5 = 11$ μs

Muon's proper transit time $= \frac{6.8}{5} = 1.4$ μs

Distance muons can travel in a proper lifetime
$= 2.2 \times 0.98c = 650$ m

Earth frame lifetime distance due to time dilation
$= 650 \times 5 = 3250$ m

Muon frame distance traveled $= \frac{2000}{5} = 400$ m (3)

*Accept answers from **one** of the alternatives.*

6 E (1)

7 the person will experience their own mass as though it is normal, irrespective of their speed; they can increase their speed as much as they want, but the resulting speed is not the sum of the additions (2)

8 (**a**) D (1)

(**b**) It depends on your frame of reference (with the pipe, with the spear, or halfway between the two speeds). (2)

B.1

Exercises

1 (a) 3.92×10^3 J (b) 3.92×10^3 J

2 1.8×10^6 J

3 3.7×10^4 J

4 67.6 J, 13.5 N

5 10 °C

6 (a) 6×10^{-21} J (b) 4.8×10^{-26} kg
(c) 500 m s^{-1}

7 (a) 5.8×10^{-6} m
(b) 3.54×10^3 W m^{-2}
(c) 18 W
(d) 1.4 W m^{-2}

8 420 kJ

9 (a) 3.6×10^6 J (b) 3.6×10^5 J $°C^{-1}$
(c) Some heat is lost to the outside.

10 1.33×10^4 J

11 (a) 1 kg (b) 3.36×10^5 J
(c) 336 s

12 (a) 3×10^5 J (b) 686.7 °C

13 (a) 3×10^5 J (b) 2.25×10^5 J
(c) 51 °C

14 (a) 80 kg (b) 1.34×10^7 J

15 3.35×10^{11} J

16 1.135×10^3 s

17 (a) 1.84×10^4 kg (b) 6.16×10^9 J
(c) 3.42×10^5 W (d) 342 W m^{-2}

Practice questions

1 (a) (i) work is done against friction; which means that energy is transferred to the atoms in the bar; temperature is linked to the average kinetic energy of the atoms (3)
(ii) 0.063 kg (2)
(iii) 8.7 N (3)
(b) (i) 31 s (2)
(ii) 1000 J (1)
(c) (i) convection currents carry hot, less dense fluid upwards; if the element were at the top, only very small currents at the top could form;
the boiler does not need to be filled to the top because water will leave from near the bottom (2)
(ii) If no water is present then the heat loss from the element will be reduced.
The element will reach a higher temperature. (2)

2 (a) 2773 K (4 s.f.) (2)
(b) conduction and convection require particles; radiation is the only mechanism of heat loss in a vacuum (2)
(c) 1.4×10^{-4} m (3)

3 (a) (165, 0) (1)
(b) *Look for these points:*
to change phase, the separation of the molecules must increase;
Some recognition that the ice is changing phase is needed.
so all the energy input goes to increasing the E_p of the molecules;
Accept something like 'breaking the molecular bonds'.
E_k of the molecules remains constant, hence temperature remains constant (3)
If E_k mentioned but not temperature then assume students know that temperature is a measure of E_k.
(c) (i) time for water to go from 0 to 15°C = 30 s;
energy required = $mc\Delta\theta = 0.25 \times 15 \times 4\,200 =$ 15 750 J;
power $= \frac{\text{energy}}{\text{time}} = 525$ W ≈ 530 W (3)
(ii) ice takes 15 s to go from −15°C to 0;
energy supplied = 15 × 530 J;
specific heat $= \frac{(530 \times 15)}{(15 \times 0.25)} = 2100$ J kg^{-1} K^{-1} (3)
(iii) time to melt ice = 150 s;
$L = \frac{(150 \times 530)}{0.25} = 320$ kJ kg^{-1} (2)

4 (a) *[1] for each appropriate and valid point e.g.* thermal energy is the E_k of the component particles of an object; thus measured in joules; the temperature of an object is a measure of how hot something is (it can be used to work out the direction of the natural flow of thermal energy between two objects in thermal contact) / measure of the average E_k of molecules; it is measured on a defined scale (Celsius, kelvin, etc.) (4)
(b) (i) correct substitution: energy = power × time;
= 1200 W × (30 × 60) s;
= 2.2×10^6 J (2)
(ii) use of $Q = mc\Delta\theta$;
to get $\Delta\theta = \frac{2.2 \times 10^6}{(4200 \times 70)} = 7.5$ K (3)
(c) *[1] naming each process up to [3].*
convection; conduction; radiation;
[1] for an appropriate (matching) piece of information / outline for each process up to [3].

e.g. convection is the transfer of thermal energy via bulk movement of a gas due to a change of density; conduction is transfer of thermal energy a intermolecular collisions; radiation is the transfer of thermal energy via electromagnetic waves; (IR part of the electromagnetic spectrum in this situation) / *OWTTE* (6)

(d) **(i)** *[1] for each valid and relevant point e.g.* in evaporation the faster moving molecules escape; this means the average E_k of the sample left has fallen; a fall in average E_k is the same as a fall in temperature (3)

(ii) energy lost by evaporation
$= 50\% \times 2.2 \times 10^6$ J;
$= 1.1 \times 10^6$ J;
correct substitution into $E = ml$
to give mass lost $= \dfrac{1.1 \times 10^6\,\text{J}}{2.26 \times 10^6\,\text{J kg}^{-1}}$
$= 0.487$ kg $= 487$ g (3)

(iii) *[1] for any valid and relevant factors up to [2] e.g.* area of skin exposed; presence or absence of wind; temperature of air; humidity of air etc.;
[1] for appropriate and matching explanations up to [2] e.g. increased area means greater total evaporation rate; presence of wind means greater total evaporation rate; evaporation rate depends on temperature difference; increased humidity decreases total evaporation rate (4)

5 D (1)

6 A (1)

7 A (1)

8 B (1)

9 **(a)** Substitution of $L = \sigma A T^4$ into $b = \dfrac{L}{4\pi d^2}$
$b = \dfrac{\sigma A T^4}{4\pi d^2}$ and σ and 4π are constants. (1)

(b) Sirius is a star and is therefore luminous. Venus is a planet; it is bright in the night sky because it reflects the Sun's light. (2)

10 D (1)

11 Cu/Al junction: 17.9°C; Fe/Cu junction: 28.6°C. (5)

B.2

Exercises

1 **(a)** 531 W m^{-2}
(b) 31 W m^{-2}
(c) 0.31
(d) 531 W m^{-2}
(e) 10.3%

Challenge yourself

1 $T = 276$ K

Practice questions

1 **(a)** (natural process of) production takes thousands / millions of years; fossil fuels used much faster than being produced / *OWTTE* (2)

(b) Any two sensible suggestions e.g. storage of radioactive waste; increased cost; risk of radioactive contamination etc. (2)
To achieve full marks the differences must be distinct.

2 **(a)** solar panel: solar energy → thermal energy (heat); solar cell: solar energy → electrical energy; (2)

(b) **(i)** input power required = 720 W (± 5 W);
area $= \dfrac{720}{800} = 0.90$ m^2; (2)

(ii) power extracted ≈ 150 W (± 20 W);
efficiency $= \dfrac{\text{power out}}{\text{power in}}$ ***OR*** $\dfrac{150}{500} = 30\%$; *(allow ECF)* (3)

3 **(a)** the solar radiation is captured by a disk of area πR^2 where R is the radius of the Earth; but is distributed (when averaged) over the entire Earth's surface, which has an area four times as large; (2)
Award **[1]** *for reference to absorption/reflection.*

(b) **(i)** 0.700; (1)

(ii) $I(= e\sigma T_A^{\,4})$;
$= 0.700 \times 5.67 \times 10^{-8} \times 242^4 = 136$ W m^{-2} (1)

(iii) $\sigma T_E^{\,4} = 136 + 245$ W m^{-2}
hence $T_E = \left(= \sqrt[4]{\dfrac{381}{5.67 \times 10^{-8}}}\right) = 286$ K (2)

(c) **(i)** the Earth emits radiation in the infrared region of the spectrum; the greenhouse gases have energy level differences (in their molecular energy levels) corresponding to infrared energies; and so the infrared photons are absorbed
OR
the Earth radiates photons of infrared frequency; the greenhouse gas molecules oscillate / vibrate with frequencies in the infrared region; and so because of resonance the photons are absorbed (3)

(ii) most incoming radiation consists of photons in the visible / ultraviolet region / photons of much shorter wavelength than those radiated by the Earth / photons of different wavelength from that radiated by Earth; and so these cannot be absorbed (2)

(iii) *Source*: emissions from volcanoes / burning of fossil fuels in power plants / cars / breathing;
Sink: oceans / rivers / lakes / seas / trees (2)

4 (a) energy emitted per unit time / power per unit area; proportional to [absolute temperature / temperature in K]^4 (2)
Must define symbols if used.
(b) (i) power
$= 5.67 \times 10^{-8} \times 4\pi \times [7.0 \times 10^8]^2 \times 5800^4$;
$\approx 4.0 \times 10^{26}$ W (1)
(ii) $\frac{\text{incident energy}}{\text{area}} = \frac{3.96 \times 10^{26}}{4\pi[1.5 \times 10^{11}]^2}$;
$= 1400 \text{ W m}^{-2}$ (2)
(iii) two of:
(albedo of Earth means) some radiation is reflected; Earth's surface is not always normal to incident radiation; some energy lost as radiation travels to Earth (2)
(iv) power absorbed = power radiated; uses
$5.67 \times 10^{-8} \times 255^4 = 240$ / evaluates $\sqrt[4]{\frac{240}{\sigma}}$ (2)
(c) radiation from the Sun is re-emitted at longer wavelengths; (longer radiation) wavelengths are absorbed by greenhouse gases; some radiation re-emitted back to Earth (3)
(d) more CO_2 / named greenhouse gas released into atmosphere; enhanced greenhouse effect; because more reradiation of energy toward surface (3)

5 (a) (i) the black pattern will be a better radiator; because the emissivity is higher (2)
(ii) black surface (1)
(iii) white surface (1)
(b) white roofs would reflect more radiation; the temperature of the Earth would not have to be so great; to achieve equilibrium with power in equal to power out (3)
(c) (i) all infrared radiation is already absorbed on entry; which means increased proportions of greenhouse gases could not absorb and re-emit any more (2)
(ii) there is no UV filter; UV radiation is harmful to DNA (2)
(iii) clouds reflect some wavelengths of radiation; which increases the albedo (2)

6 (a) (i) 228 W (2)
(ii) 4.5 W m^{-2} (2)
(b) (i) 0.14 J (2)
(ii) all radiation is absorbed; the sensor area is perpendicular to the radius (2)

7 A (1)
8 B (1)
9 C (1)
10 D (1)
11 D (1)
12 A (1)
13 D (1)

B.3

Exercises

1 (a) 7.12×10^{-6} m^3
(b) 6.022×10^{23} atoms
(c) 1.2×10^{-29} m^3
2 27 g
3 292 kPa
4 (a) 6 kPa (b) 3 kPa
5 312.5 cm^3
6 400 kPa
7 9.4 kJ
8 8.28×10^{-21} J

Challenge yourself

1 $P = 114.3$ kPa

2 We know that pressure, $P = \frac{1}{3}\rho \overline{v^2}$ and the ideal gas law states $PV = NkT$.
Substituting pressure into the ideal gas law gives $\frac{1}{3}\rho \overline{v^2} V = NkT$. Since the mass of all molecules is ρV, the mass of one molecule, $m = \frac{\rho V}{N}$, so $\overline{\frac{1}{3}m v^2} = kT$

Making kinetic energy the subject of the equation:

$$\overline{E_k} = \overline{\frac{1}{2}m v^2} = \frac{3}{2}kT$$

Practice questions

1 (a) (i) 0.83 m^3 (2)
(ii) 1.06 m^3; $\rho = \frac{m}{V} = \frac{1}{1.566} = 0.95 \text{ kg m}^{-3}$ (3)
(iii) 2380 kg (1)
(iv) 3030 kg (1)
(v) Upthrust (30 300 N) > weight (23 800 N) so the balloon will rise. (2)
(b) (i) 570 m s^{-1} (2)
(ii) 7.96×10^4 moles (2)
(iii) 3.45×10^8 J (2)

2 **(a)** **(i)** random motion; no gravitational effect; no forces of attraction between molecules/atoms; time of collision much less than time between collisions; Newton's laws apply (2)

(ii) potential energy not used/irrelevant; (because) there are no forces between molecules in an ideal gas; gas speeds vary so need to take an average (3)

(b) **(i)** $n = \frac{PV}{RT}$; = 0.18 mol (2)

*Award **[2]** for bald correct answer.*

(ii) show use of PV = constant; 1.9×10^6 Pa (2)

*Award **[2]** for bald correct answer.*

(iii) pressure = $\frac{420 \times 19 \times 10^5}{290}$

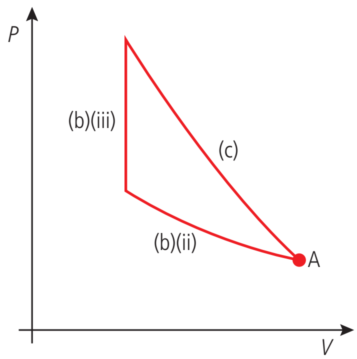
= 2.8×10^6 Pa (1)

OR

pressure = $\left(\frac{nRT}{V} =\right) \frac{0.18 \times 8.31 \times 420}{2.3 \times 10^{-4}}$

= 2.8×10^6 Pa

(c)



smooth curve, curving correct way for (b) (ii); vertical straight line for (b) (iii); smooth curve, steeper than (b) (ii) for (c) (3)

Labeled curves are not needed as such but direction must be clear.

3 **(a)** in order to keep the temperature constant ***OR*** in order to allow the system to reach thermal equilibrium with the surroundings. (1)

Accept answers in terms of pressure or volume changes only if clearly related to reaching thermal equilibrium with the surroundings.

(b) 0.5 Pa m (3)

recognizes b as gradient; calculates b in range 4.7×10^4 to 5.3×10^4

*Award **[2 max]** if POT error in b.*
Allow any correct SI unit, e.g. kg s^{-2}

(c) $V \propto H$ so $p \propto \frac{1}{H}$.

so graph should be a straight line through origin, as observed (2)

(d) 0.03 (2)

Answer must be to 1 or 2 s.f.

(e) Very large $\frac{1}{H}$ means very small volumes / very high pressures; at very small volumes the ideal gas law does not apply (2)

4 A (1)

5 D (1)

6 B (1)

7 B (1)

8 B (1)

9 C (1)

10 B (1)

11 **(a)** 48 kPa (1)

(b) 0.012 kg (1)

(c) 6.5×10^{-21} J (1)

(d) larger temperature implies larger (average) speed/larger (average) kinetic energy of molecules/particles/atoms;

increased force/momentum transferred to walls (per collision) / more frequent collisions with walls;

increased force leads to increased pressure because $P=F/A$ (as area remains constant) (3)

Ignore any mention of $PV = nRT$.

B.4

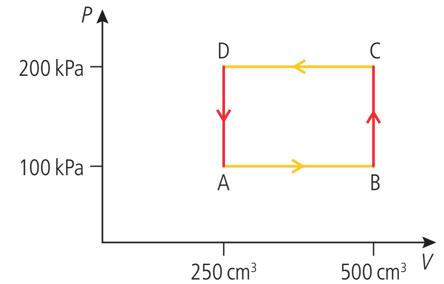
Exercises

1 **(a)** 700 K
(b) 350 K
(c) 5.25 J
(d) 3.5 J
(e) heat loss = 8.75 J

2 **(a)** 1050 K
(b) 11.6 J
(c) 11.6 J

3 **(a)** $PV^{\frac{5}{3}}$ = constant
(b) 8.3 J
(c) 1040 K
(d) 510 K
(e) −7.95 J
(f) 0.35 J (should be 0 J)

4 (a)



(b) 600 K, 1200 K, 600 K
(c) 25 J
(d) 50 J
(e) –25 J

5 (a) 245 J
(b) 50 J
(c) 320 J
(d) 135 J
(e) 185 J

6 (a) 525 K
(b) 360 K
(c) 0.31
(d) 1.4 J
(e) 4.8 J
(f) 0.29

7 (a) (i) $-1.25\ \mathrm{J\,K^{-1}}$
(ii) $2\ \mathrm{J\,K^{-1}}$
(b) $0.75\ \mathrm{J\,K^{-1}}$

8 otherwise entropy would be reduced

Practice questions

1 (a) as depth increases, pressure increases;
volume and pressure are inversely proportional for an ideal gas; (2)

(b) The pressure at depth is equal to the sum of atmospheric pressure and the pressure difference:

$p = A + \rho g h$

$V = \frac{nRT}{p} = \frac{nRT}{\rho g h + A}$

$h = \frac{nRT}{V\rho g} - \frac{VA}{V\rho g} = \frac{nRT}{\rho g V} - \frac{A}{\rho g}$ (3)

(c) some attempt made to compare the equation to

$y = mx + c$;

h is linearly related to $\frac{1}{V}$ (2)

(d) $\pm 0.0008 \approx \pm 0.001\ \mathrm{cm^{-3}}$ (2)

(e) Temperature (1)

(f) h values are measured too small; which means the magnitude of the intercept is too large (2)

2 (a) statement (implication) that work done is associated with area within the rectangle;
Do not award mark for just 'area' without reference.
calculation of $2 \times 10^5 \times 8 = 1.6 \times 10^6$ J; (2)

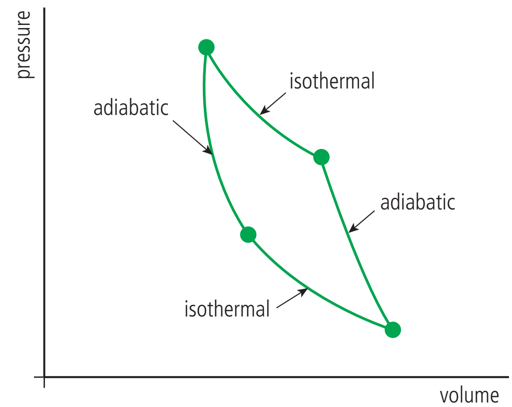
(b) thermal energy from hot reservoir
$= 1.8 \times 10^6 + 1.6 \times 10^6\ \mathrm{J} = 3.4 \times 10^6$ J;

$\text{efficiency} = \frac{\text{work done}}{\text{thermal energy from hot reservoir}}$

$= \frac{1.6 \times 10^6}{3.4 \times 10^6} = 47\%$; (2)

[0] *for* $= \frac{1.6 \times 10^6}{1.8 \times 10^6} = 89\%$

(c) closed cycle of rough approximate shape; quality of diagram (adiabatic 'steeper' than isothermal etc.) (2)



(d) (i) adiabatic (expansion and contraction);
isothermal (expansion and contraction); (2)

(ii) correct 'sense' of adiabatic followed by isothermal etc.; e.g. adiabatic (expansion) then isothermal (contraction) then adiabatic (contraction) then isothermal (expansion) then correct identification of adiabatic as the steeper curve when compared with isothermal (2)

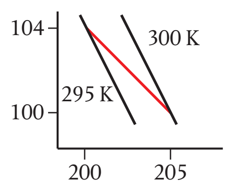
3 (a) adiabatic transformations involve no loss or gain of heat; the expansion is too fast for heat transfer (2)

(b) 0.008 moles (2)

(c) 5 K (2)

(d) 0.52 J (2)

(e) (i) (1)



(ii) The work done is the area under the graph.
Any valid method to calculate the area including the full extent of the pressure
0.5 J (3)

(f) The temperature change is too fast for accurate measurements. (2)

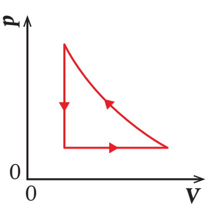
4 (a) (i) on – gas is compressed (1)
Correct answer and correct explanation.
(ii) ejected from – pressure remains constant, volume reduced so temperature must go down (1)
Correct answer and correct explanation.
(b) work done = $p\Delta V = -1.0 \times 10^5 \times 0.4$
$= -0.40 \times 10^5$ J (40 kJ); (2)
*Sign should be consistent with (a) (i) above. Work 'by' and + work would get zero for (a) (i) but **[2]** marks here.*
(c) area enclosed; 0.6 (±0.2) × 10^5 J (60 kJ ± 20 kJ); (2)
(d) efficiency = $\frac{\text{work out}}{\text{heat in}}$;
$= \frac{60}{120} = 50\%(\pm 17\%)$; (2)

5 D (1)

6 A (1)

7 (a) 0.297 **OR** 29.7% (2)
*Award **[1 max.]** if temperatures are not converted to K, giving result 0.430.*
(b) the Carnot efficiency is the maximum possible **OR** the Carnot cycle is theoretical/reversible/impossible/infinitely slow; energy losses to surroundings due to friction/electrical losses/heat losses/sound energy (2)
(c) 1.79×10^{13} J. (3)
Allow solution utilizing wasted power 78.9%
*Award **[2 max.]** if 71% used as the overall efficiency giving an answer of 1.96×10^{12} J.*
Watch for ECF from (a).
(d) Law 1: net thermal energy flow is $Q_{IN} - Q_{OUT}$ in which Q_{OUT} refers to "waste heat";
Law 1: $Q_{IN} - Q_{OUT} = \Delta Q = \Delta W$ as ΔU is zero;
Law 2: does not forbid $Q_{OUT} = 0$;
Law 2: no power plant can convert 100% of Q_{IN} into work;
Law 2: total entropy must increase so some Q must enter surroundings (3)
Max 2 marks if only one law is referred to.

8 (a) 52.6 m^3 **OR** 52.7 m^3 (2)
(b) 62.7×10^3 J (2)
(c) 1.57×10^5 J (3)
(d) (2)



(e) Energy is removed from the gas and so entropy decreases **OR** temperature decreases at constant volume (less disorder) so entropy decreases. (1)
(f) Different paradigms/ways of thinking/modeling/views **OR** allows testing in different ways **OR** laws can be applied different situations. (1)

B.5

Exercises

1 3.7×10^{-4} m

2 10.8 Ω

3 3 kΩ

4 0.3 V

5 0.02 A

6 100 Ω, 100 Ω, 25 Ω

7 1 Ω

8 11.5 V

9 (a) 500 J
(b) 3×10^4 J

10 0.031 W

11 0.5 W

12 (a) 450 kJ
(b) 37.5 kW
(c) 125 A

13 no energy is lost, no heat produced, motor is 100% efficient, no friction / no other losses

14 (a) 0.45 A
(b) 20 J

15 (a) 4.5 A
(b) 1.8×10^7 J

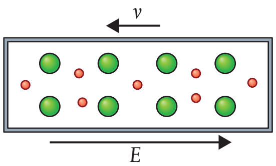
16 (a) $\frac{16}{3}$ Ω
(b) 8 Ω
(c) 28 Ω
(d) $\frac{16}{7}$ Ω

17 0.44 V

18 0.49 V

Practice questions

1 (**a**) (1)



(**b**) (**i**) when electrons collide with the lattice atoms; they lose energy (2)

(**ii**) when electrons collide with the lattice atoms, the lattice atoms gain kinetic energy; increased kinetic energy means increased temperature (2)

(**iii**) the more the lattice atoms vibrate due to increased kinetic energy, the more the electrons will collide with them;

the resistance increases after being switched on (2)

(**c**) $I = \frac{15q}{t}$

the time taken by the right-most charge carrier to pass through the left is $\frac{L}{v}$

substituting $I = \frac{15q}{\frac{L}{v}} = \frac{15vq}{L}$ (3)

2 (**a**) (**i**) 140 Ω (2)

(**ii**) 0.06 A (2)

(**iii**) 0.5 W (2)

(**iv**) 726 K (2)

(**b**) The wire is not a perfect black body. (1)

(**c**) $P = I^2R = 0.06^2 \times 1 = 0.0036$ W

$E = Pt = 0.0036 \times 60 = 0.216$ J

$Q = C\Delta T$ so $\Delta T = \frac{Q}{C} = \frac{0.216}{10} = 0.0022$ K

This increase in temperature is insufficient to damage the cell. (3)

3 A (1)

4 D (1)

5 A (1)

6 B (1)

7 C (1)

8 (**a**) emf is defined as the terminal potential difference when no current flows; in this instance, a current is present and so the potential difference will be less than the emf due to 'lost volts' in the internal resistance; (2)

(**b**) 7.2 Ω (3)

multiple solutions are possible

Award **[3]** *marks for a bald correct answer*

(**c**) 0.12 **OR** 12% (3)

(**d**) energy from Sun/photovoltaic cells is renewable **OR** non-renewable are running out;

non-polluting/clean; no greenhouse gases **OR** does not contribute to global warming/climate change (max. 2)

9 (**a**) time taken $= \frac{2.0 \times 10^4}{7} = 2857 \approx 3000$ s (1)

Must see at least 2 s.f.

(**b**) Electrical energy $= qV = 43 \times 10^3 \times 16$

$= 6.88 \times 10^5$ J

Power $= \frac{E}{t} = \frac{6.88 \times 10^5}{2857} = 241 \approx 240$ W (2)

Must see at least 3 s.f.

(**c**) use of power = force × speed **OR** force × distance = power × time; 34 N (2)

(**d**) 34 N (1)

(**e**) 3.5 m s^{-1} (2)

Award **[0]** *for solutions involving use of kinetic energy.*

Award **[0]** *for* $v = 7$ m s^{-1}.

Award **[2]** *for a bald correct answer.*

(**f**) the maximum distance will decrease;

because opposing/resistive force has increased **OR** because more energy is transferred to gravitational potential energy **OR** because velocity has decreased **OR** increased mass means more work required to move up the hill (2)

(**g**) 0.62 Ω (2)

V dropped across battery **OR** $R_{circuit} = 1.85$ Ω;

For MP1 allow use of internal resistance equations that lead to 16 − 12 = 4 V.

(**h**) 3.2 V (1)

(**i**) 0.25 Ω (2)

10 (**a**) 0.32 m (1)

(**b**) 0.068 A (2)

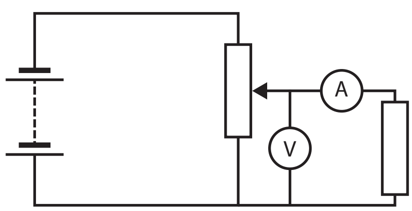
Award **[1]** *for 4.3 A where candidate has not calculated area*

(**c**) Quantities such as resistivity depend on the material **OR** they allow the selection of the correct material **OR** they allow scientists to compare properties of materials. (1)

(**d**) as area is larger and length is smaller; resistance is very much smaller (2)

Award **[1 max.]** *for answers that involve a calculation*

(**e**) complete functional circuit with ammeter in series with resistor and voltmeter across it; potential divider arrangement correct (2)



C.1

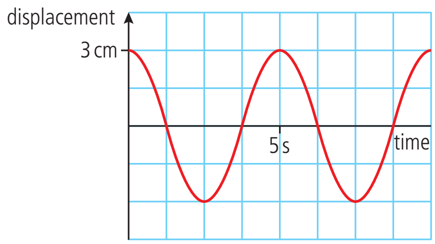
Exercises

1 Only (b) is an example of simple harmonic motion.

2 (a) 1.67 Hz (b) 10.5 rad s^{-1}

3 1.1 cm down

4



5 1.67 s

6 0.5 m s^{-1} downwards

7 (a) 2.5 m s^{-1} (b) 3.16 m s^{-2}

8 0.62 m s^{-1}

9 0.32 m

10 (a) 3π rad s^{-1} (b) 7.1×10^{-3} J
(c) 7.1×10^{-3} J (d) 5.3×10^{-3} J
(e) 1.8×10^{-3} J

Challenge yourself

1 $T = 0.6$ s

Practice questions

1 D (1)

2 A (1)

3 C (1)

4 D (1)

5 B (1)

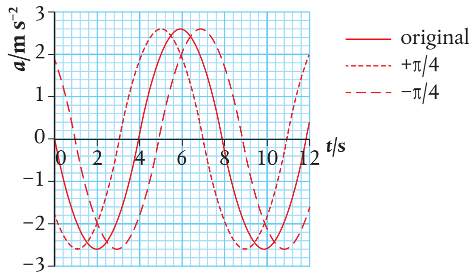
6 B (1)

7 (a) force/acceleration proportional to the displacement/distance from a (fixed/equilibrium) point/mean position;
directed toward this (equilibrium) point / in opposite direction to displacement/ distance;
Allow algebra only if symbols are fully explained. (2)

(b) 0.73 N (1)
allow answer in range of 0.71 to 0.75 N

(c) Use of $a = -\omega^2 x$
$\omega = \frac{2\pi}{T} = \frac{2\pi}{7.9} = 0.795$ or $\frac{\pi}{4}$ rad s^{-1}
$x_0 = 4.1$ m; *(allow answers in the range of 4.0 to 4.25 m)*
two significant figures in final answer whatever the value (4)

(d) shape correct, constant amplitude for new curve, minimum of 10 s shown; *(there must be some consistent lead or lag and no change in T)*
lead/lag of 1 s (to within half a square by eye); (2)



8 (a) acceleration/restoring force is proportional to displacement;
and in the opposite direction/directed toward equilibrium; (2)

(b) 0.38 kg / 0.39 kg (2)
Use of either $\frac{T_1^2}{T_2^2} = \frac{m_1}{m_2}$ **OR** $T = 2\pi\sqrt{\frac{m}{k}}$

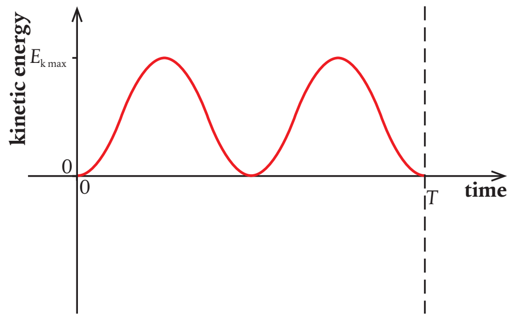
(c) 0.032 J (3)
Allow ECF from (b) and incorrect ω.
Allow answer using k from part (b).

(d) spring constant/k/stiffness would increase;
T would be smaller;
fractional uncertainty in *T* would be greater, so fractional uncertainty of mass of block would be greater; (3)

9 (a) the restoring force/acceleration is proportional to displacement (1)
Allow use of symbols i.e. $F \propto -x$ *or* $a \propto -x$ (1)

(b) 4.43 rad s^{-1}
evidence of equating $m\omega^2 x = \rho A g x$ to obtain
$\frac{\rho A g}{m} = \omega^2$ (2)
Answer to at least 3 s.f.

(c) 71.4 J **OR** 72.4 J (2)
(depending on use of 4.4 or 4.43)

(d) 

energy never negative;
correct shape with two maxima; (2)

10 (a) 1.054 Hz; 0.953 Hz (2)
(b) 0.10 Hz; 10 s (2)

C.2

Exercises

1 280 m s^{-1}

2 (a) 0.2 m (b) inverted
(c) Some of wave is reflected so energy in transmitted wave is less.

3 1.2 m s^{-1}

Challenge yourself

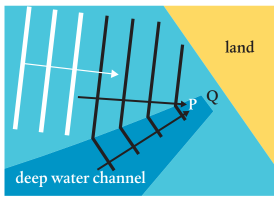
1 Your report on X-rays is likely to include ideas about William Conrad Röntgen in 1895, cathode rays (beams of electrons), a fluorescent detector and the idea of the discovery being by accident. You should also have included the references that you made use of in formulating a response. Connections to TOK include Röntgen's scope of work being related to the scientific concepts of matter, waves and energy, atypical method (i.e. not following a scientific method), typical use of tools (i.e. apparatus for measuring), perspective in the sense of convincing others of his work's significance and verifiability, and ethics in unknowingly making the first published step into understanding ionizing radiation and its uses and risks.
Your report on waves being used in technology to improve society is inherently connected to TOK because technology is one of the themes on which your exhibition can be based – provided that you have connected your response in some way to knowledge. Examples might include:

- radio waves for communications and how this relates to the ownership of knowledge through the editing of radio station content.
- ultrasound for medical imaging and the reasons that we seek knowledge (e.g. about our body).
- gamma waves for sterilisation or radiotherapy, how they are detected alternatively as photons under certain conditions, and constraints on knowledge.

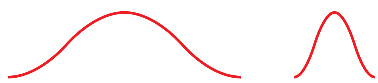
Practice questions

1 (a) longitudinal (1)
(b) (i) wavelength = 0.5 m (1)
(ii) amplitude = 0.5 mm (1)
(iii) correct substitution into speed = frequency × wavelength;
to give $v = 660 \times 0.5 = 330$ m s^{-1}; (2)

2 (a) (1)



(b) The waves from the shallow water and the channel superpose. They interfere constructively. (1)
(c) The wavelength decreases. This is because the speed of the wave decreases but the frequency is constant. (1)
(d)



Energy is conserved, and so all must remain contained within the same, shorter, crest. (1)

3 (a) (i) $v = 0.5 \times 14 = 7$ cm s^{-1} (3)
(ii) $\frac{2\pi}{8}$ **OR** 0.79 rad. (2)
(b) (i) 14 cm (1)
(ii) 0.71 Hz (1)
(iii) 9.9 cm s^{-1} (1)

4 (a) (i) distance traveled per unit time; by the energy of the wave / by a wavefront; (2)
(ii) velocity has direction; but light travels in all directions; (2)
(b) (i) distance in a particular direction; (accept in terms of energy transfer) (of a particle) from its mean position; (2)
(ii) longitudinal: displacement along;
transverse: displacement normal to;
direction of transfer of wave energy / propagation, not motion; (3)
*Award **[0]** for left / right and up / down for longitudinal / transverse.*

(c) (i) $\left(\frac{1200}{125}\right) = 9.6\text{ km s}^{-1}$ (±0.1) (1)

(ii) $\left(\frac{1200}{206}\right) = 5.8\text{ km s}^{-1}$ (±0.1) (1)

Award [1] if the answers to (i) and (ii) are given in reversed order.

(d) (i) P shown as the earlier (in-between) pulse (1)

(ii) laboratory L_3 (1)

(iii) e.g. pulses arrive sooner; smaller S–P interval; larger amplitude of pulses; (3)

Allow any feasible piece of evidence, award [1] for each up to [3].

(iv) distance from L_1 = 1060 km (± 20)
distance from L_2 = 650 km (± 20)
distance from L_3 = 420 km (± 20)
Accept 3 significant figures in all three estimates.
some explanation of working; (4)

(v) position marked, consistent with answers to (iv); to the right of line L_2L_3, closer to L_3 (1)

If the answers given in (iv) mean that the point cannot be plotted, then only allow the mark if the candidate states that the position cannot be plotted / does not make sense.

5 B (1)

6 A (1)

7 C (1)

8 C (1)

9 C (1)

10 C (1)

11 D (1)

12 B (1)

13 D (1)

14 C (1)

15 A (1)

16 (a) a wave where the displacement of particles/oscillations of particles/movement of particles/vibrations of particles is parallel to the direction of energy transfer/wave travel/wave movement.
Do not allow "direction of wave". (1)

(b) (i) 340 m s^{-1} (2)

*Either $v = f\lambda$ **OR** distance traveled ÷ time*

(ii) 213 Hz ($v = f\lambda$) **OR** 210 Hz ($F = \frac{1}{T}$) (2)

(c) (i) the displacement of the particle decreases **OR** on the graph displacement is going in a negative direction **OR** on the graph the particle goes down;
to the left; (2)

Do not allow "moving downwards" unless accompanied by reference to graph.

(ii) molecules to the left of the particle have moved left and those to the right have moved right;
hence the particle is at the center of a rarefaction; (2)

17 (a) (i) $D = 6052$ km (2)

(ii) $T = \frac{D}{\text{speed}} = \frac{6052}{800}$ hours
This is 7 hours 34 minutes. (2)

(b) After arrival of the S wave, the time delay between the P and S waves can be determined and D can be calculated. The time before the arrival of the tsunami (i.e. the warning time) is:
$t_W = \left(\frac{D}{800} - \frac{D}{3.00 \times 60 \times 60}\right)$ hours for D measured in km **OR** $t_W = 1.16 \times 10^{-3} D$ hours. (2)

C.3

Exercises

1 (a) 1.7 Hz (b) 0.24 m
(c) 24°

2 35°

3 (a) $\frac{\pi}{5}$ (b) π
(c) $\frac{3\pi}{2}$

4 29°

5 15°

6 $2 \times 10^8\text{ m s}^{-1}$

7 42°

8 27°

9 (a) 38.8° (b) 51.2°
(c) 41.8° (d) yes
(e) 62.2 μm

10 0.11 m

11 88 μm

12 9 cm

13 6 cm

Practice questions

1 (a) (i) the phase difference between light leaving S_1 and S_2 is constant (1)

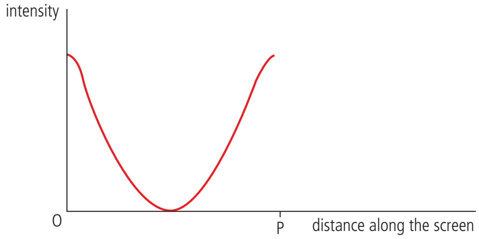
Do not penalize candidates if they state 'has the same phase'.

(ii) to produce sufficient diffraction; for the beams to overlap; *OWTTE* (2)

(b) **(i)** path difference between S_1 and S_2 is an integral number of wavelengths (1)

Accept 'waves arrive at P in phase'.

(ii)



maximum at O and P; general shape with minimum about half way between O and P (2)

(c) fringe spacing = 2.5×10^{-4} m;

$\lambda = \frac{(2.5 \times 10^{-4} \times 3.00 \times 10^{-3})}{1.50} = 5.0 \times 10^{-7}$ m (2)

2 **(a)** ray: direction in which wave (energy) is traveling; wavefront: line joining (neighboring) points that have the same phase / displacement; or suitable reference to Huygens' principle; ray is normal to a wavefront (3)

(b) **(i)** wavefront parallel to D (1)

(ii) frequency is constant; since $v = f\lambda$, $v \propto \lambda$; wavelength longer in medium I, hence higher speed in medium I; (3)

Allow solution based on angles marked on diagram or speed of wavefronts.

(iii) ratio $= \frac{V_I}{V_R} = \frac{\lambda_I}{\lambda_R}$ (or based on Snell's law);

$= \frac{3.0}{2.5} = 2.0$ *allow* ± *0.5* (2)

(c) **(i)** velocity / displacement / direction in (+) and (–) directions; idea of periodicity (2)

(ii) period = 3.0 ms; frequency $= \frac{1}{T} = 330$ Hz (2)

(iii) Accept any one of the following.

at time t = 0, 1.5 ms, 3.0 ms, 4.5 ms, *etc.* (1)

(iv) area of half-loop = 140 ± 10 squares / mean $v = 4.0$ m s^{-1} *accept ± 0.2*;

$= 140 \times 0.4 \times 0.1 \times 10^{-3}$

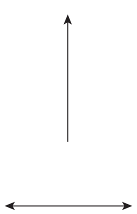
$= 5.6 \times 10^{-3}$ m (2)

Award **[1]** *for area of triangle.*

(v) (twice) the amplitude; (1)

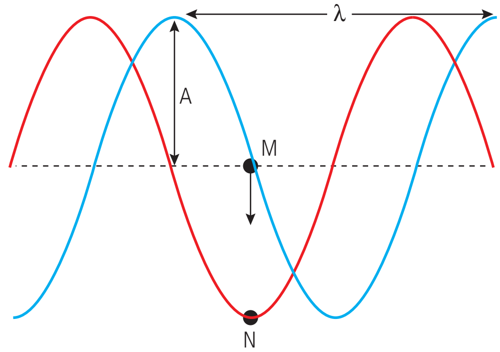
Allow distance moved in 1.5 ms.

3 **(a)** **(i)** (1)



(ii) (1)

(b)



(i) downwards (1)

(ii) correct marking of A (1)

(iii) correct marking of λ (1)

(iv) positive sine curve; correct position of N; (2)

Watch for ECF from (i).

(c) **(i)** $f = \frac{v}{\lambda}$ to give 2.0 Hz (1)

(ii) $T = 0.5$ s; $s = \frac{vT}{4} = 1.25$ (1.3) cm

OR

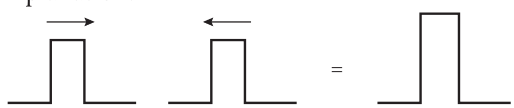
in $\frac{T}{4}$ wave moves forward $\frac{1}{4}\lambda$;

$= \frac{5}{4} = 1.25$ (1.3) cm; (2)

(d) *Principle of superposition*: when two or more waves overlap; the resultant displacement at any point is the sum of the displacements due to each wave separately / OWTTE;

Award **[2]** *for an answer that shows a clear understanding of the principle,* **[1]** *for a reasonable understanding and* **[0]** *for a weak answer.*

Explanation:



suitable diagram;

when two positive pulses (or two wave crests) overlap, they reinforce / OWTTE (4)

Any situation where resultant displacement looks as though it is the sum of the individual displacements. Mark the description of the principle and the description of constructive interference together.

(e) **(i)** $S_2X = n\lambda$;

where $n = 0, 1, 2$; (*Accept 'n is an integer'*) (2)

(ii) $\sin\theta \approx \theta$; therefore $\theta = \frac{S_2X}{d}$ (2)

(iii) $\phi = \frac{y_n}{D}$ (1)

Award the small angle approximation mark anywhere in (i) or (ii).

(f) (i) $\theta = \frac{S_2X}{d} = \frac{n\lambda}{d}$ so $\lambda = \frac{d\theta}{n}$;
substitute to get $\lambda = 4.73 \times 10^{-7}$ m (2)

(ii) θ and ϕ are small;
therefore $\frac{\lambda}{d} = \frac{y_n}{D}$ so $y = \frac{D\lambda}{d} = 0.51$ mm (3)

4 C (1)

5 D (1)

6 C (1)

7 A (1)

8 D (1)

9 D (1)

10 C (1)

11 B (1)

12 A (1)

13 B (1)

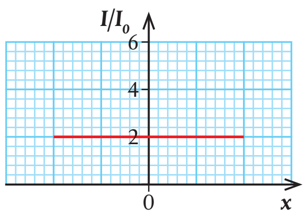
14 (a) $v = c\frac{\sin i}{\sin r} = \frac{3 \times 10^8 \times \sin(33°)}{\sin(46°)} = 2.3 \times 10^8 \text{ m s}^{-1}$ (2)

(b) ***ALTERNATIVE 1***
light strikes AB at an angle of 57°;
critical angle = 50.1°;
49.2° from unrounded value
angle of incidence is greater than critical angle so total internal reflection (3)

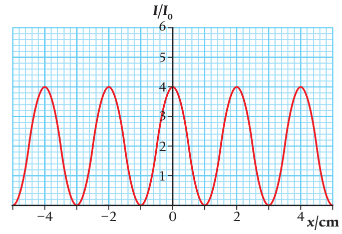
ALTERNATIVE 2
light strikes AB at an angle of 57°;
calculation showing sin of "refracted angle" = 1.1;
statement that since 1.1 > 1 the angle does not exist and the light does not emerge (3)

(c) total internal reflection shown;
ray emerges at opposite face to incidence (2)
Judge angle of incidence=angle of reflection by eye or accept correctly labeled angles
With sensible refraction in correct direction

15 (a) There is no diffraction at either lamp because there are no slits. Therefore, the intensity has no pattern. (1)



(b) This is the standard two-slit pattern.
The maximum intensity is four times the separate intensities because the amplitudes sum vectorially. The fringe spacing is calculated using $\frac{\lambda D}{d}$ to be 2.0 cm. (3)



(c) As the slit separation increases, the fringe spacing decreases. (1)

16 (a) there is constructive interference at M **OR** the amplitude doubles at M;
intensity is proportional to amplitude;
88 W m^{-2} (3)

(b) 560 nm (2)

(c) The interference pattern will be modulated by single-slit diffraction envelope and so it will be less. (1)

(d) ***ALTERNATIVE 1***
the angular position of this point is
$\theta = \frac{28 \times 10^{-3}}{1.5} = 0.01867$ rad, which coincides with the first minimum of the diffraction envelope;
$\theta = \frac{\lambda}{b} = \frac{560 \times 10^{-9}}{0.030 \times 10^{-3}} = 0.01867$ rad, so intensity will be zero (2)

ALTERNATIVE 2
the first minimum of the diffraction envelope is at
$\theta = \frac{\lambda}{b} = \frac{560 \times 10^{-9}}{0.030 \times 10^{-3}} = 0.01867$ rad;
distance on screen is $y = 1.50 \times 0.01867 = 28$ mm so intensity will be zero (2)

17 (a) 0 **OR** 2π radians **OR** 360° (1)

(b) 4λ (1)

(c) $\sin\theta = \frac{XZ}{VX} = \frac{4\lambda}{2d} \Rightarrow 2\lambda = d\sin\theta$ (1)

(d) identifies gradient with $\frac{\lambda}{d}$ **OR** use of $d\sin\theta = n\lambda$**;**
$d = \frac{\lambda}{0.08} = \frac{633 \times 10^{-9}}{0.08} = 7.91 \times 10^{-6}$ m
126 mm^{-1} or 127 mm^{-1} (4)

(e) (i) Gradient would decrease. (1)

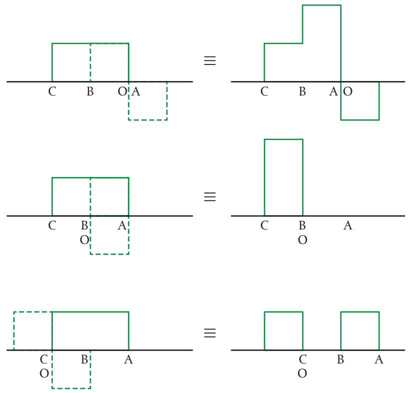
(ii) No change (1)

18 Path c (1)

The lifeguard can run faster on the beach than swimming in water. Of the three options, path c has the shortest distance in the water and so will take the least time. (1)

19 A (1)

20 The resultant wave form is the sum of the two wave forms. (4)



C.4

Exercises

1 **(a)** $182.6\ \text{m s}^{-1}$ **(b)** 143.8 Hz

2 54 N

3 812.5 Hz

4 170 Hz

5 **(a)** 33.2 cm **(b)** 2

6 **(a)** D is same length as A so resonance – this implies a $\frac{\pi}{2}$ phase difference.

B is much shorter so driver has lower frequency – it will be in phase.

F is much longer so driver has higher frequency – it will have a π phase difference.

C and E will be somewhere in between.

(b) D has highest amplitude as it resonates with the driver.

Challenge yourself

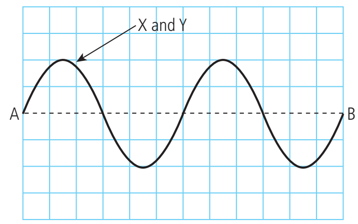
1 $y = 2A\cos\frac{2\pi x}{\lambda}\sin(\omega t)$ zero when $x = \frac{\lambda}{4}, \frac{3\lambda}{4}$ etc.

Practice questions

1 **(a)** the net **displacement** of the medium/ particles (through which waves travel); is equal to the sum of individual displacements (produced by each wave) (2)

*Award **[2]** for a good understanding and **[1]** for a reasonable one.*

(b) *Wave X and wave Y should be identical.*



correct phase for wave X; correct phase for wave Y; amplitudes the same for each wave; amplitude for each wave is two divisions (4)

2 **(a)** illustration showing node at center, antinode at each end (1)

(b) wavelength of standing wave = (2 × 280) = 560 m / *(ECF)*

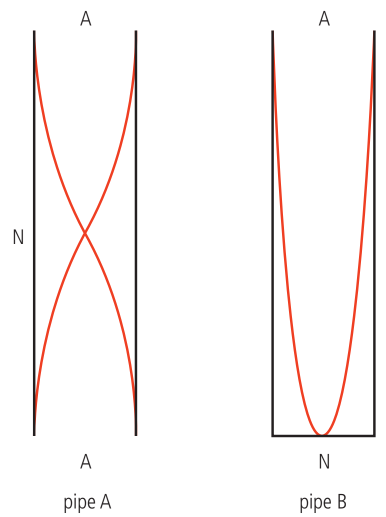
OR

$\frac{3.4 \times 10^3}{6} = 570$ m;

frequency = $\frac{3.4 \times 10^3}{560} \approx 6$ Hz

earthquake frequency is natural frequency of vibration of building / mention of resonance / multiple / *(submultiple if ECF)* (3)

3



(a) **(i)** correct wave shape for pipe A; correct wave shape for pipe B (2)

(ii) correct marking of A and N for pipe A; correct marking of A and N for pipe B (2)

(b) **(i)** for pipe A, $\lambda = 2L$, where L is length of the pipe; $c = f\lambda$ to give $L = \frac{c}{2f}$;

substitute to get L = 0.317 m; (3)

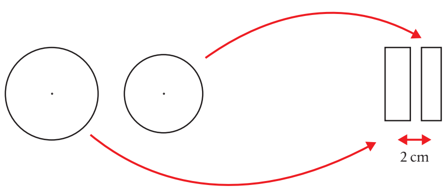
(ii) for 32 Hz, the open pipe will have a length of about 5 m; whereas the closed pipe will have half this length, so will not take up as much space as the open pipe / OWTTE (2)

The argument does not have to be quantitative. Award **[1]** *for recognition that low frequencies mean longer pipes and* **[1]** *that for the same frequency, closed pipes will be half the length of open pipes. The fact they need less space can be implicit.*

4 **(a)** **(i)** the motion corresponds approximately to the horizontal displacement of the joint;
this is sinusoidal, which is analogous to SHM (2)

(ii) because of the angle of the connecting rod;
this is reduced by the connecting rod being long (so approximately horizontal throughout) (2)

(iii) 1 cm (1)



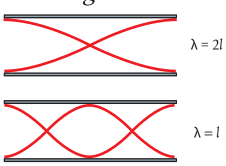
(iv) 2 Hz (1)

(b) **(i)** 2 m (1)

(ii) 4 m s^{-1} (1)

(iii) the wave reflects;
with no phase change (2)

(iv) At the point when the wave reaches the end, a standing wave has not yet been formed; only one cycle has passed.
After reflection, a standing wave will form with both ends as antinodes if the length of spring is equal to a whole number of half wavelengths. (3)



(c) From Hooke's law we know that $F_t = kx$
and assuming that $\mu = \frac{M}{x}$

$v = \sqrt{\frac{kx}{\frac{M}{x}}} = \sqrt{\frac{kx^2}{M}} = \sqrt{\frac{k}{M}}x$, which means that velocity and length are proportional. (3)

(d) Assuming SHM with maximum acceleration and acceleration equal to g: $a = \omega^2 x_0$

$\omega^2 = \frac{9.81}{0.01} = 981$;

$\omega = 31.3 = 2\pi f$;

$f = 5.0$ Hz (3)

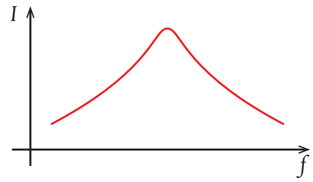
5 **(a)** if an alternating current is applied to the circuit, it will be forced to oscillate; if the frequency is the same as the first harmonic; then resonance will occur; which leads to a large current (4)

(b) Using $\omega = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{4.00 \times 10^{-3} \times 2.00 \times 10^{-12}}}$

$= 1.1 \times 10^7$ Hz

$f = \frac{\omega}{2\pi} = \frac{1.1 \times 10^7}{2\pi} = 1.8 \times 10^6$ Hz (2)

(c) increases to a maximum; then falls (2)



6 A (1)

7 C (1)

8 **(a)** traveling wave moves along the length of the string and reflects at fixed end; superposition/interference of incident and reflected waves; the superposition of the reflections is reinforced only for certain wavelengths (max. 2)

(b) $\lambda = 2l = 2 \times 0.62 = 1.24$ m;
$v = f\lambda = 195 \times 1.24 = 242$ m s^{-1} (2)
Answer must be to 3 or more s.f. or working shown for ***MP2.***

(c) straight line through origin with negative gradient (1)

(d) $\frac{62}{3} = 21$ cm (1)

9 **(a)** A horizontal line shown in center of pipe. (1)

(b) air molecule moves to the right and then back to the left; returns to X/original position (2)

(c) wavelength = 2 × 1.4 = 2.8 m;
$c = f\lambda = 120 \times 2.8 = 340$ m s^{-1};
$K = \rho c^2 = 1.3 \times 340^2 = 1.5 \times 10^5$; kg m^{-1} s^{-2} (4)

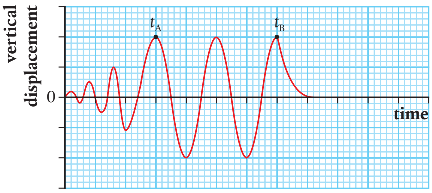
10 **(a)** energy is not propagated by standing waves;
amplitude constant for traveling waves **OR** amplitude varies with position for standing waves **OR** standing waves have nodes/antinodes;
phase varies with position for traveling waves **OR** phase constant inter-node for standing waves;
traveling waves can have any wavelength **OR** standing waves have discrete wavelengths (2)

(b) sound wave travels down tube and is reflected;
incident and reflected wave superpose/combine/interfere (2)
Do not award ***MP1*** *if the reflection is quoted at the walls/container*

(c) nodes shown at water surface ***AND*** $\frac{2}{3}$ way up tube (by eye) (1)
Accept drawing of displacement diagram for correct harmonic without nodes specifically identified.
Award **[0]** *if waveform is shown below the water surface.* (1)

(d) $\lambda = 0.74$ m;
$f = \frac{c}{\lambda} = \frac{320}{0.74} = 430$ Hz (2)

11 **(a)** **(i)** Amplitude is increasing as energy is added. (1)
(ii) energy input = energy lost due to damping (1)
(b) curve from time t_B reaching zero displacement; in no more than one cycle (2)



12 **(a)** $T = \frac{25}{10} = 2.5$ s **AND** $f = \frac{1}{T}$ ***OR*** *evidence of* $f = \frac{10}{25}$ (1)
(b) 30 m s^{-1} corresponds to $f = 1.2$ Hz;
the amplitude of vibration is a maximum for this speed ***OR*** corresponds to the resonant frequency (2)
(c) similar shape with lower amplitude;
maximum shifted slightly to left of the original curve (2)
Amplitude must be lower than the original, but allow the amplitude to be equal at the extremes

13 A (1)

14 D (1)

15 B The trick is to push the rolling ball at the right times and in the right direction. The mouse would need to match the natural rhythm of the back-and-forth of the ball. (2)

16 **(a)** when the pan is moving upwards with a retardation when approaching its amplitude, the mass will leave the pan if the retarding acceleration is less than g;
for displacement x, using $F = kx = ma$, the retarding acceleration is $-\frac{kx}{m}$ where k is the spring constant;
when $-\frac{kx}{m} < -g$, i.e. when $\frac{4\pi^2 x}{T^2} > g$
(since $T = 2\pi\sqrt{\frac{m}{k}}$) the mass leaves the pan; (3)
(b) As the amplitude varies, this will occur first when $\frac{4\pi^2 A}{T^2} = g$ i.e. $A = \frac{T^2 g}{4\pi^2}$
Substituting the data provided,
$A = \frac{0.50^2 \times 9.81}{4\pi^2} = 0.062$ m $= 6.2$ cm (3)

C.5

Exercises

1 **(a)** a lower note on the way down, and a higher note on the way up
(b) 1100 Hz
(c) 892 Hz
(d) a higher note on the way down, and a lower note on the way up

2 331.5 m s^{-1}

3 317.6 Hz

4 0.06 c

5 4.38 nm

6 3.17×10^7 m s^{-1}

7 3.25×10^7 m s^{-1}; it is further away since it is moving fast

8 2.1 Mpc

9 1440 km s^{-1}

Practice questions

1 **(a)** circular wavefronts originating from four successive source positions; bunching of wavefronts in front, spreading out at back; approximately, correct spacing of wavefronts in front, and behind source (3)
(b) f waves in distance $(V - v)$;
apparent wavelength $= \frac{(V - v)}{f}$;
apparent frequency $= \frac{f \times v}{(V - v)}$ (3)
Allow any other valid and correct approach or statement of formula. Award ***[0]*** *for quote of formula with no working shown.*
(c) $\lambda' = \lambda\frac{(V - v)}{V}$;
$5999.996 = \frac{600 \times (3 \times 10^8 - v)}{3 \times 10^8}$;
$v = 2000$ m s^{-1} (3)
Allow alternative version for red shift.

2 B (1)

3 D (1)

4 D (1)

5 B (1)

6 A (1)

7 A (1)

8 B (1)

9 C (1)

10 (**a**) mention of Doppler effect **OR** relative motion between source and observer produces frequency/wavelength change;

*Accept answers which refer to a double frequency shift. Award **[0]** if there is any suggestion that the wave speed is changed in the process.*

the reflected waves come from an approaching "source" **OR** the incident waves strike an approaching "observer";

increased frequency received by the device ***or*** by the car (2)

(**b**) ***ALTERNATIVE 1***

the car is a moving "observer" and then a moving "source"; so the Doppler effect occurs twice (2)

ALTERNATIVE 2

the reflected radar appears to come from a "virtual image" of the device; traveling at $2v$ toward the device (2)

(**c**) *For both alternatives, allow ecf to conclusion if v **OR** Δf are incorrectly calculated.*

ALTERNATIVE 1

$v = \frac{(3 \times 10^8) \times (9.5 \times 10^3)}{(40 \times 10^9) \times 2} = 36\ \text{m s}^{-1}$;

36 > 28 so car exceeded limit (2)

There must be a sense of a conclusion even if numbers are not quoted.

ALTERNATIVE 2

reverse argument using speed limit.

$\Delta f = \frac{2 \times 40 \times 10^9 \times 28}{3 \times 10^8} = 7500$ Hz;

9500 > 7500 so car exceeded limit (2)

There must be a sense of a conclusion even if numbers are not quoted.

11 (**a**) wavelength$= \frac{340}{850} = 0.40$ m;

path difference = 1.8 m;

1.8 m = 4.5λ **OR** $\frac{1.8}{0.20} = 9$ half wavelengths;

waves meet in antiphase at P **OR** destructive interference/superposition at P (4)

*Allow approach where path length is calculated in terms of number of wavelengths; along path A (56.25) and path B (60.75) for **MP2**, hence path difference 4.5 wavelengths for **MP3***

(**b**) equally spaced maxima and minima;

a maximum at Q; four additional maxima between P and Q (2)

(**c**) the amplitude of sound at Q is halved;

intensity is proportional to amplitude squared

hence $\frac{I_A}{I_0} = \frac{1}{4}$ (2)

(**d**) speed of sound relative to the microphone is less; wavelength unchanged so frequency is lower **OR** fewer waves recorded in unit time/per second so frequency is lower (2)

(**e**) $845 = 850 \times \frac{340 - v}{340}$;

$v = 2.00\ \text{m s}^{-1}$ (2)

12 (**a**) A; because it is the point nearest the Earth (2)

(**b**) C; because it is the point moving fastest toward the Earth (2)

13 (**a**) For a stationary source and observer, $c_s = f\lambda$

(**i**) $\lambda_s = \lambda + \frac{v}{f}$, where $f = 500$ Hz

The wave velocity, $c_s = \lambda_s f_s$;

Therefore, $\frac{c_s}{f_s} = \lambda + \frac{v}{f} = \frac{c_s}{f} + \frac{v}{f}$;

$f_s = \frac{c_s f}{c_s + v} = \frac{340 \times 500}{340 + v}$ (3)

(**ii**) The frequency received is obtained by replacing v by $-v$:

$f_s = \frac{340 \times 500}{340 - v}$

The frequency f_{wall} will be reflected and detected by the observer:

$f_{reflected} = \frac{340 \times 500}{340 - v}$ (3)

(**b**) $30 = \frac{340 \times 500}{340 - v} - \frac{340 \times 500}{340 + v}$;

$v^2 + \frac{340 \times 500}{15} v - 340^2 = 0$

As $\frac{v}{340} \ll 1$ we can neglect; $\left(\frac{v}{340}\right)^2$;

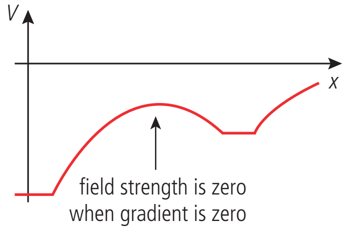
$v \approx \frac{15 \times 340}{500} = 10.2\ \text{m s}^{-1}$ (4)

D.1

Exercises

1. $1.61\ \text{m s}^{-2}$
2. $24.7\ \text{N kg}^{-1}$
3. $7.34\ \text{N kg}^{-1}$
4. $6.69 \times 10^{-8}\ \text{N kg}^{-1}$
5. $0\ \text{N kg}^{-1}$
6. $30\ \text{J kg}^{-1}$
7. 90 J
8. 240 J
9. 0 J
10. 0 J
11. (**a**) $1.6\ \text{MJ kg}^{-1}$ (**b**) 3.1×10^9 J

(**c**) and (**d**)



12 2.38×10^3 m s^{-1}

13 Hydrogen would escape.

14 3 km

15 2.74 km s^{-1}

16 graph of T^2 vs. r^3

17 4.2×10^7 m

18 1.5 hours

19 (**a**) 5.9×10^{10} J (**b**) -1.2×10^{11} J
(**c**) -6.1×10^{10} J

Challenge yourself

1 Since $\frac{1}{2}mv^2 = G\frac{Mm}{2r}$, $v = \sqrt{\frac{GM}{r}}$ where r is the orbital radius.

We have already established that $v_{escape} = \sqrt{\frac{2GM}{R}}$, where R is the radius of the body that is responsible for the field.

Notice that these equations are dimensionally equivalent. Take care in assessments to select the correct one and to use the correct distance.

Practice questions

1 A (1)

2 D (1)

3 C (1)

4 (**a**) circular motion involves a changing velocity; Tangential velocity is always perpendicular to centripetal force/acceleration; there must be a force/acceleration toward center/star; without a centripetal force the planet will move in a straight line (2)

(**b**) gravitational force/force of gravity (1)

(**c**) use of $g = \frac{GM}{R^2}$;
6.4 N kg^{-1} ***OR*** m s^{-2} (2)

5 (**a**) the force/field and the velocity/displacement are at 90° to each other ***OR*** there is no change in GPE of the moon/Phobos (1)

(**b**) ***ALTERNATIVE 1***
use of universal gravitational force/acceleration/orbital velocity equations; equating to centripetal force or acceleration; rearranges to get $k = \frac{G}{4\pi^2}$ (3)

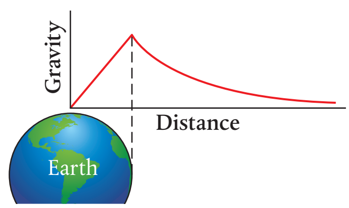
ALTERNATIVE 2
substitution of proper equation for T from orbital motion equations; substitution of proper equation for M ***OR*** R from orbital motion equations; rearranges to get $k = \frac{G}{4\pi^2}$ (3)

(**c**) $M_{\text{Mars}} = \left(\frac{R_{\text{Mars}}}{R_{\text{Earth}}}\right)^3 \left(\frac{T_{\text{Earth}}}{T_{Mars}}\right)^2 M_{\text{Earth}}$
or other consistent re-arrangement
$= 6.4 \times 10^{23}$ kg (2)

(**d**) we know that field strength and potential gradient are equal; which means that the field strengths due to the Earth and the Moon are equal and opposite at the position where the potential is maximum; at this position, we equate the gravitational field strength of the Earth and Moon (3)

6 (**a**) B (1)

(**b**) Beneath the surface, some of the Earth's mass is above you, which cancels out that between you and the center.
(1)



7 (**a**) B (1)

(**b**) The force between the Moon and the Earth (in this example) remains attractive. (1)

8 (**a**) $T^2 = \frac{4\pi^2}{GM_g}r^3$ (1)

(**b**) $M_g = 3.4 \times 10^{41}$ kg (1)

(**c**) The number of stars like the Sun ≈ 2×10^{11} (1)
In case of interest, the low marks allocation emerges from this question being on an Olympiad paper.

9 (**a**) the work done per unit mass; in bringing a (small test) mass from infinity to the point (2)
Idea of ratio crucial for first mark.

(**b**) (**i**) $g = \frac{GM_p}{r_1^{\,2}} - \frac{GM_m}{r_2^{\,2}}$;
$0 = \frac{M_p}{0.8^2} - \frac{M_m}{0.2^2}$; $\frac{M_p}{M_m} = 16$ (3)

(**ii**) $E_k = m\Delta V$;
$= 1500 \times (4.6 - 0.20) \times 10^7$;
$= 6.6 \times 10^{10}$ J (3)

Award ***[2]*** *if attempted use of* ΔV *but value used is wrong and* ***[1]*** *if an individual potential value rather than a difference is used.*

10 (**a**) (**i**) $V_{surface} = -6.3\ (\pm 0.3) \times 10^7$ J kg^{-1} (1)

(**ii**) V_h is at $R = 42 \times 10^6$ m;
$= -1.0\ (\pm 0.2) \times 10^7$ J kg^{-1} (2)

Watch for $R = 3.6 \times 10^7$ *m being used. If so award* ***[1]*** *and use ECF.*

(**b**) $\Delta V = 5.3\ (\pm 0.5) \times 10^7$ J kg^{-1};
Energy $= m\Delta V$; $= 5.3\ (\pm 0.5) \times 10^{11}$ J (3)

Award ***[2]*** *if student calculates the* E_P *of the satellite (*10^{11} *J).*

(**c**) *Any* ***two*** *of the following (****[1]*** *each):*
the satellite has to be given a horizontal velocity (or has to have E_P) to go into orbit; rocket motors lifting rocket not 100% efficient; air resistance in initial stages of launch (2)

11 (**a**) because the force is always at right angles to the velocity / motion / orbit is an equipotential surface (1)

Do not accept answers based on the displacement being zero for a full revolution.

(**b**) (**i**) equating gravitational force $\frac{GMm}{r^2}$;
to centripetal force $\frac{mv^2}{r}$ to get result (2)

(**ii**) kinetic energy is $\frac{GMm}{2r}$;
addition to potential energy $-\frac{GMm}{r}$ to get result (2)

(**c**) the total energy (at the new orbit) will be greater than before / is less negative; hence probe engines must be fired to produce force in the direction of motion / positive work must be done (on the probe) (2)

Award ***[1]*** *for mention of only potential energy increasing.*

12 A (1)

13 B (1)

14 B (1)

15 (**a**) $E = \frac{1}{2}m\frac{GM}{r} - \frac{GMm}{r} = -\frac{1}{2}\frac{GMm}{r}$;
comparison with $V = -\frac{GM}{r}$ to give answer (2)

(**b**) ***ALTERNATIVE 1***
at the position of the planet the potential depends only on the mass of the star /does not depend on the radius of the star; the potential will not change and so the energy will not change (2)

ALTERNATIVE 2
r / distance between the centers of the objects / orbital radius remains unchanged;
since $E_{Total} = -\frac{1}{2}\frac{GMm}{r}$, energy will not change (2)

16 (**a**) speed to reach infinity/zero gravitational field ***OR*** speed to escape gravitational pull/effect of planet's gravity (1)

Do not allow reference to leaving/escaping an orbit.
Do not allow "escaping the atmosphere".

(**b**) kinetic energy at take-off $= \frac{9}{16} \times \frac{GMm}{R}$;
kinetic energy at take-off + gravitational potential energy = gravitational potential energy at maximum height ***OR*** $\frac{9}{16} \times \frac{GMm}{R} - \frac{GMm}{R} = -\frac{GMm}{r}$;
solves for r and subtracts R from answer $= \frac{9R}{7}$ (3)

Award ***[0]*** *for work that assumes constant g.*

(**c**) energy reduces/lost; radius decreases; speed increases (3)

Do not allow "kinetic energy reduces" for MP1

D.2

Exercises

1 2×10^{-4} N

2 20 N C^{-1}, south

3 5.7×10^{-10} N C^{-1}

4 (**a**) 1.8×10^6 N C^{-1}
(**b**) 4.5×10^5 N C^{-1}
(**c**) 0.045 N
(**d**) 0.01 N

5 (**a**) 1×10^{-7} N
(**b**) 1×10^{-5} m s^{-2}

6 2.25×10^6 V

7 1.13×10^6 V

8 (**a**) Q_1 positive
(**b**) towards Q_2

9 F

10 (**a**) 20 V
(**b**) 10 V
(**c**) 0 V

11 (**a**) 40 J
(**b**) −20 J
(**c**) 0 J

12 50 V m^{-1}; field not uniform

13 −3 nC

14 (**a**) −10 eV
(**b**) −50 eV
(**c**) 20 eV

15 2 V

16 5 V

17 15 J

18 4 J

19 −8 J

20 (**a**) It accelerates downwards.
(**b**) 12 J

21 4 eV

22 3 eV

Challenge yourself

1 3 cm

Practice questions

1 C (1)

2 C (1)

3 A (1)

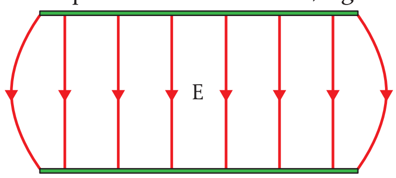
4 C (1)

5 C (1)

6 B (1)

7 (**a**) $E = \frac{k \times q}{r^2}$;
$E = \frac{8.99 \times 10^9 \times 6.0 \times 10^{-3}}{0.4^2}$
OR $E = 3.37 \times 10^8$ N C^{-1} (2)
Ignore any negative sign.
(**b**) $F = q \times E = 1.6 \times 10^{-19} \times 3.4 \times 10^8$
$= 5.4 \times 10^{-11}$ N;
$a = \frac{F}{m} = \frac{5.4 \times 10^{-11}}{9.1 \times 10^{-31}} = 5.9 \times 10^{19}$ m s^{-2} (2)
Ignore any negative sign.
Award **[1]** *for a calculation leading to a = <<m s^{-2}>>*
Award **[2]** *for bald correct answer*
(**c**) the electron moves away from the point charge/ to the right along the line joining them;
decreasing acceleration;
increasing speed (3)
Allow ECF from MP1 if a candidate mistakenly evaluates the force as attractive so concludes that the acceleration will increase

8 (**a**) minimum of three lines equally spaced and distributed, perpendicular to the plates and downwards; e.g.



edge effect shown (2)
Condone lines that do not touch plates
(**b**) 4.3×10^5 N C^{-1} (1)
(**c**) $\Delta E_p = q\Delta V = 3.2 \times 10^{-19} \times 5.2 \times 10^3$;
$= 1.7 \times 10^{-15}$ J;
negative/loss (3)

9 (**a**) B (1)
(**b**) The charge of the electrons that move is equal in terms of both surplus and deficit. (1)

10 (**a**) B (1)
(**b**) The entirety of the bird is at the same potential and so no current flows through it. (1)

11 (**a**) Electric force = En_1e;
$En_1e = mg + 6\pi\eta a u_1$
$En_2e = mg + 6\pi\eta a u_2$;
Subtracting: $Ee(n_2 - n_1) = 6\pi\eta a(u_2 - u_1)$;
$n_2 - n_1 = \frac{6\pi\eta a}{Ee}(u_2 - u_1)$;
Since $E = \frac{V}{d} = \frac{5000}{1.5 \times 10^{-2}}$ and $u = \frac{\text{distance}}{\text{time}}$;
$n_2 - n_1 = \frac{6\pi \times 1.82 \times 10^{-5} \times 2.76 \times 10^{-6}}{\left(\frac{5000}{1.5 \times 10^{-2}}\right) \times 1.6 \times 10^{-19}}\left(\frac{10^{-2}}{42} - \frac{10^{-2}}{78}\right)$
$n_2 - n_1 = 1.95$;
The change in the number of electrons is a decrease of 2. (8)
(**b**) $QE = m_1g + 6\pi\eta r_1u_1$ and $QE = m_2g + 6\pi\eta r_2u_2$;
$2QE = (m_1 + m_2)g + 6\pi\eta(r_1u_1 + r_2u_2)$
Considering the combined drop:
$2QE = m_3g + 6\pi\eta r_3u_3$
Now, $m_3 = m_1 + m_2$ so $r_3u_3 = r_1u_1 + r_2u_2$
Volume is conserved, so $\frac{4}{3}\pi r_3^{\,3} = \frac{4}{3}\pi r_1^{\,3} + \frac{4}{3}\pi r_2^{\,3}$
and $r_3 = \sqrt[3]{r_1^{\,3} + r_2^{\,3}}$
Hence, $u_3 = \frac{r_1u_1 + r_2u_2}{\sqrt[3]{r_1^{\,3} + r_2^{\,3}}}$ (5)

12 D (1)

13 A (1)

14 D (1)

15 B (1)

16 (**a**) identifies units of σ as $C\,m^{-2}$;

$\frac{C}{m^2} \times \frac{N\,m^2}{C^2}$ seen and reduced to $N\,C^{-1}$ (2)

(**b**) Horizontally, $F = T \sin 30°$

Vertically, $T \cos 30° = mg$;

$\frac{F}{mg} = \tan 30°$;

$F = mg \tan 30° = 0.025 \times 9.8 \times \tan 30° = 0.14\,N$ (3)

Allow $g = 10\,N\,kg^{-1}$

Award ***[3] marks*** *for a bald correct answer.*

Award ***[1max]*** *for an answer of zero, interpreting that the horizontal force refers to the horizontal component of the net force.*

(**c**) $E = \frac{F}{q} = \frac{0.14}{1.2 \times 10^{-6}} = 1.2 \times 10^5$;

$\sigma = 2E\varepsilon_0 = 2 \times 1.2 \times 10^5 \times 8.85 \times 10^{-12}$

$= 2.1 \times 10^{-6}\,C\,m^{-2}$ (2)

Allow ***ECF*** *from the calculated F in (b)(i)*

Award ***[2]*** *for a bald correct answer.*

(**d**) $\frac{Q}{0.22^2} = \frac{1.2 \times 10^{-6}}{0.18^2}$

$Q = +1.8 \times 10^{-6}\,C$;

2 s.f. (2)

Do not award ***MP2*** *if charge is negative*

Any answer given to 2 s.f. scores ***MP2***

17 (**a**) ***ALTERNATIVE 1***

work done on moving a positive test charge in any outward direction is negative; potential difference is proportional to this work so V decreases from A to B (2)

ALTERNATIVE 2

potential gradient is directed opposite to the field so inwards; the gradient indicates the direction of increase of V, hence V increases toward the center/decreases from A to B (2)

ALTERNATIVE 3

$V = \frac{kQ}{R}$ so as r increases V decreases;

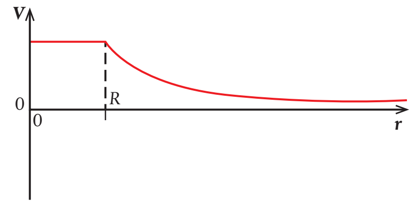
V is positive as Q is positive (2)

ALTERNATIVE 4

the work done per unit charge in bringing a positive charge from infinity;

to point B is less than point A (2)

(**b**) The sphere is solid and conducting, which means the field strength within the sphere's radius is zero (and therefore potential must be constant so that potential gradient is zero). Beyond the sphere's radius, an inverse proportionality exists: $V \propto \frac{1}{r}$



(2)

(**c**) $\Delta V = \frac{W}{q} = \frac{1.7 \times 10^{-16}}{1.60 \times 10^{-19}} = 1.1 \times 10^3\,V$ (1)

(**d**) $= 8.99 \times 10^9 \times Q \times \left(\frac{1}{5.0 \times 10^{-2}} - \frac{1}{1.0 \times 10^{-1}}\right)$;

$Q = 1.2 \times 10^{-8}\,C$ (2)

(**e**) to highlight similarities between different fields (1)

D.3

Exercises

1 (**a**) $2 \times 10^{-5}\,N$

(**b**) east

2 (**a**) $5 \times 10^{-6}\,N$

(**b**) west

3 (**a**) up

(**b**) right

(**c**) up

4 $4 \times 10^{-19}\,N$

5 (**a**) $8.0 \times 10^{-17}\,J$

(**b**) $1.3 \times 10^7\,m\,s^{-1}$

(**c**) $7.4 \times 10^{-4}\,T$

6 $4 \times 10^{-20}\,N$

Practice questions

1 C (1)

2 D (1)

3 D (1)

4 A (1)

5 A (1)

6 A (1)

7 A (1)

8 (**a**) force per unit charge;

acting on a small/test positive charge (2)

(**b**) horizontally to the left (1)

Arrow does not need to touch X

(**c**) proton moves to the right/they move in opposite directions;
force on each is initially the same;
proton accelerates less than electron initially because mass is greater;
field is stronger on right than left as lines closer;
proton acceleration increases as it is moving into stronger field ***OR*** electron acceleration decreases as it is moving into weaker field (max. 4)
Allow ECF from (b)
Accept converse argument for electron

9 (**a**) magnetic force is to the left at the instant shown ***OR*** explains a rule to determine the direction of the magnetic force; force is perpendicular to velocity/direction of motion ***OR*** force is constant in magnitude; force is centripetal/toward the center (max. 2)
NOTE: Accept reference to acceleration instead of force

(**b**) $qvB = \frac{mv^2}{R}$;
$R = \frac{1.67 \times 10^{-27} \times 2.0 \times 10^6}{1.6 \times 10^{-19} \times 0.35}$ **OR** 0.060 m (2)
NOTE: Award ***MP2*** *for full replacement or correct answer to at least 2 significant figures*

(**c**) $T = \frac{2\pi R}{v}$;
$T = \frac{2\pi \times 0.06}{2.0 \times 10^6} = 1.9 \times 10^{-7}$ s (2)

(**d**) ***ALTERNATIVE 1***
work done by force is change in kinetic energy;
work done is zero/force perpendicular to velocity (2)
NOTE: Award **[2]** *for a reference to work done is zero hence E_k remains constant*
ALTERNATIVE 2
proton moves at constant speed;
kinetic energy depends on speed (2)
NOTE: Accept mention of speed or velocity indistinctly in MP2

10 (**a**) out of the page plane / ⊙ (1)
Do not accept just "up" or "outwards"

(**b**) $8.5 \times 1.60 \times 10^{-19} \times 6.8 \times 10^5 = 9.2 \times 10^{-13}$ N (1)

(**c**) the magnetic force does not do work on the electron hence does not change the electron's kinetic energy ***OR*** the magnetic force/acceleration is at right angles to velocity (1)

(**d**) the velocity of the electron is at right angles to the magnetic field;
(therefore) there is a centripetal acceleration / force acting on the charge (2)

11 (**a**) ***ALTERNATIVE 1***
magnetic field due to upper wire on lower wire horizontal and into page;
shows force is downwards by any valid rule;
reading of balance increases (3)
Allow ECF from "out of page"
ALTERNATIVE 2
currents are antiparallel / in opposite directions;
so wires repelled (by any argument giving force direction);
reading of balance increases (3)

(**b**) 2.6×10^{-5} N m^{-1} (1)

(**c**) volume of the wire (a cylinder) = $\pi r^2 l$
$= \pi \times \left(\frac{2.5 \times 10^{-3}}{2}\right)^2 \times 0.15 = 7.36 \times 10^{-7}$ m^3;
charge in the wire
$= 8.5 \times 10^{28} \times 7.36 \times 10^{-7} \times 1.6 \times 10^{-19}$
$= 10 \times 10^3$ C;
$v = \frac{BIl}{Bq} = \frac{2.6 \times 10^{-5} \times 0.15}{1.3 \times 10^{-4} \times 10^4}$;
$= 3.0$ μm s^{-1} (4)

(**d**) parts of the wire will experience a smaller magnetic field; and hence a smaller force; so the reading of the balance will decrease (3)

12 (**a**) B (1)

(**b**) Currents flowing in the same direction 'pinch' together, because the magnetic fields between them are in opposite directions. (1)

D.4

Exercises

1 (**a**) 2×10^{-4} V
(**b**) 1×10^{-4} A
(**c**) 2×10^{-8} J
(**d**) 2×10^{-8} J
(**e**) 20 m
(**f**) 1×10^{-8} N

2 (**a**) 1×10^{-6} T m^2
(**b**) 0.25×10^{-6} T m^{-2} s^{-1}
(**c**) 0.25 μV

3 (**a**) 1.5×10^{-5} T m^2
(**b**) 1.3×10^{-5} T m^2
(**c**) 0.67 μV

4 (**a**) (**i**) 100 π rad s^{-1}
(**ii**) 3.9 V
(**iii**) 2.8 V
(**b**) 1.4 V

5 48.4 Ω

Challenge yourself

1 When the motor coil is stationary, there is no induced emf to oppose the current.

Practice questions

1 (**a**) force exerted per unit mass; on a small / point mass (2)

(**b**) from the law of gravitation, the field strength

$\frac{F}{m} = G\frac{M}{R^2} = g_0$

to give $GM = g_0R^2$ (2)

N.B. To achieve full marks, candidates need to state that $\frac{F}{m} = g_0$

(**c**) downwards

(accept 90° to B field or down the wire) (1)

(**d**) $F = Bev \cos\theta$ (1)

(**e**) work done in moving an electron the length of the wire is

$W = FL = BevL \cos\theta$;

emf = work done per unit charge;

therefore, $E = BLv \cos\theta$

OR

electric field $= \frac{F}{e} = Bv \cos\theta$;

emf E = electric field × L;

to give $E = BLv \cos\theta$ (3)

Award **[2]** *if flux linkage argument is used.*

(**f**) $F = G\frac{Mm}{R^2} = \frac{mv^2}{R}$;

such that $v^2 = \frac{GM}{R} = \frac{g_0R^2}{R}$;

$v^2 = \frac{10 \times (6.4)^2 \times 10^{12}}{6.7 \times 10^6}$

to give $v = 7.8 \times 10^3$ m s^{-1} (3)

(**g**) $L = \frac{E}{Bv\cos\theta}$;

$= \frac{10^3}{6.3 \times 10^{-6} \times 7.8 \times 10^3 \times 0.93}$

$= 2.2 \times 10^4$ m (2)

2 (**a**) (**i**) emf (induced) proportional to; rate of change /cutting of (magnetic) flux (linkage); (2)

(**ii**) magnetic field / flux through coil will change as the current changes (1)

(**b**) (**i**) sinusoidal and in phase with current (1)

(**ii**) sinusoidal and same frequency; with 90° phase difference to candidate's graph for ϕ (2)

(**iii**) emf is reduced; because B is smaller (2)

Award **[0]** *for 'emf is reduced' if argument fallacious.*

(**c**) *advantage*: no direct contact with cable required; *disadvantage*: distance to wire must be fixed (2)

3 D (1)

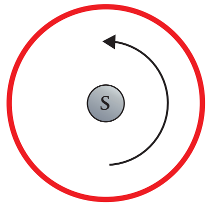
4 B (1)

5 C (1)

6 C (1)

7 (**a**) The magnetic field at the position of the ring is increasing because the magnet gets closer to the ring. (1)

(**b**) e.g. (1)



(**c**) since the induced magnetic field is upwards ***OR*** by Lenz law the change of magnetic field/flux must be opposed ***OR*** by conservation of energy the movement of the magnet must be opposed; therefore the force is repulsive/upwards (2)

8 (**a**) long sides of coil AB/CD cut lines of flux ***OR*** flux linkage in coil is changed;

induced emf depends on rate of change of flux linked ***OR*** rate at which lines are cut;

emfs acting in sides AB/CD add / act in same direction around coil;

process produces an alternating/sinusoidal emf (3)

"Induced" is required

Allow OWTTE or defined symbols if "induced emf" is given.

Accept "induced" if mentioned at any stage in the context of emf or accept the term "motional emf".

Award **[2 max.]** *if there is no mention of "induced emf"*

(**b**) 0.058 V (1)

(**c**) 160 × 0.058 = 9.2 V (1)

If 80 turns used in (b), give full credit for (b) × 2 here

9 (**a**) A (1)

(**b**) An electromagnet forms when a current-carrying conductor is wrapped around a magnetic material. When the conductor has no current, a stationary magnet cannot induce an emf. (1)

10 (**a**) A (1)

(**b**) A current is indeed induced because of the rotation of a conductor relative to a magnetic field. (1)

E.1

Exercises

1 (**a**) 17 p, 18 n

(**b**) 28 p, 30 n

(**c**) 82 p, 122 n

2 4.16×10^{-18} C, 9.04×10^{-26} kg

3 $^{235}_{92}U$

4 92 protons, 146 neutrons

5 (**a**) 1.9×10^{7} m s^{-1}

(**b**) 4.9×10^{-15} m

6 10

7 13.06 eV, 3.15×10^{15} Hz

8 0.31 eV, 7.44×10^{13} Hz

9 13.6 eV, 3.28×10^{15} Hz

10 5.3×10^{-11} m

11 2.5×10^{15} Hz

Practice questions

1 (**a**) (**i**) *Answer to include:*
missing frequencies / wavelengths;
in otherwise continuous spectrum (2)

(**ii**) *Answer to include:*
light from Sun is split into its component wavelengths; using prism / grating (2)

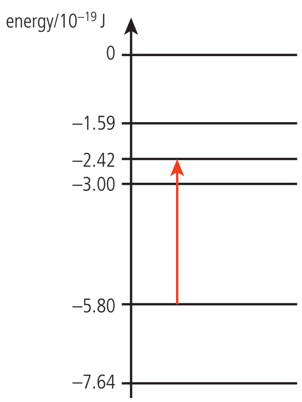
(**b**) (**i**) correct substitution into $E = hf$ and $c = f\lambda$ to give $E = \frac{hc}{\lambda}$;

$E = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{5.88 \times 10^{-7}} = 3.38 \times 10^{-19}$ J (2)

(**ii**) transition is an absorption so involves electron being 'promoted' up between two levels; energy of gap must be exactly = 3.38 $\times 10^{-19}$ J; this is between (-5.80×10^{-19} J) and (-2.42×10^{-19} J) levels; (3)

[2] can be given for other relevant information concerning, for example, the existence of photons with different energies in sunlight / the immediate reradiation in random directions. The final mark is for identifying the energy levels concerned.

This can also just be shown on a diagram.



(**c**) Bohr assumed electrons were in circular orbits around nucleus; of fixed angular momentum; that were stable (did not radiate); and thus the energy could be calculated (3)

2 (**a**) *Mark both processes, 1 and 2, together.*
Award ***[1]*** *for any two of the following:*
collisions with (external) particles; heating the gas to a high temperature; absorption of photons (2)

(**b**) (**i**) $E = \frac{hc}{\lambda}$

$= \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{658 \times 10^{-9}}$;

= 1.89 eV (2)

(**ii**) electrons absorb photons (of energy 1.89 eV) to make a transition from $n = 2$ to $n = 3$; on de-excitation, photons of energy 1.89 eV, i.e. wavelength 658 nm are emitted; in all directions, however, and not just along the initial direction, hence intensity is reduced (3)

3 B (1)

4 C (1)

5 A (1)

6 A (1)

7 D (1)

8 C (1)

9 B (1)

10 D (1)

11 (**a**) most undeflected/pass straight through;
hence mostly empty space;
few deflected *(allow "bent", "reflect", "bounce back" etc)*;
hence small dense nucleus
positive / positively charged; (max. 4)

(**b**) electron accelerated / mention of centripetal force;
should radiate EM waves/energy;
and spiral into the nucleus (3)

12 (**a**) identifies $\lambda = 435$ nm;

$E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{4.35 \times 10^{-7}}$;

4.6×10^{-19} J (3)

(**b**) −0.605 ***OR*** −0.870 ***OR*** −1.36 to −5.44 ***AND*** arrow pointing downwards (1)

Arrow ***MUST*** *match calculation in (a)*

(**c**) Difference in energy levels is equal to the energy of the photon;
Downward arrow as energy is lost by hydrogen/ energy is given out in the photon/the electron falls from a higher energy level to a lower one (2)

13 **(a)** equating centripetal to electrical force $\frac{2ke^2}{r^2} = \frac{mv^2}{r}$ to get result (1)

(b) uses (a) to state $E_k = \frac{ke^2}{r}$ **OR** states $E_p = -\frac{2ke^2}{r}$;

adds $E_{TOT} = E_k + E_p = \frac{ke^2}{r} - \frac{2ke^2}{r}$ to get the result (2)

(c) the total energy decreases **OR** by reference to $E_{TOT} = -\frac{ke^2}{r}$; the radius must also decrease (2)

*NOTE: Award **[0]** for an answer concluding that radius increases*

(d) with $n = 3$, $v = 1.44 \times 10^6\ \text{m s}^{-1}$;

$\lambda = 5.05 \times 10^{-10}$ m (2)

(e) $\frac{2\pi r}{\lambda} = \frac{2\pi \times 9 \times 2.7 \times 10^{-11}}{5.1 \times 10^{-10}} = 2.99 \cong 3$ (1)

14 **(a)** the electrons accelerate and so radiate energy; they would therefore spiral into the nucleus/ atoms would be unstable; electrons have discrete/ only certain energy levels; the only orbits where electrons do not radiate are those that satisfy the Bohr condition $mvr = n\frac{h}{2\pi}$ (max. 3)

(b) $\frac{m_e v^2}{r} = \frac{ke^2}{r^2}$ **OR** $E_k = \frac{1}{2}E_p$ hence $\frac{1}{2}m_e v^2 = \frac{1}{2}\frac{ke^2}{r}$

solving for v to get answer (1)

Answer given – look for correct working

(c) combining $v = \sqrt{\frac{ke^2}{m_e r}}$ with $m_e vr = \frac{h}{2\pi}$ using correct substitution, e.g. $m_e^{\,2}\frac{ke^2}{m_e r}r^2 = \frac{h^2}{4\pi^2}$;

correct algebraic manipulation to gain the answer (2)

Answer given – look for correct working

*Do not allow a bald statement of the answer for **MP2**.*

Some further working e.g. cancellation of m or r must be shown

(d) $r = 5.3 \times 10^{-11}$ m (1)

E.2

Exercises

1 **(a)** 9.6×10^{-20} J

(b) 7.1×10^{14} Hz

(c) 3.7×10^{-19} J

(d) 5.6×10^{14} Hz

2 **(a)** 8.6 eV

(b) 4.3 eV

(c) 4.3 V

(d) 1.0×10^{15} Hz

3 no

4 1.5×10^{15} Hz

5 **(a)** 100 eV

(b) 1.6×10^{-17} J

(c) 1.2×10^{-10} m

6 4.4×10^{-38} m; the opening is too small

7 54°

Practice questions

1 **(a)** *aspect:*

electrons will not be emitted unless the frequency of light exceeds a certain minimum value / electrons are emitted almost instantaneously with the light falling on the surface even if light is of very low intensity / the energy of the electrons emitted is not affected by the intensity of light falling on the surface (1)

corresponding explanation:

light consists of photons whose energy is hf hence no electrons are emitted unless hf is larger than the energy needed to escape the metal / an electron is emitted as soon as it absorbs a photon. If the photon has sufficient energy no delay is required / the intensity of light plays no role in the energy of the electron, only the frequency of light does (1)

(b) **(i)** the threshold frequency is found from the frequency axis intercept;

to be $3.8\ (\pm 0.2) \times 10^{14}$ Hz (2)

(ii) a value of the Planck constant is obtained from the slope;

to be $6.5\ (\pm 0.2) \times 10^{-34}$ J s (2)

*Award **[0]** for 'bald' answer of 6.63×10^{-34} J s.*

(iii) the work function of the surface is found from the intercept with the vertical axis;

to be $1.5\ (\pm 0.1)$ eV (2)

(c) straight line parallel to the first; intersecting the frequency axis at 8.0×10^{14} Hz (2)

2 **(a)** all particles have a wavelength associated with them / OWTTE;

the de Broglie hypothesis gives the associated wavelength as $\lambda = \frac{h}{p}$;

where h is the Planck constant and p is the momentum of the particle (3)

*If answers just quote the formula from the data book then award **[1]** for showing at least students recognize which formula relates to the hypothesis.*

(b) **(i)** $E_k = Ve = 850 \times 1.6 \times 10^{-19}$ J

$= 1.4 \times 10^{-16}$ J (1)

(ii) use $E = \frac{p^2}{2m}$ to get $p = \sqrt{2mE}$;

substitute $p = \sqrt{2 \times 9.1 \times 10^{-31} \times 1.4 \times 10^{-16}}$

$= 1.6 \times 10^{-23}$ N s (2)

(**iii**) $\lambda = \frac{h}{p}$;

substitute $\lambda = \frac{6.6 \times 10^{-34}}{1.6 \times 10^{-23}}$

$= 4.1 \times 10^{-11}$ m (2)

3 A (1)

4 C (1)

5 B (1)

6 C (1)

7 C (1)

8 C (1)

9 D (1)

10 (**a**) low intensity light would transfer energy to the electron at a low rate/slowly; time would be required for the electron to absorb the required energy to escape/be emitted (2)

(**b**) in the photon theory of light the electron interacts with a single photon; and absorbs all the energy ***OR*** and can leave the metal immediately (2)

*NOTE: Reference to photon-electron collision scores **MP1***

(**c**) $\phi = \frac{hc}{\lambda} - E_k$;

$E_k = 1.5$ eV;

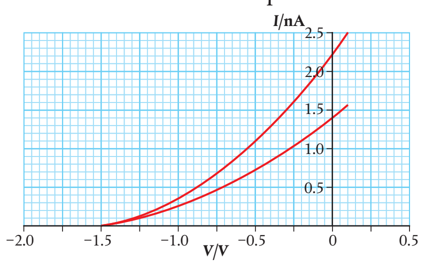
$\phi = 1.1$ eV (3)

NOTE: Allow reading from the graph of $E_k = 1.4$ leading to an answer of 1.2 eV.

(**d**) similar curve lower than original;

with same horizontal intercept

e.g. (2)



11 (**a**) $\lambda = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{1.60 \times 10^{-19} \times 4.2 \times 10^{8}} = 2.96 \times 10^{-15}$ m (1)

(**b**) the shape of the graph suggests that electrons undergo diffraction with carbon nuclei;

only waves diffract (2)

(**c**) $\sin\theta_0 = \frac{2.96 \times 10^{-15}}{4.94 \times 10^{-15}} = 0.599$;

37° ***OR*** 0.64/0.65 rad (2)

(**d**) the de Broglie wavelength of electrons is much longer than the size of a nucleus;

hence electrons would not undergo diffraction ***OR*** no diffraction pattern would be observed (2)

(**e**) volume of a nucleus proportional to $\left(A^{\frac{1}{3}}\right)^3 = A$ ***AND*** mass proportional to A;

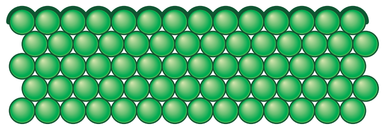
the ratio $\frac{\text{mass}}{\text{volume}}$ independent of A hence density the same for all nuclei (2)

12 (**a**) A (1)

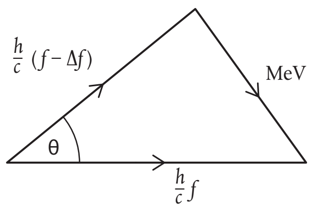
(**b**) *Lots of answers available, e.g.*

Light microscopes cannot be used for imaging individual atoms; It is possible to make smooth enough surfaces that good reflections can form (max. 1)

This solid surface is smooth to light waves larger than atoms.



13 (3)



One mark for each correctly labeled side. Deduct 1 mark if not closed.

(**b**) $(m_e v)^2 = \left(\frac{h}{c}f\right)^2 + \left(\frac{h}{c}(f - \Delta f)\right)^2 - 2\left(\frac{h}{c}\right)^2 f(f - \Delta f)\cos\theta$ (4)

One mark for each term.

(**c**) $hf = \frac{1}{2}m_e v^2 + h(f - \Delta f)$ (2)

One mark for each side of the equation.

(**d**) From the energy conservation equation:

$m_e v^2 = 2h\Delta f$;

Substituting into the equation from (b):

$$2hm_e\Delta f = \left(\frac{h}{c}f\right)^2 + \left(\frac{h}{c}(f - \Delta f)\right)^2 - 2\left(\frac{h}{c}\right)^2 f(f - \Delta f)\cos\theta$$

$$2hm_e\Delta f = \left(\frac{h}{c}\right)^2 f^2 + \left(\frac{h}{c}\right)^2(f^2 - 2f\Delta f + \Delta f^2) - 2\left(\frac{h}{c}\right)^2 f^2\cos\theta + 2\left(\frac{h}{c}\right)^2 f\Delta f\cos\theta$$

$$\frac{2m_e c^2}{h}\Delta f = f^2 + f^2 - 2f\Delta f + \Delta f^2 - 2f^2\cos\theta + 2f\Delta f\cos\theta$$

$$\frac{2m_e c^2}{h}\Delta f = f^2(2 - 2\cos\theta) + \Delta f^2 - f\Delta f(2 - 2\cos\theta)$$

$$\frac{m_e c^2}{h}\Delta f = f^2(1 - 1\cos\theta) + \frac{\Delta f^2}{2} - f\Delta f(1 - 1\cos\theta);$$

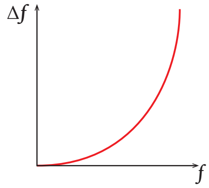
Dividing by f^2: $\frac{m_e c^2}{h}\frac{\Delta f}{f^2} = 1 - 1\cos\theta + \frac{\Delta f^2}{2f^2} - \frac{\Delta f}{f}(1 - 1\cos\theta)$;

Since $\Delta f \ll f$, $\frac{\Delta f^2}{2f^2} \approx 0$ and $\frac{\Delta f}{f} \approx 0$.

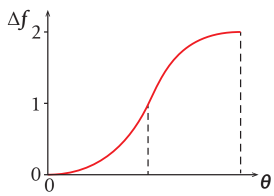
Therefore, $\frac{m_e c^2}{h}\frac{\Delta f}{f^2} = 1 - 1\cos\theta$

$\Delta f = \frac{hf^2}{m_e c^2}(1 - 1\cos\theta)$ (7)

(e) **(i)** (1)



(ii) (1)



(iii) $\Delta f_{max} = \frac{hf^2}{m_e c^2}$;

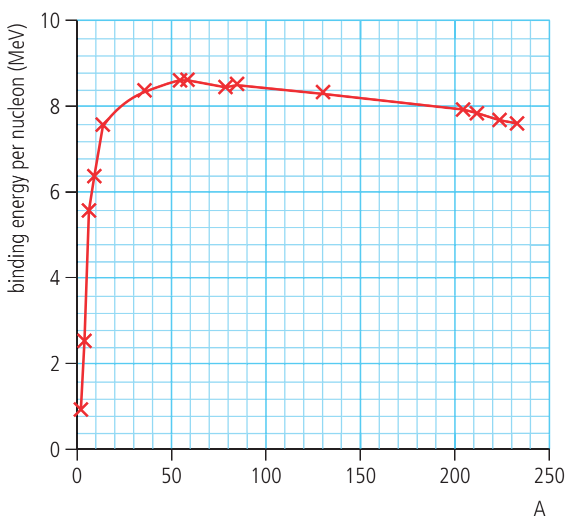
when $\theta = \pi$ (2)

E.3

Exercises

1 **(a)** 92p, 141n
(b) 234.9405 u
(c) 1.901 u
(d) 1771 MeV
(e) 7.60 MeV

2



3 8.95 MeV

4 Mass of At is bigger than Po so no energy released.

5 2.32 MeV

6 1.0×10^{19} Hz

7 12.5 g

8 12.5 s^{-1}

9 24 000 years

10 7.45 Bq

11 28.6 years

12 **(a)** 1.66×10^8 s
(b) 4.17×10^{-9} s^{-1}
(c) 1.0×10^{22}
(d) 4.17×10^{13} s^{-1}
(e) 1.2×10^{-12} g

Challenge yourself

1 For small nuclei, the range of the strong force ($\sim 10^{-15}$ m) extends across all nucleons, which means every additional nucleon (irrespective of whether a proton or neutron) has a net attraction on every existing nucleon. Therefore, the nucleus increases dramatically in stability and accordingly releases significant amounts of energy with every additional nucleon.

For large nuclei, the diameter of the nucleus is greater than the range of the strong force. Nucleons are attracted to nearby nucleons due to the strong force, but protons exert a slight electrostatic repulsion on distant protons across the nucleus and distant neutrons exert no forces. The addition or subtraction of individual nucleons therefore has a limited effect on overall stability and the energy released or required in neutron changes is smaller.

2 2.5×10^{12} J

3 1.82 MeV

4 If the probability of decay is large (i.e. approaching 100% in a given time interval), then almost all of the nuclei would decay in the time interval (and neither the number of undecayed nuclei nor activity would follow an exponential decay relationship). Similarly, if the time interval is large, then almost all of the nuclei ought to have decayed in that time.

Practice questions

1 **(a)** *Deduct* **[1]** *for each error or omission, stop at zero.* (2)

Property	Effect on rate of decay		
	Increase	Decrease	Stays the same
Temperature of sample			✓
Pressure on sample			✓
Amount of sample	✓		

(**b**) (**i**) ${}^{4}_{2}He$ / ${}^{4}_{2}\alpha$
${}^{222}_{86}Rn$; (2)

(**ii**) mass defect = 5.2×10^{-3} u; energy = mc^2
$= \dfrac{5.2 \times 10^{-3} \times 1.661 \times 10^{-27} \times 9.00 \times 10^{16}}{1u}$
= 930 MeV;
= 4.86 MeV = 7.78×10^{-13} J (3)

(**c**) (**i**) (linear) momentum must be conserved;
momentum before reaction is zero;
so equal and opposite after (to maintain zero total) (3)

(**ii**) $0 = m_\alpha v_\alpha + m_{Rn} v_{Rn}$;
$\dfrac{V_\alpha}{V_{Rn}} = -\left(\dfrac{m_{Rn}}{m_\alpha}\right)$; $= -\dfrac{222}{4} = -55.5$ (3)
Ignore absence of minus sign.

(**iii**) kinetic energy of α particle = $\frac{1}{2} m_\alpha v_\alpha{}^2$;
kinetic energy of radon nucleus = $\frac{1}{2}\left(\frac{222}{4}\right) m_\alpha \left(\frac{v_\alpha}{55.5}\right)^2$
this is $\frac{1}{55.5}$ of kinetic energy of α particle; (3)
Accept alternative approaches.

2 (**a**) an (electron) antineutrino; (1)
Reject 'neutrino'.

(**b**) idea that there is a fixed total energy of decay;
total energy shared between the (three) resulting particles / *OWTTE* (2)

(**c**) correct calculation of decay constant λ;
$\lambda = \dfrac{\ln 2}{0.82} = 0.845$
correct substitution into $N = N_0 e^{-\lambda t}$;
to give $N = N_0 e^{-8.45}$ therefore $\dfrac{N}{N_0} = e^{-8.45}$
= 0.000 213 = 0.02% (3)
N.B. Award attempts without full equation ***[1]***.

3 (**a**) ${}^{40}_{19}K \rightarrow {}^{40}_{18}Ar + \beta^+(e^+) + \nu$;
${}^{0}_{+1}\beta^+$ / ${}^{0}_{+1}e^+$ (2)

(**b**) 8.2×10^{-6} g (1)

(**c**) (**i**) $\lambda = \dfrac{\ln 2}{T_{\frac{1}{2}}}$; $= \dfrac{0.69}{1.3 \times 10^9} = 5.3 \times 10^{-10}$ year^{-1} (2)

(**ii**) from $N = N_0 e - \lambda t$, $t = \frac{1}{\lambda} \ln\left(\frac{N_0}{N}\right)$;
$= 1.9 \times 10^9 \times \ln(6.8) = 3.6 \times 10^9$ years (2)
OR
$\dfrac{1.2}{8.2} = \left(\dfrac{1}{2}\right)^n$
$n = 2.77$;
age = $2.77 \times 1.3 \times 10^9$
= 3.6×10^9 years (2)

4 B (1)

5 C (1)

6 A (1)

7 A (1)

8 A (1)

9 B (1)

10 A (1)

11 B (1)

12 D (1)

13 D (1)

14 A (1)

15 A (1)

16 D (1)

17 A (1)

18 C (1)

19 A (1)

20 D (1)

21 C (1)

22 (**a**) X: 26 and Y: 12;
Z: ν/neutrino (2)
Do not allow the antineutrino.

(**b**) total energy released is fixed;
neutrino carries some of this energy (leaving the beta particle with a range of energies) (2)

(**c**) the time taken for half the radioactive nuclides to decay / the time taken for the activity to decrease to half its initial value (1)
Do not allow reference to change in weight.

23 (**a**) energy/mass difference = 8.450 – 8.398
= 0.052 MeV;
Q = 1.7 **OR** 1.66 **OR** 1.664 MeV
OR 2.66×10^{-13} J (2)

(**b**) 11–12 days (1)

24 (**a**) ${}^{4}_{2}\alpha$ **OR** ${}^{4}_{2}He$;
${}^{222}_{86}Rn$ (2)
These ***must*** *be seen on the right-hand side of the equation.*

(**b**) ***ALTERNATIVE 1***
6 days is 5.18×10^5 s;
activity after 6 days is $A_0 e^{-1.4\times10^{-11}\times5.8\times10^5} \approx A_0$ **OR** A $= 0.9999927\, A_0$ **OR** $0.9999927\, \lambda N_0$ **OR** states that index of e is so small that $\dfrac{A}{A_0}$ is ≈ 1 **OR**
$A - A_0 \approx 10^{-15}$ s^{-1} (2)

ALTERNATIVE 2
shows half-life of the order of 10^{11} s or 5.0×10^{10} s;
converts this to year (1600 years) or days and states half-life much longer than experiment compared to experiment (2)
*Award **[1 max.]** if calculations/substitutions have numerical slips but would lead to correct deduction, e.g. failure to convert 6 days to seconds but correct substitution into equation will give **MP2**.*
*Allow working in days, but for **MP1** must see conversion of λ or half-life to day^{-1}.*

(c) ***ALTERNATIVE 1***
use of $A = \lambda N_0$;
conversion to number of molecules $= nN_A = 3.7 \times 10^{20}$ **OR** initial activity $= 5.2 \times 10^9\ s^{-1}$;
number emitted $= (6 \times 24 \times 3600) \times 1.4 \times 10^{-11} \times 3.7 \times 10^{20}$ **OR** 2.7×10^{15} alpha particles (3)
ALTERNATIVE 2
use of $N = N_0 e^{-\lambda t}$;
$N_0 = n \times N_A = 3.7 \times 10^{20}$;
alpha particles emitted = number of atoms disintegrated $= N - N_0 = N_0(1 - e^{-\lambda \times 6 \times 24 \times 3600})$
OR 2.7×10^{15} alpha particles (3)
*Must see correct substitution or answer to 2+ s.f. for **MP3***

(d) alpha particles highly ionizing **OR** alpha particles have a low penetration power **OR** thin glass increases probability of alpha crossing glass **OR** decreases probability of alpha striking atom/nucleus/molecule (1)
Do not allow reference to tunneling.

(e) conversion of temperature to 291 K;
$p = 4.5 \times 10^{-9} \times 8.31 \times \frac{291}{1.3 \times 10^{-5}}$ **OR**
$p = 2.7 \times 10^{15} \times 1.38 \times 10^{-23} \times \frac{291}{1.3 \times 10^{-5}}$;
0.83 **OR** 0.84 Pa (3)

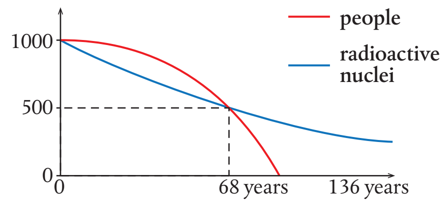
25 **(a)** B (1)

(b) Suppose Supply 2 starts with a power of '1'. The amount of power will half each year as shown below. Supply 1 starts with twice as much power: '2'. Its power halves twice per year as shown below. From the beginning of Year 2 onwards, you are better off with Supply 2.

Year	0	1	2	3
Supply 1	2	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{1}{32}$
Supply 2	1	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{8}$

26 **(a)** C (1)

(b) The 'mortality' of people and radioactive nuclei are very different over time. The probability of a human surviving from one year to the next decreases, whereas the probability of a nucleus remaining undecayed remains constant. (1)



27 **(a)** $\frac{1}{2}$ (1)

(b) Probability of no decay $= \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2}$;
which is $\frac{1}{8}$;
Probability of decay $= \frac{7}{8}$ (3)

28 **(a)** 4 (1)

(b) Tabulation of working:
1935 1 cm
1936 4 cm
1937 4^2 cm
1938 4^3 cm
1939 4^4 cm
1940 4^5 cm;
1024 cm (2)

(c) 1×10^3 cm **OR** 1×10^1 m (1)

(d) 1941 4 × 10 = 40 m
1942 4 × 40 = 160 m;
1943 4 × 160 = 640 m (2)

(e) The speed of the front page is $4^n \times 10 \div 6$ months;
$3 \times 10^8 = \frac{4^n \times 10}{\frac{365}{2} \times 24 \times 3600}$;
$4.73 \times 10^{14} = 4^n$
$14.67 = n \log 4$;
$n = 24.4$ so the year will be 1964 (4)

E.4

Exercises

1 10, 133.9 MeV

2 135.8 MeV

3 **(a)** ${}^{142}_{56}Ba \rightarrow {}^{142}_{57}La + \beta^- + \bar{\nu}$

(b) 9 years

4 (a) 7
(b) $^{239}_{94}Pu \rightarrow ^{136}_{54}Xe + ^{96}_{40}Zr + 7n^0$
(c) 164 MeV
(d) 239 g
(e) 2.5×10^{24} atoms
(f) 4.13×10^{26} MeV
(g) 6.6×10^{13} J

5 2.7×10^{12} J

6 (a) 3.6×10^{10} J
(b) 13 g

Practice questions

1 (a) (i) *fission*:
nucleus splits; into two parts of similar mass
radioactive decay:
nucleus emits;
a particle of small mass or a photon, or both (4)
(ii) $^{235}_{92}U + ^{1}_{0}n; \rightarrow ^{90}_{38}Sr + ^{142}_{54}Xe + 4^{1}_{0}n;$ (2)
Allow ECF for RHS if LHS is incorrect.
(iii) mass number unchanged; atomic number increases by +1 (2)
(b) (i) use of kinetic energy = $\frac{p^2}{2m}$ / equivalent;
correct conversion of MeV to joule (1.63×10^{-11} J);
correct conversion of mass to kilogram (1.50×10^{-25} kg);
momentum = 2.2×10^{-18} N s (4)
(ii) total momentum after fission must be zero; must consider momentum of neutrons (and photons) (2)
(iii) xenon not opposite to strontium but deviation < 30°);
arrow shorter / longer (2)
(c) (i) energy = $0.25 \times 198 \times 1.6 \times 10^{-13}$;
$= 7.9 \times 10^{-12}$ J (2)
(ii) use of $\Delta Q = mc\Delta T$;
energy = $0.25 \times 4200 \times 80$; = 8.4×10^4 J (3)
(iii) number of fissions = $\frac{(8.4 \times 10^4)}{(7.9 \times 10^{-12})}$;= 1.1×10^{16}
mass = $1.1 \times 10^{16} \times 3.9 \times 10^{-25}$; = 4.1×10^{-9} kg (4)

2 (a) (i) fission (1)
(ii) kinetic energy (1)
(b) the two neutrons can cause fission in two more uranium nuclei producing four neutrons so producing eight etc.; *OWTTE* (1)
(c) (i) the fuel rods contain a lot more ^{238}U than ^{235}U; neutron capture is more likely in ^{238}U than ^{235}U with high-energy neutrons; but if the neutrons are slowed they are more likely to produce fission in ^{235}U than neutron capture in ^{238}U (3)
The argument is a little tricky so be generous. The candidate needs to know about there being two isotopes present in the fuel and something about the dependence of the fission and capture in the two isotopes on neutron energy.
(ii) control the rate at which the reactions take place; by absorbing neutrons (2)
(d) *Look for four of the following main points and award* ***[1]*** *each.*
energy lost by the slowing of the neutrons and fission elements heats the pile; this heat extracted by the molten sodium / pressurized water / other suitable substance; which is pumped to a heat exchanger; water is pumped through the heat exchanger and turned to steam; the steam drives a turbine; which is used to rotate coils (or magnets) placed in a magnetic field (or close to coils) which produces electrical energy (4)
Alternatively, award ***[4]*** *for a good answer,* ***[2]*** *for a fair answer and* ***[1]*** *for a weak answer.*

3 A (1)

4 B (1)

5 B (1)

6 D (1)

7 B (1)

8 (a) energy required to completely separate the nucleons ***OR*** energy released when a nucleus is formed from its constituent nucleons (1)
Allow protons ***AND*** *neutrons.*
(b) the values in SI units would be very small (1)
(c) $140 \times 8.29 + 94 \times 8.59 - 235 \times 7.59$ ***OR*** 184 MeV (1)
(d) see energy = $180 \times 10^6 \times 1.60 \times 10^{-19}$
AND *mass* = $235 \times 1.66 \times 10^{-27}$;
7.4×10^{13} J kg^{-1} (2)
(e) energy produced in one day = $\frac{1.2 \times 10^9 \times 24 \times 3600}{0.36}$
$= 2.9 \times 10^{14}$ J;
mass = $\frac{2.9 \times 10^{14}}{7.4 \times 10^{13}}$ = 3.9 kg (2)
(f) specific energy of uranium is much greater than that of coal, hence more energy can be produced from the same mass of fuel / per kg ***OR*** less fuel can be used to create the same amount of energy (1)
(g) 39 (1)

(h) 75 s (1)

(i) ***ALTERNATIVE 1***

10 min = 8 $t_{1/2}$

mass remaining= $1.0 \times \left(\frac{1}{2}\right)^8 = 3.9 \times 10^{-3}$ kg (2)

ALTERNATIVE 2

decay constant = $\frac{\ln 2}{75} = 9.24 \times 10^{-3}\ \text{s}^{-1}$;

mass remaining = $1.0 \times e^{-9.24\times10^{-3}\times600}$

= 3.9×10^{-3} kg (2)

E.5

Exercises

1 (a) 3.27 MeV
(b) 4.03 MeV
(c) 18.4 MeV

2 4.2 light years

3 8 min 20 s

4 1.5×10^5 years

5 1.3 pc, 1.56 arcsec

6 40 pc

7 3.18 μm; too small to measure on photograph

8 Betelgeuse 1 (0.4)
Meissa 4 (3.5)
Bellatrix 2 (1.64)
Alnilam 3 (1.7)
Alnitak 3 (2)
Mintaka 3 (2.23)
Saiph 2 (2.09)
(actual magnitudes in brackets)

9 (a) $1.36 \times 10^3\ \text{W m}^{-2}$
(b) $3.2 \times 10^{-10}\ \text{W m}^{-2}$

10 (a) $1.2 \times 10^{-7}\ \text{W m}^{-2}$
(b) $7.9 \times 10^{-9}\ \text{W m}^{-2}$

11 5.6×10^3 light years

12 4.2×10^{30} W

13 (a) 7.25×10^3 K
(b) $1.6 \times 10^8\ \text{W m}^{-2}$

Practice questions

1 (a) a fusion reaction; since hydrogen nuclei are joining to create helium / any other relevant further detail / explanation (2)

(b) (i) atomic number: 6; mass number: 12 (2)
N.B. if 6 and 12 are reversed, ***[1]***.

(ii) mass before = $3 \times (6.648\,325 \times 10^{-27}$ kg)
= $1.994\,497\,5 \times 10^{-26}$ kg
mass of carbon = $1.993\,200\,0 \times 10^{-26}$ kg
so mass defect
= $1.994\,497\,5 \times 10^{-26} - 1.993\,200\,0 \times 10^{-26}$ kg
= $0.001\,297\,5 \times 10^{-26}$ kg ;
correct substitution into $E = mc^2$;
energy released
= 0.001 297 5 × 10–26 × 9.00 × 1016 J
= 1.17×10^{-12} J (3)

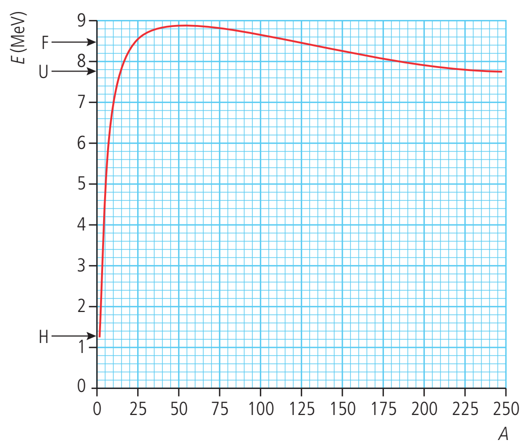
2 (a) (i) two (light) nuclei; combine to form a more massive nucleus; with the release of energy / with greater total binding energy (3)

(ii) high temperature means high kinetic energy for nuclei; so can overcome (electrostatic) repulsion (between nuclei); to come close together / collide; high pressure so that there are many nuclei (per unit volume); so that chance of two nuclei coming close together is greater (5)

3 (a) (i) a proton or a neutron (1)
Both needed to receive ***[1]***.

(ii) the difference between the mass of the nucleus and the sum of the masses of its individual nucleons / the energy required to separate a nucleus into its component nucleons / *OWTTE* (1)

(b)



Don't expect precision for any of these.

(i) F: between 8 and 9 (1)

(ii) H: between 1 and 2 (1)

(iii) U: between 7 and 8 (1)

(c) general overall shape; max at F = 56, end point U (2)

(d) mass of nucleons = (2 × 1.00728) + 1.00867 = 3.02323 u;
mass difference = 0.0072 u = 6.7 MeV;
binding energy per nucleon = $\frac{6.7}{3}$ = 2.2 MeV (3)

(e) (i) fusion (1)

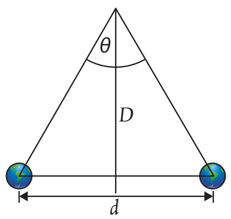
(ii) from the position on the graph, the energy required to assemble two nuclei of $^2_1$H is greater than that to assemble one nucleus of $^3_2$He; hence if two nuclei of $^2_1$H combine to form one nucleus of $^3_2$He energy must be released / *OWTTE* (2)

4 C (1)

5 B (1)

6 (a) the star is (much) closer than the other star (and close enough to Earth) / parallax effect has been observed (1)

(b) (1)



Award **[1]** *if all three (d, D, θ) are shown correctly.*
Do not allow d shown as the radius.
Accept D as a line from Earth to the star.

(c) $\sin\frac{\theta}{2} = \frac{d}{2D}$ **OR** $\tan\frac{\theta}{2} = \frac{d}{2D}$ **OR** $\theta = \frac{d}{D}$;
consistent explanation, *eg*: small angle of approximation yields $\theta = \frac{d}{D}$; (2)
Allow ECF from (b)(i), eg: if d shown as radius.

(d) any angular unit quoted for θ and any linear unit quoted for D (1)

7 (a) d = 275 pc (1)

(b) because of the difficulty of measuring very small angles (1)

8 (a) made of dust and/or gas **OR** formed from supernova **OR** can form new stars **OR** some radiate light from enclosed stars **OR** some absorb light from distant stars (1)

(b) $d = \frac{1}{8.32 \times 10^{-3}}$ **OR** 120 pc;
$120 \times 3.26 \times 3x10^8 \times 365x24 \times 3600$
$= 3.70 \times 10^{18}$ m (2)
Answer must be in meters, watch for POT.

(c) distances are so big/large **OR** to avoid using large powers of 10 **OR** they are based on convenient definitions (1)

9 (a) $\frac{L_V}{L_S} = \left(\frac{\sigma A_V [T_V]^4}{\sigma A_S [T_S]^4} = \right) \frac{\sigma [r_V]^2 [T_V]^4}{\sigma [r_S]^2 [T_S]^4}$;

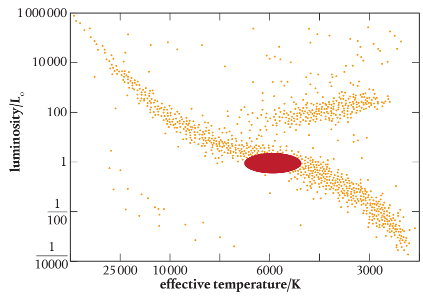
$\frac{1.54 \times 10^{28}}{3.85 \times 10^{26}} = \frac{[r_V]^2}{[r_S]^2} \times \frac{9600^4}{5800^4}$;

$r_V = \left(\sqrt{\frac{1.54 \times 10^{28}}{3.85 \times 10^{26}} \times \frac{5800^4}{9600^4}}\, r_S = \right) 2.3\, r_S$ (3)

Do not award third marking point if radius of the Sun is lost.

(b) obtain the spectrum of the star;
measure the position of the wavelength corresponding to maximum intensity;
use Wien's law (to determine temperature) *(allow quotation of Wien's equation if symbols defined)* (3)
Award **[3 max.]** *for referring to identification of temperature via different ionizations of different elements.*

10 (a) the letter S should be in the region of the shaded area (1)



(b) the fusion of hydrogen in the core eventually stops **OR** core contracts; the hydrogen in a layer around the core will begin to fuse; Sun expands AND the surface cools; helium fusion begins in the core; Sun becomes more luminous/brighter (max. 3)
Ignore any mention of the evolution past the red giant stage

(c) $\frac{L_W}{L_R} = \frac{10^{-4}}{10^4} = \frac{[r_W]^2}{[r_R]^2} \times \frac{3000^4}{10\,000^4}$;

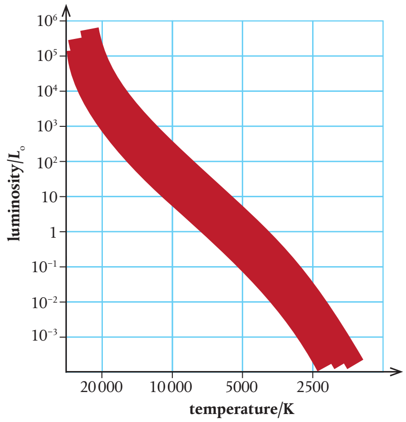
$\frac{r_W}{r_R} = \sqrt{\frac{10^{-4}}{10^4} \times \frac{3000^4}{10\,000^4}} = 9.0 \times 10^{-6}$ (2)

11 (a) photon/fusion/radiation force/pressure balances gravitational force/pressure; gives both directions correctly (outwards radiation, inwards gravity) (2)

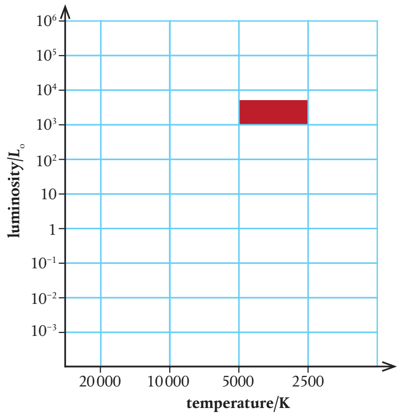
(b) $L_{Gacrux} = 5.67 \times 10^{-8} \times 4\pi \times (58.5 \times 10^9)^2 \times 3600^4$;
$L_{Gacrux} = 4.1 \times 10^{-29}$ W;
$\frac{L_{Gacrux}}{L_\odot} = \frac{4.1 \times 10^{29}}{3.85 \times 10^{26}} = 1.1 \times 10^3$ (3)

(c) if the star is too far then the parallax angle is too small to be measured **OR** stellar parallax is limited to closer stars (1)

(**d**) line or area roughly inside shape shown – judge by eye
Accept straight line or straight area at roughly 45° (1)



(**e**) at $10^3 L_\odot$, further to right than 5000 K and to the left of 2500 K (see shaded region) (1)



(**f**) ***ALTERNATIVE 1***
main sequence to red giant;
planetary nebula; with mass reduction/loss ***OR*** planetary nebula; with mention of remnant mass;
white dwarf (3)
ALTERNATIVE 2
main sequence to red supergiant region;
supernova; with mass reduction/loss ***OR*** supernova; with mention of remnant mass;
neutron star ***OR*** black hole (3)

12 (**a**) *core:* helium;
outer layer: hydrogen (2)

(**b**) line to the right of X, possibly undulating, very roughly horizontal (1)
Ignore any paths beyond this as the star disappears from diagram.

(**c**) $L = AT^4 = 5.67 \times 10^{-8} \times 4 \times (2.0 \times 10^4)^2 \times (10^6)^4$;
$L = 3 \times 10^{26}$ W OR $L = 2.85 \times 10^{26}$ W; (2)
Allow ECF for ***[1 max.]*** *if πr^2 used (gives 7×10^{26} W)*
Allow ECF for a POT error in ***MP1***.

(**d**) $\lambda = \frac{2.9 \times 10^{-3}}{10^6} = 2.9 \times 10^{-9}$ m;
this is an X-ray wavelength (2)

13 (**a**) A (1)

(**b**) The binding energy per nucleon of uranium is less than that of nuclei smaller than iron. Therefore, energy would overall have been transferred from the star to the uranium nucleons. (1)