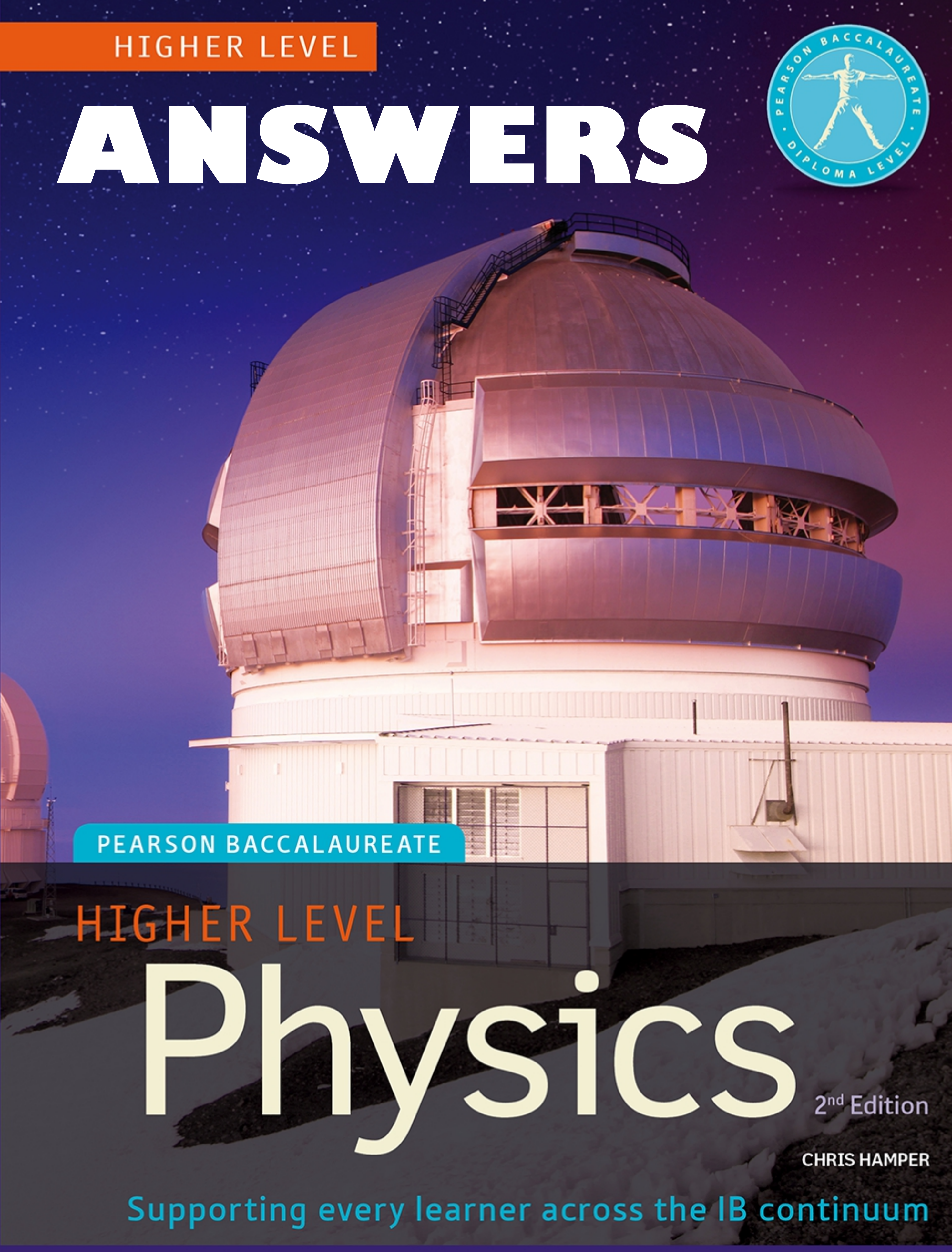
HIGHER LEVEL

ANSWERS

PEARSON BACCALAUREATE DIPLOMA LEVEL



PEARSON BACCALAUREATE

HIGHER LEVEL

Physics

2nd Edition

CHRIS HAMPER

Supporting every learner across the IB continuum

ALWAYS LEARNING

PEARSON

Answers

Chapter 1

Exercises

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

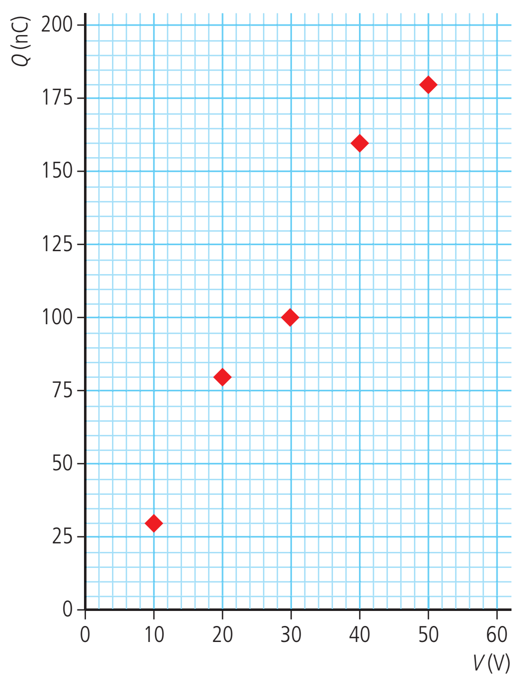
19 8.66 km

20 7.52 km

21 433 m

Practice questions

1 **(a)**



half area of graph paper at least to be used;
axis labels, including units;
scale;
data points; *((0, 0) need not be included)* [4]

(b) absolute uncertainty in Q at 10.0 V = ±3 nC;
absolute uncertainty in Q at 50.0 V = ±18 nC;

Or read from graph or elsewhere in the question and do not deduct unit mark.

correct placing on graph; [3]

(c) from top of error bar at (50, 180) to bottom of error bar at (10, 30);
use of at least half the line or algebraic indication;
value = 4.3 *or* 4.3×10^{-9}; [3]

Watch for ECF.

(d) $C\,V^{-1}$; [1]

Unit might be given in (c).

(e) recognize that the gradient $m = \frac{\varepsilon_0 A}{d}$;
therefore $\varepsilon_0 = \frac{dm}{A}$;
$= \frac{0.51 \times 10^{-3} \times 4.3 \times 10^{-9}}{0.15}$;
$= 1.5 \times 10^{-11}\,C\,V^{-1}\,m^{-1}$
($C^2\,N^{-1}\,m^{-2}$ – data book unit *or* $F\,m^{-1}$); [4]

[Total 15 marks]

2 C [1]

3 A [1]

4 C [1]

5 C [1]

6 C [1]

7 D [1]

8 B [1]

9 C [1]

10 **(a)** line of best fit is not straight / line of best fit does not go through origin; [1]

(b) smooth curve;
that does not go outside the error bars; [2]

Ignore extrapolations below n = 1.

(c) we can rewrite the suggested relation as $\log D = \log c + p \log n$;
now we can plot a graph of $\log D$ versus $\log n$;
the slope of the (straight line) graph is equal to p; [3]

Accept logs in any base.

(d) **(i)** absolute uncertainty in diameter D is $\pm 0.08\,cm$;
giving a relative uncertainty in D^2 of
$2 \times \frac{0.08}{1.26} = 0.13$ *or* 13%; [2]

*Award **[2]** if uncertainty is calculated for a different ring number.*

(ii) it is possible to draw a straight line that passes through the origin (and lies within the error bars);

or

the ratio of $\frac{D^2}{n}$ is constant for all data points; [1]

(iii) gradient = k;
calculation of gradient to give 0.23 *(accept answers in range 0.21 to 0.25)*;
evidence for drawing or working with lines of maximum and minimum slope;
answers in the form $k = 0.23 \pm 0.03$; [4]

Accept an uncertainty in k in range 0.02 to 0.04.
First marking point does not need to be explicit.

(iv) cm^2; [1]

[Total 14 marks]

Challenge yourself

1 $8 \pm 4\,m\,s^{-2}$

Answers

Chapter 2

Exercises

1 (a) $27.8\,\text{m s}^{-1}$ (b) $5.6\,\text{m s}^{-1}$

2 (a) $4.2\,\text{m s}^{-1}$ (b) $0\,\text{m s}^{-1}$
(c) $-4.2\,\text{m s}^{-1}$ (minus sign indicates travelling south) (d) 90 m

3 $22.4\,\text{m s}^{-1}$, 26.6°

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

5 $31.6\,\text{m s}^{-1}$

6 $49\,\text{m s}^{-1}$

7 $-30\,\text{m s}^{-1}$

8 40 m

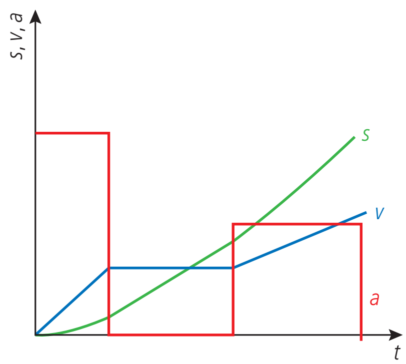
9 $3.6\,\text{m s}^{-1}$

10 4 s

11 125 m, $2.5\,\text{m s}^{-2}$

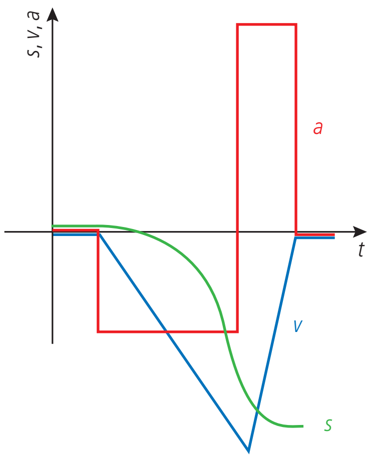
12 15 m

13

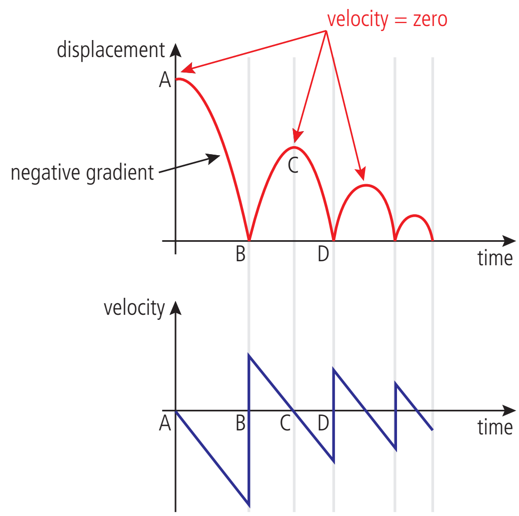


The displacement graph is quadratic in the first and last sections, and linear in between.

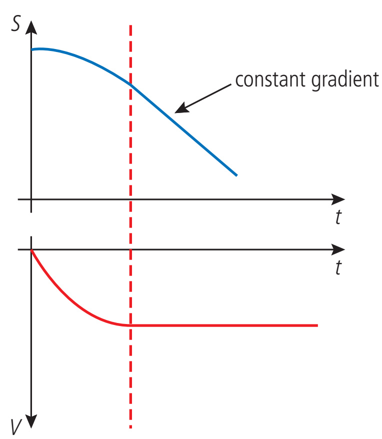
14



15



16



17 78 m

18 (a) 30° (b) 17.3 m

19 5 m

20 39.6 m

21 **(a)** 10 N to the right
(b) 5.8 N 31° above the horizontal, to the right

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

23 **(a)** –74 N to the left
(b) 45 N 63.4° above the horizontal, to the right

24 **(a)** 4 N down slope **(b)** 4 N, 37.6°

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

26 **(a)** $F = T \sin 30°$ **(b)** $10 = T \cos 30°$
(c) 11.5 N **(d)** 5.8 N

27 **(a)** $F = 50 \sin 30°$ **(b)** $50 \cos 30° = N$
(c) $F = 25$ N, $N = 43.3$ N

28 **(a)** $2T \cos 80° = 600$ N
(b) $T \sin 80° = T \sin 80°$
(c) 1728 N

29 –3 N s

30 –4.02 N s

31 6.7 m s^{-2}

32 997.5 N

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

34 2 m s^{-2}

35 682.5 N

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

37 **(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

38 **(a)** 9 m s^{-1} **(b)** –1 m s^{-1}
(c) 0.85 m s^{-1}

39 **(a)** 0.875 N s **(b)** 44 m s^{-1}

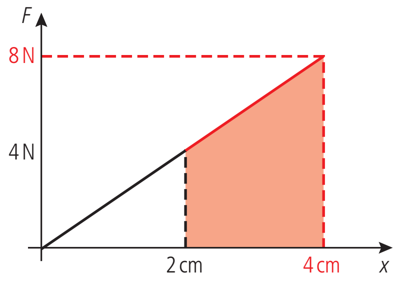
40 97.7 m

41 **(a)** –1300 J **(b)** dog

42 0 J

43 –300 J

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



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

45 1950 J

46 32 m s^{-1}

47 **(a)** 12.5 J **(b)** 12.5 J
(c) 1 cm

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

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

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

51 **(a)** 3.86×10^{5} J **(b)** 6.43×10^{5} J
(c) 1.8×10^{-2} I

52 **(a)** 1.25×10^{-4} J **(b)** 6.25×10^{-5} J
(c) 0.1 m s^{-1}

53 **(a)** –10.83 m s^{-1} **(b)** 521.3 J

54 velocities swap

55 800 W

56 1000 W

57 20 kW

58 50%

59 42 kJ

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

Practice questions

1 **(a)** **(i)** $18t$; [1]

(ii) $s = \frac{1}{2} \times 4.5 \times 6^2 = 81\,\text{m}$; [1]

(iii) $v = at = 6 \times 4.5 = 27\,\text{m s}^{-1}$; [1]

(iv) $27(t - 6)$; [1]

(b) idea of (a) (i) = (a) (ii) + (a) (iv);

$18t = 81 + 27(t - 6)$

$t = 9.0\,\text{s}$; [2]

[Total 6 marks]

2 **(a)** statement that gravitational mass and inertial mass have the same numerical value;

understanding of what gravitational mass means;

e.g. *'a quantity that determines the gravitational force on the object'*

understanding of what inertial mass means;

e.g. *'a quantity that determines the acceleration of the object'* [3]

(b) **(i)** acceleration = gradient of first section of graph;

acceleration = $\frac{0.80}{0.50} = 1.6\,\text{m s}^{-2}$; [2]

Accept bald correct answer for full marks.

(ii) total distance travelled by the lift = area under graph;

distance = $(11 \times 0.80) + (0.50 \times 0.80)$

$= 8.8 + 0.4 = 9.2\,\text{m}$; [2]

Accept bald correct answer for full marks.

(iii) minimum work done = PE gained (= force × distance);

work done = $2500 \times 9.2 = 23\,000\,\text{J}$

$= 23\,\text{kJ}$; [2]

Accept bald correct answer for full marks.

(iv) correct substitution into

power = $\frac{\text{work done}}{\text{time taken}}$

$= \frac{23\,000}{12}$;

$= 1916\,\text{W}$

$= 1.9\,\text{kW}$; [2]

(v) correct substitution into

efficiency = $\frac{\text{power out}}{\text{power in}}$

$= \frac{1.9}{5.0}$;

$= 0.38 = 38\%$; [2]

(c) graphs should show curving or 'shoulders' at the changes;

since acceleration must be finite / speed cannot change instantaneously / *OWTTE*; [2]

(d) *Mark parts (i) and (ii) together.*

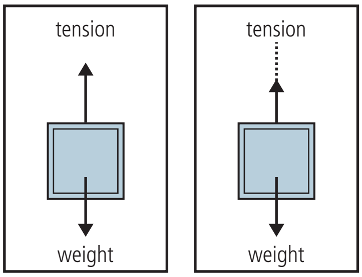
weight arrow the same in both diagrams;

magnitude of tension (size of arrow) **equal to** weight in (i);

magnitude of tension (size of arrow) **less than** weight in (ii);

(i) 0.50 to 11.50 s

(ii) 11.50 to 12.00 s

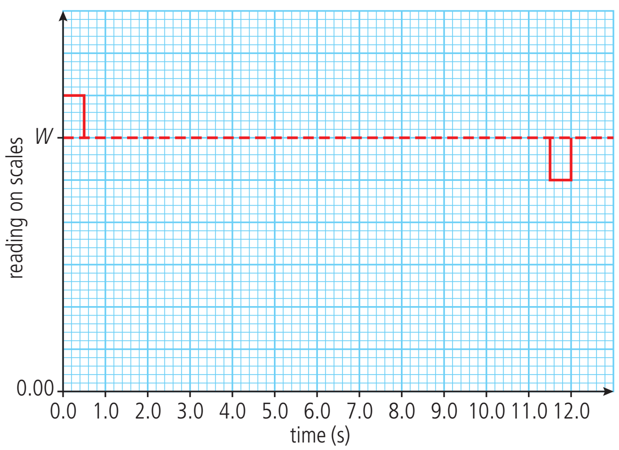


[3]

(e) a constant value **greater** than W from 0.00 to 0.50 s;

a constant value **equal** to W from 0.50 to 11.50 s;

a constant value **less** than W from 11.50 to 12.00 s;



[3]

(f) *[1] for each appropriate and valid point. Essentially [2] for journey up and [2] for journey down. Some explanation or justification is required for full marks* e.g.
the law of conservation of energy does apply to round trip;
energy is all dissipated into heat and sound;
on the way up, most electrical energy converted into gravitational PE, initially some electrical energy is converted into KE;
on the way down electrical energy does work 'braking' lift, some (not all) gravitational PE is converted into KE; [4]

Reject answers that imply that PE converts into KE as lift falls.

[Total 25 marks]

3 **(a)** **(i)** $h = \frac{v^2}{2g}$;
to give $h = 3.2\,\text{m}$; [2]

(ii) 0.80 s; [1]

(b) time to go from top of cliff to the sea
= 3.0 – (2 x 0.8) = 1.4 s;
recognize to use $s = ut + \frac{1}{2}at^2$ with correct substitution,
$s = 8.0 \times 1.4 + 5.0 \times (1.4)^2$;
to give $s = 21\,\text{m}$; [3]

Answers might find the speed with which the stone hits the sea from $v = u + at$, ($42\,\text{m s}^{-1}$) and then use $v^2 = u^2 + 2as$.

[Total 6 marks]

4 **(a)** when two bodies A and B interact, the force that A exerts on B is equal and opposite to the force that B exerts on A;

or

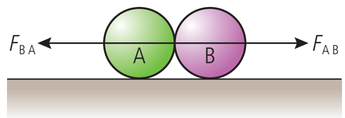
when a force acts on a body an equal and opposite force acts on another body somewhere in the Universe; [1]

Award [0] for 'action and reaction are equal and opposite' unless student explains what is meant by the terms.

(b) if the net external force acting on a system is zero;
then the total momentum of the system is constant (or in any one direction, is constant); [2]

To achieve [2] answers should mention forces and should show what is meant by conserved. Award [1] for a definition such as 'for a system of colliding bodies, the momentum is constant' and [0] for 'a system of colliding bodies, momentum is conserved'.

(c)



arrows of equal length;
acting through centre of spheres;
correct labelling consistent with correct direction; [3]

(d) **(i)** *ball B:*
change in momentum = mv_B;
hence $F_{AB}\Delta t = mv_B$; [2]

(ii) *ball A:*
change in momentum = $m(v_A - v)$;
hence from Newton 2,
$F_{BA}\Delta t = m(v_A - v)$; [2]

(e) from Newton 3, $F_{AB} + F_{BA} = 0$, **or** $F_{AB} = -F_{BA}$;
therefore $-m(v_A - v) = mv_B$;
therefore $mv = mv_B + mv_A$;
that is, momentum before equals momentum after collision such that the net change in momentum is zero (unchanged) / *OWTTE*; [4]

Some statement is required to get the fourth mark, i.e. an interpretation of the maths result.

(f) from conservation of momentum
$v = v_B + v_A$;
from conservation of energy $v^2 = v_B^{\,2} + v_A^{\,2}$;
if $v_A = 0$, then both these show that $v_B = v$;

or

from conservation of momentum
$v = v_B + v_A$;
from conservation of energy $v^2 = v_B^2 + v_A^2$;
so, $v^2 = (v_B + v_A) = v_B^2 + v_A^2 + 2v_A v_B$ therefore v_A has to be zero; [3]

Answers must show that, effectively, the only way that both momentum and energy conservation can be satisfied is that ball A comes to rest and ball B moves off with speed v.

[Total 17 marks]

5 (a) mass × velocity; [1]

(b) (i) momentum before = 800 × 5
= 4000 N s;
momentum after = 2000v;
conservation of momentum gives
$v = 2.0\,\text{m s}^{-1}$; [3]

(ii) KE before = 400 × 25 = 10 000 J
KE after = 1000 × 4 = 4000 J;
loss in KE = 6000 J; [2]

(c) transformed/changed into;
heat (internal energy) (and sound); [2]

Do not accept 'deformation of trucks'.

[Total 8 marks]

6 (a) ***Note:*** *for part (i) and (ii) the answers in brackets are those arrived at if 19.3 is used as the value for the height.*

(i) height raised = 30 sin 40 = 19 m;
gain in PE = mgh = 700 × 19
= 1.3×10^4 J (1.35×10^4 J); [2]

(ii) 48 × 1.3×10^4 J = 6.2×10^5 J
(6.5×10^5 J); [1]

(iii) the people stand still / don't walk up the escalator / their average weight is 700 N / ignore any gain in KE of the people; [1]

(b) (i) power required = $\frac{6.2 \times 10^5}{60}$ = 10 kW
(11 kW);

efficiency = $\frac{P_{out}}{P_{in}}$, $P_{in} = \frac{P_{out}}{\text{efficiency}}$;

P_{in} = 15 kW (16 kW); [3]

(ii) the escalator can in theory return to the ground under the action of gravity / *OWTTE*; [1]

(c) power will be lost owing to friction in the escalator / *OWTTE*; [1]

The location of the friction must be given to obtain the mark.

[Total 9 marks]

7 (a) the total momentum of a system is constant;
provided external force does not act; [2]

or

the momentum of an isolated /closed system;
is constant;
*Award **[1]** for momentum before collision equals collision afterwards.*

(b) (i) initial momentum = $2.0 \times 10^{-3} \times 140$;
final speed = $\frac{2.0 \times 10^{-3} \times 140}{5.6 \times 10^{-3} + 2.0 \times 10^{-3}}$;
= $4.8\,\text{m s}^{-1}$ [2]
Watch for incorrect mass values in equation.

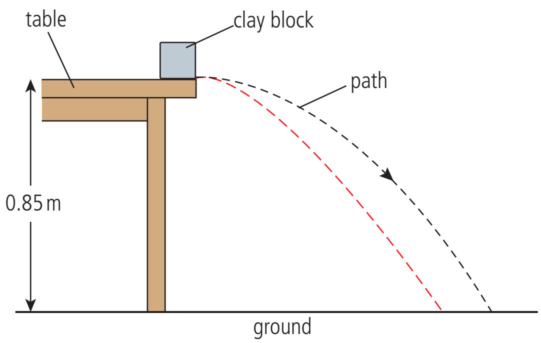
(ii) initial kinetic energy of pellet + clay block = $\frac{1}{2}mv^2$;
0.5 × 0.058 × 4.82 (= 0.67J);
force = $\frac{\text{work done}}{\text{distance travelled}}$;
= 0.24 N; [4]

or

use of appropriate kinematic equation with consistent sign usage e.g.
$a = \frac{u^2 - v^2}{2s}$;
$a = \frac{4.8^2}{2 \times 2.8}$;
$F = \frac{0.058 \times 4.8^2}{2 \times 2.8}$
= 0.24 N;

(c) (i) use of kinematic equation to yield time;
$t = \sqrt{\frac{2s}{g}}$ (= 0.41 s);
s = horizontal speed × time;
= 1.8 m; [4]
Accept g = 10 m s^{–2}; equivalent answers 1.79 from 9.8, 1.77 from 10.

(ii)



initial drawn velocity horizontal; (judge by eye) reasonable shape;
horizontal distance moved always decreasing when compared with given path / range less than original; [3]

[Total 15 marks]

Challenge yourself

1 53 m

2 1.7 m s^{-1}

Answers

Chapter 3

Exercises

1 **(a)** $7.12 \times 10^{-6}\,m^3$
(b) 6.022×10^{23} atoms
(c) $1.2 \times 10^{-29}\,m^3$

2 27 g

3 **(a)** 3.92×10^3 J **(b)** 3.92×10^3 J

4 1.8×10^6 J

5 3.7×10^4 J

6 67.6 J, 13.5 N

7 10°C

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

9 420 kJ

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

11 1.33×10^4 J

12 **(a)** 1 kg **(b)** 3.36×10^5 J
(c) 336 s

13 **(a)** 3×10^5 J **(b)** 686.7°C

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

15 **(a)** 80 kg **(b)** 1.34×10^7 J

16 3.35×10^{11} J

17 1.135×10^3 s

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

19 292 kPa

20 **(a)** 6 kPa **(b)** 3 kPa

21 $312.5\,cm^3$

22 400 kPa

Practice questions

1 **(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 PE of the molecules;
Accept something like 'breaking the molecular bonds'.
KE of the molecules remains constant, hence temperature remains constant; [3]
If KE mentioned but not temperature then assume students know that temperature is a measure of KE.

(c) **(i)** time for water to go from 0 to 15°C = 30 s;
energy required = $mc\Delta\theta$
= $0.25 \times 15 \times 4200 = 15750$ J;
power = $\frac{\text{energy}}{\text{time}} = 525\,W \approx 530\,W$; [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]

[Total 12 marks]

2 **(a)** more energetic molecules leave surface;
mean kinetic energy of molecules in liquid decreases;
and mean kinetic energy depends on temperature; [3]

*Award **[2]** if mean not mentioned.*

(b) *e.g.* larger surface area;
increased draught;
higher temperature;
lower vapour pressure; [2]

*Award **[1]** if candidate merely identifies two factors.*

(c) energy to be extracted = 0.35 × 4200 × 25;
+ 0.35 × 330 000;
+ 0.35 × 2100 × 5;
= 156 000 J

time = $\frac{156000}{86}$ = 1800 s; [4]

Allow ECF if one term incorrect or missing.

[Total 9 marks]

3 **(a)** ***[1]** for each appropriate and valid point e.g.*
thermal energy is the KE 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 KE 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 $\Delta\theta = \frac{2.2 \times 10^6}{(4200 \times 70)}$ K;
= 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 via 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 KE of the sample left has fallen;
a fall in average KE is the same as a fall in temperature; [3]

(ii) energy lost by evaporation
= 50% × 2.2×10^6 J;
= 1.1×10^6 J;
correct substitution into $E = ml$
to give mass lost $= \frac{1.1 \times 10^6\ \text{J}}{2.26 \times 10^6\ \text{J kg}{-1}}$
= 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 etc.; [4]

[Total 25 marks]

4 **(a)** **(i)** $F = Mg \sin\theta$
= 960 × 9.8 × 0.26;
= 2.4×10^3 N [2]

(ii) KE = $\left(\frac{1}{2}mv^2\right)$ = (480 × 81) = 3.9 × 10^4 J; [1]

(b) KE = Fs;
to give F = 2.6 × 10^3 N; [2]
*Award **[1]** if $v^2 = 2as$ is used.*

(c) recognize that *KE* = mass × specific heat × rise in temperature;
$\frac{3.9 \times 10^4}{2 \times 900 \times 5.2}$;
= 4.2 K;
Award full marks for bald correct answer.

no energy / heat loss to the surroundings / energy distributed evenly in each brake; [4]

[Total 9 marks]

5 **(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)** $n = \frac{PV}{RT}$;
n = 0.18 mol; [2]
*Award **[2]** for bald correct answer.*

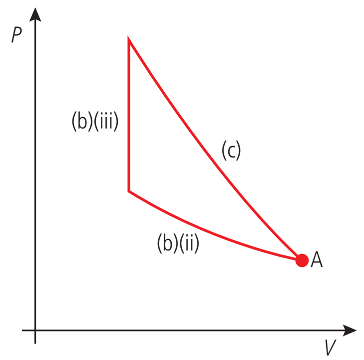
(ii) show use of PV = constant;
19 × 10^5 Pa; [2]
*Award **[2]** for bald correct answer.*

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

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

[Total 13 marks]

Challenge yourself

1 P = 114.3 kPa

Answers

Chapter 4

Exercises

1 **(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}

2 1389 N

3 15.8 m s^{-1}

4 14 m s^{-1}

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

6 1.61 m s^{-2}

7 24.7 N kg^{-1}

8 7.34 N kg^{-1}

9 6.69×10^{-8} N kg^{-1}

10 0 N kg^{-1}

11 30 J kg^{-1}

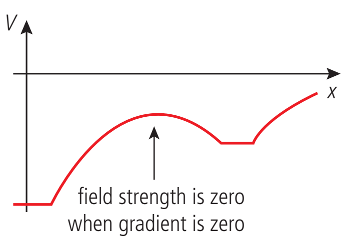
12 90 J

13 240 J

14 0 J

15 0 J

16 **(a)** 1.6 MJ kg^{-1} **(b)** 3.1×10^9 J
(c) and **(d)**



17 2.38×10^3 m s^{-1}

18 Hydrogen would escape.

19 3 km

20 2.74 km s^{-1}

21 graph of T^2 vs r^3

22 4.2×10^7 m

23 1.5 hours

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

Practice questions

1 **(a)** *Look for an answer on the following lines:*
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 PE = 0.05 × 10 × (0.8 – 0.35);
= gain in KE = $\frac{1}{2}mv^2$;
to give v = 3.0 m s^{-1};

or

use of $v = 2gh$ to give v = 4.0 m s^{-1} at point B;
and then use of $v^2 - u^2 = \sqrt{2gh}$ with v = 4.0 m s^{-1} and h = 0.35 m;
to get u = 3.0 m s^{-1}; [3]
Do not penalize the candidate if g = 9.8 m s^{-2} is used.

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

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

$N = \frac{mv^2}{r} - mg$;

$= 2.6 - 0.5 = 2.1\,\text{N}$; [4]

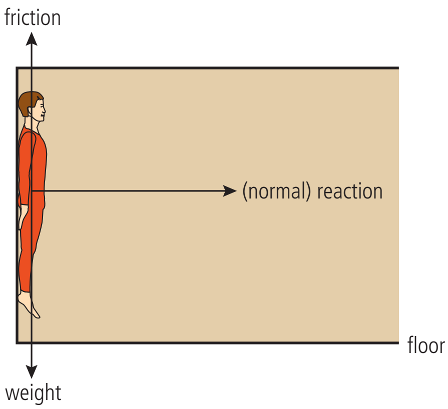
[Total 12 marks]

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 labelled to show understanding.* [3]



Use benefit of the doubt and accept things like 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, $F = mg = 800\,\text{N}$;

$R = \frac{F}{\mu}$ or $R = \frac{800}{0.4} = 2000\,\text{N}$; [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: $v = 12.247$

$\approx 12\,\text{m}\,\text{s}^{-1}$; [2]

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

[Total 10 marks]

3 (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) $\text{KE} = m\Delta V$;

$\text{KE} = 1500 \times (4.6 - 0.20) \times 10^7$;

$\text{KE} = 6.6 \times 10^{10}\,\text{J}$; [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.)*

[Total 8 marks]

4 (a) (i) $V_{surface} = -6.3\ (\pm 0.3) \times 10^7\,\text{J}\,\text{kg}^{-1}$ [1]

(ii) V_h is at $R = 42 \times 10^6\,\text{m}$;

$= -1.0\ (\pm 0.2) \times 10^7\,\text{J}\,\text{kg}^{-1}$; [2]

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

(b) $\Delta V = 5.3\ (\pm 0.5) \times 10^7\,\text{J}\,\text{kg}^{-1}$;

Energy = $m\Delta V$;

$= 5.3\ (\pm 0.5) \times 10^{11}\,\text{J}$; [3]

Award ***[2]*** *if student calculates the PE 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 KE) to go into orbit;

rocket motors lifting rocket not 100% efficient;

air resistance in initial stages of launch; [2]

[Total 8 marks]

5 (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]

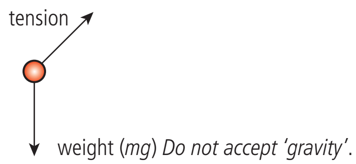
(ii) kinetic energy is $\frac{GMm}{2r}$; addition to potential energy $-\frac{GMm}{r}$ to get result; [2]

(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.*

[Total 7 marks]

6 (a) (i) 1 each for correct arrow <u>and</u> (any reasonable) labelling; [2]



*Award **[1]** for arrows in correct direction but not starting at the ball.*

(ii) no; because the two forces on the ball can never cancel out / there is a net force on the ball / the ball moves in a circle / the ball has acceleration / it is changing direction;
*Award **[0]** for correct answer with no or wrong argument.* [2]

(b) $T\left(= \frac{mg}{\cos 30°}\right) = 2.83\,\text{N}$;

$\frac{mv^2}{r} = T \sin 30°$;

$v = \left(\sqrt{\frac{Tr \sin 30°}{m}} = \sqrt{\frac{2.832 \times 0.33 \times \sin 30°}{0.25}}\right)$

$= 1.4\,\text{m}\,\text{s}^{-1}$;

or

$T \cos 30° = mg$;

$T \sin 30° = \frac{mv^2}{r}$;

$v = (\sqrt{gr \tan 30°} = \sqrt{9.81 \times 0.33 \times \tan 30°})$

$= 1.4\,\text{m}\,\text{s}^{-1}$; [3]

[Total 7 marks]

Challenge yourself

1 $72\,\text{km}\,\text{h}^{-1}$, $241\,\text{km}\,\text{h}^{-1}$

Answers

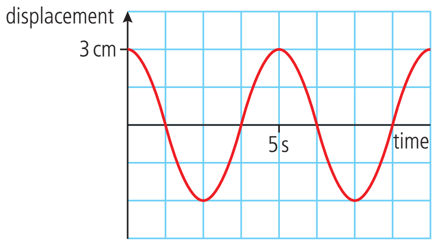
Chapter 5

Exercises

1 b

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

11 280 m s^{-1}

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

13 1.2 m s^{-1}

14 (a) 182.6 m s^{-1} (b) 143.8 Hz

15 54 N

16 812.5 Hz

17 (a) 1.7 Hz (b) 0.24 m
(c) 24°

18 35°

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

20 170 Hz

21 (a) 33.2 cm (b) 2

22 (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

23 331.5 m s^{-1}

24 317.6 Hz

25 29°

26 15°

27 2×10^8 m s^{-1}

28 42°

29 27°

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

31 0.11 m

32 88 μm

33 7×10^7 m

34 14.6 m

35 No, 0.0001 rad < 0.00014 rad

36 9 cm

37 6 cm

38 (a) 3.3 μm (b) 12.2°

39 982 lines

40 150 nm

41 95 nm

42 **(a)** no change **(b)** 387 nm

(c) 97 nm

43 104 nm

44 0.06c

45 4.38 nm

46 $\frac{I_0}{8}$

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 $v = 660 \times 0.5 = 330\,\text{m s}^{-1}$; [2]

[Total 5 marks]

2 **(a)** **ray:** direction in which wave (energy) is travelling;
wavefront: line joining (neighbouring) 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);
$= \frac{3.0}{1.5} = 2.0$ *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 $v = 4.0\,\text{m s}^{-1}$ accept ± 0.2;
$= 140 \times 0.4 \times 0.1 \times 10^{-3}$;
$= 5.6 \times 10^{-3}\,\text{m}$ [2]

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

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

Allow distance moved in 1.5 ms.

[Total 17 marks]

3 **(a)** **(i)** distance travelled 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 (left hand) 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.

(e) **(i)** illustration showing node at centre, antinode at each end; [1]

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

or

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

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

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

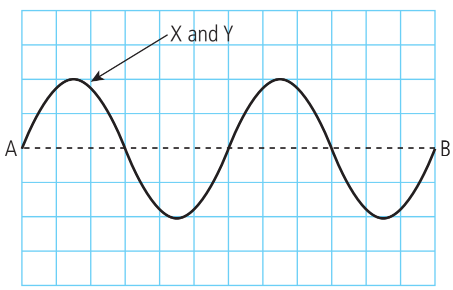
[Total 25 marks]

4 **(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]

(c) **(i)** the phase difference between light leaving S_1 and S_2 is constant; [1]

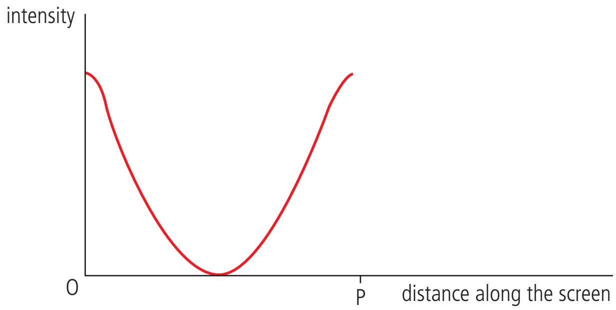
Do not penalize candidates if they state 'has the same phase'.

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

(d) **(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]

(e) fringe spacing = $2.5 \times 10^{-4}\,\text{m}$;

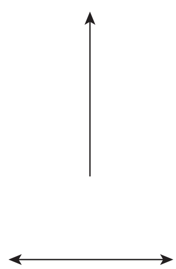
$\lambda = \frac{(2.5 \times 10^{-4} \times 3.00 \times 10^{-3})}{1.50} = 5.0 \times 10^{-7}\,\text{m}$;

[2]

[Total 14 marks]

5 Wave properties

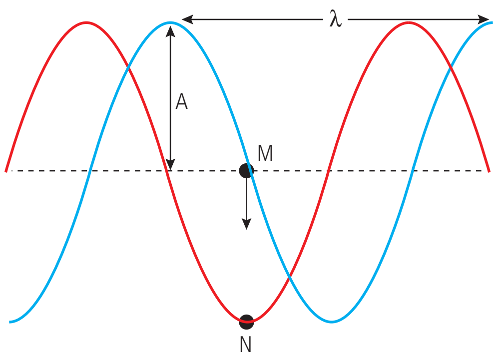
(a) **(i)** [1]



(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

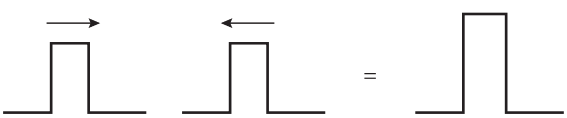
in $\frac{T}{4}$ wave moves forward $\frac{1}{4}\lambda$;

$= \frac{5}{4} = 1.25\ (1.3)$ 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]

[Total 24 marks]

6 (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) $\lambda' = \lambda\frac{(V-v)}{V}$;

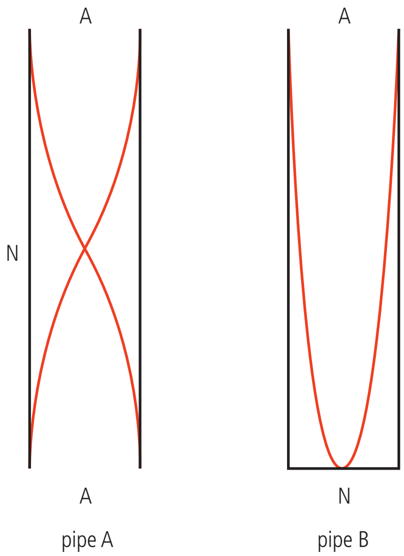
$599.996 = \frac{600 \times (3 \times 10^8 - v)}{3 \times 10^8}$;

$v = 2000\ \text{m s}^{-1}$; [3]

Allow alternative version for red shift.

[Total 9 marks]

7



(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.*

[Total 9 marks]

8 **(a)** **(i)** diffraction at the lens; [1]

(ii) circular patch – bright;
circular bright ring/darkness between patch and ring; [2]

(b) **(i)** $a = \frac{4.0 \times 10^{-6}}{17 \times 10^{-3}}$;
$= 2.4 \times 10^{-4}$ rad; [2]

(ii) $1.22\frac{\lambda}{d} = 2.4 \times 10^{-4}$ therefore
$d = \frac{1.22 \times 550 \times 10^{-9}}{2.4 \times 10^{-4}}$;
$d = 2.8$ mm; [2]

Award ***[2]*** *even if factor 1.22 is missing.*

Part (iii) is an error.

[Total 7 marks]

Challenge yourself

1 $T = 0.6$ s

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

Answers

Chapter 6

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} ms^{-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 Vm^{-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

23 (a) 7.1×10^{-6} m^{3}
(b) 8.5×10^{28} m^{-3}
(c) 9.4×10^{-5} m s^{-1}

24 3.7×10^{-4} m

25 10.8 Ω

26 3 kΩ

27 0.3 V

28 0.02 A

29 100 kΩ, 100 kΩ, 25 kΩ

30 1 Ω

31 11.5 V

32 (a) 500 J
(b) 3×10^{4} J

33 0.031 W

34 0.5 W

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

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

37 (a) 0.45 A
(b) 20 J

38 (a) 4.5 A
(b) 1.8×10^{7} J

39 $\frac{16}{3}\,\Omega$

40 8 Ω

41 $28\,\Omega$

42 $\frac{16}{7}\,\Omega$

43 0.5 A, 5 V

44 3 A, 3 V

45 1.5 A, 6 V

46 3 A, 6 V

47 2.4 V, 3.0 V, 20%

48 1.7 A, 2.0 A, 15%

49 4.8 V

50 3 A, 1.5 V

51 0.44 V

52 0.49 V

53 (a) 2×10^{-5} N
(b) east

54 (a) 5×10^{-6} N
(b) west

55 (a) up
(b) right
(c) up

56 4×10^{-19} N

57 (a) 8.0×10^{-17} J
(b) 1.3×10^{7} m s^{-1}
(c) 7.4×10^{-4} T

58 4×10^{-20} N

59 (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

60 (a) 1×10^{-6} Tm^{2}
(b) 0.25×10^{-6} Tm^{-2} s^{-1}
(c) 0.25 μV

61 (a) 1.5×10^{-5} Tm^{2}
(b) 1.3×10^{-5} Tm^{2}
(c) 0.67 μV

62 156 V

63 18 A

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

65 $48.4\,\Omega$

66 (a) 10
(b) 2 W
(c) 9.2 mA
(d) 0 A

67 (a) 5×10^{3} A
(b) 200 MW
(c) 40%
(d) 300 MW
(e) 300 MW
(f) 1.36 MA

68 1.39×10^{-11} F

69 2.78×10^{-10} F

70 8.85×10^{-9} F

71 1.2×10^{-5} C

72 (a) 2.67 μF
(b) 12 μF

73 4 V

74 9 V

75 2.03×10^{-4} J

76 (a) 1.39×10^{-10} F
(b) 8.34×10^{-10} C
(c) 2.5×10^{-9} J
(d) 5×10^{-9} J, work is done pulling plates apart.

77 8×10^{-11} V

78 **(a)** 50 s
(b) 50 mC
(c) 6.7 V
(d) 1 mA
(e) 35 s

79 **(a)** yes
(b) 1×10^{-5} A
(c) 3.35 V

Practice questions

1 **(i)** use of emf = $\frac{\text{energy}}{\text{charge}}$;
$= \frac{(8.1 \times 10^3)}{(5.8 \times 10^3)}$
= 1.4 V; [2]
*Award **[0]** for formula $E = \frac{F}{Q}$ seen or implied even if answer is numerically correct.*

(ii) pd across internal resistance = 0.2 V;

or

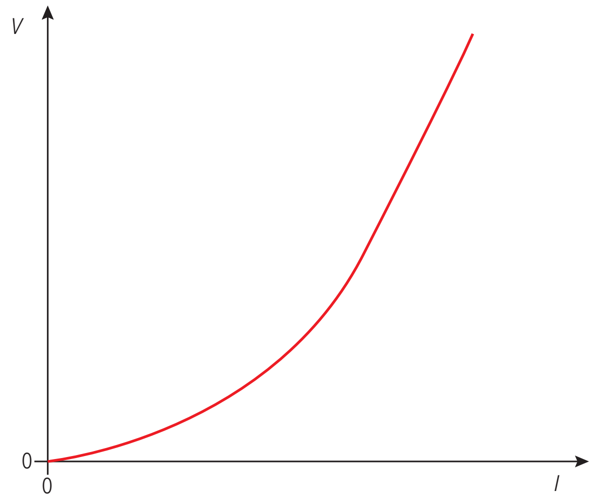
current = $\frac{1.2}{6}$ = 0.2 A;
resistance $r = \left(\frac{0.2}{1.2}\right) \times 6.0$;
total resistance = $\frac{1.4}{0.2}$ = 7.0 Ω;
= 1.0 Ω;
internal resistance = 7 – 6 = 1.0 Ω; [3]
Accept any other valid route.

(iii) idea of use of ratio of resistances;
energy transfer = $\frac{6}{7} \times 8.1 \times 10^3$
= $6.9(4) \times 10^3$ J; [2]
Accept any other valid route.

(iv) charge carriers/electrons have kinetic energy / are moving;
these carriers collide with the lattice/lattice ions *(do not allow friction)*;
causing increased (amplitude of) vibrations;
this increase seen as a temperature rise;
i.e. a transfer to thermal energy; [5]
Allow any other relevant and correct statements.

[Total 12 marks]

2 **(a)**



Any reasonable curve in the right direction.
[1]

(b) **(i)** from the value of $\frac{V}{I}$ at any point on the curve; [1]
Do not accept just 'from $\frac{V}{I}$'.

(ii) non-ohmic because the resistance ($\frac{V}{I}$ at each point) is not constant / *OWTTE*; [1]

(c) **(i)** 50 Ω; [1]

(ii) recognize that the voltage must divide in the ratio 3 : 1;
to give R = 150 Ω; [2]
Or answer could be solved via the current.

[Total 6 marks]

3 **(a)** **(i)** when connected to a 3 V supply, the lamp will be at normal brightness;
and energy is produced in the filament at the rate of 0.60 W;
Look for the idea that 3 V is the operating voltage and the idea of energy transformation.

or

when connected to a 3 V supply, the lamp will be at normal brightness;
and the resistance of the filament is 15 Ω / the current in the filament is 0.20 A; [2]

(ii) $I = \frac{P}{V}$;

to give I = 0.20 A; [2]

(b) **(i)** at maximum value, the supply voltage divides between the resistance of the variable resistor, the internal resistance, and the resistance of the filament;

i.e. response must show the idea of the voltage dividing between the various resistances in the circuit. Do not penalize if responses do not mention internal resistance here.

at zero resistance, the supply voltage is now divided between the filament resistance and the internal resistance of the supply; [2]

(ii) when resistance of variable resistor is zero, emf = $Ir + V_{lamp}$;

3.0 = 0.2 r + 2.6;

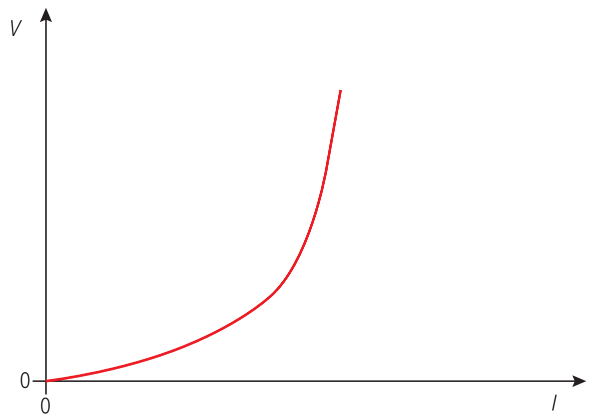
to give r = 2.0 Ω; [3]

(c) **(i)** 3.3 Ω; [1]

(ii) 13 Ω; [1]

(d) at the higher pd, greater current, and therefore hotter; the resistance of a metal increases with increasing temperature; *OWTTE*; [2]

(e)



correct approximate shape (i.e. showing increasing gradient with increasing V); [1]

(f) parallel resistance of lamp and YZ is calculated from $\frac{1}{R} = \frac{1}{4} + \frac{1}{12}$;

to give R = 3.0 Ω;

3.0 V therefore divides between 3.0 Ω and 12.0 Ω;

to give pd across the lamp = 0.60 V;

Give relevant credit if answers go via the currents i.e.

calculation of total resistance = 15.0 Ω;

total current = 0.20 A;

current in lamp = 0.15 A; [4]

[Total 18 marks]

4 **(a)** **(i)** EI; [1]

(ii) I^2r; [1]

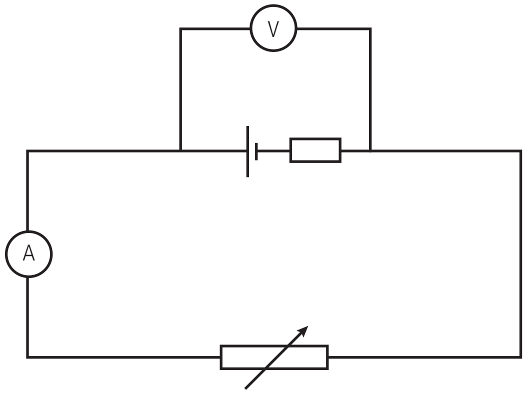
(iii) VI; [1]

(b) (from the conservation of energy),

$EI = I^2r + VI$;

therefore, $V = E - Ir$; $E = V + Ir$; [2]

(c)



correct position of voltmeter;

correct position of ammeter;

correct position of variable resistor; [3]

(d) **(i)** $E = V$ when $I = 0$;

so E = 1.5 V; [2]

(ii) recognize this is when $V = 0$;

intercept on the x-axis = 1.3 (±0.1) A; [2]

(iii) r is the slope of the graph;

sensible choice of triangle, at least half the line as hypotenuse;

$= \frac{0.7}{0.6}$;

= 1.2 (±0.1) Ω

or

when $V = 0$, $E = Ir$;

$r = \frac{E}{I}$

$= \frac{1.5}{1.3}$;

$= 1.2\,\Omega$ [3]

(e) $R = 1.2\,\Omega$;

$I = \frac{1.5}{1.2 + 1.2} = 0.63\,A$;

$P = I^2R = (0.63)^2 \times 1.2 = 0.48\,W$; [3]

[Total 18 marks]

5 **(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]

[Total 14 marks]

6 **(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]

[Total 10 marks]

7 A [1]

8 C [1]

Challenge yourself

1 3 cm

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

3 $\Delta E = 96\,\mu J$

Answers

Chapter 7

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 10

6 13.06 eV, 3.15×10^{15} Hz

7 0.31 eV, 7.44×10^{13} Hz

8 13.6 eV, 3.28×10^{15} Hz

9 5.3×10^{-11} m

10 2.5×10^{15} Hz

11 (a) 100 eV
(b) 1.6×10^{-17} J
(c) 1.2×10^{-10} m

12 4.4×10^{-38} m; the opening is too small

13 8.6×10^{9} eV

14 2.2×10^{-12} kg

15 (a) 500 eV
(b) 8×10^{-17} J
(c) 8.9×10^{-34} kg
(d) 500 eV c^{-2}

16 (a) 17 p, 18 n
(b) 28 p, 30 n
(c) 82 p, 122 n

17 4.16×10^{-18} C, 9.04×10^{-26} kg

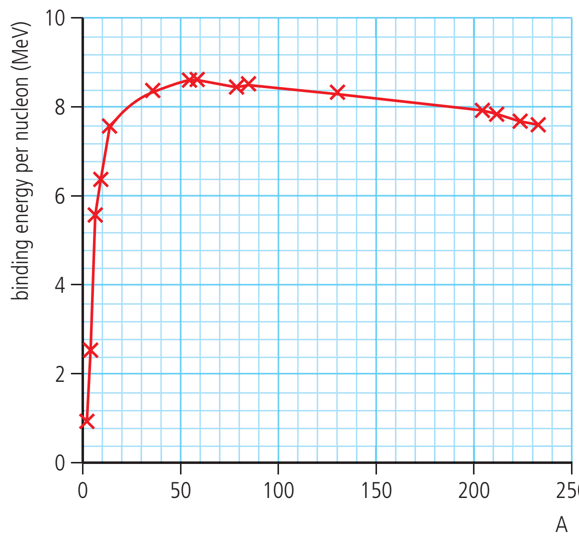
18 $^{235}_{92}U$

19 92 protons, 146 neutrons

20 (a) 1.9×10^{7} m s^{-1}
(b) 4.9×10^{-15} m

21 (a) 92 p, 141 n
(b) 234.9405 u
(c) 1.901 u
(d) 1771 MeV
(e) 7.60 MeV

22



23 8.95 MeV

24 Mass of At is bigger than Po so no energy released.

25 2.32 MeV

26 1.0×10^{19} Hz

27 12.5 g

28 12.5 s^{-1}

29 24 000 years

30 7.45 Bq

31 28.6 years

32 (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

33 (a) 3.27 MeV

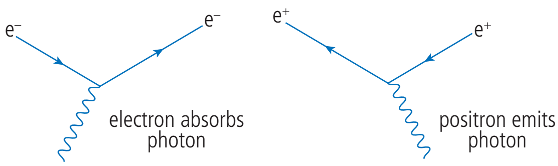
(b) 4.03 MeV

(c) 18.4 MeV

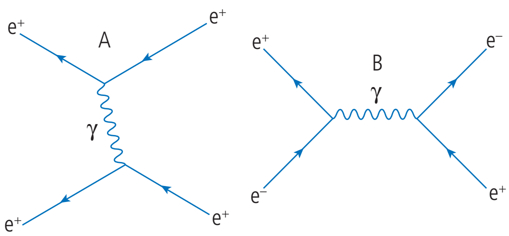
34 10, 133.9 MeV

35 135.8 MeV

36



37



(a) Positron emits photon that is absorbed by another positron.

(b) Electron and positron annihilate to form photon which forms an electron positron pair.

38 yes

39 no

40 yes

41 yes

42 yes

43 no

44 no

45 (a) $d\bar{u}$

(b) *sss*

(c) *ssd*

(d) *ssu*

46 $d \rightarrow u$

47 (a) X quark is down red

(b) Y is gluon red antigreen, Z quark is up

48 X is W^{+} and Y is a neutrino

49 X is W^{-} and Y is an antineutrino

50 Z^{0}

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 $E = \frac{hc}{\lambda}$;

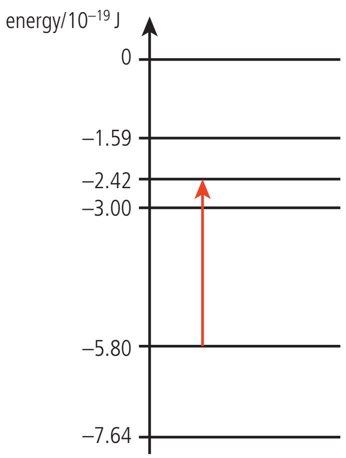
$E = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{5.88 \times 10^{-7}}$;

$= 3.38 \times 10^{-19}$ 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 re-radiation in random directions. The final mark is for identifying the energy levels concerned.*

This can also just be shown on a diagram.



(c) *Mark (i) and (ii) together.* ***[1]*** *for each relevant point e.g.*
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;
Schrödinger considers electron 'probability' waves;
only some standing waves fit the boundary conditions;
and these fix the available energies for the electron; [6]

N.B. ***[4]*** *for any one of the models.*

(d) a fusion reaction;
since hydrogen nuclei are joining to create helium / any other
relevant further detail / explanation; [2]

(e) **(i)** atomic number: 6;
mass number: 12; [2]

N.B. if 6 and 12 are reversed, ***[1]****.*

(ii) mass before

$= 3 \times (6.648\,325 \times 10^{-27}\,\text{kg})$

$= 1.994\,497\,5 \times 10^{-26}\,\text{kg}$

mass of carbon

$= 1.993\,200\,0 \times 10^{-26}\,\text{kg}$

so mass defect

$= 1.994\,497\,5 \times 10^{-26}$

$- 1.993\,200\,0 \times 10^{-26}\,\text{kg}$

$= 0.001\,297\,5 \times 10^{-26}\,\text{kg}$;
correct substitution into $E = mc^2$;
energy released
$= 0.001\,297\,5 \times 10^{-26} \times 9.00 \times 10^{16}\,\text{J}$
$= 1.17 \times 10^{-12}\,\text{J}$; [3]

(f) **(i)** an (electron) antineutrino; [1]

Reject 'neutrino'.

(ii) idea that there is a fixed total energy of decay;
total energy shared between the (three) resulting particles / *OWTTE*; [2]

(iii) correct calculation of decay constant λ;
$\lambda = \frac{\ln 2}{0.82} = 0.845$
correct substitution into $N = N_0 e^{-\lambda t}$;
to give $N = N_0 e^{-8.45}$ therefore $\frac{N}{N_0} = e^{-8.45}$
$= 0.000\,213 = 0.02\%$; [3]

N.B. Award attempts without full equation ***[1]****.*

(iv) a down quark changes into an up quark;
any other relevant detail; [2]

E.g. this involves the weak interaction / statement of quark content of proton (uud) or neutron (udd).

[Total 30 marks]

2 **(a)** *Deduct* ***[1]*** *for each error or omission, stop at zero.*

Property	Effect on rate of decay		
	Increase	Decrease	Stays the same
Temperature of sample			✓
Pressure on sample			✓
Amount of sample	✓		

[2]

(b) **(i)** ${}^{4}_{2}\text{He}$ / ${}^{4}_{2}\alpha$;

${}^{222}_{86}\text{Rn}$; [2]

(ii) mass defect = 5.2×10^{-3} u;

energy = mc^2

$= \dfrac{5.2 \times 10^{-3} \times 1.661 \times 10^{-27} \times 9.00 \times 10^{16}}{1\,\text{u}}$

= 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) $0 = m_\alpha v_\alpha + m_{\text{Rn}} v_{\text{Rn}}$;

$\dfrac{v_\alpha}{v_{\text{Rn}}} = -\left(\dfrac{m_{\text{Rn}}}{m_\alpha}\right)$

$= -\dfrac{222}{4} = -55.5$; [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 $\dfrac{1}{55.5}$ of kinetic energy of α particle; [3]

Accept alternative approaches.

(d) *e.g.* (γ ray) photon energy or radiation; [1]

(e) (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]

[Total 25 marks]

3 (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) ${}^{235}_{92}\text{U} + {}^{1}_{0}\text{n}$;

$\rightarrow {}^{90}_{38}\text{Sr} + {}^{142}_{54}\text{Xe} + 4{}^{1}_{0}\text{n}$; [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 = $\dfrac{p^2}{2m}$ / 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 = $0.25 \times 198 \times 1.6 \times 10^{-13}$;

= 7.9×10^{-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 = $\dfrac{(8.4 \times 10^4)}{(7.9 \times 10^{-12})}$;

= 1.1×10^{16}

mass = $1.1 \times 10^{16} \times 3.9 \times 10^{-25}$;

= 4.1×10^{-9} kg; [4]

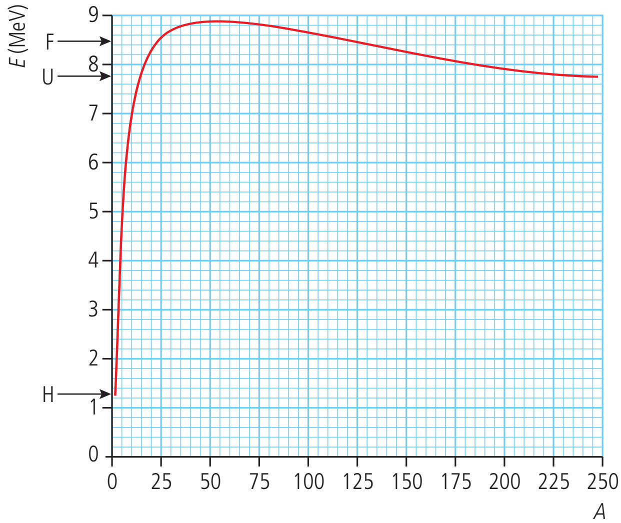
[Total 25 marks]

4 (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
$= (2 \times 1.00728) + 1.00867$
$= 3.02323\,\text{u}$;
mass difference $= 0.0072\,\text{u} = 6.7\,\text{MeV}$;
binding energy per nucleon $= \frac{6.7}{3}$
$= 2.2\,\text{MeV}$; [3]

(e) **(i)** fusion; [1]

(ii) from the position on the graph, the energy required to assemble two nuclei of $^{2}_{1}\text{H}$ is greater than that to assemble one nucleus of $^{3}_{2}\text{He}$;
hence if two nuclei of $^{2}_{1}\text{H}$ combine to form one nucleus of $^{3}_{2}\text{He}$ energy must be released / *OWTTE*; [2]

[Total 13 marks]

5 **(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)** $\text{KE} = Ve = 850 \times 1.6 \times 10^{-19}\,\text{J}$
$= 1.4 \times 10^{-16}\,\text{J}$; [1]

(ii) use $E = \frac{p^2}{2m}$ to get $p = \sqrt{2mE}$;
substitute
$p = \sqrt{2 \times 9.1 \times 10^{-31} \times 1.4 \times 10^{-16}}$
$= 1.6 \times 10^{-23}\,\text{N s}$; [2]

(iii) $\lambda = \frac{h}{p}$;
substitute $\lambda = \frac{6.6 \times 10^{-34}}{1.6 \times 10^{-23}}$
$= 4.1 \times 10^{-11}\,\text{m}$; [2]

[Total 8 marks]

6 **(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)** $E = \frac{hc}{\lambda}$
$E = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{658 \times 10^{-9}}$;
$E = \frac{3.02 \times 10^{-19}}{1.6 \times 10^{-19}}\,\text{eV}$;
$= 1.89\,\text{eV}$ [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]

(iii) (the Schrödinger model unlike Bohr's) does not have well-defined orbits for the electrons / does not treat the electron as a localized particle / assigns to an electron a probability wave;
predicts the relative intensities of various spectral lines; [2]

[Total 9 marks]

7 **(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 (±0.2) × 10^{14} Hz; [2]

(ii) a value of the Planck constant is obtained from the slope;
to be 6.5 (±0.2) × 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 (±0.1) eV; [2]

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

[Total 10 marks]

8 **(a)** $^{40}_{19}\text{K} \rightarrow {}^{40}_{18}\text{Ar} + \beta^+(e^+) + \nu$
β^+ / e^+; [2]

(b) 8.2 × 10^{-6} g; [1]

(c) **(i)** $\lambda = \frac{\ln 2}{T_{\frac{1}{2}}}$;

$= \frac{0.69}{1.3 \times 10^9} = 5.3 \times 10^{-10}\ \text{year}^{-1}$; [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;

or

$\frac{1.2}{8.2} = \left(\frac{1}{2}\right)^n$

$n = 2.77$;

age = 2.77 × 1.3 × 10^9

= 3.6 × 10^9 years; [2]

[Total 7 marks]

9 **(a)** $qvB = m\frac{v^2}{r}$;

hence $r = \frac{mv}{Bq}$; [2]

(b) $\frac{16.5}{15} = \frac{\frac{m_{16.5}v}{Bq}}{\frac{m_{15}v}{Bq}} = \frac{m_{16.5}}{m_{15}}$;

hence $\frac{Bq}{15} = \frac{m_{16.5}}{20} \Rightarrow m_{16.5} = 22\,\text{u}$; [2]

(c) atoms on 15 cm path: 10 protons and 10 neutrons;
atoms on 16.5 cm path: 10 protons and 12 neutrons; [2]

[Total 6 marks]

10 **(a)** **(i)** muon lepton number / electron lepton number; [1]

(ii) baryon number; [1]

(iii) baryon number / electric charge; [1]

(b) there are eight gluons involved in the strong interaction; [1]

Accept just the name gluons or just mesons.

[Total 4 marks]

11 **(a)** hadron;
*(Award **[1]** for 'bald' statement and if reason is wrong)*
any sensible justification; [2]
e.g. 'contains two quarks' or 'hadrons are either baryons or mesons'.

(b) three quarks;
duu; [2]

(c) attempt (even if unsuccessful) to balance quarks left and right;

to get: $\begin{pmatrix} s \\ \bar{u} \end{pmatrix} + \begin{pmatrix} u \\ d \\ u \end{pmatrix} \rightarrow \begin{pmatrix} d \\ \bar{s} \end{pmatrix} + \begin{pmatrix} u \\ \bar{s} \end{pmatrix} + \begin{pmatrix} s \\ s \\ s \end{pmatrix}$

correct discussion on how the equation balances for all quark types; [2]

e.g. compare numbers of quarks on LHS and RHS:

u: – 1 + (1 + 1) ➞ 1

d: 1 ➞ 1

s: 1 ➞ –1 – 1 + (1 + 1 + 1)

[Total 6 marks]

12 **(a)** **(i)** colour force / weak force; [1]

(ii) gluon / charged vector boson / W boson; [1]

(b) in the interaction $\bar{\nu} + p = n + e^+$ charge, lepton number, and baryon number are conserved / all conservation laws are obeyed;

in the interaction $\nu + p = n + e^+$ charge and baryon number are conserved / all conservation laws except lepton number are obeyed;

lepton number, +1 on the left, –1 on the right; [3]

*Essentially look for some detail of the conservation laws and some substantiation of the violation of lepton number to achieve **[3]**.*

[Total 5 marks]

13 **(a)** A: π^+ meson;

B: muon antineutrino; [2]

(b) rest mass is non-zero for W, zero for photon;

range of photon is infinite, not for W;

photon mediates electromagnetic force, W weak force;

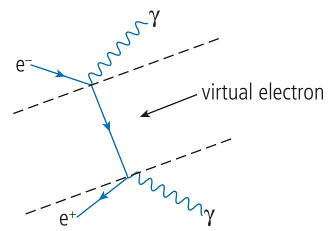
photon is uncharged, W is charged; [2]

[Total 4 marks]

14 **(a)** **(i)** a particle that cannot be made from any smaller constituents / particles; [1]

(ii) has the same rest mass (and spin) as the lepton but opposite charge (and opposite lepton number); [1]

(b)



*Award **[1]** for each correct section of the diagram.*

e^- correct direction and γ;

e^+ correct direction and γ;

virtual electron / positron; [3]

Accept all three time orderings.

(c) **(i)** $u\bar{d}$ / up and antidown; [1]

(ii) baryon number is not conserved / quarks are not conserved; [1]

(d) two identical particles that have half-integer spin / fermions cannot occupy the same quantum state; [1]

(e) quarks are subject to the Pauli exclusion principle;

the introduction of colour ensures that the principle is not violated; [2]

[Total 10 marks]

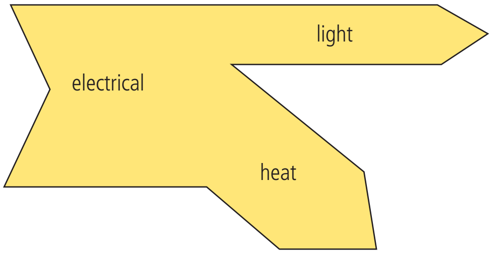
Challenge yourself

1 2.5×10^{12} J

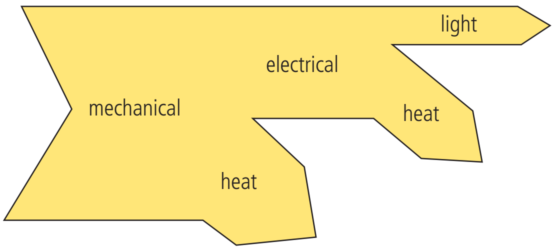
Answers

Chapter 8

Exercises

1 

(For a halogen bulb.)

2 

3 **(a)** 8.64×10^{13} J **(b)** 2.16×10^{14} J
(c) 6.65×10^{6} kg **(d)** 67 truck loads

4 **(a)** ${}^{142}_{56}\text{Ba} \rightarrow {}^{142}_{57}\text{La} + \beta^- + \bar{\nu}$
(b) 9 years

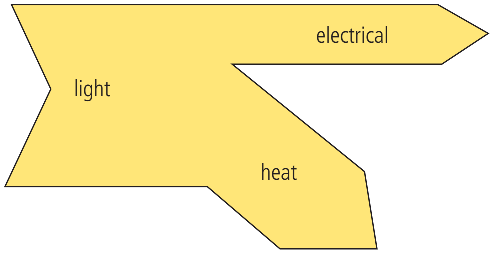
5 **(a)** 7
(b) ${}^{239}_{94}\text{Pu} \rightarrow {}^{136}_{54}\text{Xe} + {}^{96}_{40}\text{Zr} + 7\text{n}^0$
(c) 164 MeV
(d) 239 g
(e) 2.5×10^{24} atoms
(f) 4.13×10^{26} MeV
(g) 6.6×10^{13} J

6 2.7×10^{12} J

7 **(a)** 3.6×10^{10} J
(b) 13 g

8 **(a)** 4000 W
(b) 2000 J
(c) 28.6°C

9 **(a)** 0.015 W
(b) 0.03 A
(c) 5 V
(d) 0.3 A
(e) 6667

10 

11 **(a)** 5.5 MW
(b) 1.1 MW
(c) 3.7 MW

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

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

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.

[Total 4 marks]

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 = $\frac{720}{800}$ = 0.90 m^2; [2]

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

[Total 7 marks]

3 **(a)** idea of thermal energy → mechanical energy / KE → electrical energy;
idea of where or how this takes place; [2]
e.g. in turbines or coil rotated in a magnetic field.

(b) *Mark the answers for the two energy sources together,* both non-renewable;
appropriate justification for both; [2]
e.g. in both cases a resource is being used and isn't being replaced / OWTTE.

(c) **(i)** to slow down fast-moving neutrons;
so as to increase chances of neutron capture by another uranium nucleus / *OWTTE*; [2]

(ii) to absorb neutrons;
so as to control rate of reaction / *OWTTE*; [2]

(d) any appropriate advantage that coal-fired power station does not have;
e.g. does not release CO_2 / SO_2 into atmosphere / OWTTE.
appropriate discussion relating to advantage;
e.g. so global warming / acid rain effects reduced. [2]
Allow argument that 1 kg of uranium 'fuel' releases more energy w.r.t. 1 kg of coal.
*Award **[0]** for imprecise statements that are not clear e.g. bald 'nuclear power stations pollute less'.*

[Total 10 marks]

4 **(a)** power = $\frac{\text{energy}}{\text{time}} = \frac{120 \times 10^{12}}{60 \times 60 \times 24 \times 365}$;
= 3.8 × 10^6 W;
therefore, for one turbine = 0.19 MW; [3]

(b) using $p = \frac{1}{2}\rho A v^3$, $A = \frac{2p}{\rho v^3}$;
therefore, $A = \frac{2 \times 1.9 \times 10^5}{1.2 \times 9.0^3} = 4.3 \times 10^2$ m^2;
use $A = \pi r^2$ to give r = 12 m; [3]

(c) the wind speed varies over the year / not all the wind energy will be transferred into mechanical power / energy loss due to friction in the turbine / energy loss in converting to electrical energy / density of air varies with temperature; [1]
Do not accept something like 'turbines are not 100% efficient'.

(d) take up so much room;
not possible to produce enough energy to meet a country's requirements;
noisy;
and this could have an effect on local fauna, *OWTTE*; [2]
*Award **[1]** for statement of disadvantage and **[1]** for some justification of statement.*

[Total 9 marks]

5 **(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.*

[Total 12 marks]

6 **(a)** the solar radiation is captured by a disc 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) $I\ (= e\sigma T_A^4)$
$= 0.700 \times 5.67 \times 10^{-8} \times 242^4$;
$= 136\,\mathrm{W\,m^{-2}}$ [1]

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

[Total 13 marks]

7 **(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 $= 5.67 \times 10^{-8} \times 4\pi \times [7.0 \times 10^8]^2 \times 5800^4$;
$\approx 4.0 \times 10^{26}\,\mathrm{W}$ [1]

(ii) $\dfrac{\text{incident energy}}{\text{area}} = \dfrac{3.97 \times 10^{26}}{4\pi[1.5 \times 10^{11}]^2}$;
$= 1400\,\mathrm{W\,m^{-2}}$; [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 towards surface; [3]

[Total 15 marks]

Challenge yourself

1 363 m

2 $T = 276$ K

Answers

Chapter 9

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 $-0.99c$

11 $0.85c$

12 $0.96c$

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 γ if $v > c$

20 $134\,MeV c^{-1}$

21 (a) $1183\,MeV c^{-1}$
(b) $0.986c$

22 (a) 100.5 MeV
(b) 300.5 MeV
(c) $260\,MeV c^{-1}$

23 (a) 950 MeV
(b) 12 MeV
(c) 12 MV
(d) $0.16c$

24 1.5 MeV each

25 $0.59\,MeV c^{-1}$

26 0.118 MeV

27 8.56×10^3 Hz

28 (a) same
(b) received signal has lower frequency than transmitted signal

29 29.6 km

30 (a) 60.0009 s
(b) 71.5 s
(c) 84.3 s

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) $\gamma = 2$;

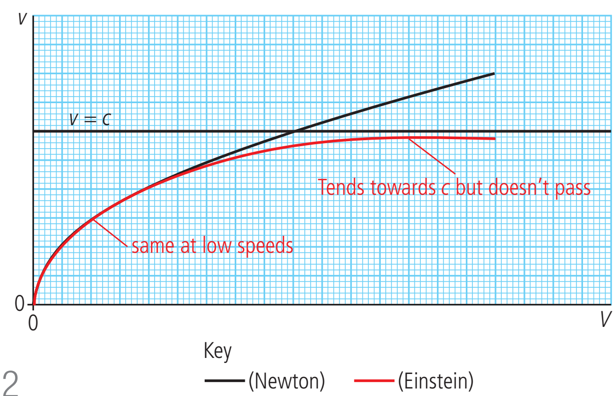
to give $u = 0.87c$ ($2.6 \times 10^8\,\mathrm{m\,s^{-1}}$); [2]

(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]

[Total 10 marks]

2 **(a)**



correct general shape;

asymptotic to c; [2]

(b) as the speed of the electrons increases SR predicts that the mass of the electrons will increase;

SR also predicts that at speed c the mass will be infinite;

so effectively the electrons can never reach the speed of light; [3]

Look for an answer that shows that mass increases and why the electrons cannot travel at the speed of light. Students might quote $m = \gamma m_0$ and this is fine.

(c) **(i)** $\gamma = \dfrac{1}{\sqrt{1-0.97^2}}$

to give $\gamma = 4.1$;

$m = \gamma m_0 = 4.1 \times 0.51 = 2.1\,\mathrm{MeV}\,c^{-2}$;

Accept $m = 3.7 \times 10^{-30}$ kg.

could also solve from KE = 1.5 MeV;

rest mass 0.51 = MeV c^{-2};

therefore total mass = 2.1 MeV c^{-2}; [3]

(ii) $E = mc^2$;

= 2.1 MeV; [2]

Accept 3.20×10^{-13} J.

[Total 10 marks]

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

(b) $T_0 = \dfrac{2D}{c}$; [1]

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

(ii) $F - R = vT$; [1]

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

$L = 2\sqrt{\{D^2 + \left(\tfrac{1}{2}vT\right)^2\}}$; [2]

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

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

use of $4D^2 = c^2T_0^{\,2}$;

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

[Total 10 marks]

4 **(a)** rest mass energy is the energy that is needed to create the particle at rest / reference to $E_0 = m_0c^2$;
total energy is the addition of the rest energy and everything else (kinetic etc.) / reference to mass being greater when in motion / $E = mc^2$; [2]

(b) realization that beta particles are electrons;
so $m_e = 0.511\,\text{MeV}\,c^{-2}$;
$\gamma = \frac{2.51}{0.511}$; (= 4.91) [3]

Ignore any spurious calculation from Lorentz factor equation here as the use of this equation is rewarded below.

(c) (i) correct substitution into Lorentz factor equation;
to give $v = 0.979c = 2.94 \times 10^8\,\text{m s}^{-1}$; [2]

(ii) correct substitution into speed $= \frac{\text{distance}}{\text{time}}$;
to give time = 1.26 ns; [2]

(d) (i) the detector / the laboratory / *OWTTE*; [1]

(ii) same answer as c(i), $2.94 \times 10^8\,\text{m s}^{-1}$; [1]

(iii) realization that length contraction applies;
distance $= \frac{37}{\gamma} = 7.5\,\text{cm}$; [2]

[Total 13 marks]

5 **(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) $u' = \frac{u - v}{1 - \frac{uv}{c^2}}$ with $v = -0.80c$ and $u = 0.80c$ so that
$u' = \frac{0.80c + 0.80c}{1 + \frac{0.80c \times 0.80c}{c^2}}$;
$u' = \frac{1.60c}{1.64}$;
$u' = 0.98c$; [3]

[Total 6 marks]

6 **(a)** *Award* ***[2]*** *for good understanding and* ***[1]*** *for some understanding.*
a means by which the position of an object can be located / *OWTTE*;
some detail e.g. reference to origin/axes; [2]
Answers will be open-ended.

(b) $c - v$; [1]

(c) c; [1]

(d) $u' = \frac{u - v}{1 - \frac{cv}{c^2}}$;
substitute $u = c$ to get $u' = \frac{c - v}{1 - \frac{cv}{c^2}}$;
$= \frac{c - v}{1 - \frac{v}{c}} = \frac{c(c - v)}{c - v} = c$; [3]

Accept answers using + instead of –.
Award ***[1]*** *for recognition of correct formula to use and* ***[1]*** *for correct substitution and* ***[1]*** *for at least some algebra.*

(e) (i) time interval of an event that is observed to happen at the same place / *OWTTE*; [1]

(ii) $\gamma = 2.0$;
$2.0 = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$;
algebra to give $v = 0.87c$; [3]

[Total 11 marks]

7 **(a) (i)** $\left(\frac{52 \text{ light years}}{0.80c}\right) = 65$ years; [1]

(ii) $\left(\frac{52 \text{ light years}}{\frac{5}{3}}\right) = 31.2$ light years; [1]

(iii) time to reach planet according to s pacecraft is $\left(\frac{31.2 \text{ light years}}{0.80c}\right) = 39$ years;
so Amanda is 59 years old;

or

leaving Earth and arriving at planet occur at the same point for Amanda;
so time taken is $\frac{65}{\frac{5}{3}} = 39$ years,
hence age is 59 years old; [2]

(b) let the required time be denoted by T; signal reaches Earth after travelling a distance of cT;
this distance is 31.2 light years plus the distance travelled by Earth in time T i.e. $31.2 + 0.80cT$;
$cT = 31.2 + 0.80cT \Rightarrow T = 156$ years; [3]
*Award **[2]** for use of $ct = 0.80\,ct + 52$ and an answer of 260 years.*

or

the events 'spacecraft leaves Earth' and 'signal arrives at Earth' are separated by a proper time interval for the Earth observers;
this time interval is 65 + 52 = 117 years;
so spacecraft observers measure a time interval of $\frac{5}{3} \times 117 = 195$ years; so signal takes 195 – 39 = 156 years to arrive on Earth;

[Total 7 marks]

8 **(a)** distance from singularity at which light can no longer escape / *OWTTE*; [1]

(b) $R_S = \left(\frac{2GM}{c^2}\right) = \frac{2 \times 6.7 \times 10^{-11} \times 2.0 \times 10^{31}}{[3.0 \times 10^8]^2}$
$= 3.0 \times 10^4$ m; [2]

(c) **(i)** photons move upwards through gravitational field and so lose energy;
since $E = hf$, frequency decreases;

or

if space station were accelerating away from starship,
signal would undergo Doppler shift towards lower frequency;
by equivalence principle, passing through gravitational field has same effect as acceleration; [2]

or

the inverse of frequency is period that can be used as a clock;
since time slows down near a massive body, the period and so frequency must change;

(ii) $\frac{\Delta t}{\Delta t_0} = \frac{1}{\sqrt{1 - \frac{R_s}{r}}} = 10$;
$\frac{1}{100} = 1 - \frac{R_s}{r} \Rightarrow \frac{R_s}{r} = 0.99$;
$r = 1.01\,R_s$ and so distance $= 0.01\,R_s$; [3]

[Total 8 marks]

9 **(a)** *particle A:* (the total energy is) the rest mass energy;
particle B: (the total energy is) the rest mass energy plus the kinetic energy;
Do not accept $E^2 = p^2c^2 + m_0^2c^4$ as answer. [2]

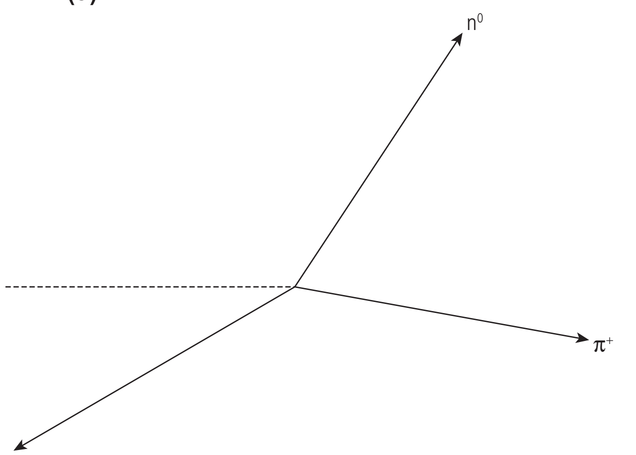
(b) **(i)** $u'_x = \frac{0.960 + 0.960}{1 + 0.960^2}c$;
$= 0.999c$; [2]

(ii) $\gamma = 3.57$;
$E = (\gamma m_0 c^2 =)\ 3.57 \times 938$ MeV;
$= 3.35$ GeV [2]

(c) **(i)** energy before collision = (3.35 + 3.35) = 6.70 GeV;
energy of p + n = (6700 – 502) = 6.20 GeV; [2]

(ii) $502^2 = p^2c^2 + 140^2$;
$p = 482\ \text{MeV}\ c^{-1}$; [2]

(d)



as shown; (accept between 7 o'clock and 9 o'clock) [1]

[Total 11 marks]

Answers

Chapter 10

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 revolutions^{-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}

30 9.4 kJ

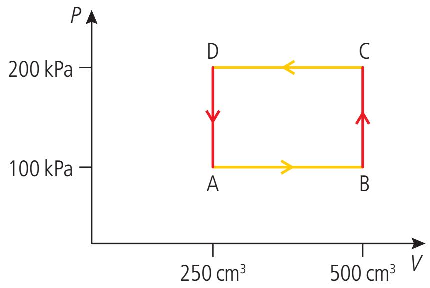
31 8.28×10^{-21} J

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

33 (a) 1050 K
(b) 11.6 J
(c) 11.6 J

34 (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)

35 (a)



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

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

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

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

39 otherwise entropy would be reduced

40 (a) 10^5 Pa
(b) 1500 N

41 569 N

42 (a) $600\,kg\,m^{-3}$
(b) 4000 N

44 $67\,cm^3$

45 $3\,m\,s^{-1}$

46 $7.6\,m\,s^{-1}$

47 $10\,m\,s^{-1}$

48 (a) $9.4 \times 10^{-4}\,m^3\,s^{-1}$
(b) $0.33\,m\,s^{-1}$
(c) 504.4 kPa

49 (a) $3.53 \times 10^{-4}\,m^3\,s^{-1}$
(b) $4.5\,m\,s^{-1}$
(c) 290 kPa

50 $21.5\,m\,s^{-1}$

51 18 kPa

52 $6.5 \times 10^{-5}\,m^3\,s^{-1}$

53 $1.97\,m\,s^{-1}$

54 $950\,kg\,m^{-3}$

55 $6.3 \times 10^{-5}\,m^3\,s^{-1}$

56 9.8

57 (a) D is same length as A so resonance – this implies a $\pi/2$ 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.

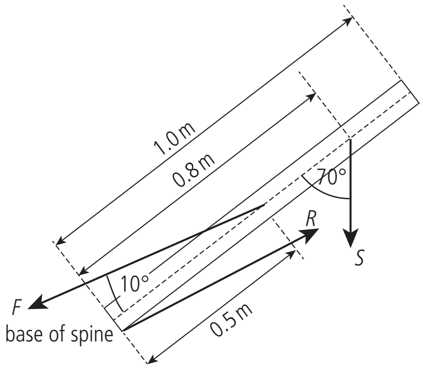
Practice questions

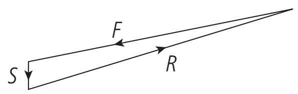
1 **(a)** no resultant force (in any direction);

no resultant torque (about any axis); [2]

(b) force from base to spine anywhere to the right and up the page;

correctly so that resultant force = zero ; [2]





(c) use of torque = force × perpendicular distance;

to give torque = $S\sin(70°) \times 0.8$ (= $0.752S$); [2]

(d) correct balance of torques;

$F\sin(10°) \times 0.5 = S\sin(70°) \times 0.8$

to give $\frac{F}{S} = \frac{0.8\sin(70°)}{0.5\sin(10°)} = 8.66 \approx 9$; [2]

[Total 8 marks]

2 **(a)** The radius should be marked as 2 m.

Moment of inertia = $I_{disc} + I_{child} = \frac{1}{2}m_d r^2 + m_c r^2$
$= 0.5 \times 60 \times 2^2 + 40 \times 2^2$;

$I = 280\,\text{kg m}^2$; [2]

(b) $L = I\omega = 280 \times \pi = 880\,\text{kg m}^2\,\text{s}^{-1}$ [1]

(c) $I_1\omega_1 = I_2\omega_2$

$I_2 = 0.5 \times 60 \times 2^2 + 40 \times 1^2 = 160\,\text{kg m}^2$

$\omega_2 = \frac{I_1\omega_1}{I_2} = \frac{880}{160} = 5.50\,\text{rad s}^{-1}$ [3]

(d) $KE = \frac{1}{2}I\omega^2$;

Initial KE = $0.5 \times 280 \times \pi^2 = 1380$ J;

Final KE = $0.5 \times 160 \times 5.5^2 = 2420$ J;

Change in KE: 2420 – 1380 = 1040 J; [3]

(e) The increase in KE is due to the work done by the child pulling himself towards the centre. [2]

[Total 11 marks]

3 C [1]

4 **(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

$= 1.8 \times 10^6 + 1.6 \times 10^6$ J

$= 3.4 \times 10^6$ J;

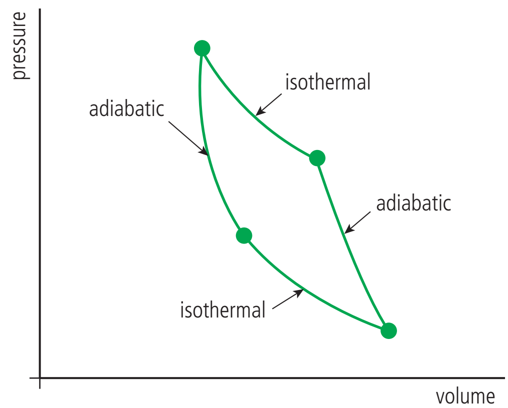
efficiency = $\frac{\text{work done}}{\text{thermal energy from hot reservoir}}$

$= \frac{1.6 \times 10^6}{3.4 \times 10^6}$

= 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]

[Total 10 marks]

5 **(a)** *isothermal:* takes place at constant temperature;
adiabatic: no energy exchange between gas and surroundings; [2]

(b) **(i)** neither; [1]

(ii) $\Delta W = P\Delta V = 1.2 \times 10^5 \times 0.05$
$= 6.0 \times 10^3$ J; [1]

(iii) recognize to use $\Delta Q = \Delta U + \Delta W$;
to give $\Delta U = 2.0 \times 10^3$ J; [2]

[Total 6 marks]

6 **(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;
$0.6\ (\pm 0.2) \times 10^5$ J (60 kJ ± 20 kJ); [2]

(d) efficiency = $\frac{\text{work out}}{\text{heat in}}$;
$= \frac{60}{120} = 50\%\ (\pm 17\%)$; [2]

[Total 8 marks]

7 **(a)** pV constant for isothermal / adiabatic always steeper;
hence AB; [2]

(b) area between lines AB, AC and BC shaded;
[1]

(c) area is 150 (±15) small squares;
(allow ECF from b)
work done = $1.5 \times 1 \times 10^{-3} \times 1 \times 10^5$;
= 150 J; [3]
*For any reasonable approximate area outside the range 150 (±15) squares award **[2]** for the calculation of energy from the area.*

(d) no thermal energy enters or leaves / $\Delta Q = 0$;
so work done seen as increase in internal energy;
hence temperature rises; [3]
*Award **[0]** for a mere quote of the 1st law.*

[Total 9 marks]

8 **(a)** Volume per second = $Av = \pi \times 0.02^2 \times 0.5$
$= 6.3 \times 10^{-4}\ \text{m}^3\,\text{s}^{-1}$; [1]

(b) Using continuity equation
$A_1 v_1 = A_2 v_2$
$\pi \times 0.02^2 \times 0.5 = \pi \times 0.015^2 \times v_2$; [1]
$v_2 = 0.9\ \text{m}\,\text{s}^{-1}$; [1]

(c) Using Bernoulli equation
$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$; [1]
$300 \times 10^3 + 0.5 \times 10^3 \times 0.5^2 + 10^3 \times 10 \times 0$
$= P_2 + 0.5 \times 10^3 \times 0.9^2 + 10^3 \times 10 \times 5$ [1]
$(300 + 0.125 - 0.405 - 50) \times 10^3$
= 250 kPa; [1]

[Total 6 marks]

9 **(a)** Using Bernoulli equation
$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$
Assume difference in height is negligible; [1]
$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2$
$P_1 - P_2 = \frac{1}{2}\rho(v_2^2 - v_1^2)$
$= 0.5 \times 1.3 \times (340^2 - 290^2)$; [1]
$\Delta P = 2.05 \times 10^4$ Pa; [1]

(b) Upward force = $\Delta P \times A = 2.05 \times 10^4 \times 90$
$= 1.8 \times 10^6$ N [2]

[Total 5 marks]

Answers

Chapter 11

Exercises

1 25 cm

2 (a) 15 cm (b) real
(c) 0.5

3 6.67 cm

4 (a) −7.5 cm (b) virtual
(c) 1.5

5 (a) 5 m (b) 5.05 cm
(c) 0.01 (d) 0.01 m

6 (a) 6.67 cm (b) 0.33

7 (a) −28.3 cm (b) 0.057

8 12 cm, real

9 8.75×10^{-3} rad

10 4×10^{-3} rad

11 4.16 cm

12 6

13 v = 17.1 cm, real
h_i = 1.42 cm

14 v = −10 cm, virtual
h_i = 4 cm

15 f = 12 cm

16 v = −3.33 cm
h_i = 1.33 cm

17 (a) 3 cm (b) 4.17 cm
(c) 7.17 cm

18 u = 1.06 cm
M = 120

19 (a) 146×10^{-6} m (b) 8.1×10^{-7} m

20 (a) 10 (b) 110 cm
(c) 11 cm

21 5 cm

22 8.75×10^{-3} rad

23 36°

24 (a) 10 dB (b) 7 dB
(c) 20 dB

25 (a) 10 dB (b) 0.1 mW

26 (a) $5.6 \times 10^{-2}\,\text{mm}^{-1}$ (b) 12.4 mm

27 (a) $0.693\,\text{mm}^{-1}$ (b) $0.0625\,\text{kW}\,\text{m}^{-2}$

28 (a) $0.153\,\text{mm}^{-1}$ (b) 4.5 mm

29 9.3%, 1.4%

30 (a) $1.63 \times 10^{6}\,\text{kg}\,\text{m}^{2}\,\text{s}^{-1}$
(b) $7.18 \times 10^{6}\,\text{kg}\,\text{m}^{2}\,\text{s}^{-1}$
(c) $1.33 \times 10^{6}\,\text{kg}\,\text{m}^{2}\,\text{s}^{-1}$

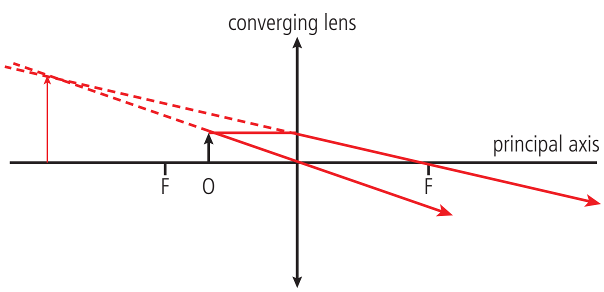
31 fat and bone

32 39.7%

33 (a) 4.5 cm (b) 4.5 cm

Practice questions

1 (a) (i) it is the point on the principal axis; through which a ray parallel to the principal axis passes after going through the lens; [2]
*Award **[0]** if focal point is defined as a distance.*



(ii) *Award **[2]** for any two appropriate rays and **[1]** for correct positioning of the image (upright).* [3]

(iii) it is virtual because no rays pass through the image / cannot be formed on a screen; [1]

*Award **[0]** if no explanation is provided.*

(b) **(i)** $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$

$\frac{1}{v} + \frac{1}{6.25} = \frac{1}{5.0}$;

$v = -25$ cm, so distance is 25 cm; [2]

Accept negative sign in answer for distance.

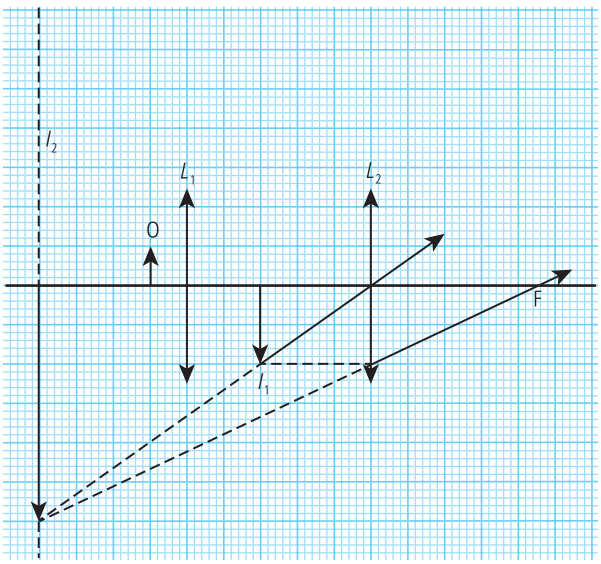
(ii) $M = \frac{v}{u}$

$M = \frac{25}{5} = 5$ (magnification is always positive)

$L' = 5 \times 0.8 = 4.0$ cm; [2]

[Total 10 marks]

2 **(a)**



two correct construction rays;

dotted lines back to I_2 to give F, 4.5 (±1) cm from L_2; [2]

(b) **(i)** 2; [1]

(ii) 3; [1]

(c) 6; [1]

[Total 5 marks]

3 **(a)** **(i)** correct use of sign convention $\left(\frac{1}{20} = \frac{1}{24} + \frac{1}{v}\right)$;

$v = 120$ mm; [2]

(ii) real because $v > 0$ / image is formed by real rays (and not their extensions) / can be focused on a screen / rays are convergent; [1]

(iii) correct use of sign convention $\left(\frac{1}{60} = -\frac{1}{240} + \frac{1}{u}\right)$;

$u = 48$ mm; [2]

(b) $M = \left[\frac{120}{24}\right] \times \left[\frac{240}{48}\right]$ or $M = \frac{120}{24} \times \left[\frac{240}{60} + 1\right]$;

$M = 25$; [2]

*Award **[1]** for answer of 20.*

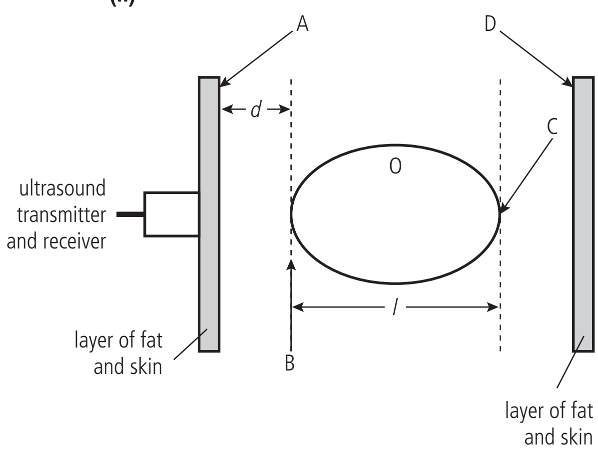
[Total 7 marks]

4 **(a)** 1 MHz → 20 MHz; [1]

(b) **(i)** to ensure that no air is trapped between transmitter and skin;

otherwise nearly all the transmitted pulse will be reflected at the surface of the skin; [2]

(ii)



A and B correct;

C and D correct; [2]

(iii) pulse takes 100 μs to travel $2d$;

therefore $d = \frac{ct}{2} = \frac{1.5 \times 10^3 \times 100 \times 10^{-6}}{2}$;

to give $d = 75$ mm;

similarly $l = \frac{1.5 \times 10^3 \times 50 \times 10^{-6}}{2}$

$= 130$ mm; [4]

Allow for ECF here e.g. if 'd' is marked as being between A and B.

(c) B-scan gives a three-dimensional image; *OWTTE*; [1]

(d) advantage:
non-ionizing (not as harmful as X-rays / *OWTTE*);
*Any **one** of the following:*
disadvantages:
small depth of penetration;
limit to size of objects that can be imaged;
blurring of images due to reflection at boundaries; [2]

[Total 12 marks]

5 **(a)** **(i)** X-rays;
because they can easily distinguish between flesh and bone to get a clear image of the fracture; [2]

(ii) ultrasound;
because it gives reasonably clear images in the womb without harmful radiation; [2]

(b) **(i)** the half-value thickness is that thickness of lead which (for this particular beam);
will reduce the intensity of the (transmitted) beam by 50%; [2]

(ii) the half-value thickness corresponds to an intensity of 10 units;
and so equals 4 mm; [2]

(iii) the transmitted intensity must be $20\% \times 20 = 4$ units;
corresponding to a thickness of lead of about 9.3 (±0.2) mm; [2]

(iv) the transmitted intensity must be $(1 - 0.8) \times 20 = 4$ units;
using $4 = 20(0.5)^{\frac{x}{8}} \Rightarrow (0.5)^{\frac{x}{8}} = 0.20$;
we find a thickness of 18.6 (±1) mm; [3]

or

the transmitted intensity must be $(1 - 0.8) \times 20 = 4$ units;
by drawing a second graph corresponding to the half-value thickness of 8 mm;
and finding the thickness corresponding to a transmitted intensity of 4 units of about 18.6 (±1) mm;

[Total 13 marks]

6 **(a)** the thickness needed to cause a beam to attenuate / be reduced in intensity by 50% / *OWTTE*; [1]

(b) indication that the ratio between the linear attenuation coefficients must be the same as the ratio between half-value thicknesses / $\mu_T x_{\frac{1}{2}T} = \mu_B x_{\frac{1}{2}B}$;
(therefore) linear attenuation coefficient for bone = 150×0.035;
$= 5.3\,\text{cm}^{-1}$ [2]

(c) **(i)** substitution into $I = I_0 e^{-\mu x}$,
$I_B = I_A e^{-0.035 \times 5.0}$;
$\frac{I_B}{I_A} = 0.84$ [2]

(ii) substitution to give $\frac{I_C}{I_B} = 2.2 \times 10^{-12}$ [1]

(d) all X-rays stopped by bone so total shadow;
few X-rays stopped by soft tissue / muscle;
so (good) contrast between (air), muscle, and bone; [3]

[Total 9 marks]

7 **(a)** **(i)** sound at frequency above 20 kHz / above the upper limit of hearing of a human being; [1]

(ii) alternating voltage is applied to a crystal;
forces the crystal to vibrate, emitting ultrasound; [2]

(b) $Z = \rho c = 2800 \times 1.5 \times 10^3$
$= 4.2 \times 10^6\,(\text{kg}\,\text{m}^{-2}\,\text{s}^{-1})$; [1]

(c) **(i)** the brain is made of uniform tissue, i.e. $Z_1 = Z_2$;
and so no features can be distinguished since no reflection can take place; [2]

(ii) $\frac{I_R}{I_O} = \left(\frac{430 - 1.6 \times 10^6}{430 + 1.6 \times 10^6}\right)$;

$\frac{I_R}{I_O} = 0.9989 \approx 1.0$; [2]

(iii) most of the ultrasound is reflected when the impedances of the two media are different;
the gel makes sure that the ultrasound enters tissue from a medium of approximately the same impedance; [2]

(d) (i) time to travel from transducer to stomach is $\frac{50}{2} = 25\,\mu s$;
distance $(1600 \times 25 \times 10^{-6})$
$= 4.0 \times 10^{-2}\,m = 4.0\,cm$; [2]

(ii) B-scans produce two-dimensional images whereas A-scans are one dimensional;
B-scans provide real time 'video' images; [2]

[Total 14 marks]

Answers

Chapter 12

Exercises

1 4.2 light years

2 8 min 20 s

3 1.5×10^5 years

4 1.3 pc, 1.56 arcsec

5 40 pc

6 3.18 μm; too small to measure on photograph

7 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 from Wikipedia in brackets)

8 (a) $1.36 \times 10^3\,\mathrm{W\,m^{-2}}$
(b) $3.2 \times 10^{-10}\,\mathrm{W\,m^{-2}}$

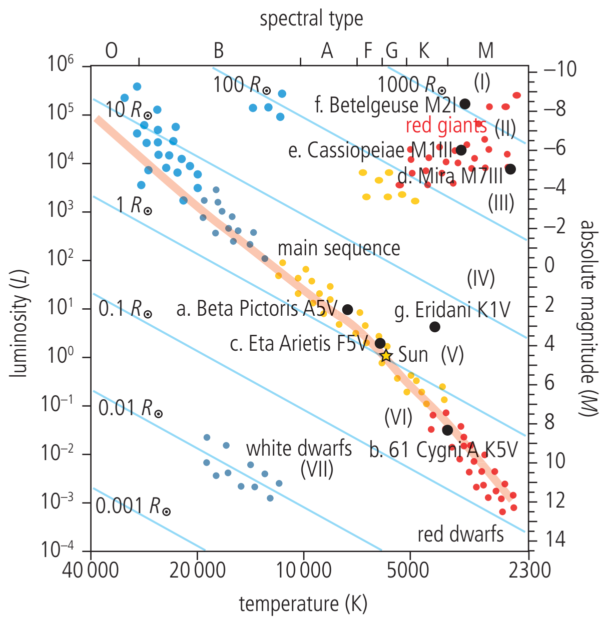
9 (a) $1.2 \times 10^{-7}\,\mathrm{W\,m^{-2}}$
(b) $7.9 \times 10^{-9}\,\mathrm{W\,m^{-2}}$

10 5.6×10^3 light years

11 $4.2 \times 10^{30}\,\mathrm{W}$

12 (a) $7.25 \times 10^3\,\mathrm{K}$
(b) $1.6 \times 10^8\,\mathrm{W\,m^{-2}}$

13



14 (a) 7250 K (b) $3.84 \times 10^{26}\,\mathrm{W}$
(c) 826 light years

15 (a) $10\,L_\odot$ (b) $2\,R_\odot$
(c) 8000 K (d) 22.2 pc

16 $M = 1.9 M_\odot$

17 490 pc

18 $0.2\,\Delta t_\odot$

19 1200 Mpc

20 $17 M_\odot$, so probably big enough to be a black hole

21 $3.17 \times 10^7\,\mathrm{m\,s^{-1}}$

22 $3.25 \times 10^7\,\mathrm{m\,s^{-1}}$; it is further away since it is moving fast

23 2.1 Mpc

24 $1440\,\mathrm{km\,s^{-1}}$

25 $9.7 \times 10^{-27}\,\mathrm{kg\,m^{-3}}$
6 atoms $\mathrm{m^{-3}}$

26 1.06 mm

27 9.7×10^{-7}, 1.09×10^{3}

28 9.2×10^{-4}

Practice questions

1 (a) (i) spectral class; [1]

Accept colour sequence.

(ii) absolute magnitude; [1]

(b) [4]

Star	Type of star
A	main sequence;
B	super red giant;
C	white dwarf;
D	main sequence;

*Award **[1]** for each correct name.*

(c) B more luminous than A;
and has lower temperature than A;
so from the Stefan–Boltzmann law;
B has greater area (radius); [3]

(d) use of $L = 4\pi bd^2$;
from the HR diagram $L_B = 10^6 L_{\odot}$;
therefore $\frac{L_B}{L_{\odot}} = 10^6 = \frac{7.0 \times 10^{-8} \times d_B^2}{1.4 \times 10^3}$;
to give $d_B = 1.4 \times 10^8$ AU (≈ 700 pc); [4]

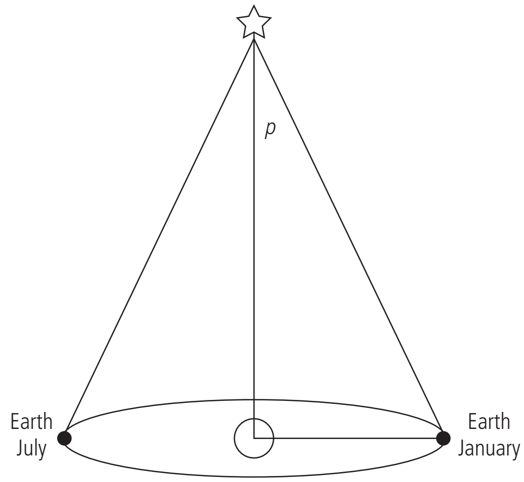
No mark is awarded for the conversion from AU to pc.

(e) at this distance the parallax angle is too small to be measured accurately;
OWTTE; [1]

Do not accept 'it's too far away'.

[Total 14 marks]

2 (a)



Mark the definition of p and description of its measurement along with the diagram.

Essentially diagram should show:
p;
position of Sun;
position of Earth;

then definition of
$p = \frac{\text{(distance of Earth from Sun)}}{\text{(distance of star from Sun)}}$;
diagram should show Earth positions separated by about six months;
then description should mention that angle of sight is measured at these two positions such that the difference between these two angles is equal to $2p$; [6]

*Award **[6]** for a clear description and diagram, **[3]** for an average and **[1]** for some rudimentary idea. Mark diagram and description together.*

(b) $d = \frac{1}{p} = \frac{1}{0.549} = 1.82$ pc;
$= 1.82 \times 3.26 = 5.94$ light years; [2]

(c) (i) the radiant power from a star;
that is incident per m^2 of the Earth's surface;

Alternatively, define from $b = \frac{L}{4\pi d^2}$
but terms must be defined to obtain the mark.
definition of L;
definition of d; [2]

(ii) $L = 4\pi d^2 b$;

therefore, $\frac{L_B}{L_S} = \frac{d_B{}^2 b_B}{d_S{}^2 b_S}$;

$d_S = 1\text{AU}$, $d_B = 3.8 \times 10^5\,\text{AU}$;

therefore,

$\frac{L_B}{L_S} = (3.8)^2 \times 10^{10} \times 2.6 \times 10^{-14}$

$= 3.8 \times 10^{-3}$; [4]

Allow any answer between 3.0×10^{-3} and 4.0×10^{-3}.

(d) (i) temperature too low for it to be a white dwarf; [1]

(ii) luminosity too low for it to be a red giant; [1]

[Total 16 marks]

3 (a) (i) luminosity is the total power radiated by a star / source; [1]

Do not accept $L = \sigma AT^4$.

(ii) apparent brightness is the power from a star received by an observer on Earth per unit area of the observer's instrument of observation; [1]

Accept $b = \frac{L}{4\pi d^2}$ if L and d are defined.

(b) the surface area / size of the star changes periodically (owing to interactions of matter and radiation in the stellar atmosphere); [1]

(c) (i) at two days the radius is larger / point A;
because then the luminosity is higher and so the area is larger; [2]

*Award **[0]** if no explanation is provided.*

(ii) *Award **[1]** for each relevant and appropriate comment to the process of using Cepheid variables up to **[3]** e.g.*

Cepheid variables show a relationship between period and luminosity;
hence measuring the period gives the luminosity and hence the distance (through $b = \frac{L}{4\pi d^2}$);
distances to galaxies are then measured if the Cepheid can be ascertained to be within a specific galaxy; [3]

Marks can be back credited from answer d (ii).

(d) (i) $b = \frac{L}{4\pi d^2} \Rightarrow 1.25 \times 10^{-10} = \frac{7.2 \times 10^{29}}{4\pi d^2}$;

$d = \sqrt{\frac{7.2 \times 10^{29}}{4\pi \times 1.25 \times 10^{-10}}}$;

$d = 2.14\,(\pm 0.2) \times 10^{19}\,\text{m}$; [3]

(ii) *Award **[1]** for each relevant and appropriate comment to the phrase 'standard candles' up to **[2]** e.g.*

the phrase standard candle means having a source (of light) with known luminosity;
measuring the period of a Cepheid allows its luminosity to be estimated / other stars in the same galaxy can be compared with this known luminosity; [2]

[Total 13 marks]

4 (a) if less than ρ_0, Universe will expand for evermore;
if greater than ρ_0, Universe will expand;
and then contract; [3]

(b) (i) substitution to give

$\rho_0 = 1.3 \times 10^{-26}\,\text{kg}\,\text{m}^{-3}$; [1]

(ii) number density $= \frac{(1.3 \times 10^{-26})}{(1.66 \times 10^{-27})}$, about 7 or 8 m^{-3}; [1]

Note: unit is m^{-3}.

[Total 5 marks]

5 (a) (i) R shown amongst scattered points in upper right of diagram
W shown in lower region below main sequence, about centrally; [1]

(ii) S shown on main sequence, about $\frac{1}{3}$ way up; [1]

Allow the position of S anywhere between $\frac{1}{4}$ and $\frac{1}{2}$ way up.

(iii) path shown to region of red giant;
then continuing to region of white dwarf; [2]

(b) (when forming a red giant) the star is expanding;
more power but over a much larger area, so cooler; [2]

[Total 6 marks]

6 **(a)** $T = \frac{2.9 \times 10^{-3}}{1.07 \times 10^{-3}}$;
$T = 2.7\,\text{K}$; [2]
Accept wavelengths in the range 1.05 to 1.10 for a temperature range 2.64 to 2.76 K.
*Award **[0]** for bald answer.*

(b) according to the Big Bang model the temperature of the Universe (and the radiation it contained) in the distant past was very high;
the temperature falls as the Universe expands and so does the temperature of the radiation in the Universe; [2]

(c) (Hubble's law shows that) the Universe is expanding;
therefore in the distant past the Universe must have been a very small / hot / dense point-like object;

or

Doppler shift of spectral lines;
indicates galaxies moving away so in the past they were close to each other; [2]

[Total 6 marks]