FOR THE
IB DIPLOMA

Physics

Study and Revision Guide

ANSWERS

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HODDER
EDUCATION

Answers

Topic 1 Measurement and uncertainties

Questions to check understanding

1 **a** $\mathrm{kg\,m\,s^{-2}}$

b $\mathrm{A\,s}$

c $\mathrm{kg\,m^2\,s^{-3}\,A^{-1}}$

d no unit

2 **a** 8.2379×10^2

b 2.840×10^{-4}

c $2 \times 10^{\circ}$

3 **a** $23 + 273 = 296\,\mathrm{K}$

b $19.3 \times 10^3 \times 3600 = 6.95 \times 10^7\,\mathrm{J}$

c $38 \times 1.6 \times 10^{-19} = 6.1 \times 10^{-18}\,\mathrm{J}$

d $\dfrac{50 \times 10^3}{3600} = 14\,\mathrm{m\,s^{-1}}$

e $365 \times 24 \times 3600 = 3.15 \times 10^7\,\mathrm{s}$

4 **a** **i** $2.4 \times 10^9\,\mathrm{kW}$

ii $2.4 \times 10^6\,\mathrm{MW}$

iii $2.4 \times 10^3\,\mathrm{GW}$

b **i** $3.47 \times 10^{-1}\,\mathrm{A}$

ii $7.84 \times 10^{-8}\,\mathrm{A}$

5 **a** 3.83

b 3.8

c 4

6 **a** 10^1 g is too small; 10^3 g is too high: 10^2 g

b 10^{-2} mm is too small; 10^0 mm is too high: 10^{-1} mm

c 10^2 K is too small; 10^4 K is too high: 10^3 K

7 If $r = 50\,\mathrm{m}$ and average depth $= 10\,\mathrm{m}$, $V \approx 1 \times 10^5\,\mathrm{m^3}$

8 **a** $p = \dfrac{\text{Force}}{\text{Area}} = \dfrac{mg}{\text{Area}} = \dfrac{1600 \times 10}{0.08} \approx 2 \times 10^5\,\mathrm{Pa}$

b $t = \dfrac{s}{c} = \dfrac{4}{3 \times 10^8} \approx 1 \times 10^{-8}\,\mathrm{s}$

c $R = \dfrac{V^2}{P} = \dfrac{230^2}{500} \approx 1 \times 10^2\,\Omega$

9 **a** $\dfrac{1500\,\mathrm{kg}}{1 \times 10^{-2}\,\mathrm{kg}} \approx 10^5$

b $\dfrac{1\,\mathrm{GW}}{2\,\mathrm{W}} \approx 10^9$

c $\dfrac{10\,\mathrm{s}}{\left(\frac{1}{1000}\right)} \approx 10^4$

10 For example, 22.3, 16.9, 19.4, 23.1 and 14.3 have an average of 19.2, so the final result is accurate, but they are not close enough to each other to be described as precise.

11 5.7 – 0.3 = 5.4 V

12 All the speeds are too high. One possible reason could be that a stop watch was used which had a zero offset error.

13 The third reading (2.1°C) is anomalous and should be ignored. The other five are precise (close together). The true result should be 0.0°C, so these results are not accurate (average ≈ 0.2°C). All results are above the true result (and none below), which suggests a systematic error.

14 a $\frac{0.1}{9.3} \times 100 = \pm 1.1\%$ (assuming that the measuring instrument was the only cause of uncertainty)

b $\text{uncertainty} = \pm\frac{0.1}{80} \approx \pm 0.001\,\text{mm}$

$\frac{9.3}{80} = 0.116 \pm 0.001\,\text{mm}$

15 a 0.02

b $0.02 \times 4.32 = 0.0864 \approx \pm 0.09\,\text{s}$

16 a i $99.5 - 100 = -0.5\,\text{g}$

ii $\frac{0.5}{100} \times 100 = 0.5\%$

b 99.9 g

c 100 g ± 0.5 g

17 $0.05 + 0.01 = \pm 0.06\,\text{kg}$

18 $\frac{Q}{m\Delta T} = \frac{5.4 \times 10^3}{1.000 \times 19} = 284$

fractional uncertainty in $c = \left(\frac{9.2 \times 10^2}{5.4 \times 10^3}\right) + \left(\frac{0.005}{1.000}\right) + \left(\frac{0.5}{19}\right) = 0.20$

absolute uncertainty $284 \times 0.20 = \pm 57$

$\Rightarrow c = (2.8 \pm 0.6) \times 10^2\ \text{J kg}^{-1}\,\text{K}^{-1}$

19 Length of side, $L = (3.0)^{1/3} = 1.44$

fractional uncertainty in $V = \frac{0.5}{3.0} = 0.167$

fractional uncertainty in $L = 0.167 \times \frac{1}{3} = 0.0556$

absolute uncertainty in $L = 0.0556 \times 1.44 = 0.0801$

$\Rightarrow L = 1.44 \pm 0.08\ \text{cm} \Rightarrow 1.4 \pm 0.1\,\text{cm}$

20 $T = 2\pi\sqrt{\frac{0.240}{120}} = 0.281$

fractional uncertainty in $T = \left(\frac{1}{2} \times \frac{5}{240}\right) + \left(\frac{1}{2} \times \frac{2}{120}\right) = 0.01875$

absolute uncertainty in $T = 0.01875 \times 0.281 = 0.0053$

$\Rightarrow T = 0.281 \pm 0.005\,\text{s}$

21 Absolute uncertainties often remain constant for the same measuring instrument, regardless of the value being measured. For example, if using a ruler involves an absolute uncertainty of ±1 mm, this is a smaller fraction of 25 cm than 2 cm.

22 ±0.5 s; ±1 m

23 An experiment may involve adding 100 g masses. Each time a mass is added, the absolute uncertainty increases, although the fractional uncertainty stays the same. Changing a measuring instrument or changing the scale on a digital instrument will affect the absolute uncertainty of the measurement.

24 a gradient = $11 \pm 2\,\text{m s}^{-1}$

b intercept = $6.5 \pm 0.5\,\text{s}$

25 Vector: acceleration, displacement

Scalar: length, temperature

26 13.6 N at 36° to 20 N force in Figure 1.10

27 Resultant (magnitude) $= \sqrt{24^2 + 15^2} = 28\,\text{m s}^{-1}$

The resultant makes an angle θ to the south which has a tan of $\frac{15}{24} \Rightarrow \theta = 32°$ (towards south east)

28 $28\,\text{m s}^{-1}$ at 32° towards south west

29 $F_H = 247 \cos 25° = 224\,\text{N}$; $F_V = 247 \sin 25° = 104\,\text{N}$

Topic 2 Mechanics

Questions to check understanding

1 a ≈600 km

b $\frac{520}{0.75} = 690\,\text{km h}^{-1}$ to the south.

2 Because you return to the same place, your displacement and average velocity will always be 0.

3 a $\sqrt{10^2 + 6^2} = 12\,\text{m s}^{-1}$

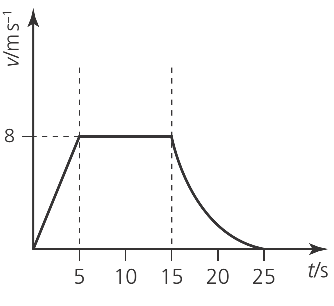
b $12\,\text{m s}^{-1}$

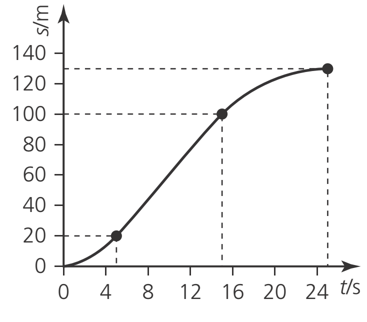
4 a $\frac{200}{22.4} = 8.93\,\text{m s}^{-1}$

b The runner started from a speed of $0\,\text{m s}^{-1}$; in order for the average to be 8.93, the runner must have travelled faster for some of the time.

c Less, because the displacement from the start to the finish is less than the distance along a curved track.

5 a





b $\frac{8}{5} = 1.6\,\text{m s}^{-2}$

c Area under graph $= \left(\frac{1}{2} \times 8 \times 5\right) + (8 \times 10) = 100\,\text{m}$

6 a $v = \frac{(0 - 80)}{(4 - 0)} = -20\,\text{m s}^{-1}$ (towards the station)

b $-20\,\text{m s}^{-1}$

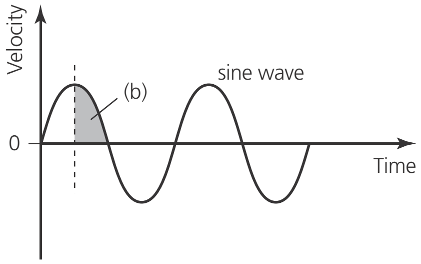
c A straight line starting at −40 m and passing through 4 s when displacement is zero.

7 **a** The object was released from rest at time $t = 0$. It then accelerated, but at a decreasing rate.

b Gradient at $t = 3.0\,\text{s} = a = \dfrac{(34-12)}{5.0} = 4.4\,\text{m s}^{-2}$

c Area under under graph $\approx \dfrac{1}{2} \times 40 \times 5 = 100\,\text{m}$

8 **a, b**



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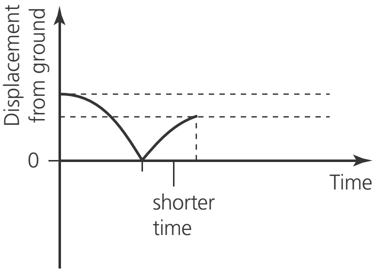


10 **a** $v = \dfrac{(24+13)}{2} = 18.5\,\text{m s}^{-1}$

b Average speed × time = $18.5 \times 4.6 = 85\,\text{m}$

c Average speed × time = $\dfrac{(24+0)}{2} \times 5.9 = 71\,\text{m}$

11 **a** $v^2 = u^2 + 2as = 0 + (2 \times 9.81 \times 2.32) \rightarrow v = 6.7\ \text{m s}^{-1}$

b No air resistance

12 **a** $s = ut + \dfrac{1}{2}at^2 = (18 \times 3.0) + \left(\dfrac{1}{2} \times -9.81 \times 3.0^2\right) = 9.9\,\text{m}$

Ball is 2.0 + 9.9 = 11.9 m above the ground

b $v = u + at = 18 + (-9.81 \times 3.0) = -11.4\,\text{m s}^{-1}$ (downwards)

13 The acceleration is not constant because the resultant force will vary due to fluid resistance increasing as the sphere accelerates.

14 **a** So that the effects of air resistance are less significant

b Advantage: the percentage uncertainty in height should be smaller with larger distances

Disadvantage: the effect of air resistance will be greater

15 $s = ut + \dfrac{1}{2}gt^2 \Rightarrow g = \dfrac{2s}{t^2}$ (since $u = 0$)

$$g = \frac{2 \times \left(76.2 \times 10^{-2}\right)}{0.40^2} = 9.53\,\text{m s}^{-2}$$

$$\frac{\Delta g}{g} = \frac{\Delta s}{s} + \frac{2\Delta t}{t} = \left(2.62 \times 10^{-3}\right) + \left(5.0 \times 10^{-2}\right) = 5.26 \times 10^{-2}$$

$$\Delta g = \left(5.26 \times 10^{-2}\right) \times (9.53) = \pm 0.5\,\text{m s}^{-2}$$

16 **a** $s = ut + \dfrac{1}{2}at^2 \Rightarrow 1.25 = 0 + \dfrac{1}{2}(9.81)t^2 \Rightarrow t = (0.505) = 0.50\,\text{s}$ to two significant figures

b $s = vt = 18 \times 0.505 = 9.1\,\text{m}$

17 a Vertical component of velocity, $v_V = 175 \times \sin 20° = 60\,\text{m}\,\text{s}^{-1}$

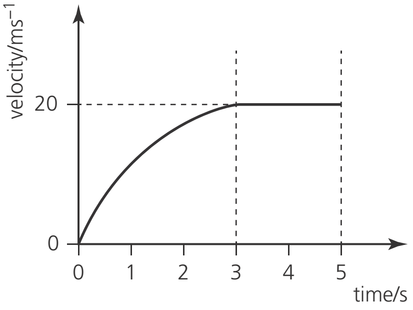
Horizontal component of velocity, $v_H = 175 \times \cos 20° = 164\,\text{m}\,\text{s}^{-1}$

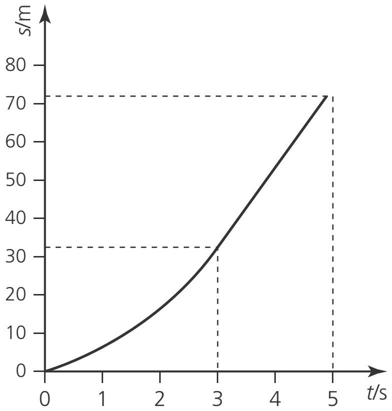
To determine time of flight, t: $v = u + at \rightarrow 60 = -60 + (9.81 \times t) \rightarrow t = 12.2\,\text{s}$

(This is unrealistic because we have ignored air resistance)

Range $= v_\text{H} \times t = 164 \times 12.2 = 2.0 \times 10^3\,\text{m}$

18





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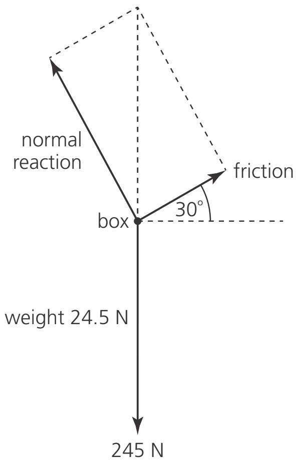


20 a Weight $= mg = 0.62 \times 3.8 = 2.4\,\text{N}$

b $3.8\,\text{m}\,\text{s}^{-2}$

21 a Weight $= mg = (68 \times 10^{-3}) \times 9.81 = 0.67\,\text{N}$

b 0.38 N at an angle of 57° to the vertical

22 Frictional force equals the component of weight acting down the slope.

$\text{F} = \text{weight} \times \sin 30° = 24.5 \times 0.5 = 12.3\,\text{N}$

23 a $\frac{16}{18} = 0.89$

b Dynamic

c Frictional force would increase and acceleration decrease, or it may decelerate.

24 a Component of weight down slope = frictional force up slope

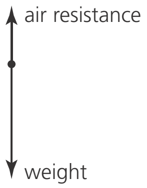
$\cancel{m}\cancel{g} \sin\theta = \cancel{m}\cancel{g} \cos\theta\, \mu_\text{d}$

$\mu_\text{d} = \tan\theta \Rightarrow \theta = 36°$

b Use oil as a lubricant; make surfaces smoother (maybe)

25 No. The unbalanced force of gravity is keeping the Moon in orbit.

26



(Skydiver is shown as a point.)

27 Greater engine power; streamlining; smaller cross-sectional area

28 a $v^2 = u^2 + 2as \Rightarrow 0.0^2 = 75^2 + (2 \times a \times 1500) \rightarrow a = -1.9\ \text{m s}^{-2}$

(Assuming the plane comes to rest.)

b $F = ma = 1.8 \times 10^5 \times 1.9 = 3.4 \times 10^5\ \text{N}$

c Friction between wheels and runway, 'spoilers'/airbrakes raised on wings to increase drag, reversal of engine thrust

29 a At constant speed forces are balanced = $8.5 \times 10^3\ \text{N}$

b $a = \dfrac{F}{m} = \left(\dfrac{(2.7 \times 10^4) - (8.5 \times 10^3)}{(1.68 \times 10^4)}\right) = 1.1\ \text{ms}^{-2}$

c $s = ut + \dfrac{1}{2}at^2 = (14.3 \times 10) + \left(\dfrac{1}{2} \times 1.1 \times 10^2\right) = 198\ \text{m}$

d The resistive force will increase if the bus moves faster.

30 The force acting on them can be determined from $F = ma$. If they land on foam, the impact will occur over a longer time and distance, so that the deceleration *(a)* is reduced, and force is reduced.

31 An equal and opposite force acts on the Sun.

32 a Force on thumb, force on finger, inwards forces on both ends of pin

b The pressures $\left(\dfrac{\text{force}}{\text{area}}\right)$ are different.

33 a $W = Fs = 150 \times 2 = 300\ \text{J}$

b Force acts in the same direction as motion.

c Internal energy (and thermal energy)

34 Work done = loss of kinetic energy

$Fs = (4.0 \times 10^3) \times s = 2.0 \times 10^5 \rightarrow s = 50\ \text{m}$

35 a $W = Fs\cos\theta = 18 \times 50 \times 0.82 = 7.4 \times 10^2\ \text{J}$

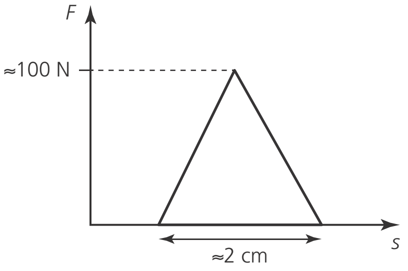
b $W = Fs = 70 \times 0.5 = 35\ \text{J}$

36 a When $F = 0$ the length would have been 1.8 cm.

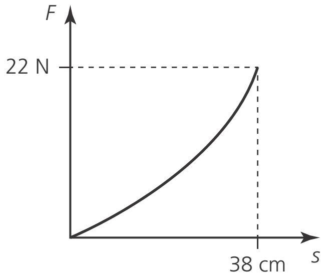
b Work done = average force × change of length = area under graph

$= 12 \times [(2.6 - 2.2) \times 10^{-2}] = 4.8 \times 10^{-2}\ \text{J}$

37



38 a



b Area under graph ≈ 3.5 J

c Some energy will be transferred to kinetic energy, some will become internal energy.

39 Energy is stored in the form of chemical energy in the battery. This is transferred to electrical energy and then to electromagnetic energy in the form of light and radio waves. Sound energy will also be produced. In the end, all forms of useful energy will become dissipated as internal energy and thermal energy.

40 Elastic strain energy in the bow will be transferred to kinetic energy of the arrow. When the arrow hits the target, the energy will be dissipated as internal energy and thermal energy.

41 Nuclear energy to internal energy in the Sun, then thermal and light electromagnetic radiation from Sun producing chemical energy in plants and animals on Earth. Millions of years later, this has been converted to chemical energy in oil which is transferred to internal energy and thermal energy in the power station and then to kinetic energy of turbines and finally electrical energy.

42 Work done = increase in kinetic energy

$$F \times s = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$$

$$\mathrm{F} \times 2000 = \tfrac{1}{2} \times 1.5 \times 10^5 \left(16^2 - 10^2\right) = 5.9 \times 10^3\ \mathrm{N}$$

43 a Because the change of kinetic energy is greater.

b Internal energy in brakes, tyres and road. Then energy spreads out as thermal energy.

44 a Maximum gravitational potential energy

$$= mg\Delta h = (84 \times 10^{-3}) \times 9.81 \times (1.38 - 1.29) = 7.4 \times 10^{-2}\ \mathrm{J}$$

b $\tfrac{1}{2}mv^2_{\text{max}} = 7.4 \times 10^{-2} \Rightarrow v_{\text{max}} = 1.3\,\mathrm{m\,s^{-1}}$

45 a $\dfrac{1}{2}k\Delta x^2 = mg\Delta h \Rightarrow \dfrac{1}{2} \times 420 \times 0.12^2 = (4.3 \times 10^{-3}) \times 9.81 \times \Delta h \rightarrow \Delta h = 72\,\mathrm{m}$

b Kinetic energy of band has been ignored. The energy dissipation in band and due to air resistance on the moving mass will also be significant.

46 a Assuming no air resistance, $\dfrac{1}{2}\cancel{m}v^2 = \cancel{m}g\Delta h \Rightarrow v = 4.9\,\mathrm{m\,s^{-1}}$

b Work done = *Fs* = loss of kinetic energy

$$F \times 0.70 \times 10^{-2} = \frac{1}{2} \times (12 \times 10^{-3}) \times 4.9^2 \rightarrow F = 21\,\mathrm{N}$$

c Sand particles will have been given kinetic energy and some gravitational potential energy. In the end, most of the original energy will have been dissipated as internal and thermal energy.

47 a Energy = $Pt = 14 \times 2 \times 3600 = 1.0 \times 10^5$ J

b Total power into bulb

c Electrical energy to electromagnetic (light) energy, internal energy and thermal energy.

48 $P = \dfrac{mg\Delta h}{t} = \dfrac{120 \times 9.81 \times 4.3}{68} = 74\,\mathrm{W}$

49 $P = Fv \Rightarrow 1.8 \times 10^9 = F \times 250 \Rightarrow F = 7.2 \times 10^6\ \mathrm{N}$

50 $\dfrac{P_{out}}{P_{in}} = 0.32 \Rightarrow P_{in} = \dfrac{1.8}{0.32} = 5.6\,\mathrm{GW}$

51 a Energy input = energy density × volume = $(3.3 \times 10^7) \times (45 \times 10^{-3}) = 1.485 \times 10^6$ J

$$\text{Efficiency} = \frac{\text{useful energy out}}{\text{total energy in}} = \frac{4.0 \times 10^5}{1.485 \times 10^6} = 0.27$$

52 All energy transfers involve increases in internal energy. This is exactly what is needed in a water heater, but not in a food mixer.

53 a $0.250 \times (+12) = +3.0\,\mathrm{kg\,m\,s^{-1}}$ (down)

b Momentum after rebounding $= 0.250 \times (-8.5) = -2.1\,\mathrm{kg\,m\,s^{-1}}$ (up)

(Signs represent directions. They may be reversed.)

c Change of momentum $-2.1 - 3.0 = -5.1\,\text{kg}\,\text{m}\,\text{s}^{-1}$

d $F = \dfrac{\Delta p}{\Delta t} = \dfrac{5.1}{0.37} = 14\,\text{N}$

54 $E_K = \dfrac{p^2}{2m} \Rightarrow p = \sqrt{2mE_K} = 6.0 \times 10^{-20}\,\text{kg}\,\text{m}\,\text{s}^{-1}$

55 $F = \dfrac{\Delta p}{\Delta t} = \dfrac{1320 \times (7.5 - 4.3)}{3.9} = 1.1 \times 10^3\,\text{N}$

56 a As the fuel and oxygen are combusted, the (mass of) the exhaust gases is ejected from the back of the rocket engine.

b $F = ma$. If the mass is decreasing, the same force will produce a greater acceleration.

57 Momentum before collision = momentum after collision.

$1.2 \times 0.82 = (1.2 + 1.8) \times v \rightarrow v = 0.33\,\text{m}\,\text{s}^{-1}$ in original direction

58 $(0.34 \times (+1.20)) + (0.22 \times (-0.85)) = 0.34v + (0.22 \times (+0.62))$

$0.408 - 0.187 = 0.34v + 0.1364$

$v = +0.25\,\text{m}\,\text{s}^{-1}$ (in original direction)

59 Momentum of bullet + momentum of rifle = 0

$[(3.6 \times 10^{-3}) \times 430] + 1.4v = 0 \rightarrow v = -1.1\,\text{m}\,\text{s}^{-1}$ (in opposite direction to bullet)

60 a $F = \dfrac{\Delta p}{\Delta t} = 2 \times \left(\dfrac{0.2}{60}\right) \times 700 = 4.7\text{N}$ (Assuming the water bounces back off the surface with the same speed)

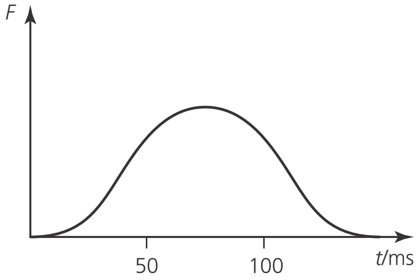
b $p = \dfrac{F}{A} \Rightarrow 6.0 \times 10^8 = \dfrac{4.7}{A} \Rightarrow A \approx 10^{-8}\,\text{m}^2$

61 a Approximate area under graph $= 800 \times 4.0 \times 10^{-3} = 3.2\,\text{N}\,\text{s}$

b Change of momentum $(46 \times 10^{-3}) \times \Delta v = 3.2 \Rightarrow \Delta v = 70\,\text{m}\,\text{s}^{-1}$

62 a $mv = 65 \times \left(\dfrac{30 \times 10^3}{3600}\right) \approx 5.4 \times 10^2\,\text{kg}\,\text{m}\,\text{s}^{-1}$

b



c Area under graph = change of momentum $\approx F_{\text{Max}} \times (50 \times 10^{-3}) \approx 540 \rightarrow F_{\text{Max}} \approx 10^4\,\text{N}$

63 a $2.1 \times (+5.0)) + (3.4 \times (-7.0)) = (2.1 \times (-9.8)) + 3.4v$

$v = +2.14\,\text{m}\,\text{s}^{-1}$ (to the right)

b KE before $= \left(\dfrac{1}{2} \times 2.1 \times 5.0^2\right) + \left(\dfrac{1}{2} \times 3.4 \times 7.0^2\right) = 110\,\text{J}$

KE after $= \left(\dfrac{1}{2} \times 2.1 \times 9.8^2\right) + \left(\dfrac{1}{2} \times 3.4 \times 2.14^2\right) = 109\,\text{J}$

Only about 1 J of energy has been dissipated, so this collision is almost elastic.

64 Collisions between steel spheres

65 $(1340 \times 29) + (9600 \times 23) = (1340 + 9600) \times v \rightarrow v = 24\,\text{m}\,\text{s}^{-1}$

Topic 3 Thermal physics

Questions to check understanding

1 A molecule in ice vibrates in a fixed position. Where the ice melts, the molecule still vibrates; but it can move from its fixed position, but it cannot move freely. When the water becomes steam, the molecule moves at high speeds, changing velocity after each collision with other molecules.

2 Thermal energy will be transferred from the surroundings through the bottle to the water. The molecules gain energy, so that we say the internal energy of the water has increased. The average random kinetic energy of the molecules also rises, which means that the temperature has increased.

3 **a** 5 K

b $90 - 273 = -183\,°\text{C}$

4 **a** Because the Kelvin temperature scale has a true zero at 0 K, but 0 °C is an arbitrary choice.

b Because it is considered to be fundamental and not limited by comparison to other phenomena.

5 **a** $Q = mc\Delta T = Pt$

$0.60 \times 4180 \times (100 - 23) = P \times (2 \times 60)$

$P = 1.6 \times 10^3\,\text{W}$

b Some of the energy supplied will be transferred to the container and surroundings as internal energy and thermal energy.

7 $Q = mc\Delta T = (\rho V)c\Delta T = 1.2 \times 50 \times 10^3 \times 10 = 6.0 \times 10^5\,\text{J}$

8 $mc\Delta T$ for water $= mc\Delta T$ for metal

$1.2 \times 4180 \times (39 - 23) = 0.56 \times c \times (750 - 39)$

$c = 2.0 \times 10^2\,\text{J}\,\text{kg}^{-1}\,\text{K}^{-1}$

9 Internal energy is the sum of the molecular energies in a material. Thermal energy is energy moving from place to place because of a temperature difference.

10 $\frac{1}{2}\times\frac{1}{2}mv^2 = mc\Delta T$

$\frac{1}{2}\times\frac{1}{2}\cancel{m}\,420^2 = \cancel{m}\times 480\times\Delta T$

$\Delta T = 92\,\text{K}$

11 **a** $\cancel{m}gh = \cancel{m}c\Delta T$

$9.81\times1.6 = 830\times\Delta T$

$\Delta T \approx 0.02\,\text{K}$

b All the gravitational potential energy of the sand was transferred to internal energy in the sand. No thermal energy was transferred to the ground or the air.

13 **a** $Pt = mL_v$

$2500 \times t = (10 \times 10^{-3}) \times 2.26 \times 10^6$

$t = 9.0\,\text{s}$

b No thermal energy transferred to the surroundings.

14 $mL_v = 1.0\times10^6 \rightarrow m = 2.9\,\text{kg}$

15 a $(mc\Delta T)_{\text{ice}} + (mc\Delta T)_{\text{melted ice}} + M_{\text{ice}}L_f = (mc\Delta T)_{\text{water}}$

$\left(0.1 \times 2100 \times 6.0\right) + \left(0.1 \times 4200 \times 4.5\right) + 0.1L_f = 0.4 \times 4200 \times 20.5$

$L_f = 3.1 \times 10^5\,\text{J kg}^{-1}$

b Thermal energy was absorbed from the surroundings. Without this, the final temperature would have been lower, making the value calculated for the specific latent heat larger.

16 a At constant pressure the volume is proportional to the absolute temperature:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$\frac{15}{291} = \frac{V_2}{373}$$

$V_2 = 19\,\text{cm}^3$

b To ensure that all the air had reached the same temperature as the water.

17 a At constant temperature, volume is inversely proportional to pressure:

$p_1V_1 = p_2V_2$

$(1.2 \times 10^5) \times 17 = (2.8 \times 10^5)\,V_2$

$V_2 = 7.3\,\text{cm}^3$

b Do the experiment slowly, so that there is time for thermal energy to flow out of the gas.

18 $$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$$

$$\frac{(2.3 \times 10^5) \times 24}{296} = \frac{p_2 \times 33}{323}$$

$p_2 = 1.8 \times 10^5\,\text{Pa}$

20 Pressure Law: When the temperature rises the molecules move faster, so that they hit the walls faster and more often.

Charles' Law: As above, but if the pressure remains constant, then the volume must increase so that there are fewer collisions per cm^2 per second of the faster moving molecules with the walls.

Boyle's Law: Molecular motions are unchanged. If the volume is decreased, there will be more molecular collisions per cm^2 per second with the walls.

21 a $\frac{1000}{12} = 83\,\text{mol}$

b $83 \times 6.02 \times 10^{23} = 5.0 \times 10^{25}$

22 a $\frac{1.5 \times 10^{24}}{6.02 \times 10^{23}} = 2.5\,\text{mol}$

b $2.5 \times 2.02 = 5.0\,\text{g}$

c $V = \frac{m}{\rho} = \frac{5.0 \times 10^{-3}}{2.7} = 1.9 \times 10^{-3}\,\text{m}^3$

23 a $\frac{44 \times 10^{-3}}{6.02 \times 10^{23}} = 7.3 \times 10^{-26}\,\text{kg}$

b 1 g has $\frac{1}{44.0} \times 6.02 \times 10^{23}$ molecules $= 1.37 \times 10^{22}$ molecules

Each molecule has three atoms, so that total number of atoms $= 1.37 \times 10^{22} \times 3 = 4.10 \times 10^{22}$

24 a $\frac{197 \times 10^{-3}}{6.02 \times 10^{23}} = 3.27 \times 10^{-25}\,\text{kg}$

b $V = \frac{m}{\rho} = \frac{3.27 \times 10^{-25}}{19 \times 10^3} = 1.7 \times 10^{-29}\,\text{m}^3$

c If we imagine that each atom occupies a cubic space, the side of that cube ≈ separation of the centres of atoms.

$$= \sqrt[3]{1.7\times10^{-29}} = 2.6\times10^{-10}\text{ m}$$

25 a i $\frac{3}{2}RT = \frac{3}{2}\times8.31\times288 = 3.6\times10^{3}\text{ J}$

ii $3.6\times10^{3}\text{ J}$

b $\frac{3}{2}nR\Delta T = \frac{3}{2}\times\left(\frac{1000}{4.0}\right)\times8.31\times1.0 = 3.1\times10^{3}\text{ J}$

26 a $\bar{E}_K = \frac{3}{2}kT = 1.5\times(1.38\times10^{-23})\times273 = 5.7\times10^{-21}\text{ J}$

b $\frac{1}{2}mv^2 = 5.7\times10^{-21} \Rightarrow v = 460\text{ m s}^{-1}$

27 $pV = nRT \rightarrow p\times(120\times10^{-6}) = 3.2\times8.31\times(273+58)$

$p = 7.3\times10^{7}\text{ Pa}$

28 $pV = nRT$

$(2.8\times1.01\times10^{5})\times(850\times10^{-6}) = n\times8.31\times(273+20)$

$n = 0.099\text{ mol}$

$m = 0.099\times44.0 = 4.3\text{ g}$

29 Ideal gas theory assumes that the molecules move independently without forces acting on them, except in collisions. These assumptions are valid for fast moving molecules which are relatively far apart from each other (on average). At high densities, the molecules are closer together. At lower temperatures, the speeds of the molecules may not be great enough for forces to be insignificant.

Topic 4 Waves

Questions to check understanding

1 a B

b Because A is longer than B

c The component of gravity (weight)

d They have different periods

2 a $T = \frac{84.7}{50} = 1.69\text{ s}$

b $\frac{50}{84.7} = 0.590\text{ Hz}$

3 Ball rolling on a V-shaped track

4 a Constant period

b $T = 0.40\text{ s}$

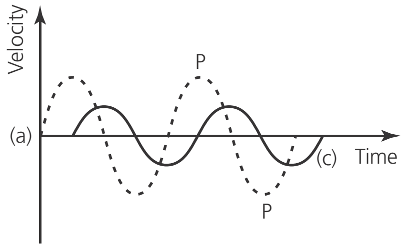
$f = \frac{1}{0.40} = 2.5\text{ Hz}$

c Maximum velocity can be determined from the maximum gradient of the graph.

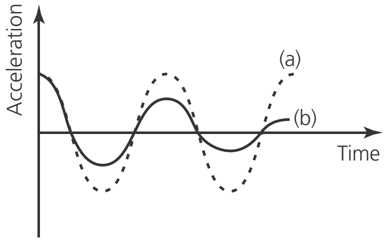
$\frac{\Delta x}{\Delta t} \approx \frac{20.0}{0.15} \approx 130\text{ cm s}^{-1}$

(For HL students, this can be confirmed using an equation from Chapter 9.)

5 a, b, c



6 a, b



7 At the maximum displacement, all the energy is in the form of elastic strain energy. When released, this is transferred to kinetic energy. In the equilibrium position, all the energy is kinetic. The process is then reversed.

8 a Transverse

b The ball will oscillate vertically but not move horizontally.

9 The vocal chords in our throat vibrate. This disturbs the surrounding air, making the molecules oscillate. These oscillations are passed between molecules as a longitudinal wave until collisions with our ear drums make them vibrate at the same frequency.

10 a $\lambda = \frac{4.80}{5} = 0.96\,\text{m}$

b $c = \frac{s}{t} = \frac{4.8}{5.4} = 0.89\,\text{m}\,\text{s}^{-1}$

c $f = \frac{c}{\lambda} = \frac{0.89}{0.96} = 0.93\,\text{Hz}$

11 $\lambda = \frac{c}{f} = \frac{335}{262} = 1.28\,\text{m}$

12 a Transverse

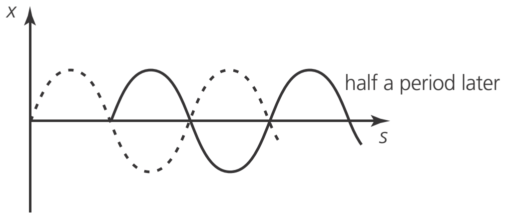
b $c = f\lambda \approx 3.0 \times 0.4 = 1.2\,\text{m}\,\text{s}^{-1}$

c Amplitude decreased

d The tension (force) in the spring will be greater, and the mass in a given length will be less. Accelerations and velocities within the system will be greater.

13 $\lambda = \frac{c}{f} = \frac{3.0 \times 10^{8}}{5 \times 10^{14}} \approx 10^{-6}\text{ m}$

14



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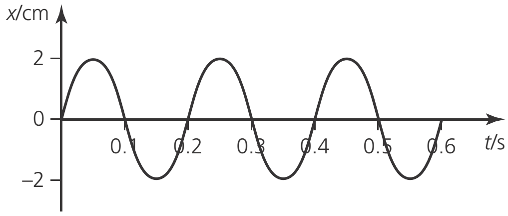


16 a $\lambda = \frac{c}{f} = \frac{3.0\times10^8}{1.9\times10^9} = 0.16\,\text{m}$

b They can penetrate into the human body.

17 Temperature, surface area, nature of the surface

18 Gamma rays. They come from radioactive (unstable) atoms. (Cosmic rays from outer space have even higher frequencies.)

19 $f = \frac{c}{\lambda} = \frac{3.0\times10^8}{0.21} = 1.4\times10^9\,\text{Hz}$, which is 1400 MHz.

21 a They had different reaction times.

b Average time = 0.54 s

$c = \frac{s}{t} = \frac{180}{0.54} = 3.3\times10^2\,\text{m}\,\text{s}^{-1}$

22 a The molecules which transfer the vibrations are moving faster at the higher temperature.

b i $\lambda = \frac{c}{f} = \frac{331}{15} = 22\,\text{m}$

ii $\lambda = \frac{c}{f} = \frac{353}{15} = 24\,\text{m}$

23 a Water density may be different.

b $s = v\times\frac{t}{2} = 1490\times\frac{0.310}{2} = 231\,\text{m}$

c With continuous waves, these is no way of knowing when the waves were sent or received.

24 Energy = power × time = $520\times4.2\times3600 = 7.9\times10^6\,\text{J}$

25 a $I \propto A^2$; if $A\times1.25$ then $I\times1.25^2 = 1.56$

(Intensity has increased by 56%)

b If $I\times0.9$, then $A\times\sqrt{0.9} = \times\,0.95$ (Amplitude has decreased by 5%)

26 $10\times\left(\frac{1.5}{2.0}\right)^2 = 5.6\,\text{kW}$

27 $\left(\frac{1.5}{1.0}\right)^2 = 2.25\times$ greater

28 The sound is not emitted equally in all directions; sound is also received by reflection off the walls.

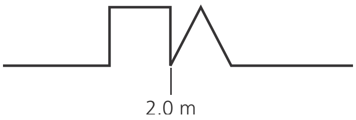
29 Ix^2 = constant

$I\times30^2 = 2I\times r^2$ (r = new distance from lamp)

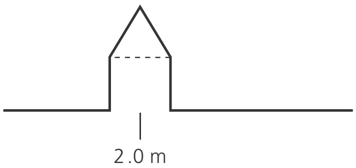
$\Rightarrow r = 21.2\,\text{m}$

So the man must walk (30 – 21.2) = 8.8 m toward the lamp.

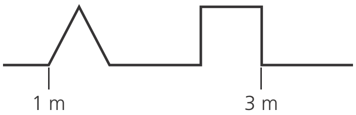
30 a



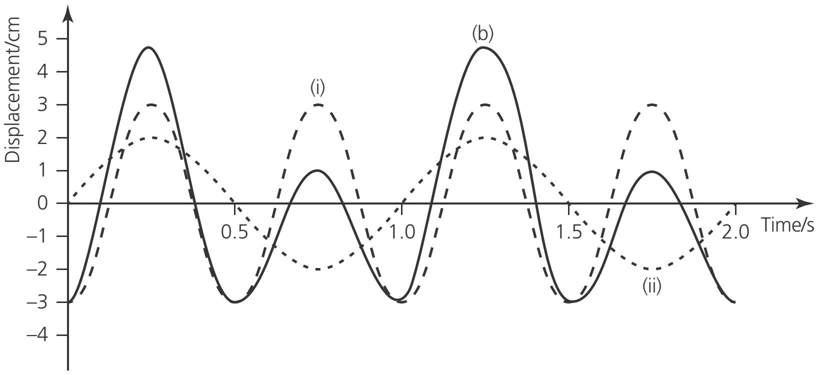
b



c



31 a, b



32 a Light is a transverse wave. Sound is a longitudinal wave. Only transverse waves can be polarized.

b Light is emitted randomly.

33 a $\frac{I}{2}$

b $\left(\frac{I}{2}\right)\cos^2 40 = 0.29I$

34 a 57°

b $\frac{\sin 57}{\sin 33} = 1.54$

c With electric field vector parallel to surface

d Rotate a polarizing filter in front of the eye when looking at the reflected light. If the intensity can be reduced to zero, the light is totally plane polarized.

35 The filter can be rotated to reduce the intensity of light reflected off insulators (e.g. water).

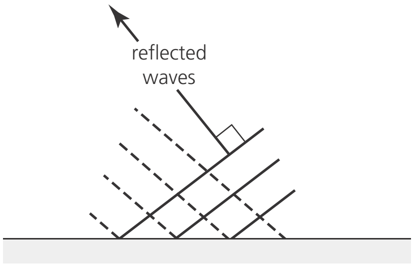
36 $I = I_0 \cos^2\theta$

$0.9 = \cos^2\theta \Rightarrow \theta = 18°$

37 To reflect sound waves coming from the traffic and stop them reaching nearby homes.

38 The diagram should show how the diverging mirror increases the ‘field of view’ behind the car for driver.

39



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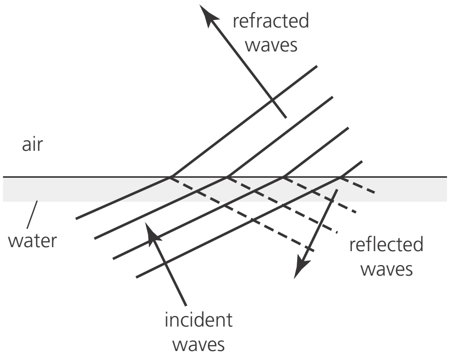


42 a $\dfrac{c_{\text{air}}}{c_{\text{plas}}} = 1.41 \Rightarrow c_{\text{plas}} = \dfrac{3.00\times10^8}{1.41} = 2.13\times10^8\ \text{m s}^{-1}$

b $\dfrac{\sin\theta_1}{\sin\theta_2} = 1.41 \Rightarrow \sin\theta_2 = \dfrac{\sin 38}{1.41} = 0.437 \Rightarrow \theta_2 = 26°$

43 a $n = \dfrac{\sin\theta_1}{\sin\theta_2} = \dfrac{0.669}{0.438} = 1.53$

b Angle of incidence on second surface = 34°.

$$\frac{\sin 34}{\sin\theta} = \frac{1}{1.53} \Rightarrow \sin\theta = 0.855 \rightarrow \theta = 59°$$

44 a Plastic (lower refractive index)

b For light passing through the second interface:

$$\frac{\sin\theta}{\sin 38°} = \frac{1.43}{1.58} \Rightarrow \sin\theta = 0.557 \rightarrow \theta = 34°$$

For the first interface:

$$\frac{\sin i}{\sin 34} = 1.58 \Rightarrow \sin i = 0.884 \rightarrow i = 62°$$

45 The air will be hotter and less dense than the surrounding air. When waves enter this air, their speed will change (gradually and slightly) so that they will gradually refract (change direction). This effect is likely to be variable.

46 a $\sin c = \dfrac{n_2}{n_1} \Rightarrow \sin 39° = \dfrac{1}{n_1} \Rightarrow n_1 = 1.59 \quad (n_2 = n_{\text{air}} = 1)$

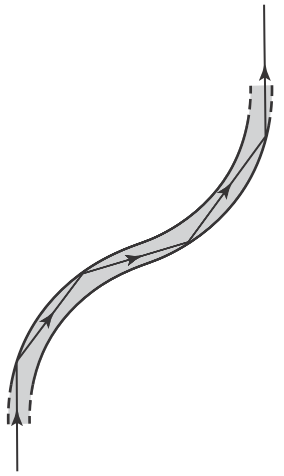
b n_2 would increase, so that sin *c* and *c* would increase.

47 a $n_{\text{water}} = \dfrac{3.00\times10^8}{2.25\times10^8} = 1.33 \quad n_{\text{glass}} = \dfrac{3.00\times10^8}{1.95\times10^8} = 1.54$

$$\sin c = \frac{n_{\text{water}}}{n_{\text{glass}}} = 0.867 \rightarrow c = 60.1°$$

b In the medium with the greater refractive index: glass.

48



49 The sounds may have to move (diffract) around various objects. Typically, these objects may have sizes of 10 m or more. For maximum diffraction the sounds should have wavelengths ≈ 10 m, which have low frequencies.

50 Width of aerial should be approximately equal to the wavelength: $\lambda = \dfrac{c}{f} = \dfrac{3\times10^8}{1.9\times10^9} \approx 0.1\text{m}$

51 $f = \dfrac{c}{\lambda} = \dfrac{0.20}{0.01} = 20\,\text{Hz}$

52 a The pattern would spread out and get dimmer.

b Different colours have different wavelengths and would diffract by slightly different amounts. The colours would overlap and the fringes would have coloured edges.

53 a Separate sources would not be coherent.

b The patterns would be sharper and clearer (but probably dimmer) compared with the patterns seen with white light.

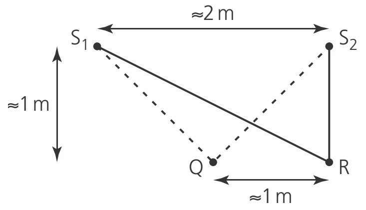
c $s = \frac{\lambda D}{d} \Rightarrow 1.9 \times 10^{-3} = \frac{\lambda \times 1.98}{5.0 \times 10^{-4}} \Rightarrow \lambda = 4.8 \times 10^{-7}\,\text{m}$

54 a $\frac{1.20}{2} = 0.60\,\text{m}$

b To avoid hearing the reflections of sounds from the walls (etc.) of a room.

55 a The student is walking between places where the sound waves arrive in phase (constructive interference) and where they arrive out of phase (destructive interference).

b This is only an estimate, so we can simplify the situation and approximate the distances as shown.



At Q the path difference is zero.

At R (the next maximum) path difference = 1λ

$S_1R - S_2R = 1\lambda$

$\sqrt{5} - 1 = 1\lambda$

$\lambda \approx 1\,\text{m} \Rightarrow f = \frac{c}{\lambda} = \frac{340}{1} \approx 300\ \text{Hz}$

c No, because the sound amplitudes received at any point will not be equal, except at the centre of the pattern, where there is constructive interference.

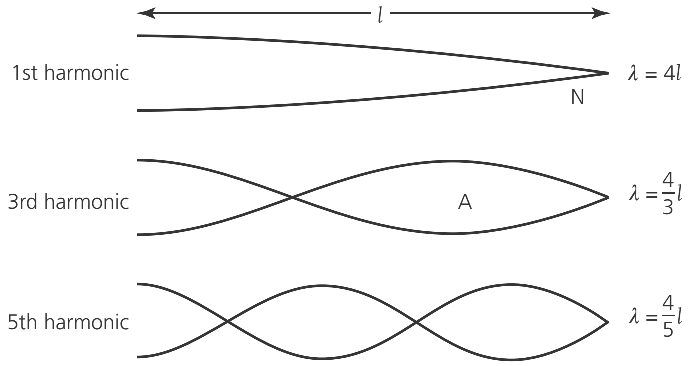
56 First, move the receiver to a location where a maximum of wave intensity is received. Then slowly move in any direction, so that the intensity drops. It will rise again to the next maximum. Wavelength can be determined from path differences.

57 a The amplitude of the sound wave oscillations

b N are nodes, i.e. the places where the air is not oscillating. Vibrations at other places move the powder to the nodes.

c 11th harmonic

58



59 If open at both ends, wavelength of first harmonic = $2L$

If open at one end, wavelength of first harmonic = $4L$

If the wavelength is doubled $(2L \rightarrow 4L)$, then the frequency will be halved $(80 \rightarrow 40\,\text{Hz})$

60 a $\lambda = 2L = 2 \times 0.950 = 1.90\,\text{m}$

$$f = \frac{c}{\lambda} = \frac{336}{1.90} = 177\,\text{Hz}$$

b $\frac{710}{177} = 4.01 \Rightarrow 4^{\text{th}}$ harmonic

61 a The string must vibrate with a greater amplitude.

b The same string could make sounds of higher frequency by using shorter lengths. To make lower frequencies, a longer string (or a thicker string) would be needed.

62 a Third

b $\frac{2}{3} \times 66 = 44\,\text{cm}$

c $c = f\lambda = 25 \times 0.44 = 11\,\text{m s}^{-1}$

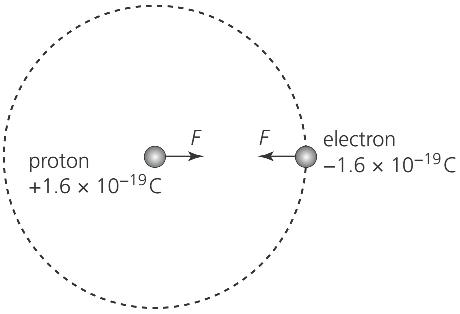
d $\frac{5}{3} \times 25 = 42\,\text{Hz}$

e By increasing the mass hanging on the end of the string. The wave speed would increase.

Topic 5 Electricity and magnetism

Questions to check understanding

1



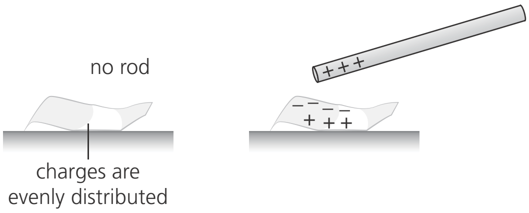
2 a $3 \times 1.6 \times 10^{-19} = +4.8 \times 10^{-19}\,\text{C}$

b $-4.8 \times 10^{-19}\,\text{C}$

c $+1.6 \times 10^{-19}\,\text{C}$

3 Electrons are transferred from the hair to the brush.

4



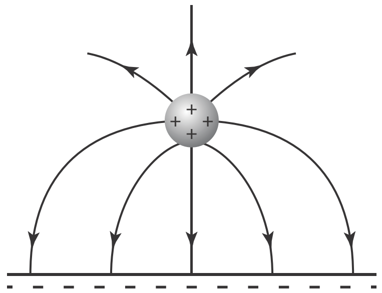
When the charged rod is placed close to the paper (without touching), some electrons are attracted to the surface near to the rod. There is then attraction between the negative charge on the surface and the positively charged rod.

5 In Figure 5.4b, there is a point midway between the charges where the forces on a test charge would be equal and opposite. Zero force means zero field.

6 a $E = \frac{F}{q} = \frac{9.3 \times 10^{-5}}{4.7 \times 10^{-8}} = 2.0 \times 10^{3}\,\text{N C}^{-1}$

b $F = Eq = (2.0 \times 10^{3}) \times (-1.9 \times 10^{-8}) = -3.8 \times 10^{-5}\,\text{N}$ in the opposite direction.

7



8 a $(3.4 \times 10^4) + (-7.1 \times 10^4) = -3.7 \times 10^4\ \text{N}\,\text{C}^{-1}$

b $\sqrt{\left(3.4\times10^4\right)^2+\left(7.1\times10^4\right)^2} = 7.9\times10^4\ \text{N}\,\text{C}^{-1}$

9 $F = \dfrac{kq_e q_p}{r^2} = \dfrac{(8.99\times10^9)(1.6\times10^{-19})^2}{\left(5.3\times10^{-11}\right)^2} = 8.2\times10^{-8}\ \text{N}$

10 $F = \dfrac{kq_1 q_2}{r^2} \Rightarrow 6.3\times10^{-8} = \dfrac{(8.99\times10^9)(8.7\times10^{-9})}{\left(15.6\times10^{-2}\right)^2} q_2 \Rightarrow q_2 = 2.0\times10^{-11}\text{C}$

11 a Force would be reduced.

b k and F would be reduced by a factor of $\dfrac{1.4\times10^{-11}}{8.85\times10^{-12}} = 1.6$

12 $E = \dfrac{F}{q} = \dfrac{\dfrac{kq_1 \cancel{q_2}}{r^2}}{\cancel{q_2}} = \dfrac{kq_1}{r^2} = \dfrac{(8.99\times10^9)\times10\times10^{-9}}{(25\times10^{-2})^2} = 1.4\times10^3\text{N}\text{C}^{-1}$

13 a $I = \dfrac{\Delta q}{\Delta t} \Rightarrow 0.24 = \dfrac{\Delta q}{3600} \Rightarrow \Delta q = 8.6\times10^2\ \text{C}$

b $\dfrac{0.24}{(1.6\times10^{-19})} = 1.5\times10^{18}$

14 $I = nAvq \Rightarrow 1.0 = \left(8.5\times10^{28}\right)\times\pi\times(0.5\times10^{-3})^2\times v\times(1.6\times10^{-19})$

$v = 9.4\times10^{-5}\text{m s}^{-1}$

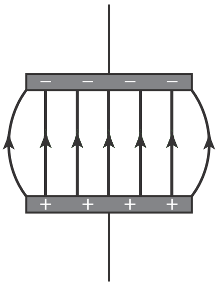
15 The magnitude and direction of the electrons' drift speed will change periodically.

16 a i $V = \dfrac{W}{q} \Rightarrow +250 = \dfrac{W}{5.6\times10^{-9}} \Rightarrow W = +1.4\times10^{-6}\ \text{J}$

ii $-1.4 + 10^{-6}$ J

b When moving through a positive p.d.

17 a



b $E = \dfrac{V}{d} = \dfrac{5000}{8.3\times10^{-2}} = 6.0\times10^4\ \text{Vm}^{-1}$

c If the drop were positively charged, the electric force upward could be equal to the gravitational force (weight) downwards.

d $\dfrac{F}{q} = E = 6.0\times10^4 \Rightarrow F = 6.7\times10^{-14}\ \text{N}$

18 $V=\frac{W}{q}=\frac{135}{3\times 5}=9\,\text{V}$

19 Energy transferred = $Pt = Vq$

If $t = 1$, $q=\frac{P}{V}=\frac{2.5}{4.5}=0.56\,\text{C}$

(more simply, $P = VI$)

20 a 500 V

b $500\,\text{eV} = 500 \times 1.6 \times 10^{-19} = 8.0 \times 10^{-17}\,\text{J}$

$\frac{1}{2}mv^2=8.0\times 10^{-17}$

$v=\sqrt{\frac{2\times 8.0\times 10^{-17}}{9.1\times 10^{-31}}}=1.3\times 10^{7}\,\text{m}\,\text{s}^{-1}$

21 a i $2 \times 5.6 \times 10^3 = 1.12 \times 10^4$ eV

ii $1.12 \times 10^4 \times 1.6 \times 10^{-19} = 1.8 \times 10^{-15}\,\text{J}$

b The initial kinetic energy of the ion was zero.

22 $\frac{2.8\times 10^{-13}}{1.6\times 10^{-19}\times 10^{6}}=1.75\,\text{MeV}$

23 $1 + 1 = 1 + 1 + I_5$

$I_5 = 0\,\text{A}$

24 In parallel. This is so that they all are connected to the full mains p.d. and can be controlled individually.

25 a $R=\frac{V}{I}=\frac{230}{0.11}=2.1\times 10^{3}\,\Omega$

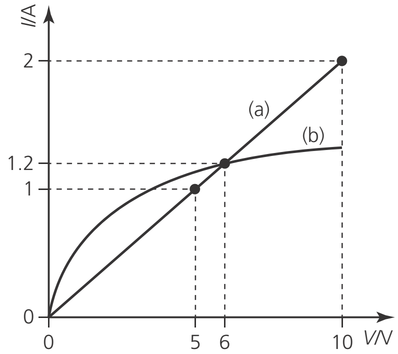
b When first turned on, the bulb may have had a lower resistance because it was colder.

c $I=\frac{V}{R}=\frac{110}{2100}=0.053\,\text{A}$

d The resistance was constant at different voltages.

26 $V = IR = (2.4 \times 10^{-3}) \times (4.7 \times 10^3) = 11\,\text{V}$

27 a, b

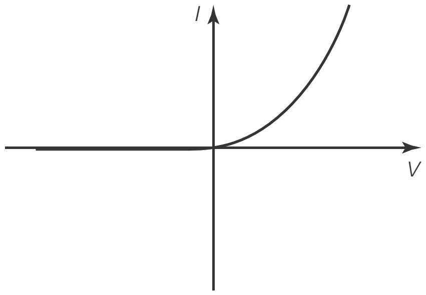


28 a Equal increases in voltage produce greater and greater increases in current. This is because the resistance is decreasing. The thermistor behaves the same when the connections are reversed.

b **i** $R = \frac{V}{I} = \frac{2.0}{0.10} = 20\,\Omega$

ii $R = \frac{V}{I} = \frac{-4.0}{-0.27} = 15\,\Omega$

c

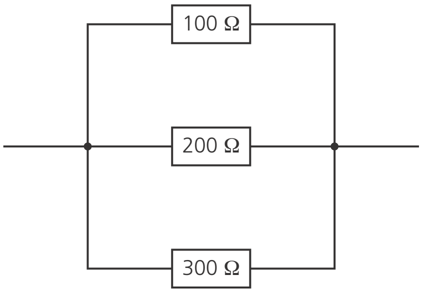


(simplified)

29 a

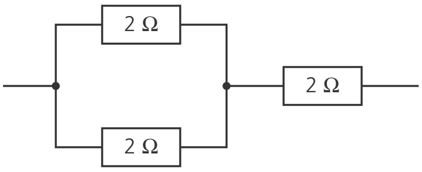
$R_T = 100 + 200 + 300 = 600\,\Omega$

b



$$\frac{1}{R_T} = \frac{1}{100} + \frac{1}{200} + \frac{1}{300} \Rightarrow R_T = 55\ \Omega$$

30



31 a C and D in series have a combined resistance of 6 + 6 = 12 Ω. C + D in parallel with E have a resistance of

$$\left(\frac{1}{12} + \frac{1}{6}\right)^{-1} = 4\,\Omega$$

C, D and E in series with A and B have a total resistance of 4 + 6 + 6 = 16 Ω

b **i** $I_\mathrm{A} = \frac{V_T}{R_T} = \frac{12}{16} = 0.75\,\mathrm{A}$

ii $V_\mathrm{CD} = \frac{4.0}{16} \times 12 = 3.0\,\mathrm{V};\ I_\mathrm{C} = \frac{V_\mathrm{CD}}{R_\mathrm{CD}} = \frac{3.0}{12} = 0.25\,\mathrm{A}$

iii $I_\mathrm{E} = 0.75 - 0.25 = 0.5\,\mathrm{A}$

c There will then be three 6 Ω resistors in series (A, B and E)

$$I_T = \frac{V_T}{R_T} = \frac{12}{18} = 0.67\mathrm{A}$$

The current through A and B will decrease so they will be dimmer. The current through E will increase, so it will get brighter.

32 a Voltmeter and 1 MΩ, in parallel have a combined resistance of 0.5 MΩ.

$$V = \left(\frac{0.5}{1.5}\right) \times 6.0 = 2.0\,\text{V}$$

b 3.0 V each

33 a Assuming that the voltmeter is ideal: 10 Ω

b If $R_{\text{var}} = 0\,\Omega$,

$$V = \frac{20}{30} \times V_S = 0.67 V_S$$

If $R_{\text{var}} = 50\,\Omega$,

$$V = \frac{20}{80} \times V_S = 0.25 V_S$$

34 a $R = \dfrac{V}{I} = \dfrac{4.7}{1.3} = 3.6\,\Omega$

b The infinite resistance of the voltmeter would stop any current flowing. The ammeter would read 0 A and the voltmeter would read 4.7 V. (Voltage across component = 0 V.)

36 $R = \rho \dfrac{L}{A} = \dfrac{(2.8 \times 10^{-8}) \times 2000}{1.8 \times 10^{-4}} = 0.31\,\Omega$

37 $I = \dfrac{V}{R} = \dfrac{V}{\rho L / A} = \dfrac{1.46 \times \pi \times (0.07 \times 10^{-3})^2}{1.1 \times 10^{-8} \times 0.98} = 2.1\,\text{A}$

38 We would expect that a material with greater charge density (more mobile charges per m^3) would have a lower resistivity.

39 a $I = \dfrac{V}{R} = \dfrac{V}{\rho L / A} = \dfrac{12 \times 5 \times 10^{-6}}{\left(1 \times 10^{12}\right)\left(0.1\right)}$

$\approx 10^{-15}\,\text{A}$

b $R = \dfrac{\rho L}{A} \Rightarrow \dfrac{12}{0.05} = \dfrac{\rho \times 0.1}{5 \times 10^{-6}} \quad \Rightarrow \rho = 0.012\ \Omega\text{m}$

40 If $R_{\text{var}} = 0\,\Omega$, $V_{\text{comp}} = 12.0\,\text{V}$

If $R_{\text{var}} = 30\,\Omega$,

$$V_{\text{comp}} = 12 \times \frac{10}{40} = 3.0\,\text{V}$$

Range = 3.0 → 12.0 V

41 As Figure 5.24, but with a lamp instead of the 'component being investigated'. The battery should supply 12.0 V. The resistance of the lamp is $\dfrac{12}{0.2} = 60\,\Omega$ (assume constant), so the value of the variable resistance should be lower, say 0 – 10 Ω. Voltmeter range = 0 – 12 V; ammeter range 0 – 0.5 A.

42 Guess that (I_1) a current I, flows upwards in the wire on the left hand side, (2) a current I_2 flows upwards in the central wire, and (3) a current I_3 flows down on the right hand side.

Then $I_1 + I_2 = I_3$

For the left hand loop: $6.0 - 6.0 = 50\,I_1 - 20\,I_2$

For the right hand loop: $6.0 + 12.0 = 20\,I_2 + 100\,I_3$

Solving these three equations leads to $I_1 = 0.045$ A, $I_2 = 0.11$ A, $I_3 = 0.16$ A (to two significant figures)

43 a $I=\frac{P}{V}=\frac{2500}{230}=11\,\text{A}$

b $\text{time}=\frac{\text{energy}}{\text{power}}=\frac{1.0\times10^6}{2500}=4\times10^2\,\text{s}$

c $R=\frac{V}{I}=\frac{230}{11}=21\,\Omega$ (or use $P=V^2/R$)

44 $P=I^2R=50^2\times20\times0.2=1\times10^4\,\text{W}$

45 a Since $P=\frac{V^2}{R}$, doubling the voltage increases the power dissipated by a factor of $2^2=4$

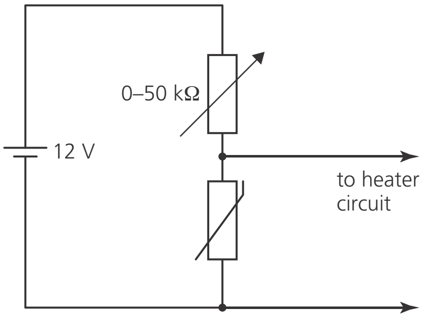
b Since $P=\frac{V^2}{R}$, if resistance is doubled, power will halve.

46 $0.150\times4\times7\times10=42$ cents

47 a The resistance decreases as it gets hotter. Equal rises in temperature cause smaller and smaller decreases in resistance.

b $1.4\times10^4\,\Omega$.

c

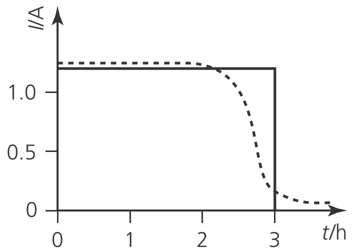


d i $\frac{25}{(25+14)}\times12=7.7\,\text{V}$

ii $\frac{25}{(25+1.5)}\times12=11.3\,\text{V}$

e To adjust the temperature at which the heater is turned on

48



Energy to be supplied = $5\times10^5\,\text{J}$ (=VIt). If $V=4\,\text{V}$ and $t=3$ h, a constant current of about 1.2 A would transfer that amount of energy (as shown by the solid black line on the figure).

In practice, the current will decrease as the battery becomes charged, and the dashed line is more realistic.

49 a Secondary

b Energy = $VIt=3.8\times(2800\times10^{-3})\times3600=(3.83\times10^4)=3.8\times10^4\,\text{J}$ to two significant figures

c Energy density = $\frac{\text{energy}}{\text{volume}}=\frac{3.83\times10^4}{6.5}=5.9\times10^3\,\text{J cm}^{-3}$

50 $E=VIt=12\times2.0\times(115\times60)=1.7\times10^5\,\text{J}$

52 a $I = \frac{V}{R+r} = \frac{1.5}{(5+0.5)} = 0.27\text{A}$

b $V_T = 5.0 \times 0.27 = 1.4\,\text{V}$

53 A large current, *I*, is needed in the starter motor. The p.d. across the circuit will fall by *Ir*, where *r* is the internal resistance of the battery.

54 $\varepsilon = 1.0\big(4.0 + r\big) = 0.50\big(10 + r\big) \Rightarrow 8.0 + 2r = 10 + r \Rightarrow r = 2.0\,\Omega$ and $\varepsilon = 6.0$ V

55 If somebody touches the high voltage terminal and a current, *I*, flows through them, the p.d. will immediately fall to a low value because *Ir* is so large.

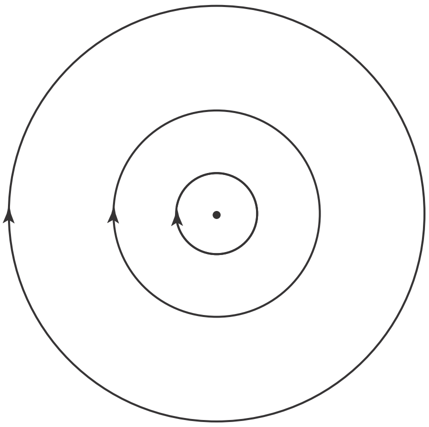
56 i Three in series: $\varepsilon = 3 \times 1.6 = 4.8\,\text{V},\ r = 3 \times 0.4 = 1.2\,\Omega$

ii Three in parallel: $\varepsilon = 1.6\,\text{V},\ \text{r} = \frac{0.4}{3} = 0.13\Omega$

iii Two in parallel with one in series: $\varepsilon = 2 \times 1.6 = 3.2\,\text{V},\ r = 0.6\,\Omega$

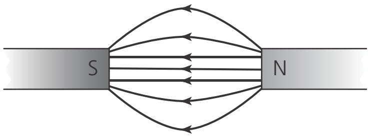
iv Two in series with one in parallel: $\varepsilon = 2 \times 1.6 = 3.2\,\text{V},\ r = 0.27\Omega$

58 a



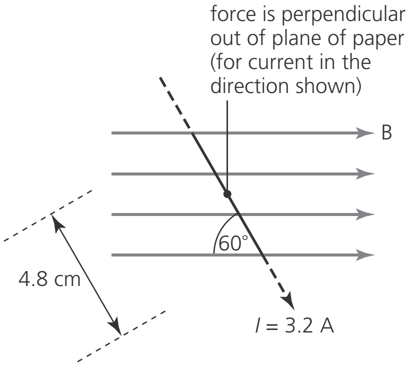
b Widely separated parallel lines pointing towards geographic north.

59 a, b



c Soft iron produces a strong magnetic field (become of its high permeability) and it is easily magnetized and demagnetized.

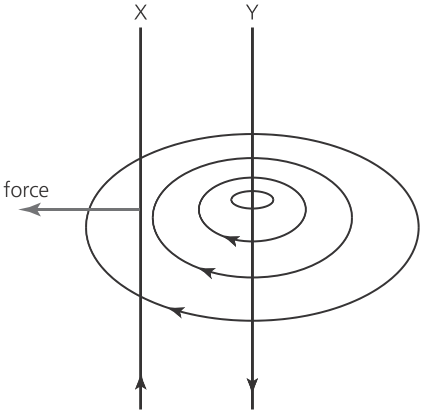
60 a



b $F = BIL\,\sin\theta$

$4.3 \times 10^{-4} = B \times 3.2 \times \left(4.8 \times 10^{-2}\right)\sin 60 \rightarrow B = 3.2 \times 10^{-3}\,\text{T}$

61 a, b



c In the opposite direction to the force on X (Newton's third law).

62 $F = NBIL\ \sin\theta,\ F_{\text{max}} = 500\times0.67\times0.43\times\left(2.4\times10^{-2}\right)\times1 = 3.5\,\text{N}$

63 a Negative (use left hand rule)

b Magnetic force is always perpendicular to motion

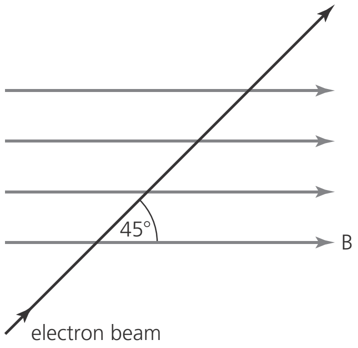
c $F = qvB\ \sin\theta = \left(1.6\times10^{-19}\right)\times\left(4.4\times10^{6}\right)\times0.12\times1.0 = 8.4\times10^{-14}\,\text{N}$

d Three ions of different mass are present.

64 Gamma rays are uncharged, so they will not be deflected. Compared to beta negative particles, alpha particles typically travel 10 × slower, and they have twice the charge (but positive). These two factors suggest that alpha particles would be deflected more (but in the opposite direction), however they have much greater mass ($\simeq 8000\times$), so that they are deflected less than beta particles.

65 If the electrons move parallel to a magnetic field, they will not be deflected, but any charge will experience a force in an electric field, whether it is moving or not.

66 a



b Out of plane of paper (for electron flow in the direction shown).

c $F = qvB\ \sin\theta \Rightarrow 7.8\times10^{-14} = \left(1.6\times10^{-19}\right)\times v\times\left(38\times10^{-3}\right)\times\sin 45 \Rightarrow v = 1.8\times10^{7}\,\text{m s}^{-1}$

67 $r = \dfrac{mv}{Bq} \Rightarrow 1.0 = \dfrac{(1.67\times10^{-27})\times\left(0.1\times3.0\times10^{8}\right)}{B\times(1.6\times10^{-19})} \Rightarrow B = 0.31\ \text{T}$

Topic 6 Circular motion and gravitation

Questions to check understanding

1 $\omega = \dfrac{\Delta\theta}{\Delta t} = \dfrac{2\pi}{3600} = 1.75\times10^{-3}\ \text{rad s}^{-1}$

2 a $T = \dfrac{2\pi r}{v} = \dfrac{2\times\pi\times0.50}{2.8} = 1.12\,\text{s}$

$f = \dfrac{1}{T} = \dfrac{1}{1.12} = 0.89\,\text{Hz}$

b $\omega = \frac{2\pi}{T} = 2 \times \frac{\pi}{1.12} = 5.6\,\text{rad}\,\text{s}^{-1} \left(\text{or use } \omega = \frac{v}{r}\right)$

c $\Delta\theta = \omega\Delta t = 5.6 \times 10 = 56\,\text{rad}$

3 a $\frac{1000}{\pi \times 0.70} = 455$

b $10\,\text{m}\,\text{s}^{-1}$

c $\omega = \frac{v}{r} = \frac{10}{0.35} = 29\ \text{rad}\,\text{s}^{-1}$

d $f = \frac{\omega}{2\pi} = 4.5\,\text{Hz}$

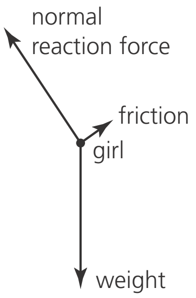
4 i They have the same angular velocity because all points pass through 2π rad each day.

ii Points have different linear speeds because $v = \omega r$ and they are different distances from the axis of rotation.

5 a i The tension in the chain

ii The seat pushing on her

b



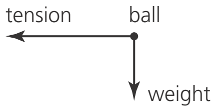
6 A component of the normal force (lift) from the air pushing on the tilted wings

7 a Friction between the track and their shoes together with the force from the track onto the spikes on the soles of the shoes.

b The track needs to have a high coefficient of friction and it also needs to be able to deform elastically.

8 a The tension in the string and/or the weight of the ball, depending on its position

b



c Tension is greatest

d At a tangent to the circle

9 a $a = \frac{v^2}{r} = \frac{12^2}{200} = 0.72\,\text{m}\,\text{s}^{-2}$

b $F = ma = 1400 \times 0.72 = 1008 = 1.0 \times 10^3\,\text{N}$ to 2 significant figures

c $\mu_D = \frac{F}{R} = \frac{1008}{1400 \times 9.81} = 0.073$

10 a The gravitational attraction from the Sun

b This force will also theoretically cause a centripetal acceleration of the Sun towards the Earth. However, the large mass of the Sun makes the effect almost negligible. The Earth and Sun both orbit a point near the centre of the Sun.

c $\omega = \frac{2\pi}{\text{T}} = \frac{2\pi}{3.15 \times 10^7} = 2.0 \times 10^{-7}\,\text{rad}\,\text{s}^{-1}$

d $F = m\omega^2 r = \left(6.0 \times 10^{24}\right) \times (2.0 \times 10^{-7})^2 \times \left(1.5 \times 10^{11}\right) = 3.6 \times 10^{22}\,\text{N}$

11 a By directing the beam perpendicularly across a uniform magnetic field

b $F = \frac{mv^2}{r} = \frac{\left(6.6\times10^{-27}\right)\times\left(1.5\times10^{7}\right)^2}{2.00} = 7.4\times10^{-13}\,\text{N}$

c $F = qvB\sin\theta$

$7.4\times10^{-13} = \left(2\times1.6\times10^{-19}\right)\times\left(1.5\times10^{7}\right)B\times1.00 \Rightarrow B = 0.15\,\text{T}$

12 $a = \frac{4\pi^2 r}{T^2} \Rightarrow 2.45 = \frac{4\times\pi^2\times1.275\times10^7}{T^2} \quad \Rightarrow T = 1.4\times10^4\,\text{s}$

$\frac{24\times3600}{1.4\times10^4} = 6$ orbits every day

13 a $F = \frac{Gm_E m_M}{r^2} = \frac{\left(6.67\times10^{-11}\right)\left(5.97\times10^{24}\right)\left(7.35\times10^{22}\right)}{\left(3.84\times10^{8}\right)^2} = 1.98\times10^{20}\,\text{N}$

b It causes the tides on the oceans.

14 $F = \frac{GMm}{r^2} \approx \frac{(6.67\times10^{-11})(1500)(1500)}{4^2} \approx 10^{-5}\,\text{N}$

15 As the previous question showed, gravitational forces between 'everyday' objects are very small. Measuring such small forces accurately can be technically difficult because other small forces may also be acting (e.g. electric or magnetic forces).

16 a $g = \frac{GM}{r^2} = \frac{(6.67\times10^{-11})(4.9\times10^{24})}{(6.052\times10^{6})^2} = 8.9\,\text{N kg}^{-1}$

b $5.0\,\text{N kg}^{-1}$

17 a $g = \frac{GM}{r^2} \Rightarrow 1.0 = \frac{\left(6.67\times10^{-11}\right)\left(5.97\times10^{24}\right)}{r^2} \Rightarrow r = 2.0\times10^{7}\,\text{m}$

b $g = \frac{GM}{r^2} = \frac{(6.67\times10^{-11})(5.97\times10^{24})}{(6.7\times10^{6})^2} = 8.9\,\text{N kg}^{-1}$

18 a $g = \frac{GM_P}{r^2} = \frac{\left(6.67\times10^{-11}\right)\left(8.3\times10^{24}\right)}{(2.2\times10^{8})^2} = (0.01144) \;=\; 0.011\,\text{N kg}^{-1}$ to two significant figures

b $0.01144 = \frac{GM_M}{r^2} = \frac{(6.67\times10^{-11})M_M}{(0.22\times10^{8})^2} \Rightarrow M_M = 8.3\times10^{22}\,\text{kg}$

c Field due to planet $= \frac{GM_P}{r^2} = \frac{\left(6.67\times10^{-11}\right)\left(8.3\times10^{24}\right)}{\left(2.64\times10^{8}\right)^2} = 7.9\times10^{-3}$

This must be added to the field due to the moon, 11.4×10^{-3}

$\Rightarrow g = 1.93\times10^{-2}\,\text{N kg}^{-1}$

19 a $g = \frac{Gm}{r^2} = \frac{\left(6.67\times10^{-11}\right)\left(2.0\times10^{30}\right)}{\left(1.5\times10^{11}\right)^2} = 5.9\times10^{-3}\,\text{N kg}^{-1}$

b $v^2 = gr = 5.9\times10^{-3}\times1.5\times10^{11} \Rightarrow v = 3.0\times10^{4}\,\text{m s}^{-1}$

c $T = \frac{2\pi r}{v} = \frac{2\pi\times1.5\times10^{11}}{3.0\times10^{4}} = 3.14\times10^{7}\,\text{s}$ (1 year)

20 $\frac{r^3}{T^2} =$ constant (see Expert tip)

$\frac{r_1^3}{T_1^2} = \frac{r_2^3}{T_2^2} \Rightarrow T_2^2 = \frac{r_2^3}{r_1^3}\times T_1^2 = 1.08\times10^{7} \quad \Rightarrow T_2 = 1.3\times10^{4}$ days

21 $v^2 = \frac{GM}{r} = \frac{(6.67\times10^{-11})(5.97\times10^{24})}{7.4\times10^{6}} = 7.3\times10^{3}\,\mathrm{m\,s^{-1}}$

22 a $T = \frac{2\pi r}{v} = \frac{2\pi\times1.07\times10^{9}}{1.09\times10^{4}} = 6.2\times10^{5}\,\mathrm{s}$

b $g = \frac{v^2}{r} = \frac{(1.09\times10^{4})^2}{1.07\times10^{9}} = 0.11\,\mathrm{N\,kg^{-1}}$

c $g = \frac{GM}{r^2} = \frac{\left(6.67\times10^{-11}\right)\left(1.48\times10^{23}\right)}{\left(2.63\times10^{6}\right)^2} = 1.43\,\mathrm{N\,kg^{-1}}$

23 $\frac{r^3}{T^2} = \frac{GM}{4\pi^2}\,(\text{see Expert tip}) \Rightarrow r^3 = \frac{(6.67\times10^{-11})(5.97\times10^{24})\times(24\times3600)^2}{4\pi^2} \Rightarrow r = 4.2\times10^{7}\,\mathrm{m}$

Topic 7 Atomic, nuclear and particle physics

Questions to check understanding

1 $E = hf = \left(6.63\times10^{-34}\right)\times\left(8.49\times10^{8}\right) = 5.63\times10^{-25}\,\mathrm{J}$

2 a $E = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34})\times(3.00\times10^{8})}{5.87\times10^{-7}} = 3.39\times10^{-19}\,\mathrm{J}$

b Helium in the outer layers of the Sun absorbs certain wavelengths from the continuous spectrum. This results in an absorption line spectrum observed from Earth.

3 a $\frac{\left(9.1\times10^{-19}\right)}{\left(1.6\times10^{-19}\right)} = 5.7\,\mathrm{eV}$

b $E = \frac{hc}{\lambda} \to \left(9.1\times10^{-19}\right) = \frac{\left(6.63\times10^{-34}\right)\times\left(3.00\times10^{8}\right)}{\lambda} \to \lambda = 2.2\times10^{-7}\,\mathrm{m}$

c Ultraviolet

4 $E = hf = \left(6.63\times10^{-34}\right)\times\left(5.0\times10^{13}\right) = 3.3\times10^{-20}\,\mathrm{J}$

Number of photons per second = Power/energy of each photon $= \frac{800}{3.3\times10^{-20}} \approx 10^{22}\,\mathrm{s^{-1}}$

5 $\frac{E_\gamma}{E_{\text{light}}} = \frac{\cancel{h}f_\gamma}{\cancel{h}f_{\text{light}}} = \frac{\lambda_{\text{light}}}{\lambda_\gamma} \approx 1\times10^{5}$

Damage is done mainly by individual, separate, photons. Gamma rays have photons with approximately 10^5 × greater energy than light photons.

6 a $13.6 - 1.51 = 12.1\,\mathrm{eV}$

b $E = \frac{hc}{\lambda} = \frac{\left(6.63\times10^{-34}\right)\times\left(3.0\times10^{8}\right)}{4.4\times10^{-7}} = 4.52\times10^{-19}$ which is about 2.83 eV

The most likely transition is from −0.54 eV to −3.39 eV.

c The lowest frequency corresponds to the smallest transition shown: from -0.061×10^{-18} to -0.086×10^{-18}, which equals 0.025×10^{-18} J.

$$E=\frac{hc}{\lambda}=\frac{\left(6.63\times10^{-34}\right)\times\left(3.0\times10^{8}\right)}{\lambda}=0.025\times10^{-18}\ \Rightarrow\lambda=8.0\times10^{-6}\text{ m}$$

which is infrared radiation

7 a Energy transition $=122.4-30.6=91.8\,\text{eV}$

$$91.8\,\text{eV}=91.8\times1.60\times10^{-19}=1.47\times10^{-17}\,\text{J}$$

then $E=hf\Rightarrow1.47\times10^{-17}=\left(6.63\times10^{-34}\right)f\Rightarrow f=2.22\times10^{16}\,\text{Hz}$

b Energy transition $=122.4-7.65=114.75$ eV

$$114.75\times\left(1.60\times10^{-19}\right)=1.84\times10^{-17}\,\text{J}$$

then $E=\dfrac{hc}{\lambda}\rightarrow1.84\times10^{-17}=\dfrac{(6.63\times10^{-34})\times(3.0\times10^{8})}{\lambda}\Rightarrow\lambda=1.08\times10^{-8}\,\text{m}$

c $122.4\times1.60\times10^{-19}=1.96\times10^{-17}\,\text{J}$

8 92 protons, 146 neutrons, 92 electrons

9 a ${}^{16}_{8}\text{O}$ and ${}^{18}_{8}\text{O}$

b $\left(10\times1.675\times10^{-27}\right)+\left(8\times1.673\times10^{-27}\right)=3.0\times10^{-26}\,\text{kg}$

c Oxygen-18 molecules will have a slower average speed because molecules of both isotopes will have the same average translational kinetic energy, but oxygen-18 molecules have greater mass.

10 A particular kind of atom (as defined by the contents of its nucleus) is called a 'nuclide'. An 'isotope' is one of two or more different nuclides of the same element.

11 Occurs randomly and without any specific cause.

12 About 170 (70 + 100)

13 $\dfrac{4\times\left(1.67\times10^{-27}\right)}{9.1\times10^{-31}}\approx7300$

14 a $\dfrac{1}{2}mv^2\left(\text{MeV}\right)=\dfrac{1}{2}\times\dfrac{\left(9.1\times10^{-31}\right)\times\left(0.72\times3.0\times10^{8}\right)^2}{\left(1.6\times10^{-19}\right)\times10^{6}}=0.13\text{ MeV}$

b $\dfrac{1}{2}mv^2\left(\text{MeV}\right)=\dfrac{1}{2}\times\dfrac{\left(4\times1.67\times10^{-27}\right)\times\left(0.05\times3.0\times10^{8}\right)^2}{\left(1.6\times10^{-19}\right)\times10^{6}}=4.7\text{ MeV}$

C $E=\dfrac{hc}{\lambda}=2.0\times10^{-3}\,\text{J}$ or $1.2\,\text{MeV}$

15 Handle with tongs/use for as short a time as possible/use shielding/do not point source at anyone.

16 Higher count rates have lower percentage random fluctuations.

17 ${}^{14}_{6}\text{C}\rightarrow{}^{0}_{-1}\text{e}+{}^{14}_{7}\text{N}$

18 ${}^{222}_{88}\text{Ra}\rightarrow{}^{4}_{2}\text{He}+{}^{218}_{86}\text{Rn}$

19 a Beta positive

b ${}^{230}_{91}\text{Pa}\rightarrow{}^{0}_{+1}\text{e}+{}^{230}_{90}\text{Th}$

20 a Above the line of stability, the alpha emitters have too large a proton to neutron ratio. Alpha emission moves the nuclide down four rows and two columns to the left.

b Below the line of stability, beta-negative emission moves the nuclide one column to the right.

21 Beta particles are the only type of radiation which will pass through thin paper but not through 2 mm of aluminium.

22 a $\frac{3\times10^6}{2\times10^5}=15\,\text{eV}$

b $\frac{4\times10^{-2}}{1000}=4\times10^{-5}\,\text{m}$

Assuming that the energy needed to ionize molecules in skin is comparable to molecules in air.

23 a $\frac{270}{4}=68\,\text{s}$

b 475 s is about 7 half-lives. $\frac{2000}{2^7}\approx 16\,\text{min}^{-1}$

24 a Three half lives $\Rightarrow\frac{1}{8}$

b Four half lives $\Rightarrow\frac{15}{16}$

25 $T_{\frac{1}{2}}=59\,\text{s}$

26 10% is between $\frac{1}{8}$ and $\frac{1}{16}$, so time taken is between 3 and 4 half lives, say 18 years.

27 a To limit the amount of radiation received by the patient

b The radiation has to penetrate through the body to the detector(s) outside the patient.

c Four half lives $\Rightarrow\frac{1}{16}$, or about 6%

29 a i $6\times1.007276=6.043656\ \text{u}$

ii $6\times1.008665=6.051990\ \text{u}$

iii $6\times0.000549=0.003294\ \text{u}$

b 12.09894 u

c This is 0.09894 u greater than the defined mass of the 12-C atom of exactly 12 u.

30 a $(1.661\times10^{-27})\times15.999=2.657\times10^{-26}\,\text{kg}$

b $931.5\times15.999=1.490\times10^4$ MeV (In the question: 15.999 u should be 15.995 u)

31 $\text{KE}=\frac{1}{2}mv^2=\frac{1}{2}\times1500\times20^2=3.0\times10^5\,\text{J}$

$$\Delta m=\frac{\Delta E}{c^2}=\frac{3.0\times10^5}{(3.0\times10^8)^2}=3.3\times10^{-12}\ \text{kg}$$

32 a 0.09894 u

b $0.09894\times931.5=92.16\,\text{MeV}$

33 a $0.528479\times\left(1.661\times10^{-27}\right)=8.778\times10^{-28}\,\text{kg}$

b $0.528479\times931.5=492.3\ \text{MeV}$

34 Mass of 8 protons, 8 neutrons and 8 electrons (all isolated) = 16.1319 u

Comparing this to 15.9994u, the mass defect is 0.1325 u. (In the question: 15.9994 u should be 15.9949 u.)

35 a ${}^{24}_{11}\text{Na}\rightarrow{}^{24}_{12}\text{Mg}+{}^{0}_{-1}\beta+\overline{\upsilon_e}$

b $23.99096-23.98504-0.000549=5.371\times10^{-3}\,\text{u}$

Kinetic energy of particles $=5.71\times10^{-3}\times931.5=5.00\ \text{MeV}$ (This is approximately the kinetic energy of the beta particle, assuming the kinetic energy of magnesium atom is negligible.)

36 a $^{226}_{88}\text{Ra} \rightarrow {}^{222}_{86}\text{Rn} + {}^{4}_{2}\alpha$

b $226.02541 = m_{\text{Rn}} + 4.00151 + \left(\dfrac{4.77}{931.5}\right) \Rightarrow m_{\text{Rn}} = 222.02\text{ u}$ (assuming kinetic energy of radon atom is negligible)

37 $\dfrac{0.1325 \times 931.5}{16} = 7.714$ MeV/nucleon (Using 15.9949 u for the mass of an oxygen-16 atom leads to an answer of 7.976 MeV/nucleon.

38 a $184 \times 8.0 = 1.5 \times 10^3$ MeV

b 8.4 MeV/nucleon

39 a ${}^{1}_{0}\text{n} + {}^{235}_{92}\text{U} \rightarrow {}^{90}_{37}\text{Rb} + {}^{143}_{55}\text{Cs} + 3{}^{1}_{0}\text{n}$

b $1.008665 + 235.044 = 89.915 + 142.927 + (3 \times 1.008665) + \text{energy}$

$\Rightarrow \text{energy} = 0.18467\text{ u}$

$= 0.18467 \times 931.5 = 172\text{ MeV}$

40 ${}^{2}_{1}\text{H} + {}^{3}_{1}\text{H} \rightarrow {}^{4}_{2}\text{He} + {}^{1}_{0}\text{n} + \text{energy}$

$2.0136 + 3.0160 = 4.0020 + 1.008665 + \text{energy}$

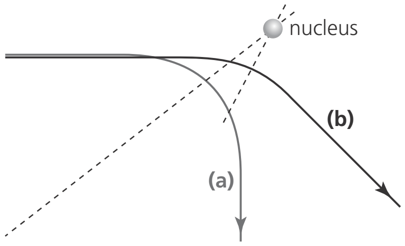
$\text{energy} = 0.1894\text{ u}$

$\text{energy} = 1894 \times 931.5 = 17.64\text{ MeV}$

41 a Alpha particles are directed in a vacuum to very thin gold foil. Some interact with the nuclei of gold atoms and are deflected from their original direction. They are detected when their kinetic energy has transferred to light when they strike the zinc sulfide.

b The scattering pattern can only be explained by the electric repulsion of the positively charged alpha particles by much greater positive charges concentrated in the relatively tiny centres of the atoms.

42 a, b



c The alpha particles would be deflected through smaller angles because the forces on them would be less and because a silver nucleus has less positive charge than a gold nucleus.

43 $F = \dfrac{kq_{\alpha}q_{pb}}{r^2} = \dfrac{8.99 \times 10^9 \times 2 \times 82 \times (1.6 \times 10^{-19})^2}{(3.0 \times 10^{-10})^2} = 4.2 \times 10^{-7}\text{N}$

44 Because it consists of other particles (quarks).

45 $\bar{c}$

Charge $= -\dfrac{2}{3}$e

46 24

47 For example,

$u\,\bar{s}$ (positive kaon) and $\bar{u}\,s$

$d\,\bar{u}$ (negative pion) and $\bar{d}\,u$

All mesons contain one quark and one antiquark.

48 $\bar{u}\bar{d}\bar{d}$

$\bar{n}$

No charge, same mass as neutron

49 **a** Baryon

b +e

c $\frac{1189}{931.5} = 1.276\,u$

50 **a** $n \rightarrow p + e^- + \bar{v}_e$

b $p \rightarrow n + e^+ + \bar{v}_e$

51 **a** $\pi^+(u\bar{d}) \rightarrow \mu^+ + \nu_\mu$

b Charge $= +\frac{2}{3} + \frac{1}{3} = +1 + 0$

Baryon number: $0 = 0 + 0$

Lepton number: $0 = -1 + 1$

Strangeness number: $0 = 0 + 0$

All quantum conservation numbers conserved, so this is possible.

52 The tau particle has sufficient mass to decay into hadrons. However, the conservation of Lepton number disallows this decay because the tau has a lepton number of +1 and the antineutrino has a lepton number of –1 (hadrons have zero lepton numbers). A tau decay to hadrons plus a neutrino is possible.

53 $F_G = \frac{Gm_p m_e}{r^2} = \frac{(6.67\times10^{-11})(1.67\times10^{-27})(9.11\times10^{-31})}{(10^{-10})^2} = 1.0\times10^{-47}\,N$

$F_E = \frac{kq_p q_e}{r^2} = \frac{(8.99\times10^9)(1.6\times10^{-19})^2}{(10^{-10})^2} = 2.3\times10^{-8}\,N$

$\frac{F_E}{F_G} = \frac{2.3\times10^{-8}}{1.0\times10^{-47}} \approx 10^{39}$ (to an order of magnitude)

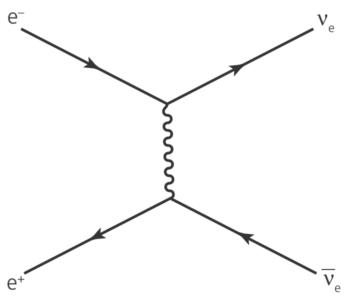
54 **a** Electromagnetic, weak nuclear, gravitational

b Electromagnetic, weak nuclear, gravitational, strong nuclear

c Acts as exchange particle for electromagnetic force

55 Note that the labelling of the electron and positron in Figure 7.27 has been mistakenly reversed. Annihilation of an electron/positron pair creating a muon and an antimuon.

56



Topic 8 Energy production

Questions to check understanding

1 **a** $800 \times 2.8 \times 10^6 = 2.22 \times 10^6\,J$

b $\frac{1}{28} = 0.036\,kg$

2 $\dfrac{\text{energy}}{\text{mass}} = \dfrac{Pt}{m} = \dfrac{3.0\times 2\times 3600}{0.01} = 2.2\times 10^6\ \text{J}\ \ \text{kg}^{-1}$

3 output power = input power × efficiency = $\dfrac{5200\times 44\times 10^6}{3600}\times 0.35 = 2.2\times 10^7\,\text{W}$

4 **a** $\dfrac{3.4\times 10^4\times 10^6}{10^6} = 3.4\times 10^4\ \text{J}$

b $\dfrac{3.4\times 10^{10}}{720} = 4.7\times 10^7\ \text{J}\,\text{kg}^{-1}$

5 $\dfrac{\text{width of output}}{\text{width of input}} = \text{efficiency} \approx 35\%$

input power $= \dfrac{\text{output power}}{0.35} \approx 30\text{MW}$

6 The chemical energy from the battery is converted to electrical energy, and then light and sound. In each transfer, there will be a significant percentage of the energy transferred to internal energy and thermal energy.

7 (1) Fossil fuels have high energy densities. (2) Fossil fuels can be relatively easily transported and stored. (3) Fossil fuelled power stations have good efficiencies. (4) The infrastructure (power stations, etc.) for their use is already in place. (5) Fossil fuels are (currently) readily available. [(6) The total costs are relatively low compared to other energy sources.]

8 Required input power $= \dfrac{3.0\times 10^9}{0.39} = 7.7\times 10^9\ \text{W}$

$\dfrac{7.7\times 10^9}{46\times 10^6} = 1.7\times 10^2\ \text{kg}\,\text{s}^{-1}$

9 Maximum power output $= (2.5\times 10^4)\times(1.9\times 10^3) = 4.75\times 10^7\,\text{W}$

Required input power $= \dfrac{4.75\times 10^7}{0.44} = 1.08\times 10^8\,\text{W}$

$\dfrac{1.08\times 10^8}{55\times 10^6} = 2.0\,\text{kg}\,\text{s}^{-1}$

10 Chemical energy in fuel → internal energy in hot gases → internal energy in water and steam → kinetic energy of steam → kinetic energy of turbines and coils → electrical energy

11 To increase kinetic energy of the steam molecules

12 **a** Radioactive decay occurs when an unstable nucleus emits a particle and changes into a new element. Fission occurs when a nucleus is split into two smaller nuclei.

b The decay of U-235 is a slow natural process and it cannot be controlled. The decay-rate decreases with time. Fission of U-235 can be induced artificially and is controllable. Each fission transfers much more energy than each decay.

13 Waste materials may be radioactive and can emit harmful radiation. This danger can last for a long time because some waste materials have very long half-lives. Such materials must be stored behind thick barriers of water or concrete in places where the public cannot enter.

14 Separation processes rely on differences in mass. ^{2}H, for example, has twice the mass of ^{1}H, but ^{237}U and ^{235}U have very similar masses.

15 The water acts as a moderator slowing the neutrons so that fusion can occur. Without the water, the nuclear reactions would stop.

16 Advantages: very high energy density, no greenhouse gases emitted, no chemical pollution.

Disadvantages: radioactive waste can be dangerous, risk of serious accidents or terrorist action, not renewable.

17 **a** $\dfrac{218.9}{0.9315} = 235.0\,\text{u}$

b $218.9 + 0.940 = 127.5 + 88.4 + (4 \times 0.940) + \text{energy}$

Energy = 0.18 GeV

c $0.18 \times \dfrac{(6.02 \times 10^{23})}{0.235} = 4.61 \times 10^{23}\,\text{GeV}$

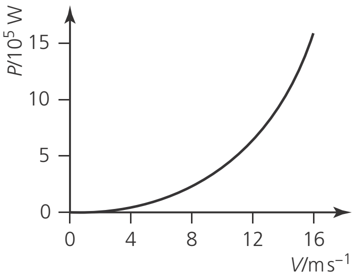
Energy $= 4.61 \times 10^{23} \times 1.6 \times 10^{-10} = (7.38 \times 10^{13}\,\text{J}) = 7.4 \times 10^{13}\,\text{J}$

d $0.30 \times \dfrac{7.38 \times 10^{13}}{3.15 \times 10^{7}} = 7.0 \times 10^{5}\,\text{W}$. (Note that actual nuclear power stations all are more powerful than this.)

e For example, if the uranium was enriched to 5%, the total mass of uranium needed would be $\dfrac{1}{0.05} = 20\,\text{kg}$

18 a $P = 0.30 \times \frac{1}{2} A\rho v^3 = 0.30 \times \frac{1}{2} \times (\pi \times 25^2) \times 1.3 \times 4.0^3 = 2.5 \times 10$

b



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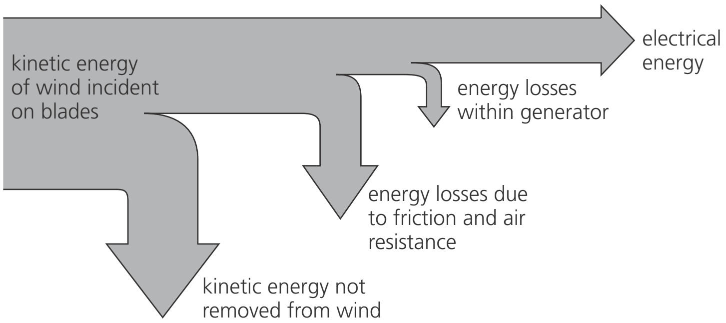


20 $P = 0.25 \times \frac{1}{2} A\rho v^3 \Rightarrow 2000 = 0.25 \times \frac{1}{2}(\pi r^2) \times 1.3 \times 8.0^3 \Rightarrow r = 2.8\,m$

21 Advantages: renewable and free source, no greenhouse gas emissions, pollution free, good for remote locations.

Disadvantages: large land area needed, limited number of suitable locations, noisy, output variable, expensive to construct.

22 a i $\omega = \dfrac{2\pi}{60/18} = 1.9\,\text{rad}\,\text{s}^{-1}$

ii $v = \omega r = 1.9 \times 85 = 1.6 \times 10^2\,\text{m}\,\text{s}^{-1}$

b $F = \dfrac{mv^2}{r} = \dfrac{10 \times 160^2}{85} = 3.0 \times 10^3\,\text{N}$

c If the speed of the tip of the blade is too great, the tension may be enough for the blade to break.

23 Advantages: renewable and free source, no greenhouse gas emissions, high efficiency, non-polluting.

Disadvantages: limited number of suitable sites, expensive construction, damages the environment, change to natural flow of rivers.

24 Most other forms of power generation involve ‘heat engines’, which use a flow of thermal energy. Such processes can never be very efficient.

25 $P = 0.87\times\dfrac{mg\Delta h}{t} = \dfrac{0.87\times1.0\times10^{4}\times9.81\times74}{60} = 1.1\times10^{5}\text{ W}$

26 Lowest power output $= 1.4\times0.40 = 0.56$ MW

Maximum power required from pumped storage $= (1.0-0.56) = 0.44$ MW

$P = \text{efficiency}\times\dfrac{mg\Delta h}{t} \Rightarrow 4.4\times10^{5} = 0.85\times9.81\times56\times\left(\dfrac{m}{t}\right)$

$\dfrac{m}{t} = 9.4\times10^{2}\text{ kg s}^{-1}$

$\dfrac{V}{t} = \dfrac{m\,/\,t}{\rho} = \dfrac{9.4\times10^{2}}{10^{3}} = 0.94\text{ m}^{3}\text{s}^{-1}$

27 A panel of solar cells means a collection of photovoltaic cells, which transfer radiant energy directly into electricity. A solar heating panel transfers radiant energy directly into internal energy in water.

29 a $3\times0.80 = 2.40\text{ V}$

b $\dfrac{1}{r_T} = \dfrac{1}{4+4+4} + \dfrac{1}{4+4+4} \Rightarrow r_T = 6.0\,\Omega$

30 a Energy $= Pt = 480\times(1.4\times0.90)\times3600 = 2.2\times10^{6}\text{ J}$

b $Q\times\text{efficiency} = mc\Delta T \Rightarrow 2.2\times10^{6}\times0.52 = 100\times4200\times\Delta T$

$\Delta T = 2.7\,°\text{C}$, so that temperature rises to 17.7 °C

c $\left(\dfrac{\text{incident energy later}}{\text{incident energy earlier}}\right)\times100\% = \dfrac{220\times\cos40\times(1.4\times0.9)}{480\times(1.4\times0.9)}\times100 = 35\%$

The incident energy on the panel has decreased by 65%.

d The radiation is absorbed more because it has a greater distance to travel through the atmosphere.

32 In the position shown in the figure, the left hand side of the room will be much warmer than the right hand side.

33 Any metallic conductors. Good conduction of thermal energy and electrical energy both require the movement of free electrons in metals.

34 The power emitted (from unit area) is much greater for 5500 K than 3500 K (the area under the graph is much greater). Radiation emitted at 5500 K has approximately equal amounts of visible light and infrared, but at 3500 K the proportion of infrared is higher. An object at 5500 K will appear (yellowy) white, but at 3500 K the appearance will be red.

35 a $P = e\sigma AT^{4} = 0.74\times(5.67\times10^{-8})\times(1.2\times10^{-2})\times373^{4} = 9.7\text{ W}$

b Objects at 100°C will emit infrared radiation.

$\left(\text{using Wien's Law}: \lambda_{\text{max}} = \dfrac{2.90\times10^{-3}}{373} = 7.8\times10^{-6}\text{ m}\right)$

36 The lamp will emit the same power that it receives, $P = e\sigma AT^{4}$

$\Rightarrow 6.0 = 1.0\times(5.67\times10^{-8})\times(2\pi\times6\times10^{-5}\times0.096)T^{4}$

$\Rightarrow T = 2.3\times10^{3}\text{ K}$

37 a Visible light

b $\lambda_{\text{max}} = \dfrac{c}{f} = \dfrac{3.0\times10^{8}}{5.2\times10^{14}} = \dfrac{2.90\times10^{-3}}{T} \Rightarrow T = 5.0\times10^{3}\text{ K}$

38 a $\lambda_{\text{max}} = \dfrac{2.90\times10^{-3}}{7200} = 4.0\times10^{-7}\text{ m}$

b $P = e\sigma AT^{4} = 1.0\times(5.67\times10^{-8})\times4\pi\times(5.0\times10^{8})^{2}\times7200^{4} = 4.8\times10^{26}\text{ W}$

39 $\text{Solar constant} = 1360 = \dfrac{P}{4\pi(1.5\times10^{11})^2} \Rightarrow P = 3.8\times10^{26}\text{ W}$

40 $P = e\sigma AT^4 = 0.61\times(5.67\times10^{-8})\times4\pi(6.4\times10^{6})^2\times289^4 = 1.2\times10^{17}\text{ W}$ (The temperature given in the question for the Earth's 'surface' may be considered as the 'effective' temperature of the Earth and its atmosphere.)

41 a Angle of incident radiation striking the lake's surface has increased.

b Total energy incident = $3.4\times10^6\times235 = 7.99\times10^8$ W. A fraction $(1-0.08) = 0.92$ is absorbed, equal to $0.92\times7.99\times10^8 = 7.4\times10^8$ W.

c $\text{Intensity} = \dfrac{\text{reflected power}}{\text{area}} = \dfrac{117.5\times0.13}{1} = 15\text{ Wm}^{-2}$

42 $(1-\alpha)\times(\text{incident power}) = \text{power radiated away}$

$(1-0.3)\times(1360\times\cancel{\pi r^2}) = e\sigma AT^4 = 1.0\times5.67\times10^{-8}\times4\cancel{\pi r^2}\times T^4$

$\Rightarrow T = 255\text{ K}$

43 Infrared radiation from the surface of the planet would radiate freely into space without the atmosphere. The wavelengths of the radiation are such that they can be absorbed by certain gases (e.g. CO_2), called 'greenhouse gases' in the atmosphere. The energy is then re-radiated, but in all directions. Some radiation returns to the planet's surface, so that it remains hotter than it would be without the atmosphere.

44 a Molecules in water vapour can absorb infrared radiation and contribute to the greenhouse effect as described in the previous answers.

b Climate change caused by the enhanced greenhouse effect (due mainly to increased levels of carbon dioxide, methane and nitrogen dioxide) may result in more water vapour in the atmosphere, which in turn may increase the changes (an example of positive feedback), but there is no evidence to suggest that levels of water vapour would increase by themselves.

c Carbon dioxide, methane, nitrous oxide (in order of abundance)

d The amount of carbon dioxide has increased because it is a product of the combustion of fuels.

45 Human activities are believed to increase the amount of greenhouse gases in the atmosphere. More of the infrared radiation from the Earth's surface is absorbed and re-radiated back to the Earth, so that its temperature rises.

46 a $1360\times\pi r^2\times(1-0.30) = 0.60\times5.67\times10^{-8}\times4\pi r^2\times T^4 \rightarrow T = 289\text{ K}$

b About 5 K

Topic 9 Wave phenomena

Questions to check understanding

1 a i $T = \dfrac{15.81}{20} = 0.7905\text{ s}$

ii $f = \dfrac{1}{T} = 1.265\text{ Hz}$

b $\omega = 2\pi f = 2\times\pi\times1.265 = 7.948\text{ rad s}^{-1}$

c $x = x_0\cos\omega t = (8.3\times10^{-2})\cos(7.948\times2.5) = 4.3\times10^{-2}\text{ m}$

2 a $\omega = 2\pi f \Rightarrow f = \dfrac{74}{2\pi} = 12\text{ Hz}$

b $a = \omega^2 x = 74^2\times(1.0\times10^{-2}) = 55\text{ ms}^{-2}$

c $v = \pm\omega x_0 = \pm 74 \times 0.033 = \pm 2.4\,\text{m s}^{-1}$

d It could be moving in opposite directions.

3 a $\omega = \frac{2\pi}{T} = \frac{2\pi}{3.0} = 2.1\,\text{rad s}^{-1}$

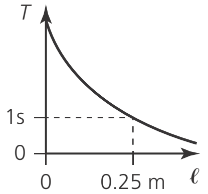
b $x = 0.1\sin(2.1\,t)$

c $v = \omega\sqrt{x_0^2 - x^2} = 2.1\sqrt{10^2 - (-8.5)^2} = 11\,\text{m s}^{-1}$ (or use $v = \omega x_o \cos\omega t$)

4 a Increasing the amplitude results in a proportional increase in the restoring force and the resulting acceleration back towards the equilibrium position.

b $T = 2\pi\sqrt{\frac{l}{g}} \Rightarrow 1.0 = 2\pi\sqrt{\frac{l}{9.81}} \Rightarrow l = 0.25\,\text{m}$

c



5 a $k = \frac{F}{x} = \frac{5.6}{4.9\times10^{-2}} = 1.1\times10^2\,\text{Nm}^{-1}$

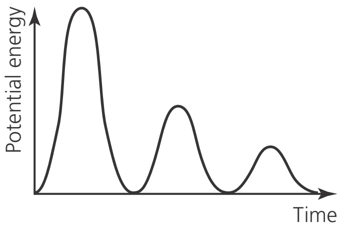
b $T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{0.900}{110}} = 0.56\,\text{s}$

c i $x = x_0\cos\omega t = (2.9\times10^{-2})\cos\left(\frac{2\pi}{0.56}\times0.80\right) = -2.6\times10^{-2}$ m (above equilibrium position)

ii $v = -\omega x_0 \sin\omega t = -\left(\frac{2\pi}{0.56}\right)(2.9\times10^{-2})\sin\left(\frac{2\pi}{0.56}\times0.80\right) = -0.14\,\text{m s}^{-1}$ (moving up)

6 a Friction and/or air resistance

b



7 a $E_T = \frac{1}{2}m\omega^2 x_0^2 = 0.5\times(2.8\times10^{-3})\times73^2\times(2.0\times10^{-2})^2 = 3.0\times10^{-3}\,\text{J}$

b $E_P = \frac{1}{2}m\omega^2x^2 = 1.1\times10^{-4}\,\text{J}$

c $E_K = \frac{1}{2}m\,\omega^2(x_0^2-x^2) = 0.5\times(2.8\times10^{-3})\times73^2\times[(2\times10^{-2})^2-(1.3\times10^{-2})^2] = 1.7\times10^{-3}\,\text{J}$

d $\frac{1}{2}mv^2 = 3.0\times10^{-3} \Rightarrow v = \sqrt{\frac{3.0\times10^{-3}\times2}{2.8\times10^{-3}}} = 1.5\,\text{m s}^{-1}$ (or use $v = \omega x_0$)

8 a i $\theta = \frac{\lambda}{b} = \frac{5.68\times10^{-7}}{8.4\times10^{-5}} = 6.8\times10^{-3}\,\text{rad}$

ii 0.39°

b $\frac{\text{width}}{3.4} = 2\times6.8\times10^{-3} \Rightarrow \text{width} = 4.6\times10^{-2}\,\text{m}$

9 a Like Figure 9.11, with first minima at $\theta = 8.1\times10^{-3}$ rad.

b The first minima is now at 16.2×10^{-3} rad and the intensities will be reduced.

10 $\frac{\lambda_B}{\lambda_R} \approx \frac{4.5 \times 10^{-7}}{7.0 \times 10^{-7}} \approx 0.6$

The pattern for blue light will be narrower with the angles reduced by a factor of ≈ 0.6.

11 Angular width of central maximum $= \frac{2\lambda}{b} = \frac{2 \times 6.12 \times 10^{-7}}{5.2 \times 10^{-5}} = 0.0235 \text{ rad}$

$0.0235 = (4.0 \times 10^{-2}) /$ slit to screen distance

Slit to screen distance $= 1.7$ m

12 $n\lambda = d\sin\theta$ $(\sin\theta \approx \theta)$

$$6\lambda = 8.5 \times 10^{-5} \times \left(\frac{5.8 \times 10^{-2}}{1.66}\right) \Rightarrow \lambda = 4.9 \times 10^{-7} \text{ m}$$

$\left(\text{or use } s = \frac{\lambda D}{d}\right)$

13 a Consisting of only one wavelength (or frequency) or, more realistically, a narrow range of wavelengths

b $\frac{n\lambda}{d} = \sin\theta (\approx \theta);\ \theta_1 = \frac{1\lambda}{d} = 3.7 \times 10^{-3} \text{ rad}$

$\theta_2 = \frac{2\lambda}{d} = 7.4 \times 10^{-3} \text{ rad}$

$\theta_3 = \frac{3\lambda}{d} = 11.1 \times 10^{-3} \text{ rad}$

14 a Destructive interference occurs at this angle because of superposition of wavelets from within each slit.

b i $n\lambda = d\sin\theta \Rightarrow 5.1 \times 10^{-7} = d\left(\frac{0.5 \times 10^{-2}}{3.4}\right) \Rightarrow d = 3.5 \times 10^{-4} \text{ m}$

ii $\theta = \frac{\lambda}{b} \Rightarrow \frac{1.5 \times 10^{-2}}{3.4} = \frac{5.1 \times 10^{-7}}{b} \Rightarrow b = 1.2 \times 10^{-4} \text{ m}$

15 White light contains a continuous range of different wavelengths. Each wavelength will travel at different angles after diffracting through the slits, therefore interfering constructively at different places on the screen.

16 $\tan\theta = \frac{9.8}{76} = 0.129 \Rightarrow \sin\theta = 0.128$ ($\sin\theta$ and $\tan\theta$ are almost the same because the angle is small.)

$n\lambda = d\sin\theta \Rightarrow 1 \times \lambda = \frac{1.0 \times 10^{-3}}{300} \times 0.128 \Rightarrow \lambda = 4.3 \times 10^{-7} \text{ m}$

17 $n\lambda = d \sin\theta \Rightarrow 1 \times (5.0 \times 10^{-7}) = (1.25 \times 10^{-6}) \sin \theta_1$

$\sin\theta_1 = 0.40 \Rightarrow \theta_1 = 24°$

$2 \times (5.0 \times 10^{-7}) = (1.25 \times 10^{-6}) \sin\theta_2 \Rightarrow \theta_2 = 53°$

18 Consider $\sin\theta = \frac{n\lambda}{d}$: different wavelengths can have constructive interference at the same angles if $2\lambda_1 = 3\lambda_2$. For example $\lambda_{\text{red}} \approx \frac{3}{2}\lambda_{\text{blue}}$

19 $n_{\text{water}} \times \lambda_{\text{water}} = n_{\text{glass}} \times \lambda_{\text{glass}}$

$1.33 \times 405 = 1.52 \times \lambda_{\text{glass}} \Rightarrow \lambda_{\text{glass}} = 354 \text{ nm}$

20 Yes, π rad, because $n_{\text{water}} > n_{\text{air}}$

21 a $2dn = m\lambda \Rightarrow 2d \times 1.46 = 1 \times 6.28 \times 10^{-7}$

$\Rightarrow d = 2.2 \times 10^{-7}\,\text{m}$

b If each molecule has a size of about 1×10^{-9} m, the number of molecules/layer

$\approx \dfrac{2.2 \times 10^{-7}}{1 \times 10^{-9}} \approx 200$

c Because $n_{\text{glass}} > n_{\text{oil}}$, there will be a phase change of π at the oil/glass boundary, so that the same thickness will now produce constructive interference.

d $2dn = \left(m + \dfrac{1}{2}\right)\lambda$

Choosing any integer for *m*, for example 5, $\Rightarrow d = 9.0 \times 10^{-7}\,\text{m}$

22 a Light reflecting off *both* surfaces will undergo a phase change of π if the material of the coating has a refractive index less than glass. Therefore, the condition for destructive interference becomes: $2 \times \text{thickness} = \dfrac{\lambda}{2}$, or $\text{thickness} = \dfrac{\lambda}{4}$.

b Average wavelength $\approx 5.5 \times 10^{-7}\,\text{m}$ (or multiple coatings could be used).

23 a $\dfrac{2.35 \times 10^{-2}}{3.50} = 6.71 \times 10^{-3}$ rad

b $\dfrac{1.22\lambda}{b} = \dfrac{1.22 \times 4.3 \times 10^{-7}}{2.8 \times 10^{-3}} = 1.9 \times 10^{-4}$ rad

c Yes, because $1.9 \times 10^{-4} < 6.71 \times 10^{-3}$

d Red light has a longer wavelength, so the resolution will be worse.

24 a $\text{Angular separation} = \dfrac{1.22\lambda}{b}$

$\Rightarrow \dfrac{1.2}{1.36 \times 10^{5}} = \dfrac{1.22 \times (5 \times 10^{-7})}{b}$ (Using 5×10^{-7} m as average wavelength)

$\Rightarrow b \approx 0.07$ m

b The aperture of the telescope may be too small to collect enough light from the stars. Resolution may be made worse by light passing through the atmosphere.

25 A slight decrease in intensity should be seen at the centre of the pattern.

26 $5.0 \times 10^{-4} \times \dfrac{\lambda_{\text{blue}}}{\lambda_{\text{red}}} \approx 5.0 \times 10^{-4} \times \dfrac{4.5}{7.0} \approx 3 \times 10^{-4}$ rad

27 a More radiation received, so that dimmer objects can be seen better.

b Image focusing may not be as good. Faults in lenses or mirrors may be more significant.

28 a Radio waves from astronomical sources have much greater wavelengths than light. Resolution depends on $\dfrac{\lambda}{b}$, so larger apertures, *b*, are needed to reduce this value (equivalent to better resolution).

b $\text{Resolution} = \dfrac{1.22\lambda}{b} \approx \dfrac{1.22 \times 0.21}{50} \approx 5 \times 10^{-3}$ rad

29 a $\Delta\lambda = \dfrac{\lambda}{mN}$; for $m = 1$, $\Delta\lambda = \dfrac{495}{1 \times 25} = 20\,\text{nm} \Rightarrow$ cannot be resolved

for $m = 2$, $\Delta\lambda = 10\,\text{nm} \Rightarrow$ maybe just resolved

for $m = 3$, $\Delta\lambda = 7\,\text{nm} \Rightarrow$ resolved

b $\text{Diameter} = \dfrac{25}{300}\,\text{mm}.\quad \text{area} = \pi \times \left(\dfrac{25}{600}\right)^2 = 5.5 \times 10^{-3}\,\text{mm}^2$

30 Similar to Figure 9.32c but with the observer (D) on the left-hand side.

31 a $220 + 12 = 232\,\text{Hz}$

b $f' = \frac{fv}{(v - u_s)} \Rightarrow 232 = \frac{220 \times 335}{(335 - u_s)} \Rightarrow u_s = 17\,\mathrm{m\,s^{-1}}$

c $f' = \frac{220 \times 335}{(335 + 33)} = 200\,\mathrm{Hz}$

32 $f' = \frac{f(v + u_o)}{v}$ with $f = \frac{340}{0.90} = 378\,\mathrm{Hz}$

$f' = \frac{378(340 + 14)}{340} = 394\,\mathrm{Hz}$

Then $\lambda = \frac{c}{f} = \frac{340}{394} = 0.86\,\mathrm{m}$

33 $\frac{\Delta\lambda}{\lambda} \approx \frac{2v}{c}$ (Factor of two is used because both incident and reflected waves are affected.)

$\Delta\lambda = \frac{2v\lambda}{c} = \frac{2 \times 260 \times 0.20}{3.0 \times 10^8} = 3.5 \times 10^{-7}\,\mathrm{m}$

34 a Redshift

b $\frac{\Delta f}{f} \approx \frac{v}{c} \Rightarrow \frac{0.022 \times 10^{14}}{6.563 \times 10^{14}} \approx \frac{v}{3.00 \times 10^8} \Rightarrow v = 1.0 \times 10^6\,\mathrm{m\,s^{-1}}$

c Away from the Earth.

d $3.0 \times 10^8 >> 1.0 \times 10^6$, so the assumption $c >> v$ is valid.

35 a Sound with frequency greater than can be heard (by humans).

b Can pass into and through the body without too much absorption, but is also partially reflected from blood cells. Not dangerous to health.

Topic 10 Fields

Questions to check understanding

1 Because the gravitational field strength, *g*, varies between the Earth's surface and the height of the orbit.

2 a Gravitational potential energy is calculated with reference to infinity, where the energy is considered to be zero. Since energy has to be supplied to a satellite to move it a long way from Earth, so that it then has zero energy, it must have negative energy on or near the Earth.

b Decreases

c Increases (larger negative value)

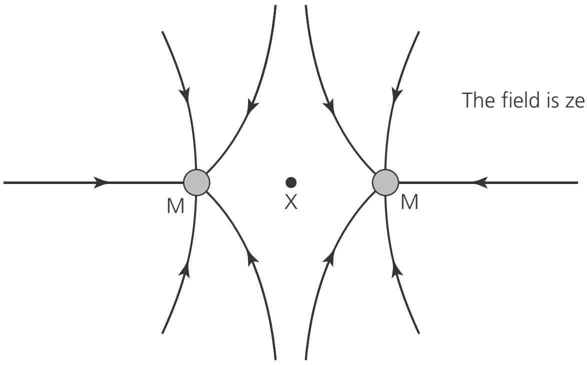
3 $F \propto \frac{1}{r^2}$ so that $F_E r_E^2 = F_J r_J^2$

$$\Rightarrow F_J = \left(\frac{r_e^2}{r_J^2}\right) F_E = \frac{(6.4 \times 10^6)^2}{(6.0 \times 10^{11})^2} \times 10 = 1.1 \times 10^{-9}\,\mathrm{N}$$

4 a $W = m\Delta V_g = 2000 \times (-2.0 - (-4.0)) \times 10^7 = 4.0 \times 10^{10}\,\mathrm{J}$

b The only force acting on the satellite is towards the centre of the orbit. There is no force acting in the opposite direction to motion.

5



The field is zero at X.

6 $\Delta V_g = \frac{W}{m} = \frac{\cancel{m}gh}{\cancel{m}} = 9.81 \times 8848 = 8.68 \times 10^4\ \text{J kg}^{-1}$

This assumes a constant value for the gravitational field strength, *g*.

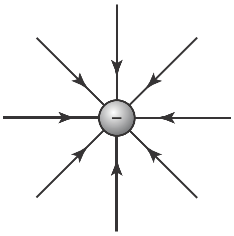
7 a $-6.26 \times 10^7\ \text{J kg}^{-1}$

b On the surface of a sphere centred on the centre of the Earth, approximately parallel to the floor.

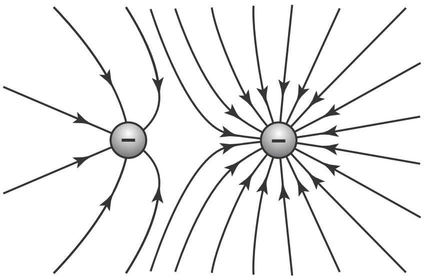
8 a $W = m\Delta V_g = 847 \times (0 - (-4.96 \times 10^7)) = 4.20 \times 10^{10}\ \text{J}$

b Work will be done in overcoming resistive forces from the atmosphere (if any). The movement of this mass will probably be achieved using an engine-powered vehicle. The vehicle and fuels will also have to be moved, and the engine will dissipate energy.

9 a



b



10 a Negative

b $\frac{2 \times 10^{-18}}{1.6 \times 10^{-19}} \approx 10\,\text{eV}$

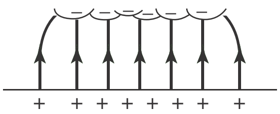
c $2 \times 10^{-18}\ \text{J}\ (10\,\text{eV})$

d 0J

11 a Positive

b The charges would be repelled from each other, gaining kinetic energy and losing electric potential energy.

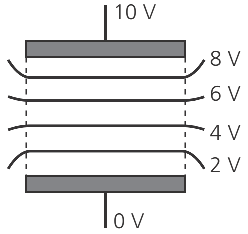
12



13 a $W = q\Delta V_e = (-26 \times 10^{-9})(\pm 500) = \pm 1.3 \times 10^{-5}\ \text{J}$

b If the charge moved from 1 kV to 1.5 kV, ΔV_e is positive and W is negative. If the charge moved from 1.5 kV to 1 kV, ΔV_e is negative and W is positive.

14



15 a The missing labels are +20 V and +40 V

b Positive

c Field lines must be perpendicular to equipotential lines and the plate.

16 $F_G = mg = 75 \times 3.8 = 285\,\text{N}$

17 $$F = \frac{GMm}{r^2} = \frac{(6.67\times10^{-11})\times(5.97\times10^{24})\times2000}{((6.4+0.55)\times10^6)^2} = 1.6\times10^4\,\text{N}$$

18 a $$F = \frac{GMm}{r^2} = \frac{6.67\times10^{-11}\times(5.97\times10^{24})^2\times(3.33\times10^5)}{(1.50\times10^{11})^2} = 3.52\times10^{22}\,\text{N}$$

b This provides the centripetal force keeping the Earth in orbit around the Sun.

19 a Potential energy = area under graph from distance R to infinity

$$\approx -\frac{1}{2}\times 2R\times200$$

$$\approx -1.2\times10^{10}\,\text{J}$$

b $$g = \frac{F_G}{m} = \frac{200}{8.5} = 24\,\text{N kg}^{-1}$$

20 $$E_p = \frac{-GMm}{r} = \frac{-(6.67\times10^{-11})\times(6.4\times10^{23})\times840}{3.6\times10^6} = -1.0\times10^{10}\,\text{J}$$

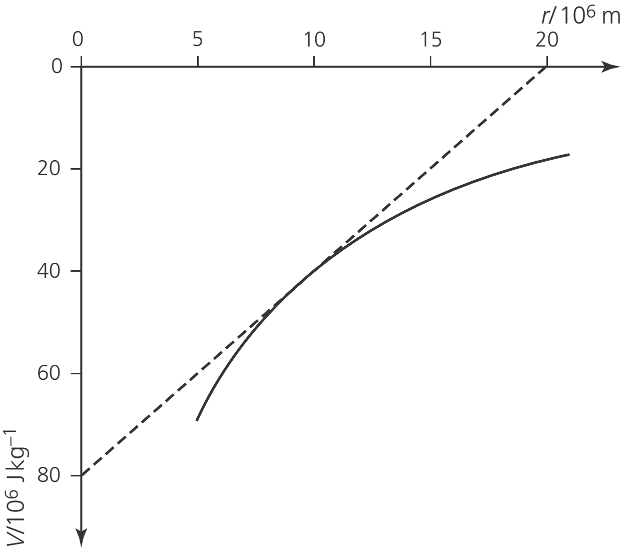
21 a $$V_g = \frac{-GM}{r} = \frac{-(6.67\times10^{-11})\times(7.3\times10^{22})}{2.7\times10^6} = (-1.803\times10^6) = -1.8\times10^6\,\text{J kg}^{-1}$$ (to two significant figures)

b Potential is entirely due to the Moon, the potential due to the Earth (approximately -1.0×10^6) has not been considered.

c Energy = mass × $(V_{1000} - V_{\text{surface}})$

$= 50 \times [(-1.803 + 10^6) - (-2.864 + 10^6)] = 5.3\times10^7\,\text{J}$ (The presence of the Earth has no significant effect on this answer.)

22 a



b $g = \frac{\Delta V_g}{r} = \frac{80 \times 10^6}{20 \times 10^6} = 4.0\,\text{N kg}^{-1}$

c $g = \frac{GM}{r^2} = \frac{(6.67\times10^{-1})\times(6.0\times10^{24})}{(1.0\times10^7)^2} = 4.0\,\text{N kg}^{-1}$

The two answers should be the same.

23 a $-30 - (-50) = +20\,\text{MJ kg}^{-1}$

b $W = m\Delta V_g$

$= 500 \times (-40 - (-63)) \times 10^6$

$= 1.15 \times 10^{10}\,\text{J}$

c The two points are at the same potential. By definition, there is no difference in the gravitational potential energy of the same mass located at these points.

24 $\frac{\cancel{G}M_s \cancel{m}}{r_s^2} = \frac{\cancel{G}M_e \cancel{m}}{r_e^2}$

r_s = distance from point to centre of Sun

r_e = distance from point to centre of Earth

$\left(\frac{r_s}{r_e}\right)^2 = \frac{M_s}{M_e} \Rightarrow \frac{r_s}{r_e} = \sqrt{\frac{2.0\times10^{30}}{6.0\times10^{24}}} = 577$

$r_s = (1.5\times10^{11}) - r_e \Rightarrow r_e = (1.5\times10^{11}) - 577r_e$

$\Rightarrow r_e = 2.6 \times 10^8\,\text{m}$

25 a $V_{g_{\text{total}}} = V_{g_e} + V_{g_m} = \left(-\frac{GM_e}{r_e}\right) + \left(-\frac{GM_m}{r_m}\right)$

$= \left(\frac{-(6.67\times10^{-11})\times(6.0\times10^{24})}{3.6\times10^8}\right) + \left(\frac{-(6.67\times10^{-11})\times(7.3\times10^{22})}{3.7\times10^7}\right)$

$= (-1.112\times10^6) + (-1.32\times10^5) = -1.24\times10^6\,\text{J kg}^{-1}$

b Using the same equation, the combined potential on the Moon's surface $= -3.91 \times 10^6\,\text{J kg}^{-1}$ (the distance of the Moon from Earth needs to be researched)

$\Delta V_g = (-3.91 - (-1.24)) \times 10^6 = -2.67 \times 10^6\ \text{J kg}^{-1}$

$W = m\Delta\ V_g = 2400 \times (-2.67\times10^6) = -6.4\times10^9\,\text{J}$ (The spacecraft gains this energy.)

26 a $v_{\text{esc}} = \sqrt{\frac{2GM}{r}} = \sqrt{\frac{2\times6.67\times10^{-11}\times5.97\times10^{24}}{6.37\times10^6}} = 11.2\times10^3\,\text{m s}^{-1}$

b A greater mass would have to gain more gravitational potential energy by being launched with greater kinetic energy, but they both increase proportionally to the mass; the velocity does not need to change.

c If $r \times 2$, volume $\times\, 2^3$ and $m \times 2^3$, so $v_{\text{esc}} \times \sqrt{\frac{8}{2}}$.

Escape speed would be two times greater (22 km s^{-1}).

27 a $v_{\text{esc}} = \sqrt{\frac{2GM}{r}} \Rightarrow 2.4\times10^3 = \sqrt{\frac{2\times6.67\times10^{-11}\times7.3\times10^{22}}{r}} \Rightarrow r = 1.7\times10^6\,\text{m}$

b The Moon has a much smaller mass (and lower density).

28 a $v_{\text{orb}} = \sqrt{\dfrac{\text{GM}}{r}} = \sqrt{\dfrac{6.67\times10^{-11}\times6.0\times10^{24}}{(6.4\times10^{6})+(200\times10^{3})}} = 7.8\times10^{3}\ \text{m s}^{-1}$

b $T = \dfrac{2\pi r}{v_{\text{orb}}} = \dfrac{2\pi\times6.6\times10^{6}}{7.8\times10^{3}} = 5.3\times10^{3}\,\text{s}$

29 $\dfrac{T^{2}}{r^{3}} = \dfrac{4\pi^{2}}{\text{GM}} \Rightarrow r = \sqrt[3]{\dfrac{(8.88\times10^{4})^{2}\times6.67\times10^{-11}\times6.4\times10^{23}}{4\times\pi^{2}}} \Rightarrow r = 2.0\times10^{7}\,\text{m}$

30 $\dfrac{1}{2}\cancel{m}v^{2} = \left(\dfrac{\text{GM}\cancel{m}}{r}\right)_{500} - \left(\dfrac{\text{GM}\cancel{m}}{r}\right)_{\text{surface}}$

$\dfrac{1}{2}v^{2} = 6.67\times10^{-11}\times6.0\times10^{24}\left(\dfrac{1}{6.4\times10^{6}} - \dfrac{1}{6.9\times10^{6}}\right)$

$\Rightarrow v = 3.0\times10^{3}\,\text{m s}^{-1}$

(using $\dfrac{1}{2}\cancel{m}v^{2} = \cancel{m}gh \quad \Rightarrow v = 3.1\times10^{3}\,\text{m s}^{-1}$ for $g = 9.81\,\text{m s}^{-2}$)

31 a i $v_{\text{orb}} = \sqrt{\dfrac{\text{GM}}{r}} = \sqrt{\dfrac{6.67\times10^{-11}\times5.97\times10^{24}}{6.68\times10^{6}}} = 7.72\times10^{3}\ \text{m s}^{-1}$

ii $\dfrac{1}{2}mv^{2} = +7.45\times10^{9}\ \text{J}$

b i $-14.9\times10^{9}\,\text{J}$

ii $-7.45\times10^{9}\,\text{J}$

32 $v_{\text{orb}} = \sqrt{\dfrac{\text{GM}}{r}}$

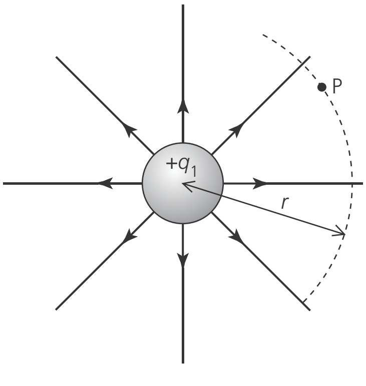
so if r increases, the necessary v_{orbit} decreases. E_K therefore decreases as well. At the greater height, E_P has increased (changed to a smaller negative number). Similarly, E_T has increased (to a smaller negative number).

33 a $v_{\text{orbit}} = \dfrac{2\pi r}{T} = \dfrac{2\pi\times1.2\times10^{9}}{15.9\times24\times3600} = 5.5\times10^{3}\ \text{m s}^{-1}$

b $\dfrac{1}{2}mv^{2} = \dfrac{1}{2}\times(1.3\times10^{23})\times(5.5\times10^{3})^{2} = \ (1.97\times10^{30})\ = 2.0\times10^{30}\ \text{J}$

c $-4.0\times10^{30}\,\text{J}$

34 If another small change $+q_2$ is at point P, it will experience an electric force $F_E = \dfrac{kq_1q_2}{r^2}$ away from q_1 (and q_1 will experience an equal and opposite force).



35 $F = \dfrac{kq_1q_2}{r^2} \Rightarrow 9.2\times10^{-6} = \dfrac{(8.99\times10^{9})(3.2\times10^{-9})^{2}}{r^{2}}$

$\Rightarrow r = 0.10\,\text{m}$

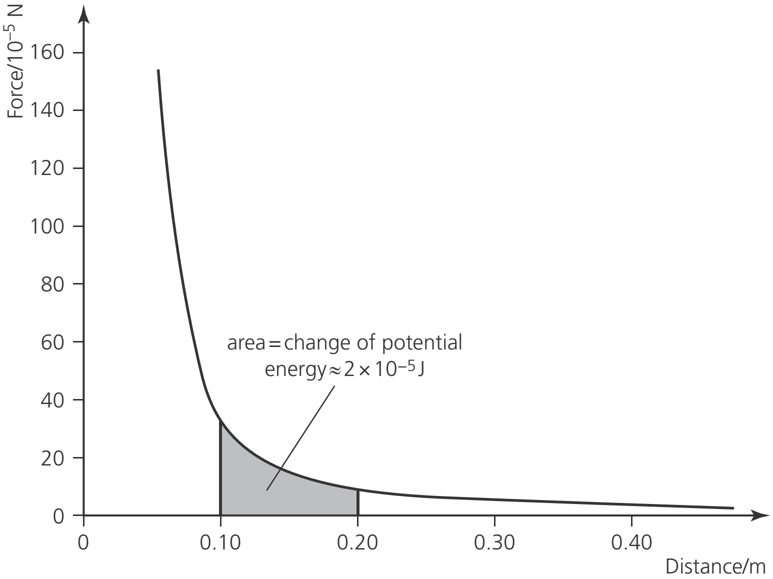
36 $F = \dfrac{(8.99\times10^{9})(1.2\times10^{-9})(-23\times10^{-9})}{0.125^{2}} - \dfrac{(8.99\times10^{9})(1.2\times10^{-9})(-34\times10^{-9})}{0.125^{2}}$

$= 7.6\times10^{-6}$ N towards the larger charge

37 a $E_p = \dfrac{kq_pq_e}{r} = \dfrac{8.99\times10^{9}\times(+1.6\times10^{-19})\times(-1.6\times10^{-19})}{5.3\times10^{-11}} = -4.3\times10^{-18}\text{J}$

b Energy would have to be supplied to separate the particles. Separated particles are considered to have zero potential energy.

38 a



b Positive. The system has gained energy as work is done to overcome the (repulsive) force.

c $E_p = \dfrac{kq_1q_2}{r} = 3.6\times10^{-5}\text{J}$

39 $V_e = \dfrac{kQ}{r} = \dfrac{(8.99\times10^{9})(-4.5\times10^{-12})}{0.15} = -0.27\text{V}$

40 $V_p = k\left(\dfrac{q_A}{r_A} + \dfrac{q_B}{r_B}\right) = (8.99\times10^{9})\left(\dfrac{12\times10^{-9}}{0.15} + \dfrac{-2.4\times10^{-9}}{0.10}\right) = 500\text{V}$

41 a Positive

b $E = \dfrac{\Delta V}{\Delta r} \approx \dfrac{18000}{0.3} \approx 6\times10^{4}\text{ V m}^{-1}(\text{N C}^{-1})$

42 a $40-(-40) = 80\text{ V}$

b $2.0\times10^{-9}\times\pm80 = \pm1.6\times10^{-7}\text{J}$

c Assuming, for example, that the 2.0 nC was positively charged, work would be done on the charge, and the energy transfer positive, if it was moved to the higher potential (+40 V), overcoming the repulsive force.

43 a $E = \dfrac{\Delta V}{\Delta r} = \dfrac{1000}{0.032} = 3.1\times10^{4}\text{ V m}^{-1}$

b About half of the field strength at the centre, $1.6\times10^{4}\text{ V m}^{-1}$

c $E = \dfrac{F}{q} \Rightarrow F = (3.1\times10^{4})\times(1.0\times10^{-9}) = 3.1\times10^{-5}\text{N}$

d It will accelerate towards the negative plate.

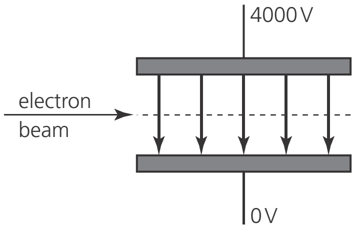
e Force remains constant (in a uniform field).

44 a $E = \frac{\Delta V}{\Delta r} = \frac{12.8\times10^{-3}}{0.20} = 6.4\times10^{-2}\,\mathrm{V\,m^{-1}}$

b $F = Eq = (6.4\times10^{-2})\times(1.6\times10^{-19}) = 1.0\times10^{-20}\,\mathrm{N}$

c $F = ma \Rightarrow a = \frac{F}{m} = \frac{1.0\times10^{-20}}{9.1\times10^{-31}} = 1.1\times10^{10}\,\mathrm{m\,s^{-2}}$

45 a



b i 5000 eV

ii $5000\times(1.6\times10^{-19}) = 8.0\times10^{-16}\,\mathrm{J}$

c $\frac{1}{2}mv^2 = 8.0\times10^{-16}$

$v = \sqrt{\frac{2\times8.0\times10^{-16}}{9.1\times10^{-31}}} = 4.2\times10^{7}\,\mathrm{m\,s^{-1}}$

d $t = \frac{s}{v} = \frac{0.06}{4.2\times10^{7}} = 1.4\times10^{-9}\,\mathrm{s}$

e $E = \frac{\Delta V}{\Delta r} = \frac{4000}{0.034} = 1.2\times10^{5}\,\mathrm{Vm^{-1}}$

f $F = Eq = (1.2\times10^{5})\times(1.6\times10^{-19}) = 1.9\times10^{-14}\,\mathrm{N}$

g $a = \frac{F}{m} = \frac{1.9\times10^{-14}}{9.1\times10^{-31}} = 2.1\times10^{16}\,\mathrm{m\,s^{-2}}$

h $s = ut + \frac{1}{2}at^2 = 0 + \frac{1}{2}(2.1\times10^{16})(1.4\times10^{-9})^2 = 2.1\times10^{-2}\,\mathrm{m}$

46 a $r = \frac{mv}{qB} = \frac{(6.64\times10^{-27})(6.1\times10^{6})}{(2\times1.6\times10^{-19})(0.46)} = 0.28\,\mathrm{m}$

b 0.028 m

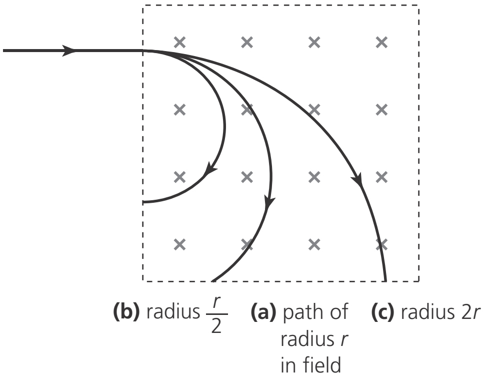
c $\frac{1}{2}mv^2 = \frac{1}{2}\times(6.64\times10^{-27})(6.1\times10^{6})^2$

$= 1.24\times10^{-13}\,\mathrm{J}$

Converting to MeV: $\frac{1.24\times10^{-13}}{1.6\times10^{-13}} = 0.77\,\mathrm{MeV}$

d The alpha particle would lose kinetic energy as it collided with air molecules. As its speed decreased, the radius of its path would get smaller.

47



Topic 11 Electromagnetic induction

Questions to check understanding

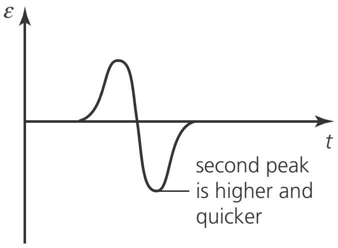
1 Any movement that is horizontal, with no vertical component

2 Because the effect needs the movement of charges (free electrons), which is not possible in insulators.

3 Faster movement, stronger magnet, more turns on the coil

4 a The magnet falls too quickly for its effects to be easily observed by other methods.

b



5 $\varepsilon = Bvl = 45\times10^{-3}\times0.32\times0.50 = 7.2\times10^{-3}\,\mathrm{V}$

6 a It greatly increases the strength of the magnetic field.

b At the instant the current in A is switched on, the magnetic field strength (due to the current) changes from zero to non-zero. Circuit B experiences this brief change of magnetic field and an emf is induced across it.

c An alternating current in A will produce a continuously changing magnetic field through both circuits. This will induce an alternating voltage in B of the same frequency (but π rads out of phase).

7 $\phi = BA\cos\theta = 35\times10^{-3}\times\left(0.050\times0.050\right)\times1 = 8.75\times10^{-5}\,\mathrm{Wl}$

8 a $\phi = BA\cos\theta \Rightarrow 5.6\times10^{-6} = B\times\pi\times0.042^2\times\cos40° \Rightarrow B = 1.3\times10^{-3}\,\mathrm{T}$

b $\phi = 480\times5.6\times10^{-6} = 2.7\times10^{-3}\,\mathrm{Wb}$

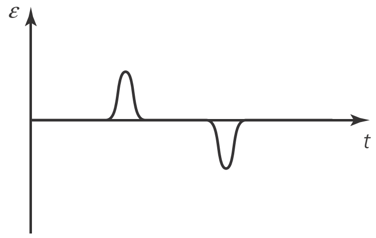
9 $\varepsilon = \dfrac{N\Delta\phi}{\Delta t} \Rightarrow NvIB\cos\theta = 1\times2.0\times1.42\times(35\times10^{-6})\times\cos70° \Rightarrow \varepsilon = 3.4\times10^{-5}\,\mathrm{V}$

10 a $\phi = BA = 5.6\times10^{-3}\times4.3\times10^{-2}\times2.7\times10^{-2} = 6.5\times10^{-6}\,\mathrm{Wb}$

b $\varepsilon = \dfrac{N\Delta\phi}{\Delta t} = 500\times\dfrac{(6.5\times10^{-6})}{0.50} = 6.5\times10^{-3}\,\mathrm{V}$

c $\varepsilon = \dfrac{N\Delta\phi}{\Delta t} = 500\times\dfrac{2\times6.5\times10^{-6}}{0.50} = 1.3\times10^{-2}\,\mathrm{V}$

d



11 a Its movement is always parallel to the magnetic field.

b Horizontal

c $v = \dfrac{2\pi r}{T} = 2\pi rf = 2\pi\times(1.8\times10^{-2})\times10 = (1.13) = 1.1\,\mathrm{m\,s^{-1}}$ to two significant figures

d $\varepsilon = \dfrac{N\Delta\phi}{\Delta t} = NvlB\cos\theta = 1\times 1.13\times(2\times 6.2\times 10^{-2})\times 0.26\times 1 = 3.6\times 10^{-2}\,\text{V}$

e Using $\varepsilon = 3.6\times 10^{-2}\times\cos\theta$

i $3.4\times 10^{-2}\,\text{V}$

ii $1.2\times 10^{-2}\,\text{V}$

iii $0\,\text{V}$

f With one loop at 50 Hz, $\varepsilon_{\text{max}} = 5\times 3.6\times 10^{-2}\,\text{V} = 0.18\,\text{V}$

Therefore, to induce 1.0 V, number of loops needed = 1/(0.18) ≈ 6

g When connected to an external circuit a current is induced around the coil which changes direction each half revolution as the sides of the coil move in opposite directions.

12 a Towards A

b From A to B

c The current in the rod produces a magnetic field which opposes its motion (Lenz's law).

d $F = BIl$

13 a The magnet which falls through the coil induces a current in the coil. The current sets up a magnetic field which opposes the motion of the falling magnet, reducing its speed compared to the other magnet.

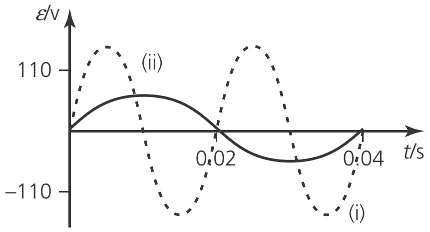
b If the switch were open, the induced emf would not be able to produce a current in the coil.

14 When the plane of the coil is horizontal, the emf has maximum values (positive and negative). The induced emf is zero when the plane of the coil is vertical.

15 This increases the strength of the magnetic field.

16 a Strong magnetic field; coil wound on iron core; many turns on coil; coil of large area (within the field)

b



17 $\varepsilon = \dfrac{N\Delta\phi}{\Delta t} = \dfrac{600\times 0.40\times 5.6\times 10^{-4}}{0.10/4} = 5.4\,\text{V}$

(Flux changes from its maximum to zero in $\frac{1}{4}$ cycle.)

18 a $V_{\text{rms}} = \dfrac{V_0}{\sqrt{2}} \Rightarrow 110 = \dfrac{V_0}{\sqrt{2}} \Rightarrow V_o = 156\,\text{V}$

b $I_{\text{rms}} = \dfrac{V_{\text{rms}}}{R} = \dfrac{110}{15.0} = 7.33\,\text{A}$

c $P = \left(I^2R = \dfrac{V^2}{R} = IV\right) = 807\,\text{W}$

19 a 48 W

b $\dfrac{48}{12} = 4.0\,\text{A}$

c $\dfrac{4}{\sqrt{2}} = 2.8\,\text{A}$

20 a $P = \frac{V^2}{R} = \frac{230^2}{28} = 1.9 \times 10^3\ \text{W}$

b 230 V

21 a 12 V

b 0 V

c $\frac{V_0}{\sqrt{2}} = \frac{12}{\sqrt{2}} = 8.5\ \text{V}$

d $\frac{1}{20 \times 10^{-3}} = 50\ \text{Hz}$

22 a Step-down

b $\frac{\varepsilon_p}{\varepsilon_s} = \frac{N_p}{N_s} \Rightarrow N_s = \frac{2500 \times 12}{230} = 130$

c $I = \frac{P}{V} = \frac{64}{12} = 5.3\text{A}$

d i $\varepsilon_p I_p = 64 \Rightarrow I_p = \frac{64}{230} = 0.28\text{A}$

ii zero

23 a There will be a greater power loss per metre in any cable which is not at high voltage, so the transmission line with a lower voltage needs to be as short as possible.

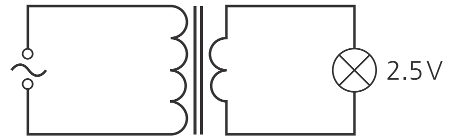
b $\frac{500 \times 10^3}{25 \times 10^3} = 20$

so ratio = $\frac{20}{1}$. In practice, the number of turns will be greater, for example, $\frac{2000}{100}$.

c $0.05 \times 25000 \times 28 = 3.5 \times 10^4\ \text{W}$

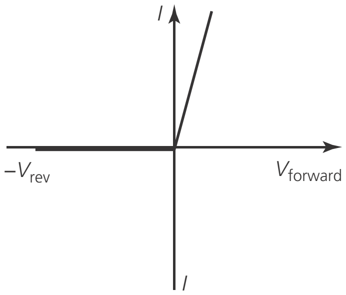
d Joule heating in the coils; eddy current heating in the core; hysteresis effects; magnetic flux leakage.

24 a



b $\frac{\varepsilon_p}{\varepsilon_s} = \frac{N_p}{N_s} \Rightarrow \varepsilon_p = \frac{2400}{60} \times 2.5 = 100\ \text{V}$

25



(This is a very simplified graph.)

26 a rms value.

b The scale on an ac ammeter has been calibrated assuming that the current is alternating and sinusoidal. The current in a circuit like Figure 11.26 is neither of these.

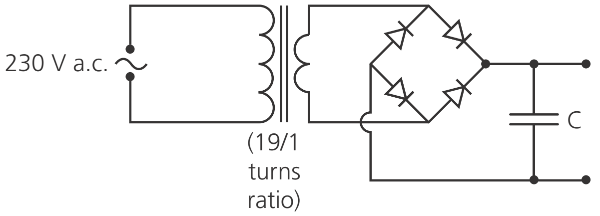
27 a The display will occur in a time of $\frac{0.10}{5.0} = 0.02\ \text{s}$.

There will be two complete oscillations of a 100 Hz supply in 0.02 s but because of the diode, only positive (or negative) voltages will be displayed.

b $I_{\text{rms}}=\frac{\overline{P}}{V_{\text{rms}}}=\frac{3.0}{6.0}=0.50\text{A}$

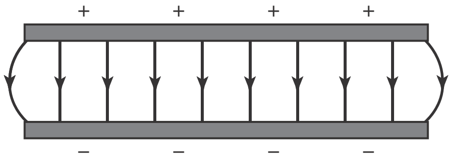
c The power will be halved, so the lamp will be dimmer.

28



29 The capacitor would discharge more quickly, so that there would be a greater drop in V_{out} between peaks.

30



31 a $q=\frac{\varepsilon_o VA}{d}=\frac{\left(8.85\times10^{-12}\right)\times80\times\left(4.8\times10^{-4}\right)}{1.0\times10^{-3}}=3.4\times10^{-10}\text{ C}$

b **i** No change

ii if $d\times2$, $V\times2$.

32 a $C=\frac{q}{V}=\frac{4.5\times10^{-6}}{1.5}=3.0\times10^{-6}\text{F}$

b $q=CV=3.0\times10^{-6}\times12=3.6\times10^{-5}\text{ C}$

33 a $C=\frac{\varepsilon A}{d}=\frac{\left(2.03\times10^{-11}\right)\times0.10^2}{\left(0.12\times10^{-3}\right)}=1.7\times10^{-9}\text{F}$

b $q=CV=1.7\times10^{-9}\times6.0=1.0\times10^{-8}\text{ C}$

34 $\frac{\varepsilon}{\varepsilon_o}=\frac{3.41\times10^{-11}}{8.85\times10^{-12}}=3.85$

35 a $C=\frac{q}{V}=\frac{200\times10^{-6}}{12}=1.7\times10^{-5}\text{F}$

b $E=\frac{1}{2}qV=\frac{1}{2}\times\left(100\times10^{-6}\right)\times6=3.0\times10^{-4}\text{J}\left(\text{or }E=\frac{1}{2}CV^2\right)$

36 $E=\frac{1}{2}CV^2\Rightarrow500=\frac{1}{2}\times C\times1000^2\Rightarrow C=1.0\times10^{-3}\text{F}$

37 $E=Pt=\frac{1}{2}CV^2\Rightarrow P\times\frac{1}{200}=\frac{1}{2}\times\left(180\times10^{-6}\right)\times250^2\Rightarrow P=1.1\times10^3\text{W}$

38 a 3 in series: C = 9 pF.

3 in parallel: C = 81 pF.

2 in series with one in parallel: C = 40.5 pF.

2 in parallel with one in series: C = 18 pF.

b Ensure that the combination is discharged and then connect it in parallel across a known capacitor charged to a known voltage. The voltage will fall and its new value can be used to determine the value of the overall capacitance, from which the capacitance of the combination being tested can be calculated (see next question).

39 a Capacitance of combination = 22 + 33 = 55 μF.

Charge = $CV = 22 \times 10^{-6} \times 9.0 = 1.98 \times 10^{-4}$ C

$$V = \frac{q}{C} = \frac{1.98\times10^{-4}}{55\times10^{-6}} = 3.6\,\text{V}$$

b i $E = \frac{1}{2}CV^2 = \frac{1}{2}\left(22\times10^{-6}\right)\times9.0^2 = 8.9\times10^{-4}\,\text{J}$

ii $E = \frac{1}{2}CV^2 = \frac{1}{2}\left(55\times10^{-6}\right)\times3.6^2 = 3.6\times10^{-4}\,\text{J}$

c Dissipated to internal energy when the current flows between the capacitors.

40 Time content = CR, which has same units as $\frac{q}{V}R$, which has same units as $\frac{q}{I}$ which is seconds.

41 a $\tau = CR \Rightarrow 12 = C\times\left(11\times10^{3}\right) \Rightarrow C = 1.1\times10^{-3}\,\text{F}$

b 0.37 × 0.37 = 0.137, or 13.7% of original value = 7.4 mA

42 a $I = \frac{V}{R} = \frac{6.0}{\left(68\times10^{3}\right)} = 8.8\times10^{-5}\,\text{A}$

b $\tau = RC = (68 \times 10^3) \times (3.9 \times 10^{-6}) = 0.27\,\text{s}$

c After 0.27 s, V falls to 6.0 × 0.37 = 2.2 V. After another 0.27 s, V falls to 2.2 × 0.37 = 0.82 V. After another 0.27 s, V falls to 0.82 × 0.37 = 0.30 V. After another 0.27 s, V falls to 0.30 × 0.37 = 0.11 V.

43 a $V = V_0 e^{\frac{-t}{\tau}} \Rightarrow 3.22 = 4.69e^{\frac{-60}{\tau}} \Rightarrow \ln\left(\frac{4.69}{3.22}\right) = \frac{60}{\tau} \Rightarrow \tau = 160\,\text{s}$

b $V = 3.22e^{\frac{-300}{160}} \Rightarrow \ln V = \ln 3.22 - \frac{300}{160} \Rightarrow V = 0.49\,\text{V}$

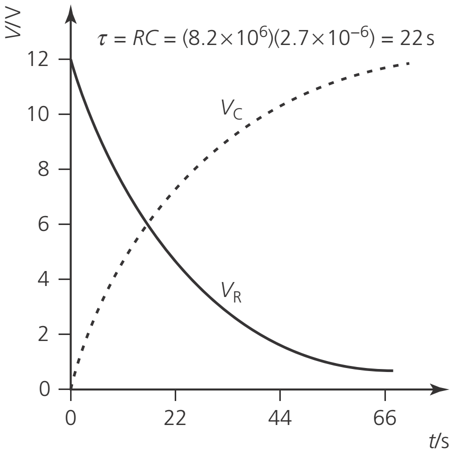
44 a $\tau = RC = \left(5.6\times10^{3}\right)\times\left(68\times10^{-6}\right) = 0.38\,\text{s}$

b $q = VC = 24\times\left(68\times10^{-6}\right) = 1.6\times10^{-3}\,\text{C}$

c $q = \left(1.6\times10^{-3}\right)e^{\frac{-t}{0.38}}$

d $\left(4.5\times10^{-5}\right) = \left(1.6\times10^{-3}\right)e^{\frac{-t}{0.38}} \Rightarrow t = 1.4\,\text{s}$

45



46 a 6.98×10^{-5} A

b $\tau = \frac{-1}{\text{gradient}} = \frac{-100}{[-12.14-(-9.57)]} = (38.9) = 39\,\text{s}$

c $\tau = 38.9 = RC = \left(820\times10^{3}\right)C \Rightarrow C = 4.7\times10^{-5}\,\text{F}$

Topic 12 Quantum and nuclear physics

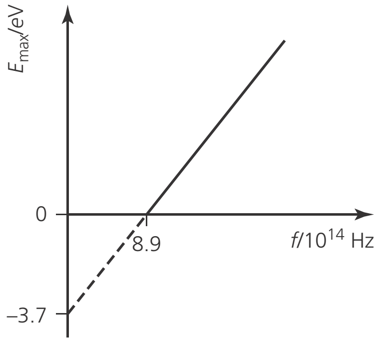
Questions to check understanding

1 **a** **i** The number of photoelectrons increases, but they each still have the same energy.

ii The photoelectrons will each have more energy, but there will be fewer of them if the intensity is constant.

b The new metal may have a work function which is greater than the energy of the photons.

2



3 **a** Caesium

b $4.5\times1.6\times10^{-19}=7.2\times10^{-19}\,\text{J}$

c $f_o=\dfrac{\phi}{h}=1.1\times10^{15}\,\text{Hz}$

d $\lambda_o=\dfrac{hc}{\phi}=1.9\times10^{-7}\,\text{m}$

e $E_{\text{max}}=hf-\phi=(6.63\times10^{-34}\times 8.\ 4\times10^{15})-(7.2\times10^{-19})=4.8\times10^{-18}\,\text{J}$

4 **a** Intercept on horizontal axis = 9.6×10^{14} Hz

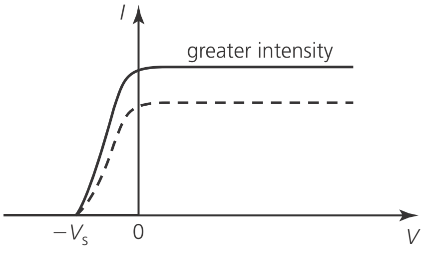
b Magnitude of intercept on vertical axis $=\phi$ = 3.9 eV

c Gradient $=h=\dfrac{4.2-(-3.9)\times1.6\times10^{-19}}{20\times10^{14}}=6.5\times10^{-34}\,\text{J s}$

5 $eV_s=hf-\phi \Rightarrow 1.6\times10^{-19}\times V_s=(6.63\times10^{-34}\times1.2\times10^{15})-(2.3\times1.6\times10^{-19})$

$\Rightarrow V_s=2.7\,\text{V}$

6



7 When $n=1$, $E=-13.6$ eV

When $n=2$, $E=-3.40$ eV

When $n=3$, $E=-1.51$ eV, etc.

8 **a** **i** $mvr=\dfrac{nh}{2\pi}=\dfrac{1\times6.63\times10^{-34}}{2\times\pi}=1.1\times10^{-34}\,\text{kg m}^2\text{s}^{-1}$

ii linear momentum $=\dfrac{\text{angular momentum}}{r}=2.0\times10^{-24}\,\text{kg ms}^{-1}$

b $n=2\Rightarrow 2.2\times10^{-34}\,\text{kg m}^2\,\text{s}^{-1}$

9 $\lambda=\dfrac{h}{p}=\dfrac{6.63\times10^{-34}}{6.64\times10^{-27}\times\left(0.05\times3.0\times10^{8}\right)}=6.7\times10^{-15}\text{m}$

10 $\lambda = \frac{h}{p} \Rightarrow 1\times10^{-10} \approx \frac{6.63\times10^{-34}}{(9.1\times10^{-31})\times v} \Rightarrow v \approx 7\times10^{6}\ \text{m s}^{-1}$

11 a $5000\times1.6\times10^{-19} = \frac{1}{2}\times(9.1\times10^{-31})\times v^{2} \Rightarrow v = 4.2\times10^{7}\,\text{m s}^{-1}$

b $mv = (9.1\times10^{-31})\times(4.2\times10^{7}) = 3.8\times10^{-23}\ \text{kg m s}^{-1}$ (assuming mass equals rest mass)

c $\lambda = \frac{h}{p} = \frac{6.63\times10^{-34}}{3.8\times10^{-23}} = 1.7\times10^{-11}\,\text{m}$

d $n\lambda = d\sin\theta$

$1\times(1.7\times10^{-11}) = (1.4\times10^{-10})\sin\theta \Rightarrow \theta = 7°$

e Answer to (a) $\times\sqrt{2}$, to (b) $\times\sqrt{2}$, to (c) $\div\sqrt{2}$, to (d), $\sin\theta\div\sqrt{2}, \theta\rightarrow 5°$

12 Without the change in motion of a third particle, it would not be possible for both mass-energy and momentum to be conserved.

13 a Minimum energy, $E_{min} = hf_{min} \Rightarrow 2\times0.511\times(1.6\times10^{-13}) = hf_{min} \Rightarrow f_{min} = 2.47\times10^{20}\,\text{Hz}$

b $\lambda = \frac{c}{f} = \frac{3.00\times10^{8}}{2.47\times10^{20}} = 1.22\times10^{-12}\,\text{m}$

14 Momentum and energy would not be conserved.

15 The human mind wants to visualize an electron as having a precise momentum in an exact position, such that it can be modelled in simple diagrams. But this is not the true nature of (subatomic) particles. All the measurable information about an electron can only be represented in terms of probabilities, and these can only be determined using a mathematical model, a wave function.

16 It is difficult to represent probabilities in drawings. One way is use 'clouds' in which the probability of finding an electron is greatest where the 'cloud' is densest.

17 Electrons are most likely to be found at distances of 1×10^{-10} m, 4×10^{-10} m and 13×10^{-10} m from the centre of the atom.

18 a A

b B

19 a $\Delta p = \frac{h}{4\pi\Delta x} \approx \frac{6.63\times10^{-34}}{4\pi\times0.5\times10^{-10}} \approx \left(1.06\times10^{-24}\right) \approx 1\times10^{-24}\,\text{kg m s}^{-1}$

b $E_K \approx \frac{p^{2}}{2m} \approx \frac{(1.06\times10^{-24})^{2}}{2\times9.1\times10^{-31}} \approx 6.2\times10^{-19}\,\text{J}$

c $E_P = \frac{kq_pq_e}{r} = \frac{(8.99\times10^{9})(+1.6\times10^{-19})(-1.6\times10^{-19})}{(0.5\times10^{-10})} = -4.6\times10^{-18}\,\text{J}$

d $-(4.6\times10^{-18}) + (6.2\times10^{-19}) = -4.0\times10^{-18}\,\text{J}$

Total energy in $\text{eV} \approx \frac{-4.0\times10^{-18}}{1.6\times10^{-19}} = -25\,\text{eV}$

≈ -10 eV to an order of magnitude

20 a $E_K = \frac{p^{2}}{2m} \approx \frac{\left(5\times10^{-20}\right)^{2}}{2\times9.1\times10^{-31}} \approx 1\times10^{-9}\,\text{J}$

b This kinetic energy is much greater in magnitude than the electric potential energy in the system (which equals the energy required to separate the electron and proton).

$E_P = \frac{kq_pq_e}{r} = \frac{(8.99\times10^{9})(+1.6\times10^{-19})(-1.6\times10^{-19})}{(5\times10^{-16})} \approx -5\times10^{-13}\,\text{J}$

21 $\Delta E \approx \dfrac{h}{4\pi\Delta t} \approx \dfrac{6.63\times10^{-34}}{4\pi\times2\times10^{-9}} \approx 2.6\times10^{-26}\,\text{J}$

$\Delta E(\text{eV}) = \dfrac{2.6\times10^{-26}}{1.6\times10^{-19}} = 1.6\times10^{-7}\,\text{eV}$

22 $\Delta t = \dfrac{h}{4\pi\Delta E} = \dfrac{6.63\times10^{-34}}{4\pi\times(1\times10^{6})(1.6\times10^{-19})} \approx 3\times10^{-22}\,\text{s}$

23 Quantum theory tells us that there are uncertainties in the position, energy and momentum of all particles, so that there is a possibility that they could be located anywhere. So, there is a small, but finite chance that particles may be able to overcome forces that classical physics tells us would be impossible. We say that they can 'tunnel through potential barriers'.

24 $\Delta E\Delta t = \dfrac{h}{4\pi} \Rightarrow 23\times10^{6}\times1.6\times10^{-19}\times\Delta t = 5.28\times10^{-35} \Rightarrow \Delta t = 1.4\times10^{-23}\text{ s}$

25 There is a small probability that protons can be located inside of the potential barrier imposed by electric repulsion. (Protons can gain enough energy to cross the barrier if the process occurs in a short enough time.)

26 a $\dfrac{1}{2}(6.64\times10^{-27})v^2 = 7.2\times1.6\times10^{-13} \Rightarrow v = 1.9\times10^{7}\,\text{m s}^{-1}$

b $\text{KE} = \dfrac{kq_\alpha q_{Pb}}{r} \Rightarrow r = \dfrac{(8.99\times10^{9})\times2\times82\times(1.6\times10^{-19})^2}{7.2\times1.6\times10^{-13}} = 3.3\times10^{-14}\,\text{m}$

c For a tiny mass, an alpha particle has a very large amount of kinetic energy. In order to be stopped by electric repulsion, it must get very close to the nucleus, where the forces become relatively very large.

d Some of the kinetic energy of the alpha particle will be transferred to the kinetic energy of the nucleus (and not to potential energy).

e Initial momentum of alpha particle = final momentum alpha particle + momentum of nucleus $(6.64\times10^{-27})\times(1.9\times10^{7}) = (6.64\times10^{-27})\times v + [(82\times1.67\times10^{-27})\times(1.8\times10^{6})]$

$\Rightarrow v = -1.8\times10^{7}\,\text{m s}^{-1}$ (in opposite direction to the motion of the nucleus) (The speed of $1.8\times10^{6}\,\text{ms}^{-1}$ given in the question should have been $7.3\times10^{5}\,\text{ms}^{-1}$, assuming that the collision was elastic.)

27 a $\approx 10^{-15}\text{m}$

b Quarks, particles containing quarks, and gluons

c Because only very energetic alpha particles can get within 10^{-15} m of the nucleons in the nucleus.

28 a $p = \dfrac{h}{\lambda} = \dfrac{6.63\times10^{-34}}{1.0\times10^{-15}} = 6.6\times10^{-19}\,\text{kg m s}^{-1}$

b If we ignore relativistic effects and use the rest mass of the electrons,

$$E_K = \frac{p^2}{2m} = \frac{(6.6\times10^{-19})^2}{2\times9.1\times10^{-31}} = 2.4\times10^{-7}\,\text{J}$$

$$E_K = \frac{2.4\times10^{-7}}{1.6\times10^{-13}} = 1.5\times10^{6}\,\text{MeV}$$

c 1.5×10^{12} V

However, this calculation is misleading because such high energy electrons will have been accelerated to speeds very close to the speed of light. Under such circumstances, relativistic effects will occur and the mass of the electrons will have greatly increased from their rest mass. The following calculation is not required knowledge in this chapter.

If we assume that the electrons have been accelerated from rest to almost the speed of light, c, and have increased in mass by Δm, the energy that they gained can be determined from $\Delta E = \Delta mc^2$ (from Chapter 7). $p = mv$ then reduces to $p = \dfrac{\Delta E}{c}$

So that, $\Delta E \approx pc \approx 2\times10^{-10}$ J, or approximately 1 GeV.

29 a $\sin\theta \approx \dfrac{\lambda}{D} \Rightarrow 0.342 \approx \dfrac{2.7\times10^{-15}}{D} \Rightarrow D \approx 7.9\times10^{-15}\ \mathrm{m}$

b If pd increases, the electron's momentum increases and its wavelength decreases. Sin θ and θ will decrease.

30 a If the radius of a nucleus was multiplied by a factor x, its volume would increase by a factor x^3. If the smaller nucleus had A nucleons, the larger nucleus would have A^3 only if we assume that the nucleons are always the same size and as close together as possible.

b It is reasonable to assume that the forces within the nucleus act equally in all directions.

31 a $R = R_o A^{\frac{1}{3}} = 1.2\times10^{-15}\times\sqrt[3]{63} = 4.8\times10^{-15}\ \mathrm{m}$

b $\rho = \dfrac{m}{V} = \dfrac{m}{\frac{4}{3}\pi R^3} = \dfrac{63\times1.67\times10^{-27}}{\frac{4}{3}\pi\times(4.8\times10^{-15})^3} = 2.3\times10^{17}\ \mathrm{kg\,m^{-3}}$

32 $R = R_o A^{\frac{1}{3}} \Rightarrow 3.6\times10^{-15} = 1.2\times10^{-15} A^{\frac{1}{3}} \Rightarrow A = 27.$ This is probably aluminium ($^{27}_{13}$Al).

33 a Assuming, for the sake of simplicity, that the radius of a neutron is approximately equal to the Fermi radius, volume associated with each neutron ≈ $(2.4\times10^{-15})^3 \approx 1.4\times10^{-44}\ \mathrm{m}^3$

Number of neutrons $\approx \dfrac{\frac{4}{3}\pi(2.0\times10^4)^3}{1.4\times10^{-44}} \approx 2.4\times10^{57}$ (assuming that they are packed closely together in a simple cubic arrangement)

b Total mass ≈ $(2.4\times10^{57})\times(1.67\times10^{-27}) \approx 4\times10^{30}\ \mathrm{kg}$

34 a $5.97 - 0.492 = 5.478\ \mathrm{MeV}$

b i 0.492 MeV

ii $E(\mathrm{J}) = \dfrac{hc}{\lambda} \Rightarrow \lambda = \dfrac{6.63\times10^{-34}\times3.0\times10^8}{0.492\times1.6\times10^{-13}} = 2.5\times10^{-12}\ \mathrm{m}$

c All transitions of electrons in hydrogen are 13.6 eV or less. These nuclear energy level changes are approximately 10^4 times greater than electron energy level changes in hydrogen.

35 When the antineutrino is emitted in the same direction as the recoiling nucleus.

36 a They have small mass, no charge and are very weakly interacting.

b Leptons

c Electron neutrino, muon neutrinos and tau neutrinos (and their antiparticles)

d Weak force and gravitational force

37 a $\lambda = \dfrac{0.693}{T_{1/2}} = 4.17\times10^{-9}\ \mathrm{s}^{-1}$

$A = \dfrac{\Delta N}{\Delta t} = -\lambda N \Rightarrow 1.5\times10^5 = (4.17\times10^{-9})N \rightarrow N = 3.6\times10^{13}$

b $A = A_o e^{-\lambda t} \Rightarrow 1.5\times10^5 = A_o e^{-4.17\times10^{-9}\times(2\times3.15\times10^7)}$

$\Rightarrow A_o = 2.0\times10^5\ \mathrm{s}^{-1}$

38 a $\lambda = \dfrac{0.693}{6\times3600} = 3.2\times10^{-5}\ \mathrm{s}^{-1}$

b $A = A_o e^{-\lambda t} = 800\times10^6\times e^{-(3.2\times10^{-5})\times(28\times3600)} \Rightarrow A = 3.2\times10^7\ \mathrm{Bq}$

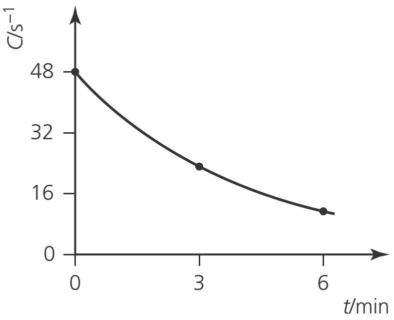
39 $N = N_o e^{-\lambda t} \Rightarrow 2.25\times10^{17} = (2.5\times10^{17})\mathrm{e}^{-\lambda(680\times10^6)} \Rightarrow \lambda = 1.55\times10^{-10}\ y^{-1}$

Then $T_{1/2} = \dfrac{0.693}{1.55\times10^{-10}} = 4.5\times10^9$ years

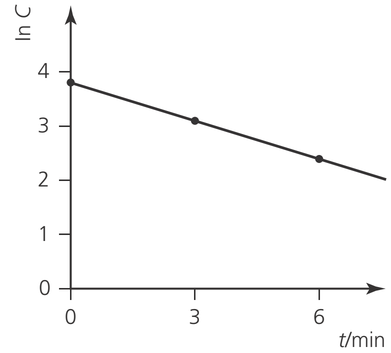
40 $C = C_o e^{-\lambda t}$ (using C for count rate) $\Rightarrow 6 = 71 \times e^{-300 \times \lambda} \Rightarrow \lambda = 8.2 \times 10^{-3}\,s^{-1}$ and $T_{\frac{1}{2}} = 84\,s$
(The actual half life of protactinium –234 is about 70 s)

41 a $C = C_o e^{-\lambda t}$ (using C for count rate) $\Rightarrow 34 = 48\, e^{-\lambda \times 90} \Rightarrow \lambda = 3.8 \times 10^{-3}\,s^{-1}$ and $T_{\frac{1}{2}} = 1.8 \times 10^2\,s$

b



c



42 a $\ln A = 13.5 \rightarrow A = 7.3 \times 10^5$ Bq

b $\lambda = -\text{gradient} = \frac{13.5 - 11}{50} = 0.050\,s^{-1}$

$$T_{1/2} = \frac{0.693}{0.050} = 14\,s$$

43 $\left(\frac{A}{A_o}\right) = e^{-\lambda t}$ with $\lambda = \frac{0.693}{T_{1/2}} = 9.6 \times 10^{-5}$

$\ln\left(\frac{A}{A_o}\right) = -(9.6 \times 10^{-5}) \times 3600 \Rightarrow \frac{A}{A_o} = 0.71$ (or 71%)

Activity decreases by 29%.

44 a $\left(\frac{\text{area of detector}}{\text{area of sphere}}\right) \times A = \left(\frac{1.2}{4\pi \times 8.4^2}\right) \times (6.3 \times 10^4) = 85\,s^{-1}$

b The answer assumes that all radiation passing into the detector is measured and that no radiation is absorbed between source and detector.

c The count is much greater that a typical background count.

45 a 14 g of ^{14}C contain 6.02×10^{23} atoms. 1 μg contains

$$\frac{6.02 \times 10^{23}}{14 \times 10^6} = 4.3 \times 10^{16} \text{ atoms}$$

b $\lambda = \frac{0.693}{5730} = 1.21 \times 10^{-4}\,y^{-1}$

c $A = -\lambda N = \left(\dfrac{1.21\times10^{-4}}{3.15\times10^{7}}\right)\times 4.3\times10^{16} = 1.7\times10^{5}\ \text{Bq}$

46 1.8×10^8 Bq

Option A 13 Relativity

Questions to check understanding

1 Using Galilean transformation,

$x_2 = x'_2 + vt$

$x_1 = x'_1 + vt$

The length of the rod in S is $x_2 - x_1$

Length = $x_2 - x_1 = (x'_2 + vt) - (x'_1 + vt)$

$x_2 - x_1 = x'_2 - x'_1$

The above result shows that the length of rod AB as measured in frame S is equal to the length measured in frame S′. Therefore, in Galilean relativity, length is absolute.

2 **a** $v = 45 + 10 = 55\ \text{m s}^{-1}$

b $v = 45 - 10 = 35\ \text{m s}^{-1}$

3 Momentum calculation in rest frame (e.g. ground):

Momentum before collision = momentum after collision

$3000\ \text{kg} \times 30\ \text{m s}^{-1} = (3000 + 1500)\ \text{kg} \times v$

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

The speeds as measured in moving frame ($v = 10.0\ \text{m s}^{-1}$)

Before collision, lorry is moving at $20.0\ \text{m s}^{-1}$ to the right, while the car is moving at $10.0\ \text{m s}^{-1}$ to the left. After collision, the two vehicles move together at $10\ \text{m s}^{-1}$.

Momentum calculation in moving frame ($v = 10\ \text{m s}^{-1}$).

Before collision: $(3000\ \text{kg} \times 20\ \text{m s}^{-1}) + (1500\ \text{kg} \times -10\ \text{m s}^{-1}) = 45\,000\ \text{km s}^{-1}$

After collision: $(3000 + 1500)\ \text{kg} \times 10\ \text{m s}^{-1} = 45\,000\ \text{m s}^{-1}$

Momentum before collision is equal to the momentum after collision in the moving frame.

4 When $v = 0.1, c\gamma = \dfrac{1}{\sqrt{1-\dfrac{v^2}{c^2}}} = \dfrac{1}{\sqrt{1-\dfrac{(0.1c)^2}{c^2}}} = 1.005$

When $v = 0.6, c\gamma = \dfrac{1}{\sqrt{1-\dfrac{v^2}{c^2}}} = \dfrac{1}{\sqrt{1-\dfrac{(0.6c)^2}{c^2}}} = 1.25$

5 Using space-time invariance:

In frame S, where proper time is measured, $\Delta x = 0$.

$$\left(\Delta x'\right)^2 - (c\Delta t')^2 = -(c\Delta t)^2$$

$$((12-3)\times10^9)^2-((60-10)c)^2=-(c\Delta t)^2$$

$$\frac{(9\times10^9)^2}{c^2}-50^2=-(\Delta t)^2$$

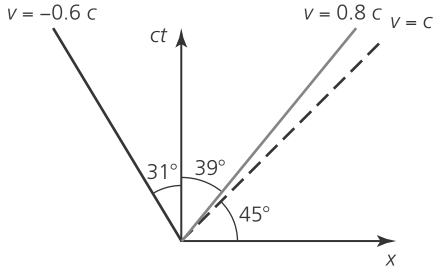
$$\Delta t=40\,\text{s}$$

6 To draw the worldlines, the angle the worldline makes with the *ct*-axis must be calculated.

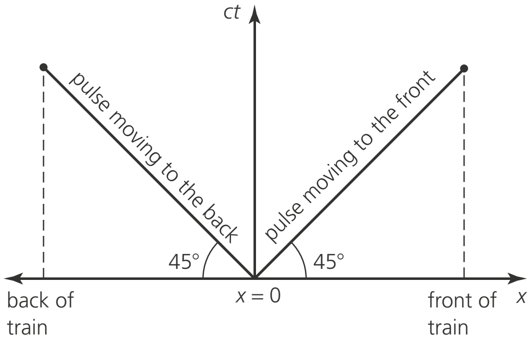
$$v=0.8c,\ \theta=\tan^{-1}\frac{0.8c}{c}=39°$$

$$v=0.6c,\ \theta=\tan^{-1}\frac{0.6c}{c}=31°$$

When the velocity is directed to the right, the angle θ is positive, and negative when velocity is leftward. The figure below shows the worldlines of the two particles.



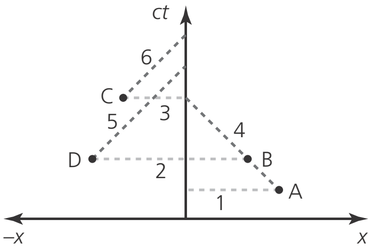
7 Since it is a light pulse, then the worldline should make an angle of 45° with the *x*-axis starting at $x=0$, as shown in the figure below.



8 The order at which they occurred can be obtained by drawing lines that are parallel to the *x*-axis from the flashes to *ct*-axis. These lines are shown as lines 1, 2 and 3 in the figure below.

Therefore, flash A occurred first, followed simultaneously by flashes B and D and then flash C.

Determine the order in which an observer in frame S located at $x=0$ would see the flashes.



Position $x=0$ is along the *ct*-axis. The order at which the light pulses will reach the observer is obtained by drawing 45° lines from the flashes to the *ct*-axis. These lines are shown as lines 4, 5 and 6 in the figure above.

Therefore, flashes A and B simultaneously reach the observer first, followed by flash D and then flash C.

9 $E^2 = p^2c^2 + m_0^2c^4$

$E^2 = (8.0\,\text{GeV}\,c^{-1})^2 \times c^2 + (6.0\,\text{GeV}\,c^{-2})^2 \times c^4$

$E^2 = 100\,\text{GeV}^2$

$E = 10\,\text{GeV}$

To determine speed, first obtain the value of γ

$E = \gamma m_o c^2 = \gamma(6.0\ \text{GeV}\,\text{c}^{-2})c^2 = 10\,\text{GeV}$

$\gamma = \frac{10}{6} = 1.67$

$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \rightarrow 1.67 = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \rightarrow v = 0.80c$

10 a $\frac{1}{2}m_0v^2 = eV$

$\frac{1}{2}(0.511\ \text{MeV}\,c^{-2})\ v^2 = 2.5\,\text{MeV}$

$v^2 = 9.78\,c$

$v = 3.1c$

Note that the speed v of the electron is more than three times the speed of light. This is not possible according to relativistic mechanics.

b $E_K = (\gamma - 1)m_0c^2$

$qV = (\gamma - 1)m_0c^2$

$2.5\ MeV = (\gamma - 1)\ (0.511\ MeV\ \ c^{-2})c^2$

$4.9 = (\gamma - 1)$

$\gamma = 5.9$

$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$

$5.9 = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$

$v = 0.83\ c$

11 a The colliding protons have both kinetic energy and rest energy. The kinetic energy of the colliding protons was converted into mass.

b Assumption: To obtain the total minimum energy, it is necessary to assume that the four particles are at rest after the reaction. They only have rest energies.

The total energy after the reaction is equal to the sum of the rest energies of the four particles.

Total energy = $4 \times 935 = 3740\,\text{MeV}$

The colliding protons have the same total energy.

Energy of each colliding proton = $\frac{3740}{2} = 1870\,\text{MeV}$

c $E^2 = p^2c^2 + m_0c^2$

$1870^2 = p^2c^2 + 938^2$

$p = 1620 \text{ MeV } c^{-1}$

12 a The total energy before collision must be equal to the total energy after collision.

Total energy before collision = Total energy of the electron + total energy of positron

Total energy before collision $= (0.511 + 1.000) + (0.511 + 0) = 2.022\,\text{MeV}$

This energy is divided equally between the two photons.

Energy of each photon $= \dfrac{2.022}{2} = 1.011\,\text{MeV}$

b i For a photon $E = pc \rightarrow p = \dfrac{E}{c} = 1.011\,\text{MeV}c^{-1}$

ii Wavelength can be obtained by using De Broglie's equation

$$\lambda = \frac{h}{p} = \frac{h}{1.011\text{ MeV}c^{-1}}$$

$$\lambda = \frac{hc}{1.011\,\text{MeV}} = \frac{(6.63\times10^{-31})(3.0\times10^{8})}{(1.011\times10^{5})(1.6\times10^{-19})} = 1.23\times10^{-8}\text{ m}$$

Option B 14 Engineering physics

Questions to check understanding

1 a $\Gamma = Fr\sin\theta = 72\times0.16\times\sin58°$

$= 9.8\,\text{Nm}$

b With $\sin\theta = 1$, $\Gamma = 120\times0.16 = 19\,\text{N m}$

2 Turning a tap or a key

3 $\Gamma = 2\times(8.3\times10^{-2})\times100\times\sin68 = 15\,\text{Nm}$

4 a $I = mr^2 = 1.2\times3.3^2 = 13\,\text{kg m}^2$

b It can be considered to be a point mass.

5 Radius

6 a $I = \dfrac{2}{5}mr^2 = \dfrac{2}{5}\times0.38\times(5.0\times10^{-2})^2 = 3.8\times10^{-4}\text{ kg m}^2$

b A calculation of density shows $\rho \approx 700\,\text{kg m}^{-3}$, which might be wood.

c Mass would increase by a factor $2^3 = 8$

$$I = \frac{2}{5}\times(0.38\times8)(10.0\times10^{-2})^2 = 1.2\times10^{-2}\text{ kg m}^2$$

7 Moment of inertia of each sphere

$mr^2 = 0.35\times[(3.1+20)\times10^{-2}]^2$

$= 1.87\times10^{-2}\,\text{kg m}^2$

Moment of inertia of rod $= \dfrac{mL^2}{12} = \dfrac{0.064\times0.40^2}{12} = 8.5\times10^{-4}\,\text{kg m}^2$

Total $I = (2\times1.87\times10^{-2}) + (8.5\times10^{-4}) = 3.8\times10^{-2}\,\text{kg m}^2$

8 a A fan just after it has been switched off

b The wheel on a bicycle moving with constant velocity

9 a $80 \times \frac{2\pi}{360} = 1.40\,\text{rad}$

b $\omega = \frac{1.40}{0.73} = 1.9\,\text{rad}\,\text{s}^{-1}$

10 a $\omega = \frac{2\pi}{T} \Rightarrow T = \frac{2\pi}{540} = (0.0116) = 0.012\,\text{s}$ to two significant figures

b $f = \frac{1}{T} = 86\,\text{Hz}$

c i $v = \omega r = 540 \times 0.022 = (11.9) = 12\,\text{m}\,\text{s}^{-1}$ to two significant figures

ii $5.9\,\text{m}\,\text{s}^{-1}$

11 a $\omega_f = \omega_i + \alpha_t = 0 + (\pi \times 3.2) = 10\,\text{rad}\,\text{s}^{-1}$

b $2.4 = 10 + \alpha 7.3$

$\alpha = -1.0\,\text{rad}\,\text{s}^{-2}$

12 a $\alpha = \frac{(w_f - w_i)}{t} = \frac{12.3 - 2.8}{8.4} = 1.1\,\text{m}\,\text{s}^{-2}(1.13)$

b $\alpha = \frac{a}{r} = \frac{1.13}{0.18} = 6.3\,\text{rad}\,\text{s}^{-2}$

13 $s = \left(\frac{u+v}{2}\right)t$

$v = u + at$

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

$v^2 = u^2 + 2as$

14 a $\theta = \left(\frac{\omega_i + \omega_f}{2}\right)t = \left(\frac{4.0 + 9.3}{2}\right)\ 3.9 = 26\,\text{rad}$

b Convert to degrees: $26 \times \frac{360°}{2\pi} = 1.5 \times 10^{3°}$

15 $\omega_f = \omega_i + \mathrm{a}\,t$

$2.3 = \omega_i + (-0.87)4.5 \Rightarrow \omega_i = 6.2\ \text{rads}^{-1}$

16 $\theta = \omega_i t + \frac{1}{2}\alpha t^2$

$= \left(\frac{400\pi}{60} \times 10\right) + \left(\frac{1}{2} \times 12 \times 10^2\right) = 8.1 \times 10^2\ \text{rad}$

17 $\omega_f^2 = \omega_i^2 + 2\alpha\theta$

$0 = 1.2^2 + 2\alpha(10\pi) \Rightarrow \alpha = -0.023\ \text{rad}\ \text{s}^{-2}$

18 $\omega_f^2 = \omega_i^2 + 2\alpha\,\theta = (8\pi)^2 + (2 \times 5.0 \times 40\pi) \Rightarrow \omega_f = 43\,\text{rads}\ \text{s}^{-1}$

19 a For the first 5 s, the object accelerated, but at a decreasing rate. Between 5 s and 12 s, it had a constant angular velocity. It then had a constant deceleration until it stopped after 20 s.

b $\alpha = \frac{(0 - 15)}{(20 - 12)} = -1.9\ \text{rad}\ \text{s}^{-2}$

c Total angle is equal to the area under the graph $\approx (5\times12)+(7\times15)+\left(\frac{1}{2}\times8\times15\right)\approx 2.3\times10^2$ rad

20 a $\Gamma = I\alpha \Rightarrow 25 = I\times20 \Rightarrow I = 1.25\ \text{kg m}^2$

b $\Gamma = I\alpha = 1.25\left(\dfrac{0-60}{8.0}\right) = -9.4\,\text{N m}$

21 $\Gamma = I\alpha \Rightarrow 10\times0.124 = \dfrac{2}{3}\times0.625\times0.124^2\times\alpha$

$\Rightarrow \alpha = 1.9\times10^2\ \text{rad s}^{-1}$

22 a $\omega = \dfrac{20\pi}{8.47} = 7.42\,\text{rad s}^{-1}$

b $L = I\omega = mr^2\omega = (20\times10^{-3})\times0.76^2\times7.42 = 8.6\times10^{-2}\,\text{kg m}^2\,\text{s}^{-1}$

23 a $I = mr^2 = 0.1\times(8.5\times10^{-2})^2 = 7.2\times10^{-4}\,\text{kg}$

b Angular momentum before = Angular momentum after

$1.38\times10^{-3}\times11.3 = \left(\left(1.38\times10^{-3}\right)+\left(7.2\times10^{-4}\right)\right)\times\omega_f$

$\omega_f = 7.4\ \text{rad s}^{-1}$

24 Area under graph $= (4.0\times1.0)+\dfrac{1}{2}(4.0\times2.0) = 8.0\,\text{kg m}^2\text{s}^{-1}$ (or Nm s)

25 $\dfrac{1}{2}mv^2+\dfrac{1}{2}I\omega^2 = \dfrac{1}{2}(60\times10^{-3})10^2+\dfrac{1}{2}(5\times10^{-5})(8\pi)^2 = 3.02\,\text{J}$

26 a 13.9 ms^{-1}

b $\omega = \dfrac{v}{r} = \dfrac{13.9}{0.22} = 63\,\text{rad s}^{-1}$

27 a $E_k = \dfrac{1}{2}mv^2+\dfrac{1}{2}I\omega^2$

$= \dfrac{1}{2}m\omega^2r^2+\dfrac{1}{2}\left(\dfrac{2}{5}mr^2\right)\omega^2 = m\omega^2r^2\left(\dfrac{1}{2}+\dfrac{2}{10}\right)$

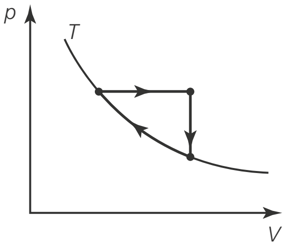
$\Rightarrow E_k = \dfrac{7}{10}m\omega^2r^2$

b $\cancel{m}gh = \dfrac{7}{10}\cancel{m}\omega^2r^2 \Rightarrow \omega = 13\,\text{rad s}^{-1}$

c $v = \omega r = 13\times0.142 = 1.8\ \text{m s}^{-1}$

28 $pV = nRT \Rightarrow (7.9\times10^4)\times(25\times10^{-6}) = n\times8.31\times265 \Rightarrow n = 9.0\times10^{-4}\,\text{mol}$

29 a, b



30 Steam engine, internal combustion (car) engine, jet (plane) engine, power station

31 Ideal gases follow the ideal gas law ($pV = nRT$) under all circumstances and cannot be liquefied. Real gases can be turned to liquids under suitable conditions, and at high pressure and density, and at low temperatures, the equation $pV = nRT$ does not accurately predict their behaviour.

32 a $U=\frac{3}{2}nRT=\frac{3}{2}\times1\times8.31\times273=3.4\times10^3$ J

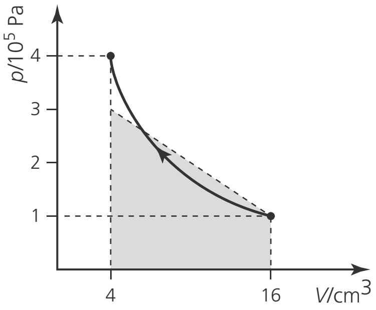
b Translational kinetic energy of molecules.

c $\Delta U=\frac{3}{2}nR\Delta T=\frac{3}{2}\times4\times8.31\times25=1.2\times10^3$ J

33 a $W=p\Delta V=pA\Delta s=(1.45\times10^5)(8.72\times10^{-4})(2.3\times10^{-2})=2.9$ J

b Molecules in the gas have less energy and move slower. This reduces pressure in the gas to less than the pressure from the surroundings.

34 a



b Area under graph $=\left[\frac{1}{2}\times(12\times10^{-6})\times(2.0\times10^5)\right]+\left[(12\times10^{-6})\times(1.0\times10^5)\right]=2.4$ J

35 a $Q=\Delta U+W\rightarrow340=\Delta U+450\rightarrow\Delta U=-110$ J

b This is a decrease in internal energy, so the gas became colder.

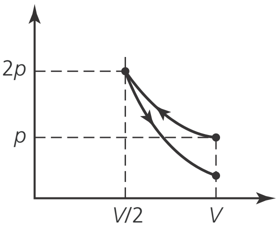
36 a $Q=\Delta U+W=280+(-620)=-340$ J

b Thermal energy was removed from the gas.

37 a Constant

b $\Delta U=0,$ so $Q=W$

c i



ii Final temperature is lower because the energy needed for expansion was taken from the internal energy of the gas.

38 a Isobaric change

b $W=p\Delta V=(1.0\times10^5)(2.2\times10^{-6})=0.22$ J

c i $Q=\Delta U+W\Rightarrow1.0=\Delta U+0.22\Rightarrow\Delta U=+0.78$ J

ii Since ΔU is positive, the gas got hotter.

39 By increasing the temperature

40 a $pV^{\frac{5}{3}}=\text{constant}\Rightarrow(3.3\times10^5)(0.174)^{\frac{5}{3}}=(1.7\times10^5)V^{\frac{5}{3}}$

$$\left(\frac{3.3\times10^5}{1.7\times10^5}\right)=\left(\frac{V}{0.174}\right)^{\frac{5}{3}}\Rightarrow\log1.94=\frac{5}{3}\times\log\left(\frac{V}{0.174}\right)\Rightarrow V=0.26\,\text{m}^3$$

b If it occurred quickly in a well-insulated container

c Decreased

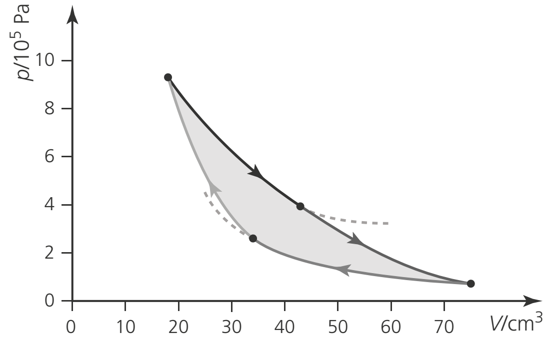
41 Since there is no transfer of thermal energy, the work done in compression raises the internal energy of the gas. If the compression is large and fast, the temperature rise can be great enough to cause ignition.

42 a i $pV = \Delta RT \Rightarrow (9.3\times10^5)(18\times10^{-6}) = 0.004\times8.31\times T \Rightarrow T = 5\times10^2$

ii $p_1V_1 = p_2V_2 \Rightarrow (9.3\times10^5)(18\times10^{-6}) = p_2(43\times10^{-6}) \Rightarrow p_2 = 3.9\times10^5\,\text{Pa}$

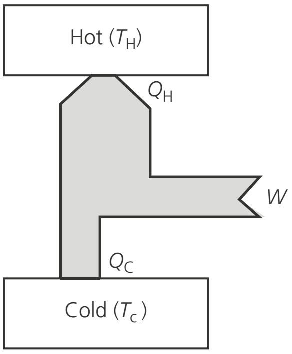
(or use $pV = nRT$ again)

b



c Shaded area ≈ 8 J

43



44 $30\% = \dfrac{\text{useful work}\times100}{\text{energy input}} \Rightarrow 0.3 = \dfrac{W}{2500\times60} \Rightarrow W = 4.5\times10^4\,\text{J}$

45 a $n = 1 - \dfrac{T_C}{T_H} = 1 - \dfrac{320}{650} = 0.51$

b $1 - \dfrac{280}{610} = 0.54$

46 Fossil-fuelled power stations use heat engines and their efficiency is limited by the laws of thermodynamics and the temperature of the surroundings. Hydroelectric power generation is much more efficient because there are no essential transfers of thermal energy.

47 The kinetic energy of the ball decreases to zero, while the same amount of energy is dissipated into the surroundings as internal energy and thermal energy. The total energy of the system is constant.

As the energy spreads out it becomes more disordered, which means that the total entropy of the system increases.

48 If an amount of thermal energy ΔQ is transferred from object A to object B (which have different, but constant temperatures), B will have its entropy increased, while A will have a decrease in entropy. The entropy version of the Second Law tells us that the increase in entropy of B must be greater than the decrease in entropy of A, so that there is an overall increase. This is only possible if $\dfrac{\Delta Q}{T_B} > \dfrac{\Delta Q}{T_A}$, which is not possible if T_B is greater than T_A.

49 a $Q = mL_f = 0.1\times3.3\times10^5 = 3.3\times10^4\,\text{J}$

b $\Delta S = \dfrac{\Delta Q}{T} = \dfrac{3.3\times10^4}{273} = (1.21\times10^2) = +1.2\times10^2\,\text{JK}^{-1}$ to two significant figures

c $\Delta S = \dfrac{\Delta Q}{T} = \dfrac{-3.3\times10^4}{303} = (-1.09\times10^2) = -1.1\times10^2\,\text{JK}^{-1}$to two significant figures

So that the overall change in entropy $= 121 + (-109) = 12\ \text{JK}^{-1}$

50 $p = \dfrac{m}{V} \Rightarrow 1.18 = \dfrac{m}{(3.2\times2.3\times4.7)} \Rightarrow m = 41\text{k}$

51 $p = \dfrac{F}{A} \Rightarrow 2.5\times10^5 = \dfrac{F}{(150\times10^{-4})} \Rightarrow F = 3.8\times10^3\ \text{N}$

52 a $p = \rho_f gd \Rightarrow 1.0\times10^5 = \rho_f \times 9.81\times12000 \Rightarrow \rho_f = 0.85\,\text{kg m}^{-3}$

b $p = \rho_f gd = 0.85\times9.81\times(12000-8848) = 2.6\times10^4\,\text{Pa}$ (actual value = $3.4\times10^4\,\text{Pa}$)

53 a $p = \rho_f gd \Rightarrow 1.0\times10^5 = 1000\times9.81\times d \Rightarrow d = 10\ \text{m}$

b The pressure of the water needs to be twice the pressure of the air.

$p = \rho_f gd \Rightarrow 2.0\times10^5 = (1.03\times10^3)\times9.81\times d \Rightarrow d = 20\ \text{m}\ (19.8\ \text{m})$

54 $p = \rho_f gd = 1.35\times10^4\times9.81\times0.087 = 1.2\times10^4\,\text{Pa}$ above atmospheric pressure

55 a i $B = \rho_f V_f g;\ B = 1.2\times(5000\times10^{-6})\times9.81 = 0.059\ \text{N}$

ii $B = 1000\times(5000\times10^{-6})\times9.81 = 49\ \text{N}$

b It will rise if the upthrust is greater than its weight. If its weight is, for example, 5N, it will fall in air but rise in water.

56 Weight $= mg = 0.420\times9.81 = 4.12\,\text{N}$

Volume $= \dfrac{m}{\rho} = \dfrac{0.420}{3.7\times10^3} = 1.14\times10^{-4}\text{m}^3$

Resultant force = weight – upthrust = $4.12 - (1000\times1.14\times10^{-4}\times9.81) = 3.0\,\text{N}$ dow

57 Your volume increases, you displace more water and experience a greater upthrust.

58 a Most woods have densities less than the density of water. They can displace a volume of water which has a weight equal to the weight of the wood, without sinking.

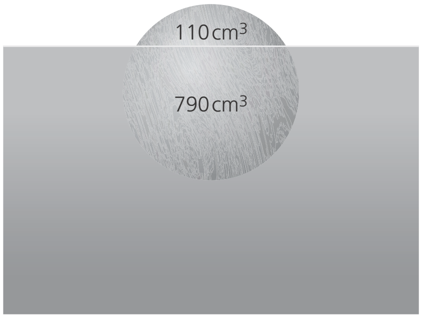
b $V = \dfrac{4}{3}\pi6.0^3 = 9.0\times10^2\,\text{cm}^3\ (= 9.0\times10^{-4}\ \text{m}^3)$

c Weight $= \rho Vg = 870\times(9.0\times10^{-4})\times9.81 = 7.7\,\text{N}$

When floating, $B = \rho_f V_f g = 7.7\text{N}$

$\Rightarrow V_f \dfrac{7.7}{1000\times9.81} = 7.9\times10^{-4}\,\text{m}^3(790\,\text{cm}^3)$

d



59 a $\dfrac{1450\times9.81}{540} = \dfrac{F_1}{3.8} \Rightarrow F_1 = 100\,\text{N}$

b $\dfrac{\text{Work done on car}}{\text{Work done by } F_1} = 0.80 \Rightarrow 100 \times s_1 = 1450 \times 9.81 \times \dfrac{1.50}{0.8} \Rightarrow s_1 = 2.70 \times 10^2 \text{m}$

60 a $Av = \pi r^2 v = \pi \times \left(\dfrac{0.17}{2}\right)^2 \times 0.23 = 5.2 \times 10^{-3} \text{m}^3\text{s}^{-1}$ (5.22)

b $Av = \text{constant} \Rightarrow 5.22 \times 10^{-3} = \pi \times \left(\dfrac{0.15}{2}\right)^2 \times v \Rightarrow v = 0.3 \text{m s}^{-1}$

61 a $Av = (24 \times 8.7) \times 0.58 = 1.2 \times 10^2 \text{m}^3\text{s}^{-1}$

b $(31 \times 7.2) \times v = 1.2 \times 10^2 \Rightarrow v = 0.54 \text{m s}^{-1}$

c No water has flowed into or out of the river between the two points.

62 a $\dfrac{1}{2}\cancel{\rho} v^2 - \cancel{\rho} gz \Rightarrow \dfrac{1}{2}v^2 = 9.81 \times 0.54 \Rightarrow v = 3.3 \text{m s}^{-1}$

b $Av = 3.0 \times 10^{-6} \times 3.3 = 9.9 \times 10^{-6} \text{m}^3\text{s}^{-1}$

c $(\pi r^2)3.3 = 20 \times 10^{-6} \Rightarrow r = 1.4 \text{mm}$

d The equation assumes steady flow of an ideal fluid. In practice, there will be some friction and turbulence, which will reduce the flow rate.

63 Units of pressure are $\dfrac{F}{A}$ or $\dfrac{ma}{A} = \dfrac{\text{kg m s}^{-2}}{\text{m}^2} = \text{kg m}^{-1}\text{s}^{-2}$.

Units of $\dfrac{1}{2}\rho v^2$ are $\dfrac{\text{kg}}{\text{m}^3}(\text{m s}^{-1})^2 = \text{kg m}^{-1}\text{s}^{-2}$

64 $\dfrac{1}{2}\rho v^2 + p = \text{constant} \Rightarrow \dfrac{1}{2}\rho v^2 = \Delta\rho$ (if v at y reduces to zero.)

$\Rightarrow \dfrac{1}{2} \times 2.4 \times v^2 = \rho_f gd = 1000 \times 9.81 \times 0.046 \Rightarrow v = 19 \text{m s}^{-1}$

65 a The pressure due to air entering the tip of the tube, p_y is greater than the pressure of air entering the side of the tube, p_x. The difference, which is recorded by the transducer, is proportional to the speed of the plane squared (for a specified density of air).

b $\dfrac{1}{2}\rho v^2 = \Delta p \Rightarrow \dfrac{1}{2} \times 0.69 \times v^2 = (0.11 \times 10^5)$

$\Rightarrow v = 180 \text{m s}^{-1}$

66 a $Av = 24 = 0.37v \Rightarrow v = 65 \text{ cm s}^{-1}$

b If A increases to 0.81 cm², $v = 30 \text{ cm s}^{-1}$

$$\frac{1}{2}\rho v_x^z + \cancel{\rho g z_x} + p_x = \frac{1}{2}\rho v_Y^2 + \cancel{\rho g z_y} + p_y$$

$$p_x - p_y = \frac{1}{2}\rho(v_y^2 - v_x^2)$$

$$= \frac{1}{2} \times 1050 \times \left(\left(65 \times 10^{-2}\right)^2 - \left(30 \times 10^{-2}\right)^2\right)$$

$$= 1.7 \times 10^2 \text{ (175) Pa}$$

c $p = \rho_f gd \Rightarrow 175 = (1.05 \times 10^3) \times 9.81 \times d \Rightarrow d = 1.7 \times 10^{-2} \text{m}$ (lower in the central tube)

67 a $Av = 6.7 \times 72 = 2.9v \Rightarrow v = 166 \text{cm s}^{-1} = 1.7 \times 10^2 \text{cm s}^{-1}$ to two significant figures

b $\left(\dfrac{1}{2}\rho v^2 + \rho gz + p\right)_x = \left(\dfrac{1}{2}\rho v^2 + \rho gz + p\right)_y$

$$p_x - p_y = \frac{1}{2}\rho(v_y^2 - v_x^2) + \rho g(z_y - z_x)$$
$$= \frac{1}{2} \times 840 \times (1.66^2 - 0.72^2) + (840 \times 9.81 \times 0.20)$$
$$= 2.6 \times 10^3 \text{ Pa}$$

68 There is a boundary layer of air which spins with the ball. The combined speeds of the air past the ball and the surface layer of air is greater on the lower surface (as shown). This reduces the pressure on that side, so that there is a resultant force as shown.

69 The flow of air over the outer convex surface of the sail is faster, this reduces the pressure on that side, so that there is a resultant force perpendicular to the sail, which has a component in the direction of the boat's motion.

70 a $F_D = 6\pi\eta rv = 6\pi \times (1.8 \times 10^{-5}) \times (5.2 \times 10^{-3}) \times 8.3$

$= 1.5 \times 10^{-5}\text{ N}$

b Flow is streamlined; sphere is smooth.

c $a = \frac{F}{m} = \frac{1.5 \times 10^{-5}}{4.8 \times 10^{-3}} = 3.1 \times 10^{-3}\text{ m s}^{-2}$

71 $6\pi\eta rv_t + \rho_f v_f g = mg$

$$(6\pi \times 0.24 \times (3.5 \times 10^{-3})v_t) + \left(880 \times \frac{4}{3}\pi(3.5 \times 10^{-3})^3 \times 9.81\right) = (2.7 \times 10^{-3}) \times 9.81$$

$\Rightarrow v_t = 1.6\text{ m s}^{-1}$

72 a $1000 = \frac{vr\rho}{\eta} = \frac{1.0 \times r \times 9.3 \times 10^2}{0.22} \Rightarrow r = 0.24\text{ m}$

b The viscosity would probably be more, so that the Reynolds number would be less under the same conditions. This means that turbulence would be less likely.

73 $R = \frac{vr\rho}{\eta} = \frac{1.0 \times 0.05 \times 1.22}{1.8 \times 10^{-5}} = 3400$

This is greater than 1000, so flow can be expected to be turbulent.

74 a i Length

ii Mass and force constant of spring

b Length and mass extending from fixed point, force constant

75 If decrease is exponential

$$\frac{5.1}{5.8} \approx \frac{4.5}{5.1} \approx \frac{A}{4.5} \Rightarrow A \approx 4.0$$

76 a Under-damped

b Increase the air resistance, for example by sticking a cardboard sheet onto it

77 Amplitude decreases to 88% each cycle, so that energy $(\propto A^2)$ decreases to 77.4% and 22.6% is dissipated.

$$Q = 2\pi\left(\frac{1}{0.226}\right) = 28$$

78 a Door closes quickly after someone passes through.

b Door would keep swinging after someone passes through.

c Door would take a long time to close.

79 a x is the extension.

k is the force constant (force/extension).

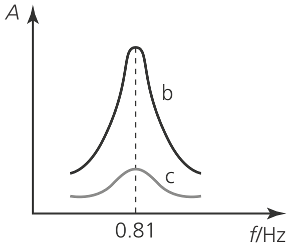
b $$\frac{\text{energy at end of oscillation}}{\text{energy at start of oscillation}} = \left(\frac{5.3}{5.7}\right)^2 = 0.86$$

Fraction of energy dissipated in oscillation $= 1 - 0.86 = 0.14$

$$Q = 2\pi\left(\frac{1}{0.14}\right) = 46$$

80 a $$f = \frac{1}{T} = \frac{1}{2\pi}\sqrt{\frac{k}{m}} = \frac{1}{2\pi}\sqrt{\frac{7.8}{0.3}} = 0.81\,\text{Hz}$$

b, c



The graph for (c) may be shifted slightly to a lower frequency.

81 $Q = 2\pi \times \text{resonant frequency} \times \dfrac{\text{energy stored}}{\text{power loss}} \Rightarrow 95 = 2\pi \times 4.6 \times \dfrac{0.740}{P} \Rightarrow P = 0.23\ \text{W}$

82 $Q = 2\pi \times 20 \times \left(\dfrac{4.5 \times 10^{-2}}{0.95}\right) = 5.9$

83 Atoms within the molecules of some gases in the Earth's atmosphere (e.g. carbon dioxide) oscillate at the same frequencies as infrared radiation travelling away from the Earth's surface. When the radiation interacts with the molecules, energy is transferred to the molecules because of resonance. It is then re-radiated away in all directions, and some returns to warm the surface to the Earth.

84 If parts of any structure can vibrate with the same natural frequency as the waves from an earthquake, energy may be transferred to them by resonance.

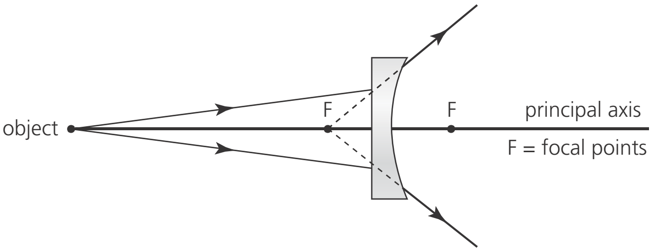
Option C 15 Imaging

Questions to check understanding

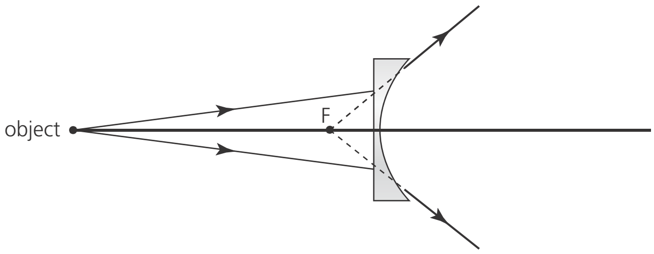
1 a Curved, but with a curvature less than that of the wavefronts that have passed through the lens.

b The image would be formed closer to the lens.

2 a



b



3 a $P = \frac{1}{f} = \frac{1}{0.25} = +4.0\,\text{D}$

b i Diverging lens

ii $P = -1.5 = \frac{1}{f} \Rightarrow f = -0.67\,\text{m} = -67\,\text{cm}$

4 a Light rays travel to the image on a screen at the camera. It is a real image. An image in a plane mirror is formed where the light rays appear to have come from, but no rays actually come from the image. It is a virtual image.

b i and ii Real: light rays actually strike light sensitive surfaces.

5

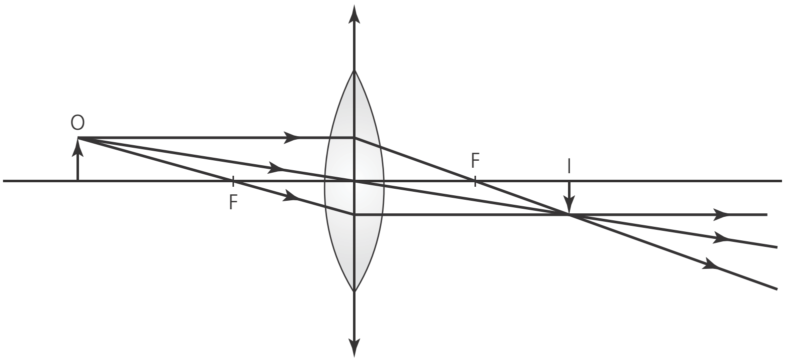
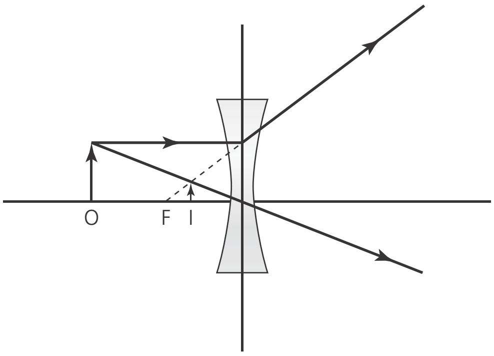


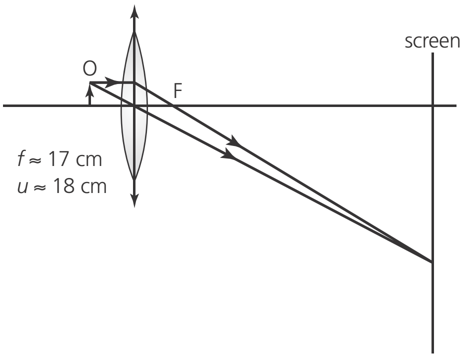
Image is real, inverted, diminished and 17 cm from the lens.

6

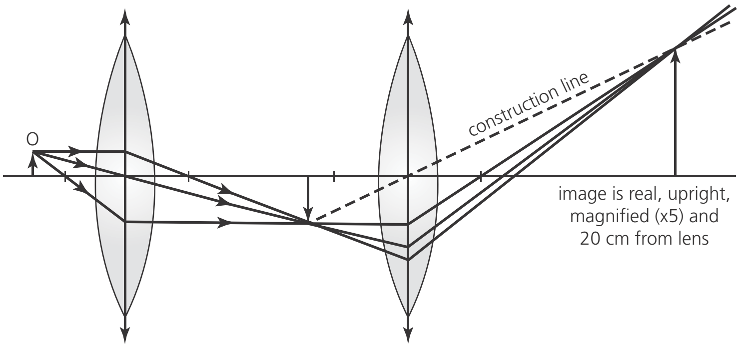


Object is 12 cm from the lens and 3 cm high.

7



8



9 a $f = \frac{1}{P} = 0.1\,\text{m} = 10\,\text{cm}$

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{10} - \frac{1}{24} = 0.058 \Rightarrow v = 17\,\text{cm}$$

Image is formed 17 cm from the lens and is real (since v is positive).

b $m = \frac{-v}{u} = \frac{-17}{24} = -0.71$

The image is diminished and inverted (since m is negative).

10 a Negative sign shows that image is inverted, so the lens must be converging.

b $m = -\frac{v}{u} \Rightarrow -2.4 = \frac{-v}{4.5} \Rightarrow v = 11\,\text{cm}$

c $\frac{1}{f} = \frac{1}{v} + \frac{1}{u} = \frac{1}{11} + \frac{1}{4.5} = 0.315 \Rightarrow f = 3.2\,\text{cm}$

11 For first lens: $\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{-16} - \frac{1}{25} \Rightarrow v = -9.8\,\text{cm}$

For second lens: $u = 9.8 + 14 = 23.8\,\text{cm}$

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{12} - \frac{1}{23.8} \Rightarrow v = 24\,\text{cm}$$

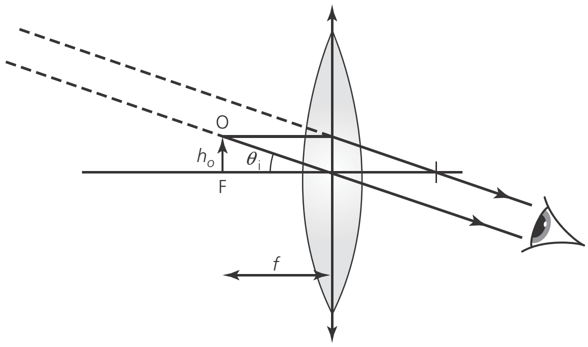
Overall magnification $= m_1 \times m_2 = \frac{9.8}{25} \times \frac{-24}{23.8} = -0.40$

12 a angle $\approx \frac{1}{25} = 0.04\,\text{rad}$ (depends on individual circumstances)

b angle subtended by Sun $= \frac{1.4 \times 10^6}{1.5 \times 10^8} = 0.0093$

$$\text{M} = \frac{0.04}{0.0093} \approx 4.3$$

13 a



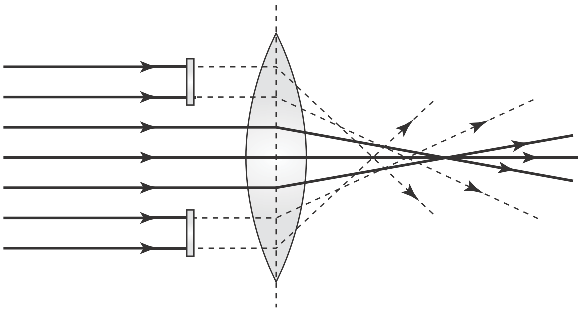
b $M_{\text{infinity}} = \dfrac{\theta_i}{\theta_o} = \dfrac{h_o/f}{h_o/D} = \dfrac{D}{f}$

14 a $\dfrac{1}{u} = \dfrac{1}{f} - \dfrac{1}{v} = \dfrac{1}{10} - \dfrac{1}{-25} = 0.14 \Rightarrow u = 7.1\,\text{cm from lens}$

b $m = \dfrac{-v}{u} = \dfrac{25}{7.1} = 3.5$

c $M_{\text{np}} = \dfrac{D}{f} + 1 = \dfrac{25}{10} + 1 = 3.5$

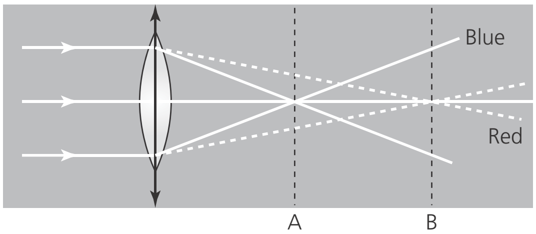
15 a



The rays which pass through the outer areas of the lens are focused in a different place to the central rays.

b Their surfaces have greater curvatures.

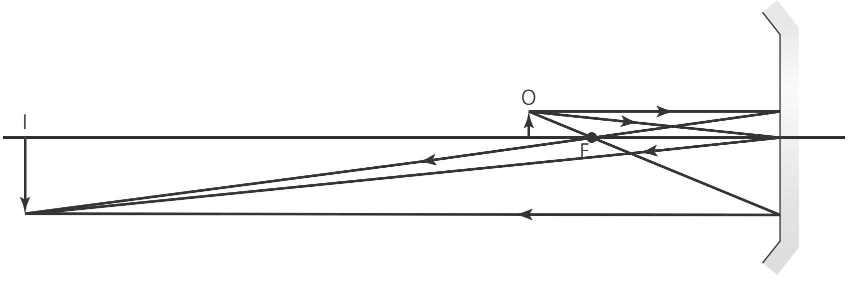
16 a



Because different colours are refracted by different amounts, if a screen is placed at A the image will have red edges. If the screen is placed at B the image will have blue edges.

b The effect is called chromatic aberration.

17 a



b Image is 48 cm from mirror, inverted, real and magnified to a height of 6.0 cm.

18 Wing mirrors on a car. Diverging mirrors give a wider field of view than a plane mirror.

19 Parabolic reflecting surfaces can direct rays to a sharper focus.

20 Move the object closer to the lens.

21 a The drawing should be similar to Figure 15.23, but drawn according to the data in the question, with the object placed just beyond the focal point of the objective.

b The drawing in (a) will not have produced a final image at the near point unless the object was placed at the right place (about 3.5 cm from the objective). Under these circumstances the linear magnification of the objective is about 6 and the angular magnification of the eyepiece is 3.1, making an overall magnification of about 20.

22 a $M_{\text{np}} = \frac{D}{f} + 1 \Rightarrow 8.25 = \frac{25}{f} + 1 \Rightarrow f = 3.4\,\text{cm}$

b image distance for objective $= \frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{1.5} - \frac{1}{1.9} \Rightarrow v = 7.1\,\text{cm}$

linear magnification of objective $= \frac{v}{u} = \frac{7.1}{1.9} = 3.75$

overall angular magnification $= 3.75 \times 8.25 = 31$

23 a Images will be brighter and have better resolution.

b Greater lens aberrations.

24 a $\frac{\text{linear separation}}{1.5} = \frac{1.22 \times (5.5 \times 10^{-7})}{1.0 \times 10^{-2}}$

(taking average wavelength of the light used to be 5.5×10^{-7} m) ⇒ separation $= 1.0 \times 10^{-4}$ cm

b Resolution will be limited by the quality of the lenses.

25 Because blue light has a smaller wavelength, the resolution should be improved, but any coloured effects and contrast will be lost, and the image will be dimmer.

26 Greater resolution because light is not randomly scattered and refracted.

Greater sensitivity because light is not absorbed.

Can operate 24h/day.

Not limited by weather conditions.

27 a Similar to Figure 15.27.

b $M = \frac{f_o}{f_e} = \frac{20}{5} = 4$

28 Advantages: greater resolution, more sensitive (receives more power from the same sources).

Disadvantages: more spherical aberration, more difficult to construct and support.

29 $M = \frac{f_o}{f_e} \Rightarrow 50 = \frac{90}{f_e} \Rightarrow f_e = 1.8\,\text{cm}$

30 Less chromatic aberration; less spherical aberration; easier to construct larger objectives, producing better resolution and brighter images

31 The scattering of light from the Sun by the atmosphere affects optical telescopes but not radio telescopes. Radio waves are also unaffected by the weather.

32 a Resolution $= \frac{1.22\lambda}{\text{b}} = 1.22 \frac{\left(\frac{3.0 \times 10^8}{1666 \times 10^6}\right)}{64} = 3.4 \times 10^{-3}$

b $\frac{1.22\lambda}{\text{b}} = \frac{1.22 \times (5.5 \times 10^{-7})}{(2.7 \times 10^{-2})} = 2.5 \times 10^{-5}\,\text{rad}$

The optical telescope's resolution is over 100 times better.

33 a $A = 27 \times \pi \times 12.5^2 = 1.3 \times 10^4\,\text{m}^2$ for 27 dishes, compared to a single dish, $A = \pi r^2 = \pi \times 65^2 = 1.3 \times 10^4\,\text{m}^2$. The two areas are similar (within 1%), so the claim seems accurate.

b Resolution $\approx 1.22 \frac{\lambda}{b} = \frac{1.22 \times 1.0}{1000} \approx 0.001\,\text{rad}$, assuming $\lambda = 1$ m, and typical separation of extreme dishes is 1 km (although the spacing of the dishes can be varied and increased).

34 $$\frac{\text{Area of FAST}}{\text{Area of Arecibo}} = \frac{\pi \times 500^2}{\pi \times 305^2} \approx 2.7$$

This suggests that FAST is about 2.7 times more sensitive.

$$\frac{\text{Resolution of FAST}}{\text{Resolution of Arecibo}} = \frac{1.22\lambda / b_F}{1.22\lambda / b_A} = \frac{b_A}{b_F} = 0.61$$

This suggests that FAST has a resolution about 1.6 × better. There are many other factors that must be considered before a full answer to this question can be given.

35 If a pulse's energy spreads over a longer time, the intensity (power/area) must decrease.

36 Sound is attenuated as it pass through, for example, a wall.

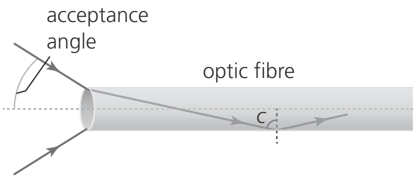
37 The changing current has a changing magnetic field around it. This passes through the second wire and a changing emf is induced by electromagnetic induction.

38 a i $$\frac{n_1}{n_2} = \frac{1}{\sin c} = \frac{1.55}{1.0} \Rightarrow \sin c = \frac{1}{1.55} = 0.645 \Rightarrow c = 40°$$

ii $$\frac{1}{\sin c} = \frac{1.55}{1.48} \Rightarrow \sin c = 0.95 \Rightarrow c = 73°$$

b The air outside the fibre is replaced with glass of a refractive index greater than air but less than the fibre. This increases the critical angle, so that all the rays which undergo repeated internal reflection are nearly travelling parallel to the axis of the fibre. This reduces the amount of waveguide dispersion.

39



40 a $$\frac{d}{I} = \frac{1.0 \times 10^{-5}}{1.5 \times 10^{-6}} \approx 7$$

b Conditions for total internal reflection are more favourable.

c A ray model involves radiation travelling only in straight lines, but when the wavelength becomes comparable to the dimensions of the fibre, diffraction will occur.

41 $$\text{For first wavelength, } v_1 = \frac{2.9979 \times 10^8}{1.5578} = 1.9244 \times 10^8\,\text{m s}^{-1}$$

$$\text{For second wavelength, } v_2 = \frac{2.9979 \times 10^8}{1.5516} = 1.9321 \times 10^8\,\text{m s}^{-1}$$

$\Rightarrow \Delta t = 2.1 \times 10^{-9}$ s

42 Approximately 1300 nm or 1500 nm

43 $$10 \log\left(\frac{I}{I_o}\right) = 10 \log\left(\frac{0.1}{1.0}\right) = -10\,\text{dB}$$

44 $$-0.5 = 10 \log\left(\frac{I}{I_o}\right) \Rightarrow \frac{I}{I_o} = 0.89$$

The output is 11% less than input.

45 a $$-1.25 = 10 \log\left(\frac{P}{20}\right) \Rightarrow P_1 = 15\,\text{mW}$$

b $$-1.25 = 10 \log\left(\frac{P}{15}\right) \Rightarrow P_2 = 11\,\text{mW}$$

c Repeated calculations will show that $P_5 = 4.7\,\text{mW}$

$$\text{Att} = 10\log\left(\frac{4.7}{20}\right) = -6.2\,\text{dB}$$

46 $\text{Att} = -1.5 = 10\log\left(\frac{I}{I_o}\right) \Rightarrow \frac{I}{I_o} = 0.71$

Intensity drops to 71% every km. After 2 km, intensity falls to 50%; after 3 km, intensity has fallen to 36%; after 4 km, 25%; and after 5 km, 18%. So, regeneration needs to occur about every 4.5 km.

47 $E = \frac{hc}{\lambda} \Rightarrow 10^4 \times 1.6 \times 10^{-19} = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{\lambda} \Rightarrow \lambda = 1.2 \times 10^{-10}\,\text{m}$

48 They are usually distinguished only by their origin: gamma rays come from unstable nuclei, while X-rays come from decelerated electrons.

49 Because bone contains elements which have higher proton numbers.

50 The mass attenuation coefficient is about ten times greater for bone.

51 $10\log\left(\frac{35}{100}\right) = -4.6\,\text{dB}$

52 a In equal distances, the same percentage of X-rays will be absorbed or scattered.

b Mass attenuation coefficient $= \frac{\mu}{\rho} \rightarrow 0.227 = \frac{\mu}{1.06} \Rightarrow \mu = 0.241\,\text{cm}^{-1}$

c Smaller wavelengths are more penetrating, so attenuation coefficients would be smaller.

53 $I = I_0\,\text{e}^{-0.52 \times 1.4}$

$$\ln\left(\frac{I}{I_0}\right) = -0.728 \rightarrow \frac{I}{I_0} = 0.48 \rightarrow I = 0.48\,\text{I}_0$$

54 a $\mu x_{\frac{1}{2}} = \ln 2 \rightarrow \mu = \frac{0.693}{1.18} = 0.587\,\text{cm}^{-1}$

b Massattenuation coefficient $= \frac{\mu}{\rho}$

$$0.534 = \frac{0.587}{\rho} \Rightarrow \rho = 1.10\,\text{g}\,\text{cm}^{-3}$$

c $0.1 = \text{e}^{-0.587x}$

$$\ln 0.1 = -0.587 \times x$$

$$x = \frac{-2.30}{0.587} = 3.92\,\text{cm}$$

55 $\mu = 1.02 \times 0.18 = 0.184\,\text{cm}^{-1}$

$$\frac{I}{I_0} = \text{e}^{-0.184 \times 0.22}$$

$$\ln\left(\frac{I}{I_0}\right) = -0.0404$$

$I = 0.96\,I_0$ Intensity reduced by 4%

56 For B: $I_B = I_0\text{e}^{-0.12 \times 17}$

$$\Rightarrow \frac{I_B}{I_o} = 0.13$$

Intensity has fallen by 87%.

For A:

In flesh, $I = I_0 \times \text{e}^{-0.12 \times 9.3}$

$$\Rightarrow \frac{I}{I_0} = 0.33$$

In bone, $I = I_0 \times e^{-0.62\times 2.4}$

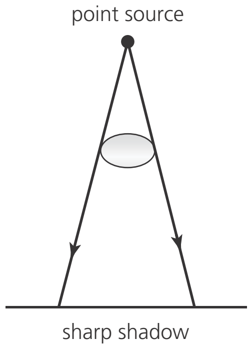
$$\frac{I}{I_0} = 0.23$$

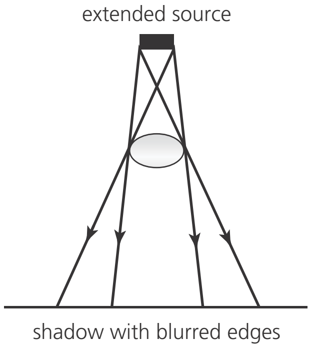
In flesh, $\frac{I}{I_0} = 0.33$ as before.

Overall $I_A = 0.33\times 0.23\times 0.33 = 0.025\, I$. Intensity has fallen by 97.5%.

57 (1) Small source; (2) large patient–source distance; (3) small patient–detector distance; (4) reduce movement of patient; (5) reduce low energy X-rays with a filter; (6) use sensors which are very close together; (7) use collimating grid; (8) use intensifying screens; (9) enhance image with software.

58





59 X-rays are waves and waves diffract, reducing resolution. However, because the wavelength of the X-rays used is much smaller than the parts of the body that they are used to examine, diffraction effects are not significant.

60 Ultrasound waves cannot pass effectively through the bone of the skull or into the air in the lungs.

61 They will refract when they change speed as they pass from one medium to another at any angle of incidence which is less than 90°.

62 $\lambda = \frac{c}{f} = \frac{340}{1.0\times 10^{6}} = 3.4\times 10^{-4}$ m in air

63 a Each pulse contains three waves

$$3T = \frac{3}{f} = \frac{3}{5\times 10^{6}} = 6\times 10^{-7}\ \text{s}$$

b Time to travel to/from organ $= \frac{2\times 0.08}{1550} = 1.03\times 10^{-4}$ s

The time between pulses must be more than this, estimate 1.2×10^{-4} s.

$$f = \frac{1}{1.2\times 10^{-4}} \approx 8\times 10^{3}\ \text{Hz}$$

64 a $Z = \rho c = 1.08\times 10^{3}\times 1600 = 1.73\times 10^{6}\ \text{kg m}^{-2}\ \text{s}^{-1}$

b $5\times 1.73\times 10^{6} \approx 2.16\times 10^{3}\times c \Rightarrow c \approx 4\times 10^{3}\ \text{m s}^{-1}$

65 a $$\frac{I_r}{I_0} = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2} = \frac{(1.66 - 1.42)^2}{(1.66 + 1.42)^2} = 6.1\times 10^{-3}$$

Percentage reflected $100\times 6.1\times 10^{-3} = 0.61\%$

b The same, 0.61%

c No change

66 a $-0.54 = 10\log\left(\frac{I}{I_0}\right) \Rightarrow I = 0.88 I_o$

Percentage scattered and absorbed = 12%

b $\text{Attenuation per cm}\left(\text{dB}\right) = 10\log\left(\frac{0.76}{1.0}\right) = -1.2\ \text{dB cm}^{-1}$

67 a Resolution is proportional to λ/b (the smaller the better). Ultrasound wavelengths are much greater than light wavelengths.

b Higher frequencies have smaller wavelengths and therefore diffract less.

68 Lower frequencies have less attenuation, so that they can penetrate deeper without losing too much intensity.

69 a $\frac{I_r}{I_0} = \left(\frac{Z_{\text{skin}} - Z_{\text{air}}}{Z_{\text{skin}} + Z_{\text{air}}}\right) \approx 1.0,$ which means that nearly all of the ultrasound is reflected at a skin/air boundary.

b Similar to the acoustic impedance of the skin and the surface of the transducer

70 a Waves are more attenuated by travelling the extra distances.

b A much greater percentage of the waves is reflected off bone than the other reflecting surfaces.

c i $Z = \rho c \Rightarrow 1.62 \times 10^6 = 1050\, c \Rightarrow c = 1.54 \times 10^3$ m

ii $c = \frac{2s}{t} \Rightarrow s = \frac{ct}{2} = \frac{1540 \times \left(2.8 \times 10^{-4}\right)}{2} = 0.22\,\text{cm}$

71 No ionizing radiation enters the body.

72 Assuming Larmor frequency is proportional to magnetic flux density and equals 4.3×10^7 Hz at 1 T (as given on page 107), $\frac{f_{2.5}}{f_{1.0}} = \frac{2.5}{1.0} \Rightarrow f_{2.5} = 1.1 \times 10^8$ Hz

73 RF waves transmitted from the coils transfer energy by resonance to hydrogen atoms in the patient; when the transmission stops the atoms 'relax' and re-emit the radiation, which can be detected by the same coils.

74 Each gradient field is an adjustable magnetic field which varies continuously in strength with position along a chosen axis of the patient. Using these fields, different planes or locations within the patient can be given a different Larmor frequency.

75 An external oscillating source of energy (RF waves) is used to transfer energy to a system (hydrogen atom) which oscillates at the same frequency.

76 RF waves can pass through the skull, but ultrasound waves cannot (most of their energy is reflected).

Option D 16 Astrophysics

Questions to check understanding

1 Because they are relatively close to the Earth, so that their apparent position (compared to the star background) changes.

2 Both are systems in equilibrium. Inward forces (gravity or tensile forces in the elastic) are balanced by gas (and radiation) pressure outwards.

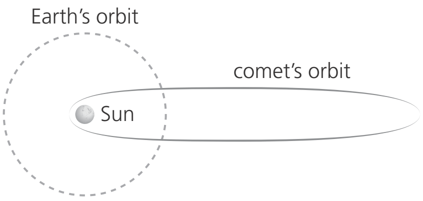
3 $\frac{3.85 \times 10^{26}}{27 \times 10^6 \times 1.6 \times 10^{-19}} \simeq 9 \times 10^{37}$ (using data from page 111)

4 Typically, stellar clusters contain a smaller number of stars, which have a common origin. Galaxies contain stars, interstellar matter, dark matter and regions where new stars are being born.

5 a i Comets are relatively small.

ii Most of the orbit of a comet is a long way from Earth.

b, c



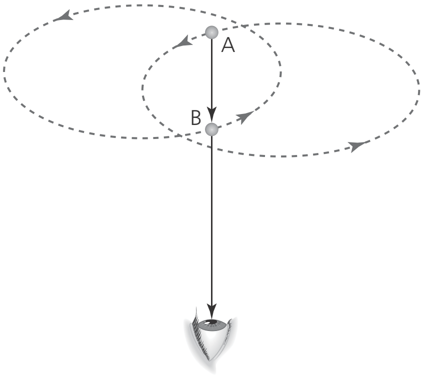
d Radiation from the Sun provides the energy needed to release gases, carrying with them some dust. The solar radiation and 'solar wind' direct the material away from the Sun.

6 There are many reasons, but most assume that life elsewhere would require similar conditions to life on Earth. Only planets may be solid, with suitable chemicals (including water), atmospheres, temperatures and gravitational field strengths. The energy flux arriving at the planet from its star also needs to be considered.

7 $$\frac{(r_p)^3}{(T_p)^2} = \frac{(r_e)^3}{(T_e)^2} \Rightarrow \left(\frac{T_p}{T_e}\right)^2 = \left(\frac{r_p}{r_e}\right)^3 = 1.25\times10^5$$

$$\Rightarrow \frac{T_p}{T_e} = \sqrt{1.25\times10^5} \quad \Rightarrow T_p = 3.5\times10^2 \text{ years}$$

8 a



Star B passes 'in front of' (eclipses) star A (or vice versa).

b The orbits and the observer need to be in the same plane.

9 a $\frac{9\times10^{26}\,\text{m}}{9.46\times10^{15}} \approx 10^{11}\,\text{ly}$

b $\frac{12\times10^{12}}{1.5\times10^{11}} \approx 80\,\text{Au}$

c $\frac{2.4\times10^{22}}{3.26\times9.46\times10^{15}} \approx 8\times10^5\,\text{pc}$

10 a $\frac{1}{0.22} = 4.5\text{ pc}$

b $\Rightarrow 4.5\times3.26\times9.46\times10^{12} = 1.4\times10^{14}\text{ km}$

11 a $\frac{11.4}{3.26} = 3.50\,\text{pc}$

b $\frac{1}{3.50} = 0.286\,\text{arcseconds}$

c Yes, because $3.50 << 100\,\text{pc}$

12 a $\frac{6\times10^{20}}{3.26\times9.46\times10^{15}} \approx 2\times10^4\text{ pc}$

This estimate assumes (incorrectly) that the Sun is near the centre of the galaxy.

b Only a small percentage of the stars in the Milky Way are within the range of 100 pc, beyond which stellar parallax is not measurable.

13 a $L = \sigma A T^4 = 5.67 \times 10^{-8} \times 4\pi \times (8.8 \times 10^{11})^2 \times 3590^4 = 9.2 \times 10^{31}\,\mathrm{W}$

b $b = \dfrac{L}{4\pi d^2} = \dfrac{9.2 \times 10^{31}}{4\pi \times (6.1 \times 10^{18})^2} = 2.0 \times 10^{-7}\,\mathrm{W m^{-2}}$

14 $L = \sigma A T^4 = \sigma 4\pi r^2 T^4 \Rightarrow 9.8 \times 10^{27} = \left(5.67 \times 10^{-8}\right) \times 4\pi \times r^2 \times 9940^4 \Rightarrow r = 1.2 \times 10^9\,\mathrm{m}$

15 Some radiation may have been absorbed or scattered between the star and Earth. This would reduce the apparent brightness, leading to an increased value for distance.

16 $b = \dfrac{L}{4\pi d^2} \Rightarrow 1360 = \dfrac{3.85 \times 10^{26}}{4\pi d^2} \Rightarrow d = 1.5 \times 10^{11}\,\mathrm{m}$

17 $b = \dfrac{L}{4\pi d^2} = \dfrac{11 \times 3.85 \times 10^{26}}{4\pi \times (17 \times 9.46 \times 10^{15})^2} = 1.3 \times 10^{-8}\,\mathrm{W}$

18 More radiation is emitted towards the longer wavelength end of the visible spectrum. The star will appear slightly red to the human eye.

19 a $\lambda_{\max} T = 2.9 \times 10^{-3} \Rightarrow \lambda_{\max} = \dfrac{2.9 \times 10^{-3}}{5500} = 5.3 \times 10^{-7}\,\mathrm{m}$

b Green

20 $\lambda_{\max} T = \dfrac{cT}{f_{\max}} = 2.9 \times 10^{-3} \quad \Rightarrow \quad \dfrac{3.0 \times 10^8 \times T}{3.0 \times 10^{14}} = 2.9 \times 10^{-3} \Rightarrow T \approx 2.9 \times 10^3\,\mathrm{K}$

21 The coolest stars emit mostly longer wavelengths of visible light, so they will appear slightly red. The hotter stars will emit mostly shorter wavelengths of visible light, so they will appear slightly blue.

22 a i A continuous spectrum contains all possible wavelengths, without any gaps. A line spectrum only contains certain specific wavelengths, which are usually displayed as lines.

ii An emission spectrum is produced by atoms moving to lower energy levels and emitting specific wavelengths, which are usually displayed as coloured lines.

An absorption spectrum appears as black lines on a continuous spectrum. Each line corresponds to a wavelength that has been absorbed, raising an atom to a higher energy level.

b The energy which was travelling towards Earth is absorbed, but then re-emitted in random directions. A small part of this energy will still reach Earth.

23 a There is a greater rate of nuclear fusion because the larger gravitational forces have resulted in greater particle speeds (temperatures) in the core.

b Higher surface temperature

24 a $\dfrac{L_x}{L_y} = 2 = \left(\dfrac{\mathrm{M}_x}{\mathrm{M}_y}\right)^{3.5} \Rightarrow \dfrac{\mathrm{M}_x}{\mathrm{M}_y} = 1.22$

b Star X

25 a $\dfrac{L_u}{L_s} = 1.48 = \left(\dfrac{\mathrm{M}_u}{\mathrm{M}_s}\right)^{3.5} \Rightarrow \dfrac{\mathrm{M}_u}{\mathrm{M}_s} = 1.12 \Rightarrow \mathrm{M}_u = 2.2 \times 10^{30}\,\mathrm{kg}$

b The star is on the main sequence.

26 a Approximately 13 000 K

b Blue/white

c Approximately 0.005 × radius of Sun

d White dwarf

27 a $\frac{L_B}{L_D} \approx \frac{3\times10^6}{8\times10^{-5}} \approx 4\times10^{10}$

b $4\times10^{10} = \left(\frac{M_B}{M_D}\right)^{3.5} \Rightarrow \frac{M_B}{M_D} \approx 1100$

28 a Bottom right of figure

b The rate of nuclear fusion is relatively low because their low masses have resulted in smaller gravitational forces, and particles which have lower speeds and lower temperatures.

29 A star of known luminosity, so that its distance from Earth can be determined from measurement of its apparent brightness. The distance calculated can be taken as representative of the whole galaxy.

30 There is an approximately linear relationship between the logarithm of the luminosity and the logarithm of the period.

31 a $L \approx 2500\times3.85\times10^{26} \approx 1\times10^{30}\,\text{W}$

b $b = \frac{L}{4\pi d^2} \Rightarrow 2.2\times10^{-6} = \frac{1\times10^{30}}{4\pi d^2} \Rightarrow d = 1.9\times10^{17}\,\text{m}$ or $d \approx 6$ pc

32 The luminosity–period relationship summarizes general behaviour of cepheids. Any particular cepheid may vary from this pattern. The equation linking *L* and *b* assumes that there is insignificant absorption of radiation in interstellar space. For distant stars this may not be true.

33 a After a long time the percentage of hydrogen in the core reduces to the point where the rate of fusion is not great enough to resist the inwards gravitational forces.

b The particles gain kinetic energy as the core collapses and this raises the temperature high enough to start further rapid fusion outside the core, causing the star to become much more luminous and expand.

34 $L_{\text{rg}} = 3000\,L_{\text{ms}}$ and $A_{\text{rg}} = 150^2\times A_{\text{ms}}$

$\cancel{\sigma} A_{\text{rg}} T_{\text{rg}}^4 = 3000\times \cancel{\sigma} A_{\text{ms}} T_{\text{ms}}^4 \Rightarrow T_{\text{rg}} = 3400\,\text{K}$

35 a After finishing their lifetime as giant stars, the smaller red giants will become white dwarfs, while the larger red supergiants will become neutron stars or black holes.

b Their lives as giant stars will end when all nuclear fusion stops.

36 a White dwarf stars are stable because electron degeneracy pressure opposes gravitational collapse, but this is only possible up to a certain mass.

b This mass is known as the Chandrasekhar limit.

37 A small star composed of tightly packed neutrons. Formed following the supernova of a small red supergiant.

38 After a supernova, the core remaining may resist collapse because of neutron degeneracy pressure. But if the mass is greater than the Oppenheimer–Volkoff limit, the degeneracy pressure is not great enough and the star will collapse to form a black hole.

39 a $(5.38+0.11)\times10^{-7} = 5.49\times10^{-7}\,\text{m}$

b $z = \frac{\Delta\lambda}{\lambda_0} = \frac{0.11}{5.38} = 0.020\ (0.0204)$

c $v = zc = 0.0204\times3.0\times10^8 = 6.2\times10^6\,\text{m s}^{-1}$

40 a $z = \frac{v}{c} = \frac{5.3\times10^6}{3.0\times10^8} = 0.018\ (0.0177)$

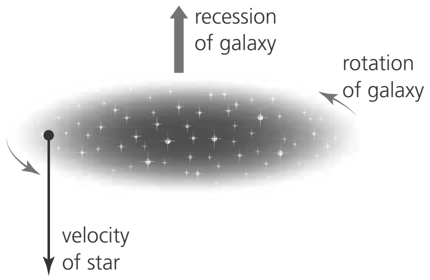
b $\frac{\Delta\lambda}{(442-\Delta\lambda)} = 0.0177 \Rightarrow \Delta\lambda = 7.7$ nm, so that the emitted wavelength was $442-7.7=434$ nm

The emitted wavelength will be smaller than the received wavelength $=442-66=376\,\text{nm}$

41 a As space expands, so too do the wavelengths of radiation. Between the time it was emitted and the time it was received, a wavelength increases. If the radiation is visible light, this means its wavelength moves towards the red end of the spectrum.

b Doppler effects detected on Earth involve relative motion between a source of waves and a receiver, not the expansion of space.

42



At this time the star, which is rotating within its galaxy, is moving more quickly towards Earth than its galaxy is receding away from Earth due to the expansion of space.

43 a The radiation from almost all galaxies is redshifted. This indicates they are moving apart from each other (the space between them is expanding).

b The radiation received from the more distant galaxies has greater redshifts. This leads to the conclusion that the recession speed of a galaxy is proportional to its distance away. Going backward in time, this suggests that galaxies must have begun moving at the same place and time.

44 $v = H_0 d \Rightarrow 6.2 \times 10^3 = 73 \times d \Rightarrow d = 84 \text{ mpc}$

45 $\dfrac{73 \times 1000}{(3.26 \times 10^6)(9.46 \times 10^{15})} = 2.4 \times 10^{-18} \text{s}^{-1}$

46 (1) The value of H_0 is not known with certainty. (2) The calculation assumes a constant rate of expansion.

47 $H_0 = \dfrac{1}{T} = \dfrac{1}{(13.8 \times 10^9) \times (3.15 \times 10^7)} \Rightarrow 2.30 \times 10^{-18} \text{s}^{-1} \left(\text{or } 70 \text{ kms}^{-1} \text{ mpc}^{-1}\right)$

48 $\lambda_{\text{max}} \; T = 2.9 \times 10^{-3} \Rightarrow \lambda_{\text{max}} = 5.8 \times 10^{-4} \text{m}$

49 It was conclusive evidence for the Big Bang theory

50 a $(7.29 - 6.87) \times 10^{-7} = 0.42 \times 10^{-7} \text{m}; \; z = \dfrac{0.42}{6.87} = 0.0611$

b $0.0611 = \dfrac{R}{R_0} - 1 \Rightarrow R_0 = 0.94$

51 a $z = \dfrac{R}{R_0} - 1 \Rightarrow \dfrac{R}{R_0} = 6.1 + 1 = 7.1$

with $R = 1$, $R_0 = 0.14$

b $0.14 \times 4.4 \times 10^{26} = 6.2 \times 10^{25} \text{m}$

52 a $z = \dfrac{v}{c} \text{and} \, v = H_0 d \Rightarrow z = \dfrac{H_0 d}{c} = \dfrac{73 \times 500}{3 \times 10^5} = 0.12$

b $0.12 = \dfrac{R}{R_0} - 1 \rightarrow R_0 = 0.89$

53 The expansion of the universe is opposed by gravitational forces. The size of these forces depends on the masses involved.

54 Astronomers are able to calculate the distances to these supernovae, and the distances were greater than predicted by the theories at the time (involving only gravitational forces).

55 a The rate of expansion of the universe is increasing.

b Gravity is an attractive force. It cannot explain an acceleration away from mass. There must be something throughout space exerting a 'negative pressure'.

56 Particles collide with a given area more frequently and with greater velocities.

57 Star formation occurs when gravitational potential energy is greater than kinetic energy. The same number of particles have less kinetic energy at lower temperatures.

58 $pV = nRT \Rightarrow \left(1.0\times10^5\right)\times1.0 = n\times8.3\times300 \Rightarrow n\approx40$

No. of molecules $\approx 40\times6\times10^{23}\approx2\times10^{25}$

59 $\frac{\mathrm{M}_1}{\mathrm{M}_2}=\sqrt{\frac{n_2}{n_1}}=\sqrt{\frac{10^9}{10^{12}}}=0.032$

60 More massive stars have greater gravitational forces, resulting in greater particle speeds. This increases the rate of fusion, which has a much greater effect on the star's lifetime than the increase in mass.

61 $\frac{T_x}{T_s}=\left(\frac{\mathrm{M}_s}{\mathrm{M}_x}\right)^{2.5}\Rightarrow T_x=3.2\times10^{12}$ years

62 a Equation as above, $M_x = 40\times$ mass of Sun

b A star which has about 40 × the mass of the Sun will have a radius of about $\sqrt[3]{40}\times$ greater than the Sun (if we assume for simplicity that they have similar densities). Many stars on the HR diagram fit this description, but calculations show that the star's luminosity is of the order of $10^5\times$ greater than the Sun's luminosity. Stars of this luminosity and radius are blue-white and have surface temperatures greater than 10000 K.

63 The fusion of hydrogen into helium

64 a $\Delta E=\Delta mc^2 \Rightarrow 3.4\times10^{26}\times3.15\times10^7=\Delta m\times(3.0\times10^8)^2$

$\Delta m = 1.2\times10^{17}\,\mathrm{kg}$

b $\text{Number of fusions to helium}=\frac{3.4\times10^{26}}{27\times10^6\times1.6\times10^{-19}}=7.9\times10^{37}$

65 a Greater gravitational forces accelerate particles to higher speeds.

b These stars do not have temperatures high enough to produce the necessary particle energy for the fusion of more massive nuclei.

66 a ${}^{16}_{8}\mathrm{O}+{}^{4}_{2}\mathrm{He}\Rightarrow{}^{20}_{10}\mathrm{Ne}+\gamma$

b The average binding energy per nucleon of neon is greater than oxygen and helium.

67 Because the average binding energy per nucleon would decrease, requiring a large energy input (rather than emission).

68 During slow neutron capture, a nucleus has time to decay before further capture occurs. In rapid neutron capture, there is time for several neutrons to be captured before decay occurs.

69 ${}^{71}_{31}\mathrm{Ga}+{}^{1}_{0}n\rightarrow{}^{72}_{31}\mathrm{Ga}\left(+\gamma\right)\rightarrow{}^{72}_{32}\mathrm{Ge}+{}^{0}_{-1}e+\overline{v}$

70 a Capture of five neutrons followed by beta negative decay.

b To increase density (flux) of neutrons.

c In supernovae

71 a The collapsed core of a red giant.

b If it can attract sufficient mass from another star (in a binary system) to take its mass over the Chandrasekhar limit.

72 Because they are all supernovae created in the same way from equal masses.

73 An explosion resulting from the extremely high temperatures that are produced when the core of a red supergiant collapses (after nuclear fusion has ended).

74 $b=\dfrac{L}{4\pi d^2}=\dfrac{10^{10}\times3.8\times10^{26}}{4\pi\left[(500\times10^{6})\times3.26\times(9.46\times10^{15})\right]^{2}}=1.3\times10^{-15}\,\mathrm{W}$

75 a $\dfrac{1\times10^{10}}{3\times10^{9}}\approx3$

b 200 days

76 a There are more stars seen in the direction towards the centre of the Milky Way.

b No, because the homogeneity is judged on a much larger scale than our galaxy.

77 a Homogeneity

b $\dfrac{\text{Scale of homogeneity}}{\text{diameter of observable universe}}=\dfrac{10^{8}}{9.2\times10^{10}}\,\mathrm{ly}\approx\dfrac{1}{1000}$

Each homogeneous part occupies about 1 × 10^{-7} % of the volume of the universe.

78 In whichever direction we look, we make the same observations (on the large scale), and these are explained by the known laws of physics. Such observations are made on galaxies enormous distances away and using radiation emitted billions of years ago.

79 If we lived in a universe with an observable 'edge', the view towards the edge would be different than towards the centre, even if it was homogeneous.

80 a No part of the universe is contracting.

b Their cosmological redshifts will be less (than for distant stars), so that the magnitude of their Doppler blueshifts minus cosmological redshifts could be greater.

81 a Centripetal force = gravitational force $\Rightarrow\dfrac{mv^2}{r}=\dfrac{\mathrm{G}\mathrm{M}m}{r^2}\Rightarrow v=\sqrt{\mathrm{G}\dfrac{\mathrm{M}}{r}}$

where M is mass within radius *r*.

Substituting $\mathrm{M}=\dfrac{4}{3}\pi r^2\rho$ leads to the equation quoted in the question.

b The density of the galaxy is not constant, but decreases significantly with large values of *r*.

82 a $z\approx\dfrac{v}{c}\Rightarrow3.8\times10^{-4}\approx\dfrac{v}{3.0\times10^{8}}\Rightarrow v\approx1.14\times10^{5}\,\mathrm{m\,s^{-1}}$ = 1.1 × 10^5 $\mathrm{ms^{-1}}$ to two significant figures

b $v=\sqrt{\dfrac{4\pi G\rho}{3}}.r\Rightarrow1.14\times10^{5}=\sqrt{\dfrac{4\times\pi\times6.67\times10^{-11}\times\rho}{3}}\times\left(510\times9.46\times10^{15}\right)$

$\Rightarrow\rho\approx2\times10^{-18}\,\mathrm{kg\,m^{-3}}$

83 a $\rho=\dfrac{m}{V}\approx\dfrac{2.2\times10^{42}}{\frac{4}{3}\pi(5\times10^{20})^{3}}\approx4\times10^{-21}\,\mathrm{kg\,m^{-3}}$

b $v=\sqrt{\dfrac{4\pi\mathrm{G}\rho}{3}}.r\approx\sqrt{4\pi\times6.67\times10^{-11}\times4\times10^{-20}}\times\left(5\times10^{19}\right)\approx3\times10^{5}\,\mathrm{m\,s^{-1}}$

84 WIMPs are undiscovered small particles. MACHOs are small stars or planets that have not been observed because they are not luminous.

85 Because the rotational speeds of stars a long way from the centre of a galaxy have values which are much greater than predicted from calculations involving the known mass of the galaxy.

86 a A flat universe will continue to expand but contains just the right amount of mass that the expansion will stop after infinite time. The density of the universe required to achieve this is called the 'critical density'.

b **i** Under this condition, the universe will continue to expand for ever. The expansion rate will reduce, but never go to zero.

ii Under this condition, the universe's expansion will reduce to zero, after which it will then contract. See Figure 16.39.

87 **a** Consider Figure 16.38. A mass *m* moving away from a universe of mass M and average density ρ_c with a speed v will eventually lose all its kinetic energy $\left(\frac{1}{2}mv^2\right)$ as it is converted to gravitational potential energy $\frac{GMm}{r}$ after infinite time.

$$\frac{1}{2}\cancel{m}v^2 = GM\frac{\cancel{m}}{r}$$

But $v = Hr$ and $M = \frac{4}{3}\pi r^3 \rho_c \Rightarrow \frac{1}{2}(Hr)^2 = G\frac{4}{3}\frac{\pi r^3}{r}\rho_c \Rightarrow \frac{1}{2}H^2 = \frac{4}{3}G\pi\rho_c$

Rearranging gives $\rho_c = \frac{3}{8}\frac{H^2}{\pi G}$

b $$\rho_c = \frac{3}{8}\times\frac{\left(73\times10^3\right)^2}{\left(10^6\times3.26\times9.46\times10^{15}\right)^2\times\pi\times6.67\times10^{-11}} = 1.0\times10^{-26}\,\text{kg}\,\text{m}^{-3}$$

Number of particles/ $\text{m}^3 = \frac{1.0\times10^{-26}}{1.7\times10^{-27}} \approx 6$

c Assume mass of particle ≈ mass of hydrogen atom ≈ mass of proton

88 It will increase in proportion.

89 The known amount of mass in the universe (including dark matter) predicts a flat universe. It cannot explain the confirmed observation that the universe is 'accelerating' (rate of expansion is increasing).

Dark energy (not matter) was introduced as a concept to provide a 'negative pressure' forcing the acceleration.

90 $T \propto \frac{1}{R}$, RT = constant

a If the universe were to keep expanding at approximately the same rate, after 14 billion years $R \rightarrow 2$ so that T will halve, reducing to about 1.4 K.

b After 7 billion years, $R \rightarrow 1.5$, so that $T \rightarrow 1.8$ K.

(To include acceleration in these calculations will result in slightly larger *R*s and lower *T*s.)

91 Different temperatures

92 $0.04\%\text{ of }2.725\,\text{K} = \frac{0.04}{100}\times2.725 = 1.1\times10^{-3}\,\text{K}$

93 This radiation was emitted a relatively short time after the Big Bang (4×10^5 years).