OXFORD IB DIPLOMA PROGRAMME

ANSWERS

2014 EDITION

PHYSICS

COURSE COMPANION

David Homer
Michael Bowen-Jones

OXFORD

Solutions for Topic 1 – Measurements and uncertainties

1. **a)** kg ms^{-2}

b) kg m^2s^{-3}

c) kg $m^{-1}s^{-2}$

d) A s

e) kg $m^2s^{-1}A^{-1}$

2. **a)** 258

b) 0.00235

c) 0.178

d) 7870

e) 2.00

3. **a)** 4.3

b) 6.4×10^{-2}

c) 2.16×10^3

d) 2.0×10^9

e) 3.8×10^2

4. **a)** 11 kV

b) 0.422 mm or 422 μm

c) 85 GW

d) 0.422 μm or 422 nm

e) 0.35 pC or 350 fC

5. **a)** 10^{-1} m (a few 10s of cm)

b) $10^{-4} - 10^{-2}$ kg (flies come in many different shapes and sizes!)

c) 10^{-19} C (1.6×10^{-19} C)

d) 10^{10} year (13.7 billion years)

e) 10^8 ms^{-1} (3.0×10^8 ms^{-1})

6. **a)** $\dfrac{2 \times 3 \times 5}{500} = \dfrac{6}{100} = 0.06$

b) between 70 and 74 mJ

7. 3.0 ± 0.4; $\pm 13.3\%$ (*or rounding up* $\pm 14\%$)

8. $\dfrac{\Delta s}{s} = \dfrac{\Delta g}{g} + 2\dfrac{\Delta t}{t} = 0.02 + (2 \times 0.03) = 0.08 = \pm 8\%$

9. $\dfrac{\Delta r}{r} = \dfrac{1}{2}\left(\dfrac{\Delta h}{h} + \dfrac{\Delta V}{V}\right) = 0.5 \times 0.02 \times 0.05 = 0.035 = \pm 4\%$

10. **a)** check line of best fit reasonable

b) A = y-intercept; B = gradient

c) use difference between steepest and shallowest gradients

11. **a)** check line of best fit reasonable

b) $\log F = n \log x + \log k$; plot $\log F$ against $\log x$ and find gradient of graph which is n

c) $p = \dfrac{8.5 \times 10^{-2}}{\pi \times 4.5 \times 10^{-6}} = 1.3 \times 10^9$ Nm^{-2}

d) $\dfrac{\Delta A}{A} = 2\dfrac{\Delta r}{r} = 2 \times \dfrac{0.1 \times 10^{-6}}{4.5 \times 10^{-6}} = 0.04 = \pm 4\%$

12. (1850 ± 50) m at angle of N (60 ± 5) °E from scale starting point

13. magnitude $= \sqrt{5^2 + 3^2} = 5.8$ N

$\tan\theta = \dfrac{5}{3}$; $\theta = 31°$ to horizontal

14. **a)** magnitude of velocity $= \sqrt{1.5^2 + 0.8^2} = 1.7$ m s^{-1}

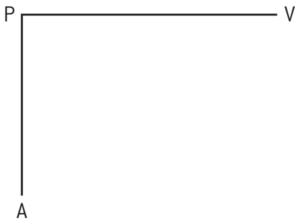
$\tan\theta = \dfrac{0.8}{1.5}$; $\theta = 28°$ with original direction

b) $s \cos 28 = 50$; displacement $s = 57$ m

15. component parallel to slope $= mg \sin\theta = 850 \times 9.8 \sin 25 = 3500$ N

Solutions for Topic 2 – Mechanics

1. a)



b) horizontal speed = 15 × cos 45 = 10.6 m s^{-1}

vertical speed = 15 × sin 45 = 10.6 m s^{-1} upwards

$v^2 = u^2 + 2as$; $v^2 = 10.6^2 + 2 \times 9.8 \times 25 = 112 + 490 = 602$

$v = \pm$ 24.5 m s^{-1} (positive value is correct one to use)

so speed is $\sqrt{10.6^2 + 24.5^2}$

= 27 m s^{-1}

2. a) (i) $h = \frac{v^2}{2g} = 3.2$ m

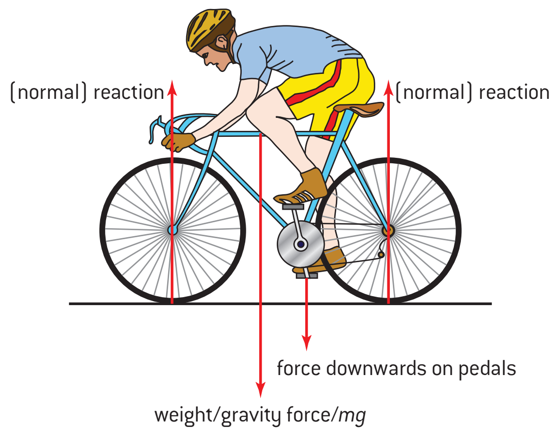
(ii) $t = \frac{u}{g} = 0.80$ s

b) time to go from top of cliff to the sea = 3.0 – 1.6 = 1.4 s
$s = 8.0 \times 1.4 + 5.0 \times (1.4)^2 = 21$ m;

3. travels vertically 1.25 m in 0.5 s;
$g = \frac{2s}{t^2}$
to give $g = 10\ (\pm 1)$ m s^{-2}

4. a) (i) Zero

(ii)



(iii) The drag force is equal to the forward force; the net force is zero and therefore the acceleration is zero.

b) (i) acceleration = $\frac{\text{resistive force}}{\text{mass}} = \frac{40}{70} = 0.57$ m s^{-2}

(ii) $v^2 = u^2 + 2as$; $0 = 64 - (2 \times 0.57 \times s)$; $s = 56$ m

(iii) air resistance ***or*** bearing friction ***or*** effectiveness of brakes depends on speed; air resistance reduced as speed drops, estimate will be too low, stopping distance will be further

5. The net force on the car is 0.3 × 1000 = 300 N. There is an additional drag force of 500 N.
$T = 300 + 500 = 800$ N.

6. $T_1 \sin 60 = T_2 \sin 30$

$T_1 \cos 60 + T_2 \cos 30 = 3800$

$T_1 = 1900$ N; $T_2 = 3300$ N

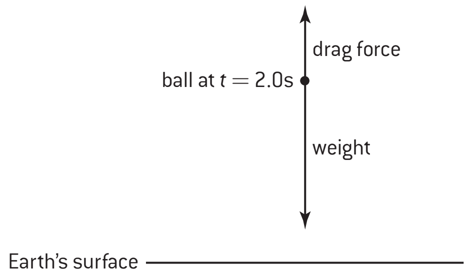
7. a) power is 0.66 kW (read off from graph)

b) power = frictional force × speed

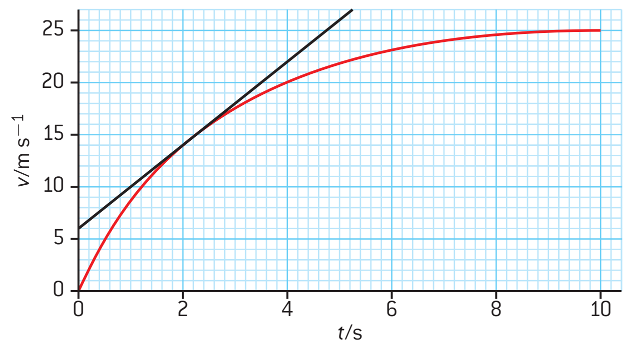
force $= \frac{660}{2} = 330$ N

8. a) use the area under the graph as this is $v \times t$

b) (i)



(ii)



the acceleration of the ball is equal to the gradient of the graph gradient $= \frac{25-6}{4.8-0}$

$= 4.0$ m s^{-2}

(iii) The net force on the ball is 2 N, the weight is 4.9 N, so the difference between these is the magnitude of the drag force = 2.9 N.

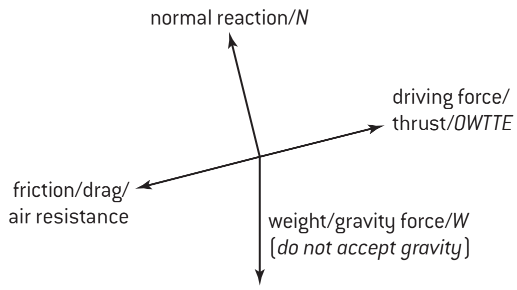
(iv) At 5.0 s the gradient is smaller and therefore the acceleration is less than at 2.0 s. The weight is constant and therefore the drag force is greater.

c) gain in kinetic energy $= \frac{1}{2} \times 0.5 \times 25^2 = 156$ J

loss in gravitational potential energy $= 0.5 \times 9.8 \times 190 = 931$ J

change (loss) in energy $= 931 - 156 = 775$ J

9. a) (i)



(ii) zero

b) input power $= \frac{\text{output power}}{\text{efficiency}} = \frac{70}{0.35}$

$= 200$ kW

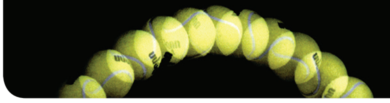
c) height gained in 1 s $= 6.2 \sin(6) = 0.648$ (m)

rate of change of PE $= 8.5 \times 10^3 \times 9.81 \times 0.648$

$= 5.4 \times 10^4$ W

d) $F = \left(\frac{p}{v}\right) = \frac{1.6 \times 10^4}{6.2}$

$= 2.6$ kN



10. a) (i) momentum before = $800 \times 5 = 4\ 000$ N s

momentum after = $2\ 000v$

conservation of momentum gives $v = 2.0$ m s^{-1}

(ii) KE before = $400 \times 25 = 10\ 000$ J   KE after = $1\ 000 \times 4 = 4\ 000$ J
loss in KE = 6 000 J;

b) transformed / changed into heat (internal energy) and sound

11. a) momentum of object = $2 \times 10^3 \times 6.0$

momentum after collision = $2.4 \times 10^3 \times v$

use conservation of momentum, $2 \times 10^3 \times 6.0 = 2.4 \times 10^3 \times v$

$v = 5.0$ m s^{-1}

b) KE of object and bar + change in PE = $0.5 \times 2.4 \times 10^3 \times 25 + 2.4 \times 10^3 \times 10 \times 0.75$
use $\Delta E = Fd$, $4.8 \times 10^4 = F \times 0.75$
$F = 64$ kN

12. a) time = $\dfrac{81}{2.2 \times 10^{-25} \times 77 \times 10^{18}} = 4.8 \times 10^7$ s

b) rate of change of momentum of the xenon atoms

$= 77 \times 10^{18} \times 2.2 \times 10^{-25} \times 3.0 \times 10^4$

$= 0.51$ N

= mass × acceleration

where mass = (540 + 81) kg

acceleration of spaceship = $\dfrac{0.51}{621}$

$= 8.2 \times 10^{-4}$ m s^{-2}

c) $a = \dfrac{F}{m}$

since m is decreasing with time, then a will be increasing with time

d) change in speed = area under graph

$= (8.0 \times 4.8) \times 10^2 + \frac{1}{2}(4.8 \times 1.4) \times 10^2$

final speed = $(8.0 \times 4.8) \times 10^2 + \frac{1}{2}(4.8 \times 1.4) \times 10^2 + 1.2 \times 10^3\ 5.4 \times 10^3$ m s^{-1}

13. a) centripetal force = $\dfrac{(350 \times 2.6^2)}{5.8} = 410$ N

tension = $410 + (350 \times 9.8) = 3800$ N

b) idea of use of area under graph

distance = $\frac{1}{2} \times 0.15 \times 2.6$

$= 0.195$ m

c) idea of momentum as mv

total change $(= 2.6 \times 350) = 910$ N s

Solutions for Topic 3 – Thermal physics

1. **a)** specific heat capacity depends on mass of object; objects of the same specific heat capacity will require more energy to heat a larger mass to the same temperature

b) area of contact will only affect the rate of transfer, not the direction

c) higher specific heat capacity means heat is transferred more readily

d) energy will be transferred from the object with the higher temperature to that of lower temperature

2. If the objects are at the same temperature, there is no transfer of energy between them, so their internal energy must be the same.

3. **a)** internal energy is the sum of the potential energy of the particles (arising from intermolecular forces) and the random kinetic energy of the particles

b) $c = \frac{Q}{m\Delta T} = \frac{1.2 \times 10^3}{0.25 \times 20} = 240 \text{ J kg}^{-1} \text{ K}^{-1}$

4. $Q = 3.0 \times (120 - 20) \times 490 = 1.47 \times 10^5 \text{ J}$

5. $\Delta T = 8K$; $Q = (0.07 \times 8 \times 4200) + (0.08 \times 8 \times 390) = 2.6 \text{ kJ}$

6. rate of flow of air $= \frac{7 \times 10^3}{1.01 \times 10^3 \times 30} = 0.23 \text{ kg s}^{-1}$

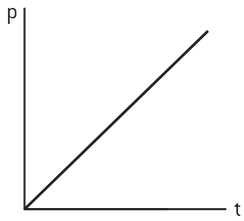
7. **a)** $Q = mL = 2 \times 3.34 \times 10^5 = 6.7 \times 10^5 \text{ J}$

b) $Q = mL = 2 \times 2.26 \times 10^6 = 4.5 \times 10^6 \text{ J}$

c) Freezing requires bonds to be formed; boiling requires breaking of intermolecular bonds which requires more energy

8. 20 g of neon = 1 mole; 8 g of helium = 2 moles; ratio of Ne to He $= \frac{1}{2}$

9.



10. high temperature and low pressure

11. **a)** **(i)** Ideal gases ignore intermolecular forces between molecules in between collisions. In real gases, there is a short-range repulsive force and a long-range attractive force between molecules.

(ii) potential energy is ignored as it is assumed there are no intermolecular forces between molecules

b) p, n and R all constant

using ideal gas law and converting temperature to Kelvin,

$V_2 = \frac{T_2}{T_2} \times V_1 = 873 \text{ cm}^3$

$\Delta V = V_2 - V_1 = 3 \text{ cm}^3$

12. **a)** **(i)** $p \propto V^{-1}$

(ii) $V \propto T$

b) **(i)** $\frac{p_1}{T_1} = \frac{p_2}{T'}$

(ii) $\frac{V_1}{T'} = \frac{V_2}{T_2}$

c) $T' = \frac{p_2}{p_1} T_1 = \frac{V_1}{V_2} T_2$ constant K

so pV = KT

13. a) $V_2 = \frac{263 \times 1.01 \times 10^5 \times 0.25}{303 \times 0.65 \times 10^5} = 0.34\ m^3$

b) no gas molecules enter or leave the balloon; helium behaves as an ideal gas (intermolecular forces are negligible)

c) number of moles $n = \frac{1.01 \times 10^5 \times 0.25}{303 \times 8.31} = 10.0$ mol

Solutions for Topic 4 – Oscillations and waves

1. a) (i) point at minima of curve (acceleration maximum when displacement is minimum)

(ii) either point of intercept with time axis (maximum speed at zero displacement)

b) weight of the bob is opposed by the component of tension along the vertical axis i.e. $T \sin\theta = mg$

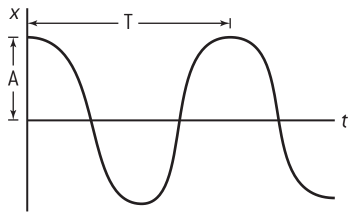
2. a) displacement graph shifted by $-\dfrac{\pi}{2}$

b) velocity graph is the gradient of the displacement graph; velocity is maximum when displacement is zero

3. a) magnitude of acceleration is proportional to the displacement from a fixed point; direction of acceleration is towards that fixed point

b) (i) $A = 0.5 \times d$

(ii) and **(iii)**



4. a) a wave in which the positions of maximum and minimum amplitude travel through the medium

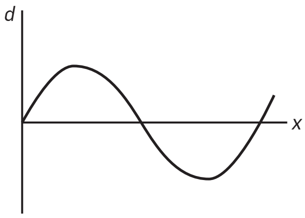
b) 4.0 mm; 2.4 cm; 3.3 Hz; 7.9 cm s^{-1}

5. a) transverse: direction of energy transfer perpendicular to direction of travel
longitudinal: direction of energy transfer parallel to direction of travel

b) frequency = (time for one period)$^{-1}$ = $(0.135)^{-1}$ = 7.4 Hz;
amplitude = maximum displacement = 8 mm

c) $c = f\lambda$; $\lambda = \dfrac{0.15}{7.4} = 0.020$ m = 2.0 cm

d)



6. a) (i) ray: line showing direction in which wave transfers energy;

(ii) wave speed is the distance wave has travelled per unit time; wave energy is the sum of the kinetic energy (maximum when speed is maximum) and potential energy (maximum when speed is zero)

b) (i) $f = \dfrac{1}{6 \times 10^{-3}} = 167$ Hz

(ii) at t = 1.0 ms, x_A = 1.7 mm, x_B = 0.7 mm, so total displacement = 1.7 + 0.7 = 2.4 mm

at t = 8.0 ms; x_A = 1.7 mm; x_B = – 0.7 mm, so total displacement = 1.7 – 0.7 = 1.0 mm

7. a) transverse: direction of energy transfer perpendicular to direction of travel

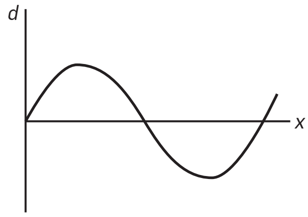
b) (i) frequency is 1 ÷ time period (time between successive crests) = 1 ÷ 0.13 = 7.7 Hz

(ii) amplitude is maximum displacement = 8 mm

longitudinal: direction of energy transfer parallel to direction of travel

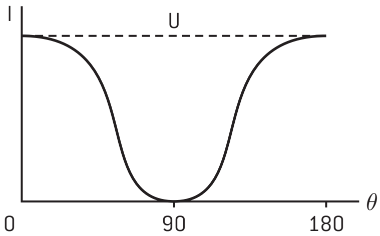
c) $c = f\lambda$; $\lambda = \dfrac{0.12}{7.7} = 0.016$ m = 1.6 cm

d)



e) $\theta = \sin^{-1}\frac{12}{18} = 42°$

8. a) & b)



9. C; sound waves are diffracted around the headland

10. a) (i) amplitude is maximum displacement = 1.0 mm

(ii) wavelength is distance between successive crests = 6mm

(iii) T = 0.027 s so $f = \frac{1}{0.027} = 37$ Hz

(iv) $c = f\lambda = 37 \times 0.006 = 0.22$ m s^{-1}

b) (i) wavefront is a surface that travels with a wave; ray is a line showing direction in which wave transfers energy; rays and wavefronts are perpendicular to each other

(ii) $1.4 \sin\theta = \sin 60$; $\theta = 38°$

(iii) lines bent towards normal in shallower water

c) (i) lines of minimum disturbance caused by destructive interference between two sets of waves; crest of one wave coincides with trough of another

(ii) positions of minimum disturbance will move closer together as separation of waves decreases

11. a) standing wave has points at which displacement is always zero (nodes); there is no energy transferred by standing wave

b) (i) sound wave is reflected at boundary, producing two waves of equal amplitude in opposite directions

(ii) at boundary between water and air

(iii) displacement increased so it is more than half a wavelength; moved past the first harmonic

c) $\lambda = 2 \times 0.368 = 0.736$ m; $c = f\lambda = 440 \times 0.736 = 324$ m s^{-1}

12. a) standing wave has points at which displacement is always zero (nodes); no energy transferred by wave; maximum amplitude at harmonics

b) (i) P at open end of pipe

(ii) $l = \frac{\lambda}{4} = \frac{330}{4 \times 16} = 5.2$ m

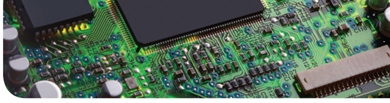
c) 1st harmonic at high frequency; to get lower sounds, need a closed pipe

13. a) maxima/minima caused by waves interfering constructively/destructively

b) (i) 9 maxima so order = 4; $\lambda = \frac{130}{4.5} = 29$ mm

(ii) $f = \frac{c}{\lambda} = \frac{3 \times 10^8}{0.029} = 10$ GHz

c) Place two polarising filters in path of microwaves between transmitter and receiver. Rotate one filter 360, should see intensity at transmitter rise to maximum and fall to zero twice in the course of one rotation.



Solutions for Topic 5 – Electricity and magnetism

1. a) (i) substitute for $r = a\sqrt{2}$

into $E = \frac{kQ}{r^2}$ to get

$$E = \frac{kQ}{2a^2}$$

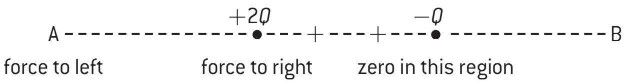
(ii) arrow pointing downwards

(iii) E for each component $= \frac{kQ}{a^2}$

add vectorially

to get $E_{tot} = \sqrt{2}\,\frac{kQ}{a^2}$

2.



3. a) the charges equalize when the spheres are touched together. So total charge becomes + 4.0 nC.

This is shared on separation so +2.0 nC on each.

b) The original force $F = \frac{6.0\text{ nC} \times -2.0\text{ nC}}{r^2} = -\frac{12\ nC}{r^2}$

after touching, force is $\frac{2.0\text{ nC} \times 2.0\text{ nC}}{r^2} = -\frac{F}{3}$

The force becomes repulsive and drops to one-third of the original magnitude.

4. The charges double, so E goes up by four times.
The weight of the top sphere remains constant, but the electrostatic force on this sphere goes up four times too.
Therefore the distance between the spheres must double to reduce E by four times so that the overall electrostatic force must remain the same.

5. a) (i) *at A*: constant;
at B: decreasing

(ii) field line gives the direction of the force (on mass or charge)
if lines touched (or crossed), particle would move in two directions at the same time and this is impossible

b) pattern is the same in all four quadrants *ie* symmetry; correct pattern in one quadrant; field directions correct

6. a) (i) power = p.d. × current = 12 × 0.5 = 6.0 W

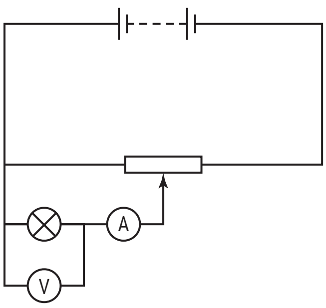
(ii) $V = I \times R$ to give $R = \frac{12}{0.5} = 24\Omega$

b) correct positioning of ammeter in series with lamp
correct positioning of voltmeter in parallel with lamp

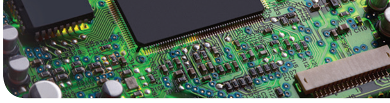
c) (i) there must be some resistance in the circuit some p.d. is used up so less than 12 V is available

(ii) low voltage requires low current and thus large resistance max resistance of variable resistor is not infinite

d) (i)



(ii) 12 V is shared by the two halves of the resistor if the left-hand half has zero resistance, then the p.d. will be zero



7. a) (i) Ohm's law states that V proportional to I provided physical conditions constant temperature is not constant as current varies

(ii) lamp B must have greater power dissipation since it has a greater current for the same p.d.

b) (i) current lamp A equals the current in lamp B

(ii) answer between 0.3 A and 0.5 A each lamp does not have the same pd find the current from the graph when the individual p.d.s *sum* to 12 V 0.4 A (±0.1)

(iii) lamp A will have greater power dissipation since current the same, but it takes greater share of pd

8. a) from the value of $\frac{V}{I}$ at any point on the curve

b) (i) 50 Ω

(ii) recognize that the voltage must divide in the ratio 3 : 1 150 Ω

9. a) (i) 4.0 A

(ii) use of $R = \frac{V}{I}$ (**not** gradient of graph)
resistance = 1.5 Ω

b) (i) straight-line through origin, quadrants 1 or 3 or both passes through $V = 4.0$ V, $I = 2.0$ A

(ii) p.d.s across X and across R will be 3.7 V (±0.1 V) and 6.0 V

total p.d. = 9.7 V

10. a) (i) resistance = 15 Ω

(ii) power = 0.6 W

b) (i) resistance of circuit too high identification of high resistance component/other appropriate and relevant comment

(ii) voltmeter reads 3 V because most of the pd is across the voltmeter

11. a) there are no positions the lamp is effectively in series with 100 kΩ no matter what the position of S this means that the pd across it will always be close to zero

b) $I = \frac{V}{R} = \frac{12}{15} = 0.80$ A

12. a) (i) $I = 0.40$ A
$R = \frac{V}{I} = \frac{10}{0.4} = 25$ Ω

(ii) the rate of increase of I decreases with increasing V because the conductor is heating up as the current increases and resistance increases with increasing temperature

b) (i) resistance of Y at 0.20 A = 12.5 Ω

(ii) total series resistance = 12.5 + 25 = 37.5 Ω

total p.d. across resistance = 0.2 × 37.5 = 7.5 V = e.m.f.

13. a) e.m.f. $= \frac{\text{energy}}{\text{charge}} = \frac{(8.1 \times 10^3)}{(5.8 \times 10^3)}$
$= 1.4$ V

b) p.d. across internal resistance = 0.2 V
resistance $r = \left(\frac{0.2}{1.2}\right) \times 6.0$
$= 1.0$ Ω

c) energy transfer $= \frac{6}{7} \times 8.1 \times 10^3$ 6.900 J

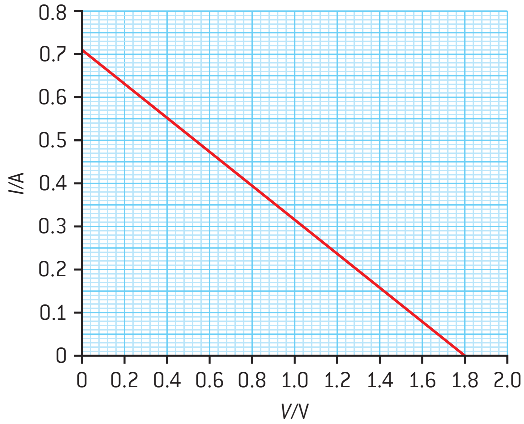
d) charge carriers have kinetic energy
these carriers collide with the lattice ions
causing increased amplitude of vibrations
this increase is seen as a temperature rise
which is a transfer to thermal energy

14. 1500 J of energy is used in the battery and 2500 J in the external circuit making 4000 J in total.

2000 C of charge moved through the circuit.

So the emf $= \frac{4000}{2000} = 2.0$ V

15. The I–V graph for the data is



emf = 1.8 V (x-intercept)

$r = 2.5\ \Omega$ (from $\frac{1}{\text{gradient}}$)

16. a) When the switch is closed energy must be used to drive charge through the internal resistance of the battery. The energy disappears as *lost* p.d. in the cell so terminal p.d. drops.

b) (i) 12 V

(ii) $I = \frac{11.6}{25} = 0.464$ A

$12 = 11.6 + 0.464\, r$

$r = 0.86\ \Omega$

c) 0.4 V is dropped across the battery and the current in it is 0.464 A.
The power dissipated is P = IV = 0.464 × 0.4 = 0.19 W

17. $F = q\, v\, B = q\, E$

$v = \frac{E}{B} = 1.5 \times 107\ \text{m s}^{-1}$

18. The question provides the force per unit length, not the total force, therefore

$F \times l = B \times I \times l \times \sin\theta$

Re-arranging the expression $\text{B} = \frac{F}{(\text{I} \sin\theta)}$

19. $F = BIl = 0.058 \times 35 \times 0.75 = 1.5$ N

20. The appropriate equation is $F = B\, Q\, v \sin\theta$, $\theta = 90°$ so $\sin\theta = 1$

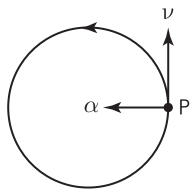
$\text{F} = 4.6 \times 10^{-4} \times 3.2 \times 10^{-19} \times 4800 = 7.1 \times 10^{-19}$ N

Acceleration $= \frac{(7.1 \times 10^{-19})}{(2.7 \times 10^{-26})} = 2.6 \times 10^{7}\ \text{m s}^{-2}$

The acceleration is directed towards the east.

Solutions for Topic 6 – Circular motion and gravitation

1.



2. friction between the tyres and the road.

3. $F = \frac{mv^2}{r}$.

4. **a)** **(i)** The drops are increasingly far apart and so the speed is increasing.

(ii) 5.6 s is 6 time intervals so the distance travelled is 14.4 cm on the scale, or 57.6 m on the ground.

b) **(i)** centripetal force; acting towards the centre of the circle

(ii) Passengers are in a rotating frame of reference. Seen from above the passengers would move in a straight line from Newton's First Law of motion but friction acts at seat to provide centripetal force to centre of circle. Passenger interprets the reaction to this force as being flung outwards.

5. **a)** Circumference is $2\pi \times 85 = 534$ m. So linear speed is $\frac{534}{30 \times 60} = 0.297$ m s^{-1}.

b) **(i)** change in weight $= m\frac{v^2}{r}$ so fractional change $= \frac{m\frac{v^2}{r}}{mg} = \frac{v^2}{gr} = \frac{0.59^2}{9.8 \times 170} = 2.1 \times 10^{-4}$

(ii) a smaller apparent weight as in passenger frame of reference there is an apparent additional upward force

c) Capsule turns 2π rad in 30 minutes, so 3.5 mrad s^{-1}.

6. Angular speed of Earth $= \frac{2\pi}{24 \times 60 \times 60} = 7.3 \times 10^{-5}$ rad s^{-1}

Linear speed $v = \omega r \cos\theta$ where θ is the latitude.

a) 14′ of arc = 4.1 mrad, linear speed $= 7.3 \times 10^{-5} \times 6.4 \times 10^{6} \times 1 = 470$ m s^{-1}

b) 46° gives 320 m s^{-1}

c) At the geographical south pole the linear speed is zero.

7. **a)** Maximum friction force $= 6500 \times 9.8 \times 0.7 = 44.6$ kN

Centripetal force required $= m\frac{v^2}{r} = \frac{6500}{150}v^2$. So $v_{max} = \sqrt{\frac{44600 \times 150}{6500}} = 32$ m s^{-1}

b) $m\frac{v^2}{r} < mg$; $v > \sqrt{rg}$. Maximum speed $= \sqrt{75 \times 9.8} = 27$ m s^{-1}

8. The component of the normal reaction force acting horizontally contributes to the centripetal force so the faster the cyclist is travelling, the greater the component required and this is achieved by moving up the slope to a point where the slope angle is greater.

9. Gravitational force on planet provides the centripetal force on the planet (Keplar's third law)

so $m_p\,\omega^2 R = G\frac{m_S\,m_p}{R^2}$

re-arranging $\omega^2 = G\frac{m_S}{R^3}$

$\omega = 2\pi f = \frac{2\pi}{T}$

and $T^2 = \frac{4\pi^2 R^3}{Gm_s}$

10. a) Speed is a scalar but velocity is a vector. The direction of the velocity is constantly changing, so the vector velocity is changing too. Acceleration occurs when velocity changes and so there is acceleration in this case.

b) Work done = distance travelled × force in direction of distance travelled. The force (acceleration) acting and the distance travelled are at 90° to each other so in this case no work is done. ***OR***
Work is done when kinetic energy or potential energy change. The speed is constant so kinetic energy is constant. Distance from Earth is constant so gravitational potential energy does not change. So no work is done.

11. $g = \frac{Gm}{r^2}$

$$\frac{Gm_E}{r_E^{\ 2}} = \frac{Gm_M}{r_M^{\ 2}}$$

Where r_E and r_M are the distances from the centres of Earth and Moon respectively to the point where the field strengths are equal (known as the Lagrangian point).

So $\frac{r_E^{\ 2}}{r_M^{\ 2}} = \frac{m_E}{m_M} = \frac{6 \times 10^{24}}{7.3 \times 10^{22}} = 82$

$\frac{r_E}{r_M} = \sqrt{82} = 9.06$

Therefore the point is $\frac{9}{10}$th of the way from the Earth to the Moon (3.42×10^8 m).

12. a) (i) force on 1 kg of water $= \frac{G\,m_M}{r^2} = 3.4 \times 10^{-5}$ N due to Moon

(ii) force on 1 kg of water $= \frac{G\,m_S}{r^2} = 6.0 \times 10^{-3}$ N due to Sun

b) When the Moon is overhead there is a gravitational force of attraction (a tide) on objects. So fluids are able to respond to this by an increase in the water level (tides are also observed in the rocks). There are two tides because there is a corresponding bulge in the surface on the opposite side of the Earth.

13. a) $g = -\frac{GM}{r^2} = \frac{6.7 \times 10^{-11} \times 6 \times 10^{24}}{(7.4 \times 10^6)^2} = 7.3 \text{ N kg}^{-1}$

b) The satellite orbits in 24 hours; orbital time = 86400 s. Angular speed $= \frac{2\pi}{86400} =$ 7.3×10^{-5} rad s^{-1}

c) $\frac{mv^2}{r} = \frac{GM_E\,m}{r^2} = \frac{6.7 \times 10^{-11} \times 6 \times 10^{24} \times 1.8 \times 10^3}{(3.6 \times 10^7)^2} = 560$ N

Solutions for Topic 7 – Atomic, nuclear, and particle physics

1. a) use collimator and pass through diffraction grating to disperse light

b) $E = hf = \frac{hc}{\lambda} = 4.09 \times 10^{-19}$ J

c) **(i)** need line at -1.35×10^{-19} J to give correct wavelength transitions

(ii) arrow from -1.35×10^{-19} J to -2.41×10^{-19} J: 1880 nm transition
arrow from -1.35×10^{-19} J to -5.44×10^{-19} J: 486 nm transition

2. a) $E = hf = \frac{hc}{\lambda} = 3.03 \times 10^{-19}$ J $= 1.9$ eV

b) **(i)** line from -1.5 to -3.4 eV level

(ii) $\Delta\lambda = 486$ nm so $\Delta E = 2.6$ eV so line from -0.85 to -3.4 eV level

3. a) Isotopes are nuclides of the same element with the same number of protons but different numbers of neutrons

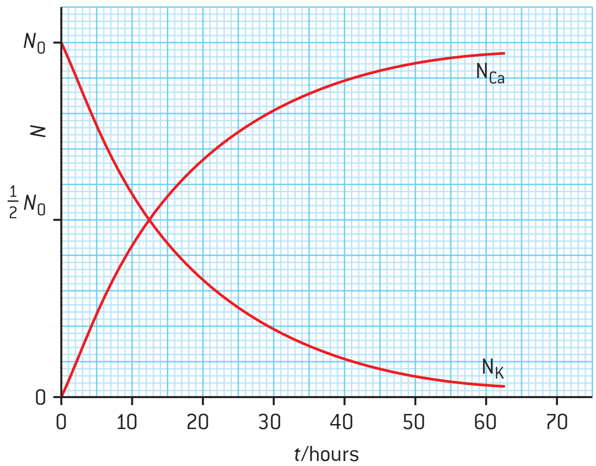
b) beta minus decay – proton number increases by one as neutron is converted to proton; electron antineutrino produced

c) check a sensible line of best fit (exponential decay curve) is drawn

d) half life = time for activity to decrease to half original value
Activity decreases from 3.2×10^5 Bq to 1.6×10^5 Bq in around 8 days

4. a) neutron converting into proton, so beta minus decay; nucleon number (total number of protons and neutrons) stays the same; electron and electron antineutrino also produced

b)



c) point on graph where number of calcium nuclei is 7 times greater than number of potassium nuclei

5. a) proton or neutron

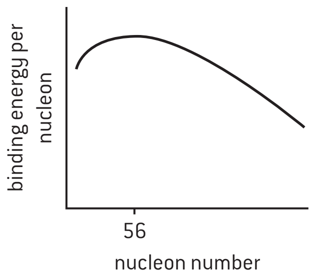
b) work needed to break nucleus into its constituent nucleons

c) most stable nuclide is Fe-56; lighter nuclei are less tightly bound so can release energy when they are fused together; heavier nuclei are less stable and can split into smaller constituents, releasing energy in fission

6. a) mass defect is $3.01603 - (2 \times 1.00728) - 1.00867 = -7.2 \times 10^{-3}$ u
total binding energy is $7.2 \times 10^{-3} \times 931.5 = 6.7$ MeV
3 nucleons so binding energy per nucleon is 2.2 MeV

b) (i) fusion reaction

(ii)



(iii) Helium nucleus is less stable than most stable nuclide, so energy is released when two nuclei are fused together

7. a) nuclear fission is the splitting of a heavy nucleus into smaller nuclei, producing energy; radioactive decay is when an unstable nucleus will spontaneously change into a different nuclear configuration

b) (i) get number of neutrons by balancing charges
$^{235}_{92}U + ^{1}_{0}n - ^{90}_{38}Sr + ^{142}_{54}Xe + 4\,^{1}_{0}n$

(ii) neutron turns into proton, so nucleon number remains the same but proton number increases by one

8. a) nuclear fission

b) $(235.0439 + 1.0087) - (95.9342 + 137.9112 + 2 \times 1.0087) = 0.1898$ u
Energy $= 0.1898 \times 931.5 = 177$ MeV

c) neutrons released can go on to cause more fission reactions, leading to a chain reaction

d) nuclear binding energy

9. a) weak

b) W^+ boson

c) electron neutrino

10. a) (i) allowed (charge and lepton number conserved)

(ii) not allowed (baryon number not conserved)

(iii) not allowed (charge and baryon number not conserved)

b) can have W^+, W^-, or Z boson

11. a) meson (2 quark structure)

b) uud

c) $s\bar{u} + uud = d\bar{s} + u\bar{s} + sss$
baryon number and strangeness both conserved

12. a) exchange particle carries the force between particles; said to be virtual because it is not detected during exchange

b) W^- boson (diagram shows β^- decay)

Solutions for Topic 8 – Energy production

1. a) power produced $\left(\frac{24}{0.32}\right) = 75$ MW;

energy produced in a year $(75 \times 10^6 \times 365 \times 24 \times 60 \times 60 =)\ 2.37 \times 10^{15}$ J;

number of reactions required in one year $\left(\frac{2.37 \times 10^{15}}{3.2 \times 10^{-11}}\right) = 7.39 \times 10^{25}$;

mass used $(7.39 \times 10^{25} \times 235 \times 1.66 \times 10^{-27}) \approx 29$ kg

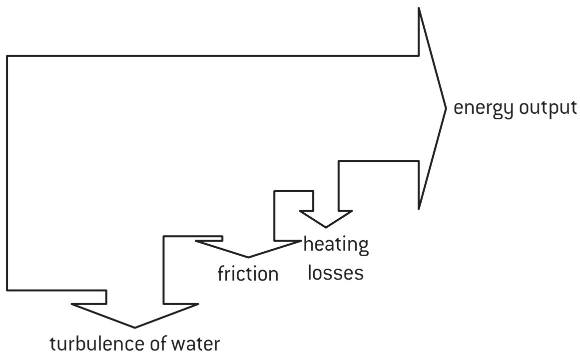
b) The reactions produce plutonium from uranium 238. This isotope of plutonium may be used to manufacture nuclear weapons and plutonium is extremely toxic. It can be used as fuel in other reactors.

2. a) mass $= 50 \times 5.0 \times 10^4 \times 10^3$
loss in GPE $= 50 \times 5.0 \times 10^4 \times 10^3 \times 310 \times 9.81$
$= 7.6 \times 10^{12}$ J

b) flows for 6250 s
1.2×10^9 W

3. a) 53%

b)



4. a) (i) U-235 fissions occur with the emission of neutrons with high energy. The neutrons are fast moving and transfer kinetic energy to the moderator. The energy of the core and the moderator are transferred to the coolant.

(ii) The heat exchanger allows transfer of thermal energy between the reactor and coolant. The coolant transfers thermal energy to steam and the steam allows the turbine to drive the generator.

b) Heating the working fluid in the exchanger ***OR*** cooling the working fluid having passed through the turbine ***OR*** named friction process in power station machinery

5. The solar radiation is captured by a disc of area πR^2 where R is the radius of the Earth but is distributed (when averaged) over the entire Earth's surface which has an area four times as large.

6. a) 0.700;

b) $I = e\sigma T_a^4$
$= 0.70 \times 5.67 \times 10^{-8} \times 242^4$
$= 136$ W m^{-2}

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

7. a) The Earth radiates photons of infrared frequency. The greenhouse gas molecules vibrate with frequencies in the infra-red region. So because of resonance the photons are absorbed.

Because most incoming radiation consists of photons is in the visible and ultraviolet region. These photons are of much shorter wavelength than those radiated by the Earth and so these cannot be absorbed.

b) *Source*: emissions from volcanoes/burning of fossil fuels in power plants or cars
Sink: oceans/rivers/lakes/seas/trees

8. **a)** infrared

b) The nitrogen oxide in the atmosphere readily absorbs infrared radiation radiated from the surface of Earth. This radiation is then re-radiated in random directions; this prevents the energy radiated from Earth escaping into space.

9. **a)** **(i)** power per unit area of atmosphere $= e\,\sigma\,T^4$
$= 0.720 \times 5.67 \times 10^{-8} \times 242^4$
$= 140 \text{ W m}^{-2}$

(ii) solar power absorbed per unit area at the surface $= 0.720 \times 344$
$= 250 \text{ W m}^{-2}$

b) **(i)** new power radiated by atmosphere $= [0.720 \times 5.67 \times 10^{-8} \times 248^4]$
$= 150 \text{ W m}^{-2}$

(ii) new power absorbed by Earth $= (150 + 250) = 400 \text{ W m}^{-2}$

c) $400 = 5.67 \times 10^{-8} \times T^4$
$T = 290$ K
to give $\Delta T = 2$ K

10. present $\frac{I_{out}}{I_{in}} = 0.30$ so present $I_{out} = 102$ (W m^{-2})

after doubling new $I_{out} = (340 \times 0.29) = 98.6$(W m^{-2})
change $= 102 - 98.6$
$= 3.4 \text{ W m}^{-2}$

The estimate assumes that:

all the radiated energy is in the infra-red
all the extra gas absorbs the radiated radiation
no change in radiated power due to Earth temperature change

Solutions for Topic 9 – Wave phenomena (AHL)

1. **a)** acceleration is directly proportional to displacement; acceleration in opposite direction to displacement

b) $a = -\omega^2 x$

gradient of graph $= -5 \times 10^6$ so $\omega = \sqrt{5 \times 10^6} = 2236$ rad s^{-1}

frequency $= \frac{2240}{2\pi} = 350$ Hz

c) amplitude = maximum displacement = 0.60 mm

2. **a)** **(i)** maxima or minima of curve (max acceleration at max or min displacement)

(ii) either point of intercept with time axis (maximum speed at zero displacement)

b) SHM part of circular path; centripetal force towards centre of circle = $T - mg$, therefore $T > mg$.

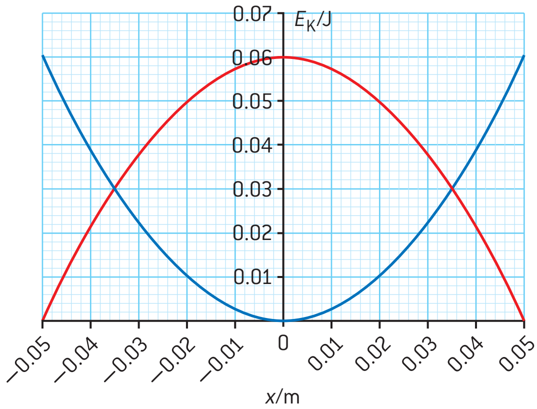
c) **(i)** potential energy mgh converted to kinetic energy $\frac{1}{2}mv^2$

so $v = \sqrt{2gh} = 0.70$ m s^{-1}

(ii) $T = \frac{mv^2}{r} + mg = 0.035 + 0.56 = 0.59$ N

3. **a)** restoring force $F = -kx$ (opposite direction to displacement)

b) **(i)**

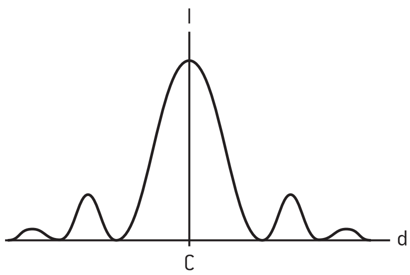


(ii) $E_K = \frac{1}{2}mv^2$ gives maximum velocity of 0.63 m s^{-1}

$v_{max} = \omega x_0$ where $x_0 = 0.05$ m so $f = \frac{0.63}{2\pi \times 0.05} = 2.0$ Hz

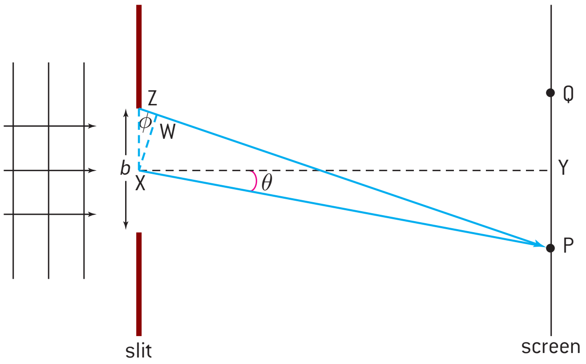
4. **a)** diffraction of light occurs when light passes through a narrow slit, causing waves to bend and create an interference pattern

b)



c) width $= \frac{2 \times D \times \lambda}{a} = 5.9$ mm

5. a)



b) path difference is half of a wavelength for destructive interference

c) ZW $= \frac{\lambda}{2} = \frac{b}{2}\sin\theta$; use small angle approximation and rearrange to get answer

d) angular width $\frac{2 \times 450 \times 10^{-9}}{0.15 \times 10^{-3}} = 6.0 \times 10^{-3}$ rad

6. a) waves between A and B at same intensity with same spacing as original graph

b) $\sin\theta = \frac{\lambda}{d} = \frac{450 \times 10^{-9}}{1.25 \times 10^{-6}}$ gives $\theta = 21°$

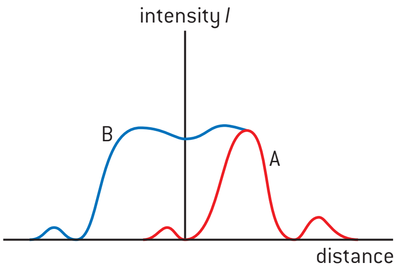
7. a) $\frac{d}{\lambda} = \frac{1}{6.0 \times 10^{5} \times 590 \times 10^{-9}} = 2.8$ so maximum order in each direction is 2, plus zero order gives 5.

b) second order peak will be **wider** and **fainter** than first order peak

8. a) **(i)** 180° or π **(ii)** 0

b) minimum thickness is $\frac{\lambda}{2} \times \frac{1}{n} = \frac{620 \times 10^{-9}}{2} \times \frac{1}{1.4} = 2.2 \times 10^{-7}\ m$

9. a) b)



c) $\theta = 1.22\frac{\lambda}{a} = 2.4 \times 10^{6}$

separation $s = \theta \times d = 2.4 \times 10^{6} \times 8.1 \times 10^{16} = 2.0 \times 10^{11}$ m

10. a) ratio of the wavelength of the light to the smallest difference in wavelength that can be resolved by the grating

b) **(i)** $\frac{2000}{0.2} = 10000$ lines mm^{-1}

(ii) $\Delta\lambda = 0.2$ nm

$\frac{\lambda}{\Delta\lambda} = 3280$ which is greater than the resolvance, so no.

11. wave speed remains the same, wavelength measured by observer is smaller as wave fronts are closer together due to approaching sound source.

12. a) f′ is higher than f due to Doppler effect; observer is walking towards source so intercepts crests of wavefront at higher rate than they are emitted

b) $f' = f\frac{v}{v - u_s}\ 3.0 \times 10^{2} \times \frac{330}{315} = 314$ Hz

13. all lines shifted to the right to slightly higher wavelengths (redshift); shift is greater at higher wavelengths

Solutions for Topic 10 – Fields (AHL)

1. $\frac{3g}{4}$

2. The acceleration a of the spacecraft is $\frac{v-u}{t} = \frac{300}{600} = 0.50 \text{ m s}^{-2}$

This is also the gravitational field strength, $g = 0.50 \text{ N kg}^{-1}$

3. **a)** a conductor contains *free* electrons and insulators do not

b) electrons must move along the wire and so an electric force must act on them this is provided by the electric field

c) $55 \times 1.6 \times 10^{-19}$
$= 8.8 \times 10^{-18}$ N

d) *Similarity:*
both follow an inverse square law

Differences:
gravitational force is much weaker than electric force

electric force can be attractive or repulsive, gravity only attractive

e) **(i)** 25 N kg^{-1}

(ii) $M = \frac{25\,R^2}{G}$

$= \frac{25 \times 7.0^2 \times 10^{14}}{6.7 \times 10^{-11}}$

$= 1.8 \times 10^{27}$ kg

4. the astronaut and the spacecraft experience the same acceleration

5. **a)** work done in moving mass from infinity to a point;

b) **(i)** accurate read-offs at –12.6 and –3.2
or gain in gravitational potential $[12.6 \times 10^6 - 3.2 \times 10^6]$
$9.4 \times 10^6 \times 12 \times 10^6 = 1.13 \pm 0.05 \times 10^5$ MJ

(ii) use of gradient of graph to determine g

values substituted from drawn gradient $\left(\text{typically } \frac{6.7 \times 10^6}{7 \times 3.3 \times 10^6}\right)$

$= (0.23 \pm 0.3) \text{ N kg}^{-1}$

c) g at surface $= 4^2$ g at $4R$

and $\frac{3.7}{0.23} = 16.1$

$= 3.7 \text{ N kg}^{-1}$

d) escape speed for Earth > escape speed for Mars
potential less/more negative at Earth

6. $F_X = \frac{GM}{d^2} = 90$ N

$F_Y = \frac{4GM}{(ad)^2} = \frac{4}{9}F_X = 40$ N

Solutions for Topic 11 – Electromagnetic induction (AHL)

1. **a)** **(i)** M shown at peak or trough

(ii) Z shown on t-axis

b) by Lenz's law, emf (or current) must change direction as flux cutting changes direction as magnet oscillates, flux is cut in opposite directions

2. $BS \sin \phi$

3. **a)** induced e.m.f. proportional to rate of change of magnetic flux linkage as current increases, magnetic field in coil increases thus change in flux linkage and e.m.f. induced

b) direction of induced e.m.f. such as to tend to oppose the change producing it induced e.m.f. must oppose e.m.f. of battery / growth of current in circuit

c) energy is supplied by the battery in making charge move against the induced e.m.f.

4. **a)** magnetic flux through coil will change as the current changes

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

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

(iii) emf is reduced because B is smaller

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

5. **a)** for e.m.f. to be induced in secondary, flux must be changing *in the core* changing flux is caused by varying current in primary

b) induced currents in core are kept small to reduce heating/energy losses

c) use of $\dfrac{N_s}{N_p} = \dfrac{V_s}{V_p}$

to give $N_P = 8600$ turns

and $I_p \left(= \dfrac{42}{230}\right) = 180$ mA

6. At 25 s pd has fallen to 4 V. Therefore $4 = 12e - \dfrac{t}{R \times 220\mu F}$

$\ln 0.333 = -\dfrac{t}{R \times 220\mu F}$ and $R = -\dfrac{25}{\ln 0.333 \times 2.2 \times 10^{-4}}$

$= 100$ kΩ

7. **a)** **(i)** 65 s – 70 s

(ii) $RC = 95$ s

$R = 470$ kΩ

(iii) $I = V/R$

$23.5 \rightarrow 26$ μA

b) **(i)** $\dfrac{1}{C_T} = \dfrac{1}{C_1} + \dfrac{1}{C_2}$

67μF

(ii) curve aiming for 12 V Ω

t value about 0.3 of original Ω

8. **a)** **(i)** 1 μC of charge per volt.

(ii) straight line through the origin
line up to (6, 1μC)

(iii) read charge and pd from the graph

energy $= \frac{1}{2} QV$

b) (i) use of 0.5 CV^2Ω
9.4 J Ω

(ii) energy output $= mgh = 0.25 \times 9.8 \times 0.90 = 2.2$ J
efficiency = useful power out / power input

efficiency $= \frac{2.2}{9.4} = 24$ %

9. charge stored = 20 μC
energy stored $= 0.5 \times 20\ \mu\text{C} \times 10^2 = 1$ mJ

10. a) correct curvature starting at 6 V at time = 0
points plotted correctly at 3 and 6 minutes with reasonable curve (2.2 V and 0.8 V)

b) time alarm rings read correctly from the graph at 3 V

c) $R = \frac{180}{2.2 \times 10^{-3}}$

82 kΩ

d) $3 = 9\ e^{\frac{-300}{CR}}$

120 kΩ

e) replace capacitor with one of higher value

11. a) the capacitance is smaller time constant is lower

b) (i) time to fall to $\frac{1}{e} = 29$ s

$t_{\frac{1}{2}} = 0.69\ C\ R$

132 kΩ

(ii) total $C = 68 – 74\ \mu$F

use of $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$

99 – 111 μF

12. a) (i) $Q = CV$

33 μF

(ii) series combination = 15 μF

18 μF

(iii) uses ratio idea

9.0 V

b) (i) $\frac{V_0}{2} = V_0 e^{-\frac{t}{CR}}$

time to halve = 3.6 s

(ii) $V = V_0 e^{-\frac{t}{CR}}$

2.6 V

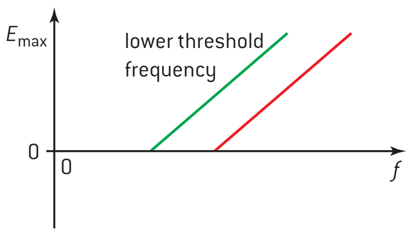
13. a) $C = \frac{\varepsilon_0 \varepsilon_r A}{d}$

$A = 4.7 \times 10^{-3}$ m²
76 mm

b) $E = \frac{1}{2} C V^2$
4.1×10^{-10} J

Solutions for Topic 12 – Quantum and nuclear physics (AHL)

1. a)



b) electron ejected when energy of light $E = hf$ is greater than the work function (threshold frequency) of the metal

2. a) (i) no change in ammeter

(ii) reading will increase as more electrons are being produced per second

b) (i) photon energy is the sum of the energy of emitted electron plus the work function

(ii) $\varphi = \frac{hc}{\lambda} - eV = 6.4 \times 10^{-20}$ J

3. a) why certain transitions are more likely to occur than others

b) electrons in an atom exist in stationary states; electrons may move from one stationary state to another by absorbing or emitting a quantum of electromagnetic radiation

c) substitute r into equation for E_n to get required expression

d) binding energy of that level

e) electron described by wavefunction; energy levels can be thought of as standing waves in a potential well; harmonics of standing wave give different levels

4. a) uncertainty in position is ± half of slit width so minimum uncertainty

$$\Delta p = \frac{6.63 \times 10^{-34}}{4\pi \times 0.01 \times 10^{-3} \times 0.5} = 1.1 \times 10^{-29} \text{ N s}$$

b) component parallel to gap

5. a) particle brought to rest when all kinetic energy has been converted to potential energy, so e.p.e. is 3.8 MeV = 6.1×10^{-13} J

b) Z = 46 so $d = \frac{kZe \times 2e}{E_\alpha} = 3.5 \times 10^{-14}$ m

c) higher Z so d would be greater

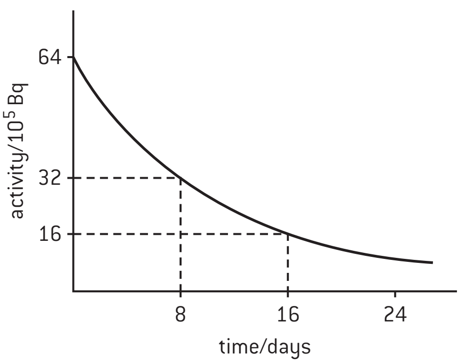
d) (i) mass = A × u

(ii) $\rho = \frac{m}{v} = \frac{3u}{4\pi \times (1.2 \times 10^{-15})^3} = 2 \times 10^{17}$ kg m^{-3}

6. a) nucleus or atom with specific number of protons and neutrons

b) beta minus decay so neutron turns into proton so atomic number must decrease by one; electron antineutrino also produced

c) (i)



(ii) $\lambda = \frac{\ln 2}{t_{\frac{1}{2}}} = 0.087 \text{ day}^{-1}$

(iii) $A = A_0 e^{-\lambda t}$

$$t = -\frac{1}{0.087} \ln \frac{0.5}{6.4} = 29 \text{ days}$$

7. a) (i) proton or neutron

(ii) proton: uud; neutron: udd

(iii) argon-39 has more neutrons so there is a higher chance of it undergoing beta decay by changing a neutron into a proton

b) (i) Z = 19; N = 39; x is electron antineutrino

(ii) emitted electrons have continuous energy spectrum, so third particle must be produced so that momentum and mass-energy are conserved

(iii) $(38.96431 - 38.96370) \times u \times c^2 = 9.1 \times 10^{-14}$ J

c) (i) separate pure sample of nuclide in a known chemical form, measure its mass then take count rate; use dimensions of G-M tube to calculate activity

(ii) use mass and activity of sample to find half life

8. a) separate pure sample of nuclide in a known chemical form, measure its mass then take count rate; use dimensions of G–M tube to calculate activity

b) fraction remaining = $2^{-1.6} = 0.33$

Solutions for Option A – Relativity

1. frame of reference is at rest or moving at constant velocity OR reference frame within which Newton's first law is valid

2. **a)** The moving electron is subject to an attractive electrostatic force due to the proton stationary with respect to the wire. The electrons moving in the wire give rise to a magnetic field. Fleming's left-hand rule will indicate the direction of this field.

b) The protons now appear to be moving so far as the moving electron is concerned. They therefore give rise to a magnetic field so far as the moving electron is concerned. The electrons in the wire also give rise to forces. The net effect of all forces will be the same whichever frame of reference is used according to the first postulate of relativity.

3. reference frame of one electron moves with respect to the other by $-0.002c$
$u = u' - (-0.002c)$ and $u = 0.004c$

4. **a)** **(i)** the length of an object as measured by an observer at rest with respect to the object

(ii) the time interval between two events measured in the reference frame in which the two events occur at the same place

b) **(i)** half-life $= \dfrac{1370}{0.95c}$

4.8×10^{-6} s

(ii) $\gamma = 3.2$

$T = 1.5 \times 10^{-6}$ s

(iii) $L = \dfrac{L_0}{\gamma} = 430$ m

c) muons regard themselves as being at rest and "measure" the proper time for half of them to decay in the laboratory, the muons will take a longer time to decay and this is the time that to them, it takes the muons to travel between the counters the laboratory observers measure the proper length since the counters are at rest in their reference frame to the muons it will seem that counter 2 is travelling towards them and in the time that it takes half of them to decay they will measure counter 2 as having travelled a contracted distance 430 m

5. **a)** **(i)** correct substitution into Lorentz factor equation $v = 0.979c = 2.94 \times 10$ m s^{-1}

(ii) speed $= \dfrac{\text{distance}}{\text{time}}$ 1.26 ns

b) **(i)** 2.94×10^8 m s^{-1}

(ii) length contraction applies here 7.5 cm

6. **a)** frame of reference is at rest or moving at constant velocity / reference frame within which Newton's first law is valid

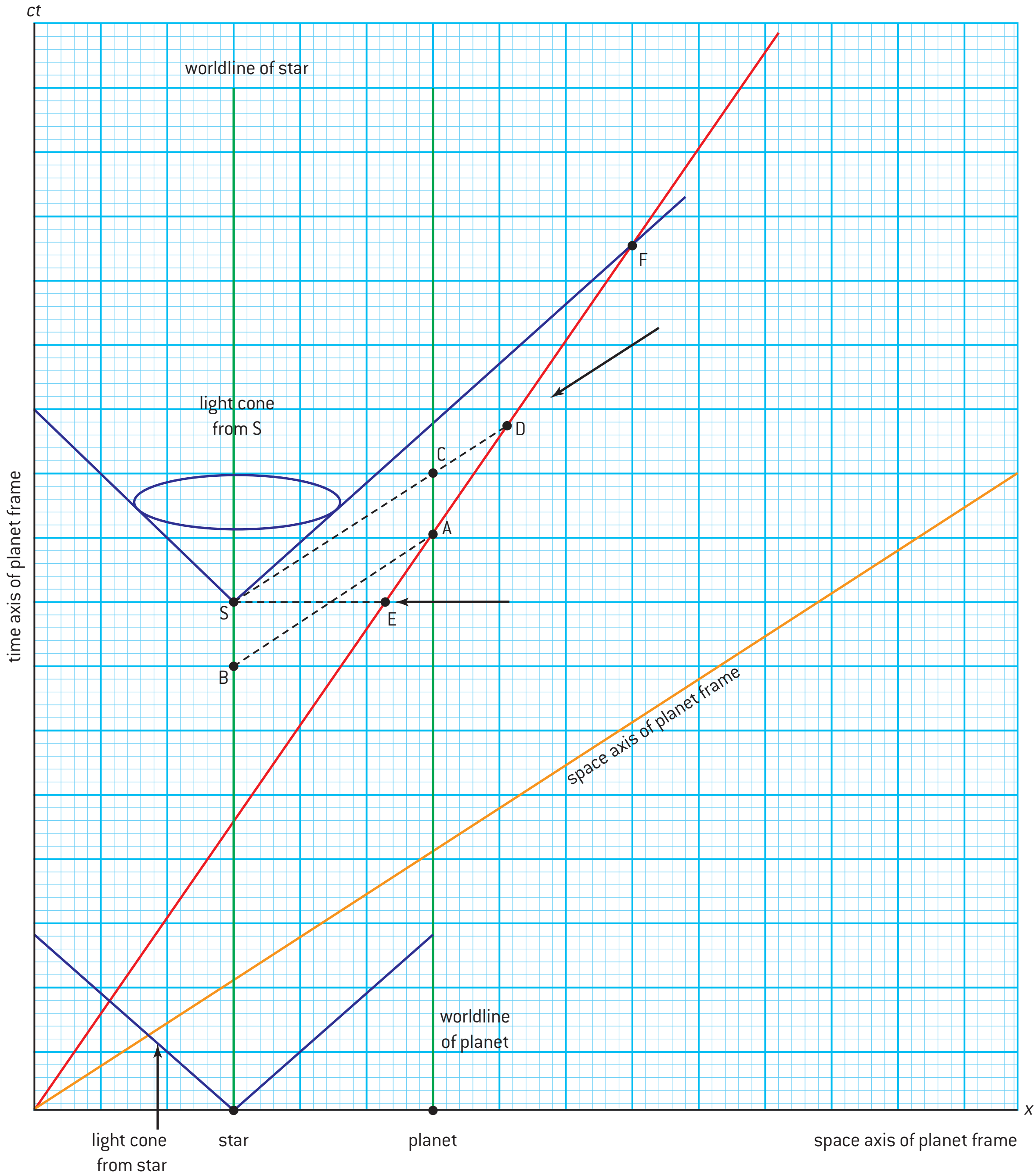
b) **(i)** *time*: larger;
length: smaller;
mass: larger

(ii) volume decreases and mass increases

density $= \dfrac{\text{mass}}{\text{volume}}$;

density increases

7.



a) **(i)** intersection of planet worldline and spaceship world line (A)

(ii) continue spaceship x axis back from A (to B)

b) **(i)** The supernova is simultaneous with C and with D

Because they are on the same line parallel to the spaceship *x* axis

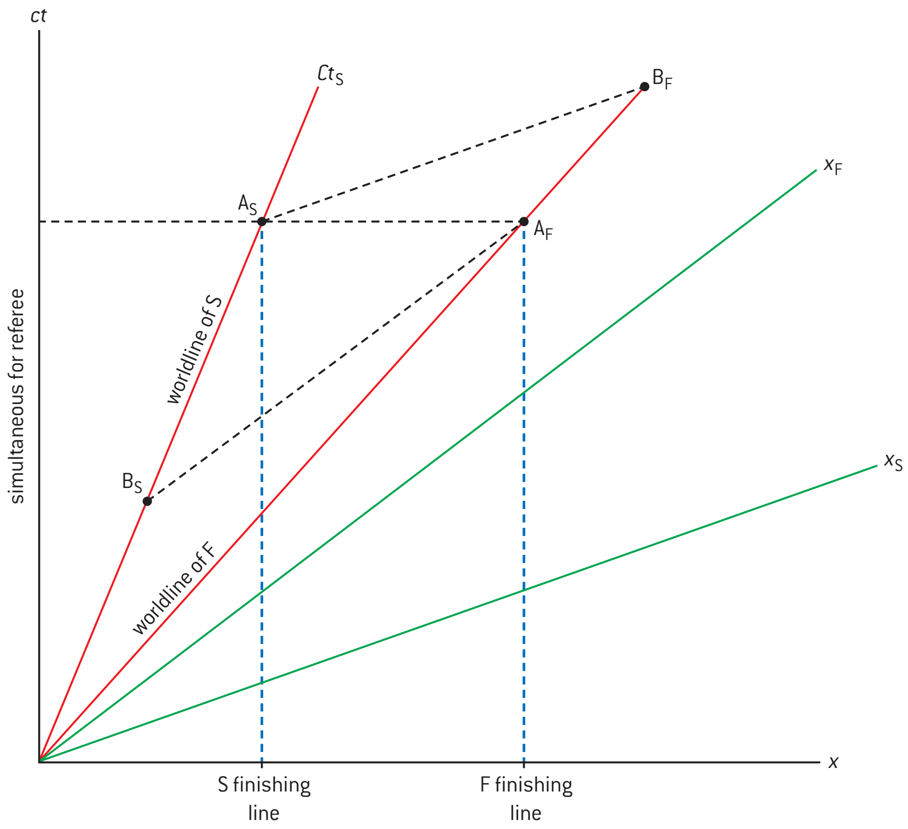
(ii) The supernova is simultaneous with E in the planet frame

Because S and E are on a line parallel to the *x* axis

c) The students see the supernova at the intersection of the nova lightcone and the spaceship trajectory

This is at point F on the diagram

8.



a) **(i)** F crosses the F finishing line at A_F
at this instant S is at B_S
F thinks he has won

(ii) S crosses the S finishing line at A_S
At this instant F is at B_F
S thinks F has won

(iii) in the referee frame AS and AF are simultaneous the referee thinks the result is a draw

b) The athletes both agree that F has won the referee disagrees with this but because he is in a different frame there is no reason why simultaneity should apply in this situation

9. **a)** mass measured when object is stationary relative to observer

b) for large V, calculated value of v would be greater than c which is not possible mass increases, so mass is not m_0

c) $c^2\Delta m = eV$ or $\Delta m = \dfrac{(1.6 \times 10^{-19} \times 5.0 \times 10^6)}{(3.0 \times 10^8)^2}$

$\Delta m = 8.9 \times 10^{-30}$ kg

10. a) $mc^2 = m_0c^2 + Ve$

$\gamma\, m_0c^2 = m_0c^2 + Ve$

$$\gamma = 1 + \frac{Ve}{m_0c^2}$$

b) $\gamma = 1 + \dfrac{500}{938} = 1.53$

substitute into $\gamma = \dfrac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$ to give $v = 0.76\,c$

11. $E = 2.0 \times 10^9$ eV $+ 938 \times 10^6$ eV $= 2.9(38) \times 10^9$ eV

$p^2c^2 = (2938\text{MeV})^2 - (938\text{MeV})^2$

2.8×10^3 MeVc^{-1}

12. a) rest mass energy is rest mass $\times c^2$
total energy is rest mass energy + kinetic energy
assuming no potential energy

b) 938 MeV

c) $\gamma\, m_0c^2 = m_0\, c^2 + V e$

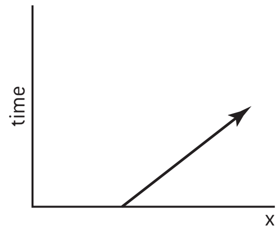
$V e = \gamma\, m_0c^2 - m_0c^2$

$V e = m_0c^2\ (\gamma - 1)$

$V e = 938(4.0)$

$V = 3750$ MV

13. a)



spacetime diagram constructed straight line for trajectory particles move in both space and time and so the motion of the particle can be represented by a path in spacetime

b) mass warps space time any sensible straight line path all particles follow the shortest path in spacetime if the Earth were not present the satellite would move in a straight line the warping of spacetime forces the satellite to follow an orbital path

c) if an object is dense enough it will cause extreme warping of spacetime such that any light leaving the surface will not be able to escape the spacetime surrounding the object

d) $R_{sch} = \dfrac{2GM}{c^2} = \dfrac{2 \times 6.6 \times 10^{-11} \times 2 \times 10^{30}}{9 \times 10^{16}}$ 3000 m

14. a) (i) straight line path

(ii) a path curving towards the base

(iii) light travels in a straight line in a gravity-free region of space for the accelerating observer, the spaceship would be displaced in the direction of the acceleration in the time the light takes to go across it in this frame of reference, this displacement is attributed to the beam the observer in the accelerating frame of reference would attribute this to the light beam "bending 'downwards

b) for the observer in the spaceship the constant acceleration (in a gravity-free region of space) is indistinguishable from an inertial frame of reference in a uniform gravitational field – which is the equivalence principle

15. a) a frame of reference accelerating far from all masses with acceleration a is completely equivalent to a frame of reference at rest in a gravitational field of field strength equal to a

b) (i) B the scale reads the weight of the mass

(ii) C the scale reads a force F where $F = m\, g + m\, a$

(iii) A there is no acceleration and no gravitational force on the mass

c) B the equivalence principle states that the accelerating frame is equivalent to a frame at rest on Earth's surface

16. a) **(i)** centre is single point to which all mass would collapse surface is where the escape speed is equal to c within the surface, mass is lost from the universe

(ii) distance from point of singularity to the event horizon

(iii) $R_{sch} = \frac{2GM}{c^2} = \frac{(2 \times 6.7 \times 10^{-11} \times 2 \times 10^{31})}{(3 \times 10^8)^2}$ 3.0×10^4 m

b) theory suggests that light is affected by gravitational fields two images are formed by gravitational lensing in which two light rays are bent each side of the Sun by warping of spacetime

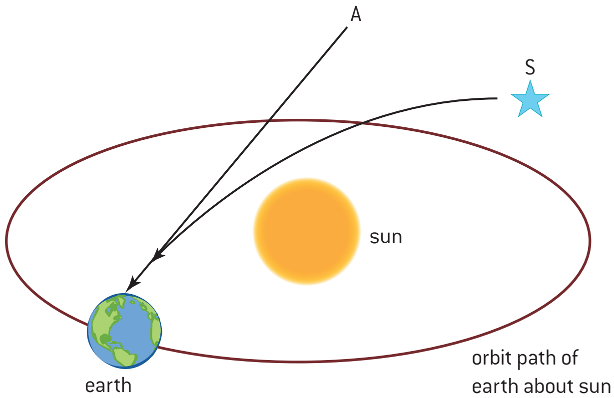
17. a) an observer cannot tell the difference between the effect of acceleration (in one direction) and a gravitational field (in the opposite direction)

b) light would be expected to be bent in an accelerating frame application of principle of equivalence to show that light must also be bent in a gravitational field gravitational lensing is the bending of light around a massive astronomical object to produce multiple images or magnified images of a region of space that is further away

18. a) in order that the star could be seen

b) in order that the degree / amount of bending of the light by the Sun can be measured

c)



d) the theory predicts that spacetime is warped by the presence of matter the light ray takes the shortest path between the star and Earth in the warped spacetime

e) see diagram for correct position

19. a) **(i)** region of extreme curvature in space-time such that escape speed is c (or greater)

(ii) radius of boundary inside which mass must fit for black hole to be possible

(iii) 5.9×10^4m
no mass lost

b) **(i)** deflect the path of spacecraft

(ii) matter distorts spacetime particles in space-time follow shortest path path curved as mass approaches black hole this is interpreted as a force

20. a) since the speed of light is independent of the speed of the source Alan's source will appear to be moving away from Brenda so according to the Doppler effect the light will appear to be redshifted

b) because of the principle of equivalence the situation is the same as if Brenda was observing light emitted from the surface of a planet

Solutions for Option B – Engineering physics

1. a) $\alpha = mg \times r = 3.0 \times 9.81 \times 0.75 = 22 \text{ rad s}^{-2}$

b) torque $= \text{F} \times \text{r} = 0.5 \times \text{MR}^2 \times \alpha$

$\text{F} = 30\text{N gives } \alpha = \dfrac{30 \times 2}{7 \times 0.25} = 34 \text{ rad s}^{-2}$

2. a) conservation of angular momentum gives $\text{I}_1\omega_1 = \text{I}_2\omega_2$

so $\omega_2 = \dfrac{2.85 \times 2.0}{1.5} = 3.8 \text{ rad s}^{-1}$

b) rotational kinetic energy is $0.5 \times \text{I} \times \omega^2$

so change in energy is $0.5 \times (1.5 \times 3.8^2) - (2.85 \times 2^2) = 5.1 \text{ J}$

3. a) work done $= \Gamma\theta$

$\theta = 320$ rads

torque $= \text{I} \times \alpha = 5.3 \text{ N m}$

work done $= 5.3 \times 320 = 1.7 \text{ kJ}$

b) power $= \Gamma\omega = 4.4 \times 65 = 290 \text{ W}$

4. a) AB is isotherm (less steep than adiabat)

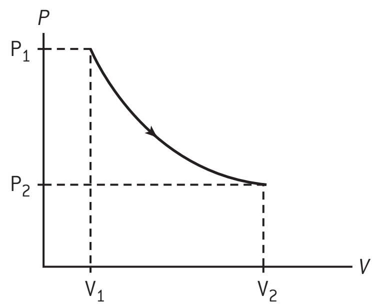
b) area enclosed by three lines

c) work done = area in part (b) = 150 J

d) in adiabatic change, Q = 0 so internal energy must increase during compression of gas so temperature will rise

5. a) $P = \dfrac{4.0 \times 10^5 \times 3.0}{5.0} = 2.4 \times 10^5 \text{ Pa}$

b)

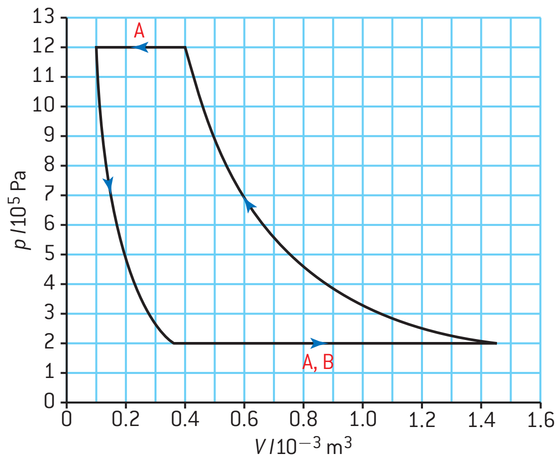


c) **(i)** work done is area under curve

(ii) adiabat is steeper so area enclosed would be smaller

6. a) change occurs at constant pressure

b)



c) work done = area enclosed = 450 – 550 J

d) **(i)** Entropy of the universe always increases in real processes.

(ii) entropy inside refrigerator decreases but heat energy is lost to surroundings so overall entropy change is still positive

7. **a)** **(i)** $3.0 \times 10^{-4} \times 0.40 = 1.2 \times 10^{-4}$ m³ s⁻¹

(ii) $A_1v_1 = A_2v_2$ so $v_2 = \frac{3.0}{1.6} \times 0.40 = 0.75$ m s⁻¹

b) flow is accelerated through the constriction so that the flow rate remains constant (conservation of mass)

8. **a)** pressure difference $= \rho g \Delta z = 1.4 \times 10^4 \times 9.81 \times 0.08 = 11$ kPa

b) $\frac{v_2}{v_1} = \frac{A_1}{A_2} = 4$

c) **(i)** Bernoulli: $\frac{1}{2}\rho v^2 + P = \text{const}$

so $\Delta P = \frac{1}{2}\rho(v_2{}^2 - v_1{}^2) = \frac{1}{2}\rho((4v_1)^2 - v_1{}^2) = \frac{15}{2}\rho v_1{}^2$

rearrange to get $v_1 = 1.35$ m s⁻¹

(ii) flow rate $= 8.0 \times 10^2 \times 1.35 \times 4.0 \times 10^{-2} = 43$ kg s⁻¹

9. **a)** **(i)** continuity equation: Av = constant
so narrower pipe with smaller A will have faster flow

(ii) $\frac{1}{2}\rho v^2 + P = \text{const}$

b) **(i)** flow will increase in velocity through B so will decrease in pressure, causing a partial vacuum once it emerges into D

(ii) $\Delta P = \frac{1}{2}\rho(v_D{}^2 - v_C{}^2)$

since water at C is moving very slowly, can approximate $v_D{}^2 - v_C{}^2 = v_D{}^2$

so $v_D = \sqrt{\frac{2 \times 55000}{1000}} = 10.5$ m s⁻¹

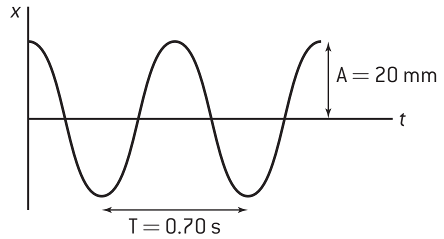
(iii) flow rate $= \pi \times (1.0 \times 10^{-3})^2 \times 10.5 = 3.3 \text{ x } 10^{-5}$ m³ s⁻¹

10. **a)** **(i)** spring constant $k = \frac{2.0}{0.05} = 40$ N m⁻¹

$\omega = \sqrt{\frac{k}{m}} = \sqrt{\frac{40}{0.5}} = 8.9$ rad s⁻¹

$T = \frac{2\pi}{\omega} = 0.70$ s

(ii)



b) resonant frequency is $\frac{1}{T} = 1.4$ Hz

(i) driving frequency less than resonant frequency so system undergoes light damping i.e. amplitude decreases with each oscillation

(ii) system undergoes resonance, oscillates at maximum amplitude

11. a) resonance

b) system at resonance vibrates with maximum amplitude so bridge will oscillate from side to side

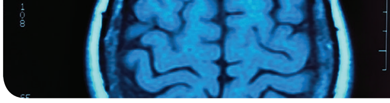
c) add loads to bridge to make it heavier; use different materials with higher resonant frequency

12. a) (i) vibrations that occur when regularly changing external force is applied to a system, resulting in system vibrating at the driving frequency

(ii) if driving frequency is the same as the natural frequency of the system, it will vibrate at maximum amplitude

b) (i) Damping is when the amplitude of an oscillating system decreases over time due to energy being lost over time.

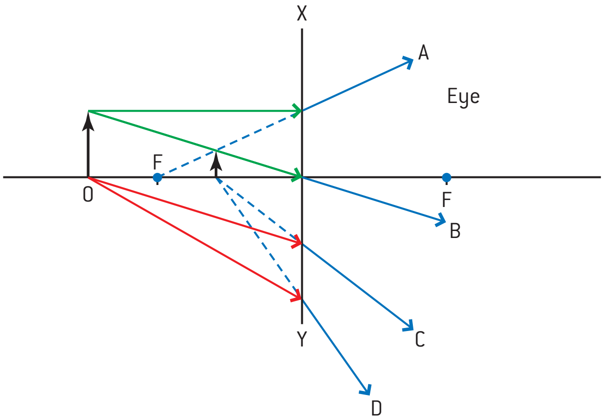
(ii) degree of damping affects the system's resonant response



Solutions for Option C – Imaging

1. **a)** the point on the principal axis to which rays parallel to the principal axis are brought to a focus after refraction by the lens

b) **(i)**



A correct
B correct
correct location of the image
C and D correct

(ii) to the right of the lens

c) virtual because any two rays from any one point of the object are not brought to a focus by the lens

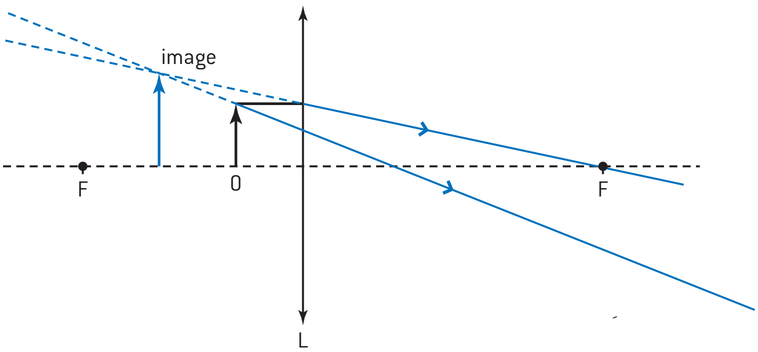
d) use $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ with $f = -50$

to give $v = -30.0$ cm

to give $m = \frac{-30}{75} = -0.4$

e) no effect on linear magnification only effect on appearance is that image will be fainter

2. **a)**



(i) as ray diagram for magnifying glass

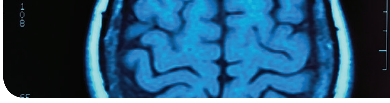
(ii) it is virtual because it cannot be formed on a screen

b) **(i)** $\frac{1}{v} = \frac{1}{6.25} - \frac{1}{50}\ \frac{1}{v} = \frac{1}{62.5} - \frac{1}{50}$

$v = -250$ mm

(ii) $M = \frac{250}{50} = -5$

$L' = 50 \times 0.8 = 40$ mm



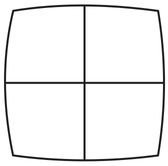
3. a) 18 cm

b) (i) rays only appear to go to X

(ii) $u = -6$ cm
$f = -24$ cm
hence distance of image from lens = 8.0 cm

c) parallel rays focused further from P so focal length is longer

4. a)



straight-line cross

b) use two thin lenses OR reduce aperture using only paraxial rays same f as the fatter lens OR to reduce rays going through edge of lens

5. a) rays continued to eye lens, emerging parallel and in correct direction parallel lines to left of eyepiece to show image formation at infinity

b) (i) $\dfrac{\textit{angle subtended at eye by image}}{\textit{angle subtended by eye at object}}$

(ii) correct identification of angles state that $\tan\alpha \rightarrow \alpha$ for small angles

$m_O = \dfrac{h}{f_0}$ AND $m_E = \dfrac{h}{f_E}$

magnification $= \dfrac{f_O}{f_E}$

c) bigger diameter so collects more light OR there is less diffraction OR there is greater resolution

6. a) $u = 23.0 - 15.6 = 7.4$ cm

b) $\dfrac{1}{v} = \dfrac{1}{11.0} - \dfrac{1}{7.4}$

$v = -22.6$ cm, so distance is 22.6 cm

c) $M = \dfrac{22.6}{7.4} \times \dfrac{15.6}{1.3}$

$M = 36.7 \approx 37$

7. a) *attenuation*: impurities in the glass core of the fibre

dispersion: material dispersion *i.e.* dependence of refractive index on wavelength OR modal dispersion *i.e.* rays of light of the same wavelength that follow different paths along the fibre

b) (i) loss of $5.4 \times 2.8 = 15$ dB

$\left(-15 = 10\log\dfrac{80}{P} \Rightarrow\right) P = 2.5$ mW

(ii) 15 dB

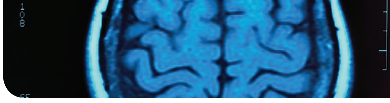
c) after amplification the signal and noise powers are

$\left(15 = 10\log\dfrac{P'_{signal}}{P_{signal}} \Rightarrow\right) P'_{signal} = 10^{1.5}\,P_{signal}$ and $P'_{signal} = 10^{1.5}\,P_{noise}$

and so the new signal-to-noise ratio is $10\log\dfrac{P'_{signal}}{P'_{noise}} = 10\log\dfrac{P_{signal}}{P_{noise}} = 20$ dB

8. a) (i) area (under line) represents energy smaller area so energy loss

(ii) (output) curve is not smooth showing random additional power/energy



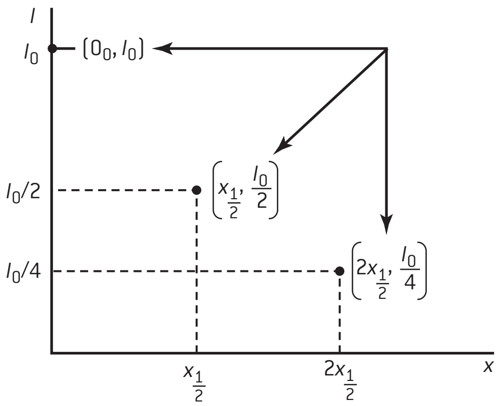
b) **(i)** material dispersion (dependence of wave speed on wavelength)
modal dispersion (dependence of wave speed on path taken)

(ii) pulses would overlap

9. **a)** how penetrating different X-rays beams are through a material

b) the thickness of the material that reduces the initial intensity by half

c)



d) correct position of $x_{\frac{1}{2}}$ on the graph

e) scattering OR photoelectric effect

10. a) **(i)** X-rays: to detect broken bones because bone and tissue show different attenuation

(ii) ultrasound: analysis takes advantage of reflections off organ boundaries OR pre-natal scans because there is no risk from ionizing radiation

(iii) NMR: any situation where detailed tomography is required OR large scale investigations where dose of ionizing radiations would be too great

b) ***three*** *of the following points.*
techniques required that can:
have different absorption properties for different types of tissue and bone
distinguish boundaries of organs
be used to provide complete three dimensional images
monitor static / dynamic conditions
investigate at small / large scales
be used to study concentrations of specific types of tissue or pharamaceuticals
monitor specific organ functions

11. a) photoelectric effect
which is when a photon is absorbed causing ionization a second photon is produced when another electron falls into the vacant level

b) **(i)** probability of a single photon being absorbed in 1 m of the material

reference to $\frac{\Delta I}{I} = -\mu \Delta x$ symbols defined

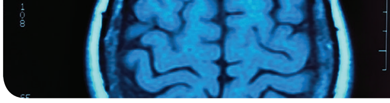
(ii) thickness required to reduce the intensity of radiation to half its initial value

reference to $x_{\frac{1}{2}} = \frac{\ln 2}{\mu}$ symbols defined

c) **(i)** substitution into ratio $= \frac{(13.9)^3}{(7.4)^3}$

to get ratio $= 6.62 \approx 6.6$

(ii) X-rays can provide good contrast for broken bone diagnosis
fat-muscle ratio of attenuation coefficients = 1.97
realization that this is not very different from 1
therefore not enough contrast for muscle-fat boundary



12. a) (i) X-rays
because they can distinguish between flesh and bone to get a clear image

(ii) ultrasound
because it gives clear images without harmful radiation

b) (i) the half-value thickness is that thickness of lead which
will reduce the intensity of the transmitted beam by 50 %

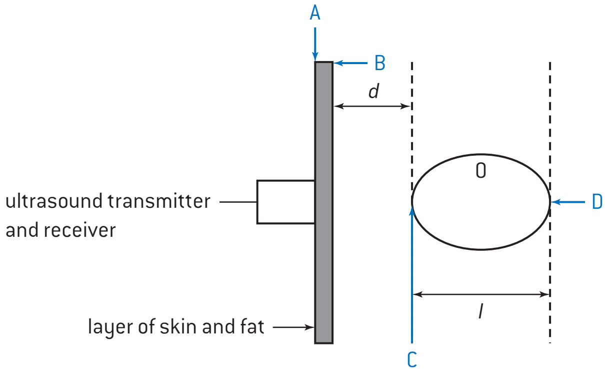
(ii) the half-value thickness corresponds to an intensity of 10 units and so equals 4 mm

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

13. 30 keV is less attenuated by the muscle
but is still likely to be well attenuated by the bone

14. a) 1 MHz → 20 MHz

b) (i)



A and B correct
C and D correct

(ii) pulse takes 50 μs to travel 2*d*

therefore $d = \frac{ct}{2} = \frac{1.5 \times 10^3 \times 50 \times 10^{-6}}{2}$

$d = 38$ mm

$l = \frac{1.5 \times 10^3 \times 175 \times 10^{-6}}{2} = 130$ mm

c) B-scan gives a three-dimensional image

d) advantage:
non-ionising

Any one of the following:
disadvantages:
small depth of penetration limit to size of objects that can be imaged blurring of images due to reflection at boundaries

15. a) shows up outline of stomach or intestines because barium meal absorbs the X-rays

b) prevents reflections of ultrasound at skin surface because much reflection at skin/air boundary / other good comment

c) gradient field localizes the resonating atoms because Larmor frequency depends on magnitude of magnetic field therefore measurement and intensity of Larmor frequency gives information about density of hydrogen atoms

Solutions for Option D – Astrophysics

1. a) (i) take image of star in January and July and measure the distance star appears to have moved

(ii) $d = \frac{1}{p} = \frac{1}{0.419} = 2.39\text{ pc} = 7.78\text{ ly}$

(iii) it is difficult to measure parallax of stars at great distances due to absorption and scattering of light in the atmosphere

b) $b \propto \frac{L}{d^2}$ so $\frac{\textit{luminosity of Wolf 359}}{\textit{luminosity of Sun}} = 3.7 \times 10^{-15} \times \left(\frac{7.78}{1.58 \times 10^{-5}}\right)^2 = 8.9 \times 10^{-4}$

2. a) $L = 4\pi \times (1.50 \times 10^{11})^2 \times 1.37 \times 10^3 = 3.9 \times 10^{26}\text{ W}$

b) $L = \sigma AT^4$ so $T = \left(\frac{3.9 \times 10^{26}}{5.67 \times 10^{-8} \times 4\pi \times (6.96 \times 10^8)^2}\right)^{\frac{1}{4}} = 5.8 \times 10^3\text{K}$

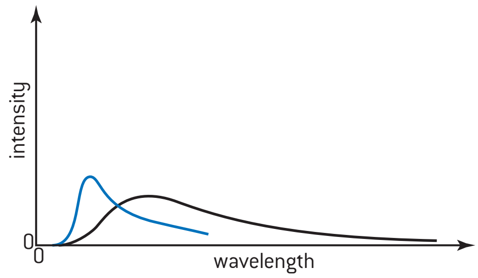
3. a) red super-giant → supernova → black hole

b) (i) above this mass, gravity is too strong to be opposed by electron degeneracy pressure

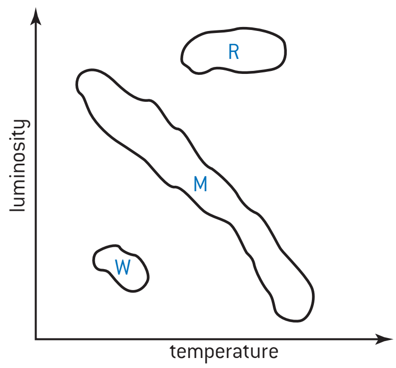
(ii) star can throw off mass to form planetary nebula

4. a) total power radiated by a star

b)



c)



d) luminosity also depends on size of star

5. a) A & D are main sequence stars; B is red giant; W is white dwarf

b) A and B have similar luminosities but A is far hotter. Luminosity is proportional to the area of the star and the temperature so if A is hotter than B must be larger.

c) luminosity of sun = $4\pi d^2 b$
from HR diagram, luminosity of B = $10^6 \times L_{Sun} = 3.6 \times 10^{33}$ W

$d_B = \sqrt{\frac{L_B}{4\pi b}} = 6.4 \times 10^{19}\text{ m} = 700\text{ pc}$

6. a) thermal radiation left over from the Big Bang – universe shows spectrum of blackbody emitter at around 3 K

b) CMB is isotropic (looks the same in all directions), provides evidence of the high temperature early universe that cooled as it expanded

7. a) lines from distant galaxy are red-shifted as galaxy is receding away from us

b) Hubble's law: $v = H_0 d$; can estimate v by determining redshift and so estimate distance d.

c) more accurate techniques exist, such as using Cepheid variables

8. a) Milky Way is a spiral galaxy and contains more gas and dust than elliptical galaxies

b) (i) $v = H_0 d$

(ii) To measure Hubble constant, plot graph of v against d. v can be obtained by measuring redshift of galaxies; d can be determined using Cepheid variables

c) (i) $v = 68\,000 \times 4.6 = 313 \text{ km s}^{-1}$

(ii) age of universe $= H_0^{-1} = 4.5 \times 10^{17}$ s

9. a) an intergalactic cloud of gas and dust where all stars begin to form

b) Jeans criterion is met when gravitational attraction within a gas is strong enough to overcome radiation pressure and begin forming a star

10. a) proton-proton chain: three stage chain, using four hydrogen nuclei and producing He-4 as a product

b) CNO cycle: six-stage process, also uses four hydrogen nuclei, uses carbon-12 as a fuel. C-12 and He-4 produced.

11. a) (i) Neutrons are captured by the nucleus of other atoms through the strong force, producing a heavier isotope of the same element.

(ii) ${}^{A}_{Z}A + {}^{1}_{0}n \rightarrow {}^{A+1}_{Z}B$

b) s-process: slow neutron capture; stars provide small neutron flux as a by-product of carbon, oxygen and silicon burning; nuclides have time to undergo beta decay before further neutron captures so produce heavier and heavier isotopes of element

r-process: not enough time for beta decay to occur so successively heavier isotopes are built up very quickly; high neutron flux

12. Massive stars need higher core temperatures and pressures to prevent gravitational collapse, and so fusion reactions occur at a greater rate than smaller stars.

13. After a star goes supernova, left with a white dwarf: gravity is opposed by electron degeneracy pressure. However, if the star is greater than the Chandrasekhar limit, electron degeneracy pressure is not strong enough to oppose gravity, and star collapses to form a neutron star, where gravity is instead opposed by neutron degeneracy pressure.

14. a) critical density is the necessary density of matter in the universe for it to expand to a maximum limit

b) (i) $1.3 \times 10^{-26} \text{ kg m}^{-3}$

(ii) number of nucleons per unit volume $= \dfrac{\rho_c}{m_p} = 7.8 \text{ m}^{-3}$

15. a) redshift of distant galaxies; CMB

b) necessary density of matter in the universe for it to expand to a maximum limit

c) fate of universe; big bang vs. big crunch

16. a) implies universe is open and will keep expanding forever

b) (i) evidence points to additional mass in universe; suggested that there is a dark matter *halo* surrounding the luminous matter in the universe which gives it extra mass

(ii) MACHOS: high density stars, hidden as they are far away from any luminous object
WIMPs: non-baryonic subatomic particles, weakly interacting with baryonic matter; need huge quantities to make up dark matter