RAFFLES INSTITUTION
2018 Preliminary Examination

PHYSICS	**9749/01**
Higher 2	
	25 September 2018
Paper 1 Multiple Choice Questions	**1 hour**

Additional Materials: OMR Form

READ THESE INSTRUCTIONS FIRST

Write in soft pencil.
Do not use staples, paper clips, glue or correction fluid.
Write your index number, name and class on the OMR Form in the spaces provided. Shade the appropriate boxes.

There are **thirty** questions on this paper. Answer **all** questions. For each question there are four possible answers **A, B, C** and **D**.
Choose the one you consider correct and record your choice **in soft pencil** on the OMR Form.

Read the instructions on the OMR Form very carefully.

Each correct answer will score one mark. A mark will not be deducted for a wrong answer.
Any rough working should be done in this booklet.
The use of an appropriate scientific calculator is expected, where necessary.

This document consists of **17** printed pages.

Data

speed of light in free space	c	=	3.00×10^{8} m s^{-1}
permeability of free space	μ_0	=	$4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space	ε_0	=	8.85×10^{-12} F m^{-1}
		=	$(1/(36\pi)) \times 10^{-9}$ F m^{-1}
elementary charge	e	=	1.60×10^{-19} C
the Planck constant	h	=	6.63×10^{-34} J s
unified atomic mass constant	u	=	1.66×10^{-27} kg
rest mass of electron	m_e	=	9.11×10^{-31} kg
rest mass of proton	m_p	=	1.67×10^{-27} kg
molar gas constant	R	=	8.31 J K^{-1} mol^{-1}
the Avogadro constant	N_A	=	6.02×10^{23} mol^{-1}
the Boltzmann constant	k	=	1.38×10^{-23} J K^{-1}
gravitational constant	G	=	6.67×10^{-11} N m^{2} kg^{-2}
acceleration of free fall	g	=	9.81 m s^{-2}

Formulae

uniformly accelerated motion	s	=	$ut + \frac{1}{2}at^2$
	v^2	=	$u^2 + 2as$
work done on/by a gas	W	=	$p\Delta V$
hydrostatic pressure	p	=	ρgh
gravitational potential	ϕ	=	$-Gm/r$
temperature	T/K	=	T / °C + 273.15
pressure of an ideal gas	p	=	$\frac{1}{3}\frac{Nm}{V}\langle c^2 \rangle$
mean translational kinetic energy of an ideal gas molecule	E	=	$\frac{3}{2}kT$
displacement of particle in s.h.m.	x	=	$x_0 \sin\omega t$
velocity of particle in s.h.m.	v	=	$v_0 \cos\omega t = \pm\omega\sqrt{x_0^2 - x^2}$
electric current	I	=	$Anvq$
resistors in series	R	=	$R_1 + R_2 + \ldots$
resistors in parallel	$1/R$	=	$1/R_1 + 1/R_2 + \ldots$
electric potential	V	=	$\frac{Q}{4\pi\varepsilon_0 r}$
alternating current/voltage	x	=	$x_0 \sin\omega t$
magnetic flux density due to a long straight wire	B	=	$\frac{\mu_0 I}{2\pi d}$
magnetic flux density due to a flat circular coil	B	=	$\frac{\mu_0 NI}{2r}$
magnetic flux density due to a long solenoid	B	=	$\mu_0 nI$
radioactive decay	x	=	$x_0 \exp(-\lambda t)$
decay constant	λ	=	$\frac{\ln 2}{t_{\frac{1}{2}}}$

1 The density of a liquid is calculated by measuring its mass and its volume. The measurements taken are as shown.

$$\text{mass of beaker} = (20 \pm 1)\ \text{g}$$

$$\text{mass of beaker and liquid} = (70 \pm 1)\ \text{g}$$

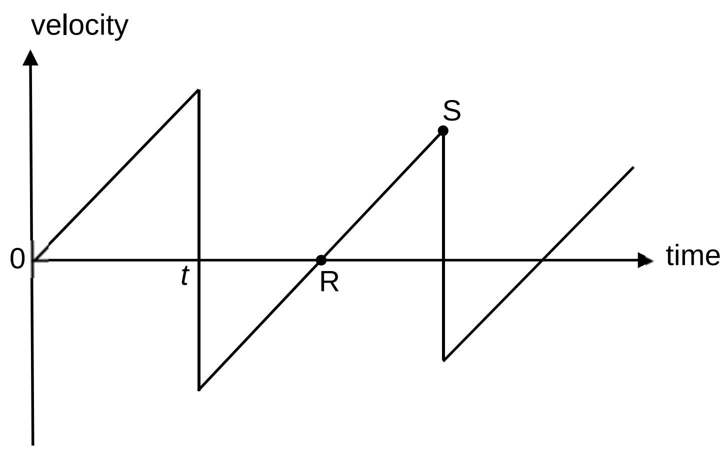
$$\text{volume of liquid} = (10.0 \pm 0.6)\ \text{cm}^3$$

The density of the liquid calculated is 5.0 g cm^{-3}.

What is the uncertainty in this value of density?

A 0.1 g cm^{-3} **B** 0.4 g cm^{-3} **C** 0.5 g cm^{-3} **D** 2.6 g cm^{-3}

2 A ball released from rest above a hard, horizontal surface undergoes several bounces. The graph shows the variation with time of the velocity of the bouncing ball.

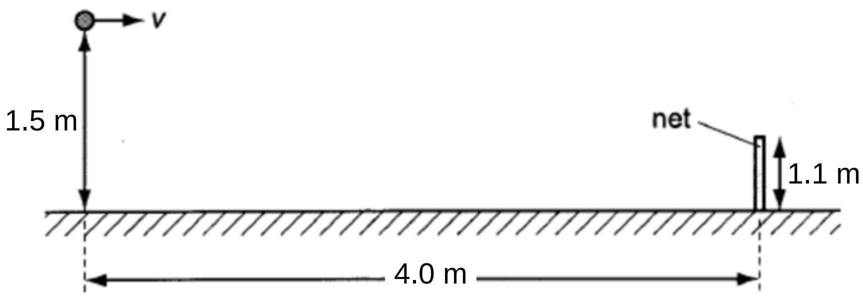


The time taken for the ball to first reach the ground after release is *t*. With each bounce, the ball loses $\frac{7}{16}$ of the kinetic energy it has just before the bounce.

Assuming air resistance is negligible, which of the following gives the time duration, in terms of *t*, between points R and S on the graph?

A 0.44 *t* **B** 0.56 *t* **C** 0.66 *t* **D** 0.75 *t*

3 In a junior tennis match, a player hits an incoming tennis ball such that it leaves his racket horizontally with speed v as shown.

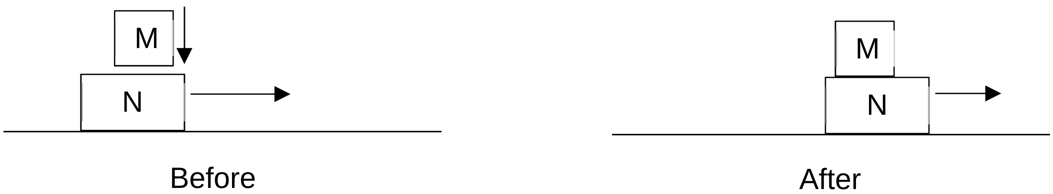


The tennis ball is hit at a height of 1.5 m above the ground and 4.0 m from the net. It just clears the net, which is 1.1 m high. Neglect the effects of air resistance.

What is the value of v?

A 7.2 m s^{-1} **B** 8.4 m s^{-1} **C** 14 m s^{-1} **D** 49 m s^{-1}

4 Mass M is dropped gently onto another mass N that is initially sliding on a smooth horizontal surface at constant velocity. After landing, the two masses move forward as one body as shown.



Which of the following statements regarding the two masses is incorrect?

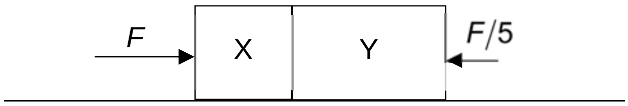
A The total mechanical energy of the two masses is conserved because they move with the same velocity after the collision.

B Mass N slows down during the collision because M exerts a decelerating force on N.

C The total horizontal momentum of the two masses is conserved because the resultant horizontal force acting on them is zero.

D There is heat produced in the collision because the collision is inelastic.

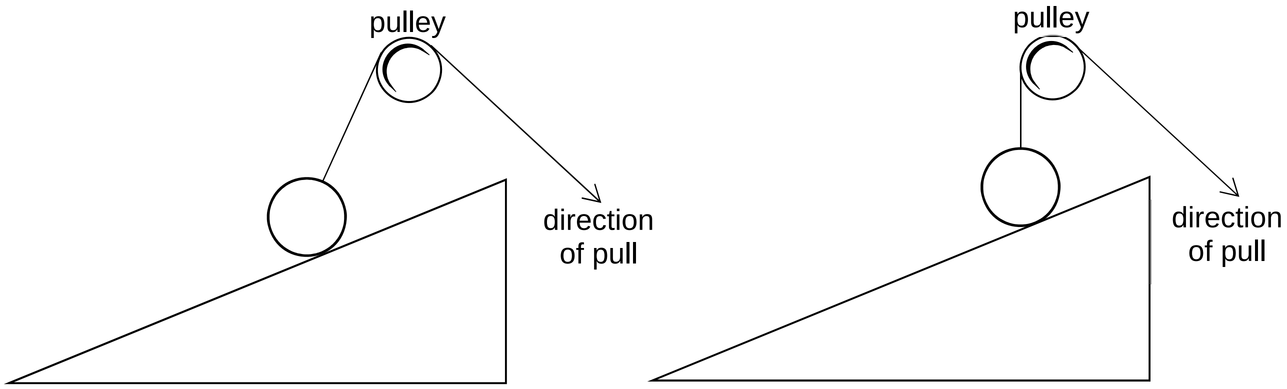
5 Two blocks X and Y, of masses m and $3m$ respectively, are placed in contact on a smooth horizontal surface. Forces F and $F/5$ are applied on either side of the blocks as shown.



What is the magnitude of the force exerted by block X on block Y during their subsequent motion?

A $\frac{F}{5}$ **B** $\frac{3F}{5}$ **C** $\frac{3F}{4}$ **D** $\frac{4F}{5}$

6 A sphere resting on a smooth inclined plane is tied to a string that loops over a pulley as shown in Fig. (a).



Initial position Final position

Fig. (a) **Fig. (b)**

The string is slowly pulled until the end connected to the sphere becomes vertical as shown in Fig. (b). At this instant, the forces acting on the sphere are

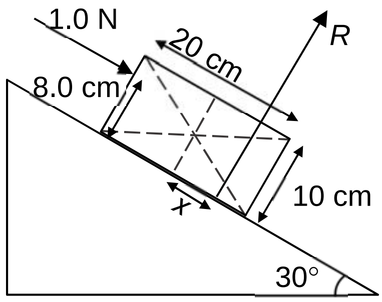
A weight, tension and normal reaction.

B weight and tension.

C weight and normal reaction.

D tension and normal reaction.

7 A uniform rectangular block of dimensions 20 cm by 10 cm and weight 5.0 N is placed on a rough surface inclined at 30° to the horizontal. A force of 1.0 N parallel to the surface is then applied on the block 8.0 cm from its base.



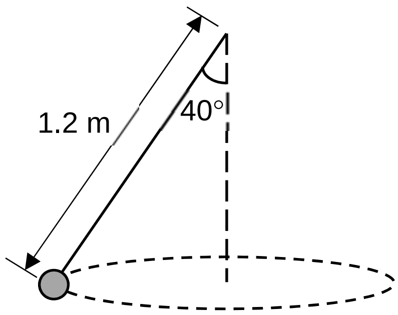
Given that the block remains in equilibrium, what is the distance *x* between the line of action of the normal contact force *R* exerted by the surface on the block and the centre of the block?

A 0.7 cm **B** 1.8 cm **C** 2.9 cm **D** 4.7 cm

8 It takes 4.0 J of work to stretch a spring 10 cm from its unstretched length. Given that the spring obeys Hooke's Law, what is the additional work required to stretch it a further 10 cm?

A 4.0 J **B** 6.0 J **C** 12 J **D** 16 J

9 A simple pendulum of length 1.2 m is swung such that the mass goes round in a uniform circular motion in the horizontal plane. The string makes an angle of 40° with the vertical.



What is the speed of the mass in its circular path?

A 2.5 m s^{-1} **B** 2.8 m s^{-1} **C** 3.0 m s^{-1} **D** 3.3 m s^{-1}

10 A satellite is moved from a circular orbit of radius R_1 around the Earth to a new circular orbit of radius R_2 where $R_2 > R_1$.

What happens to its gravitational potential energy and kinetic energy?

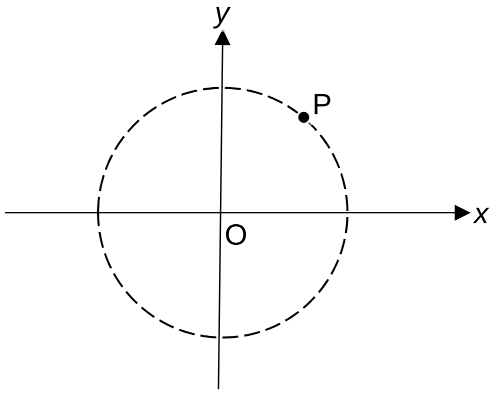
	potential energy	kinetic energy
A	increases	decreases
B	decreases	decreases
C	increases	increases
D	decreases	increases

11 The ratio of the densities and the ratio of the radii of Planet X to Planet Y are $\frac{9}{4}$ and $\frac{3}{1}$ respectively.

What is the ratio $\dfrac{\text{escape speed from the surface of Planet X}}{\text{escape speed from the surface of Planet Y}}$?

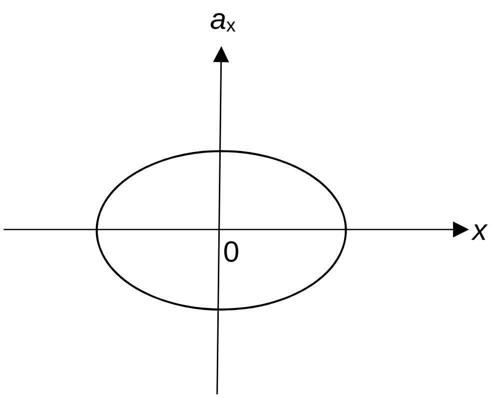
A 0.578 **B** 2.60 **C** 4.50 **D** 13.5

12 A particle P performs uniform circular motion about the origin O in the x-y plane as shown.

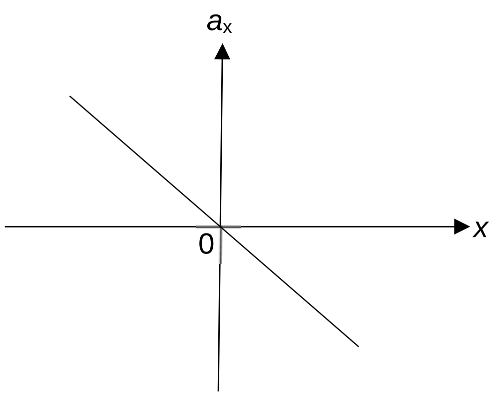


Which of the following graphs shows the relationship between the *x*-component of the acceleration a_x and the displacement in the *x*-direction?

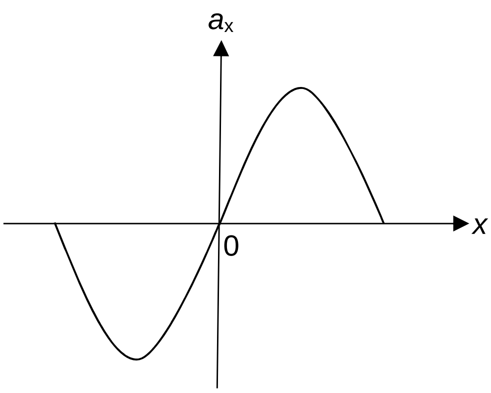
A



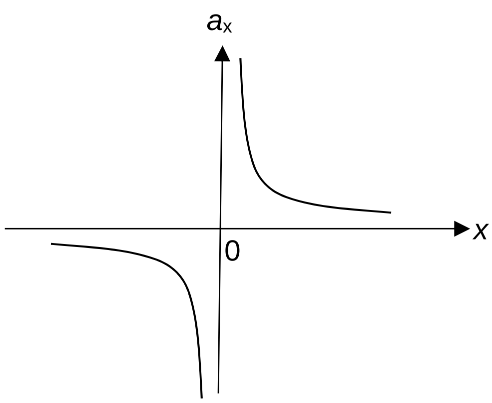
B



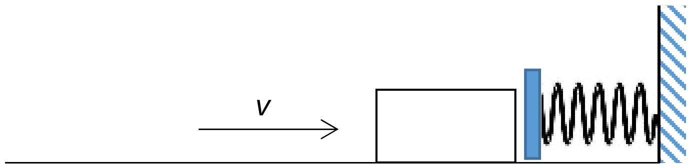
C



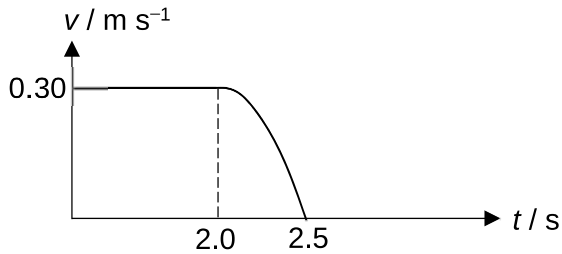
D



13 A block of mass 0.500 kg sliding on a smooth table at 0.30 m s^{-1} collides with a board attached to a spring which obeys Hooke's Law.



The graph shows the variation with time *t* of the velocity *v* of the block up to the moment just before it reverses its motion.

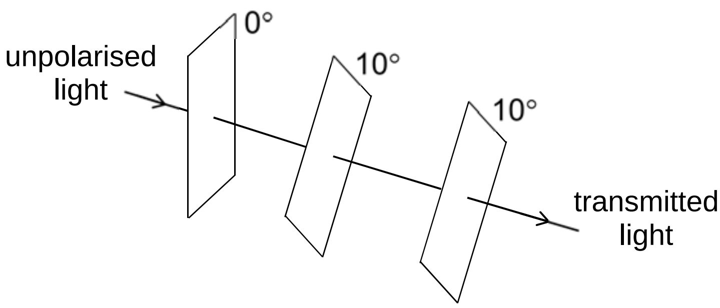


Given that the magnitude of the acceleration of the block is directly proportional to the compression of the spring, what is the maximum compression experienced by the spring?

A 0.024 m **B** 0.075 m **C** 0.095 m **D** 0.94 m

14 A narrow, parallel beam of unpolarised light is directed towards three ideal polarising filters.

The beam meets the first filter with its axis of polarisation vertical. The axis of polarisation of the second filter is at an angle of 10° to the first filter. The third filter has its axis of polarisation parallel to the second filter as shown.

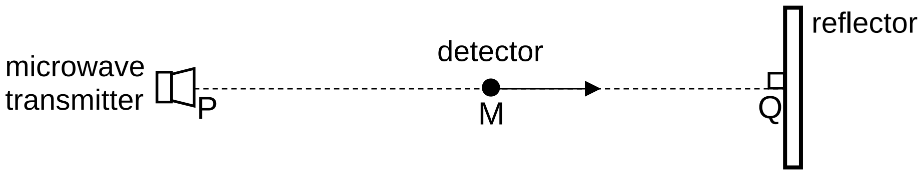


The third filter is now turned.

At what angle must the third filter be with respect to the second filter so that the intensity of the transmitted light is reduced to one-third of the intensity of the unpolarised light?

A 34° **B** 44° **C** 47° **D** 54°

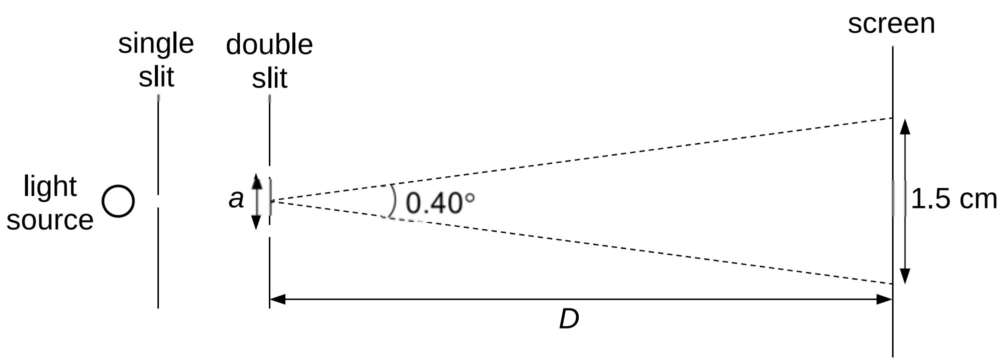
15 A microwave transmitter emits waves that are incident normally on a reflector. A microwave detector is initially at the point M where it detects a maximum intensity. As it moves along the line PQ towards Q, the detector picks up a series of maximum and minimum intensity signals.



If the detector moves with a speed of 2.0 m s^{-1} and the frequency at which maximum intensity signals are picked up is 10 Hz, what is the distance moved by the detector from its initial position at M when it detects the first minimum intensity signal?

A 0.05 m **B** 0.10 m **C** 0.20 m **D** 0.40 m

16 A two-source interference experiment is set-up as shown. The light source emits light of wavelength 600 nm. The distance between the second order bright fringes on the screen is 1.5 cm and their angular separation is $0.40°$.



What are the values of the slit separation *a* and the distance *D* between the double slits and the screen?

	a / mm	*D* / m
A	0.17	1.1
B	0.34	1.1
C	0.17	2.1
D	0.34	2.1

17 The root-mean-square (r.m.s.) speed of the molecules of a fixed mass of an ideal gas at a certain temperature is *c*. If the pressure is increased by 25% while its volume is decreased by 25%, what will be the r.m.s. speed of the molecules?

A 0.88 *c* **B** 0.94 *c* **C** 0.97 *c* **D** *c*

18 A frictionless and well-insulated bicycle pump is used to inflate a basketball. After several compression cycles, the air in the basketball becomes warmer than the surrounding air.

Which one of the following statements best explains this observation?

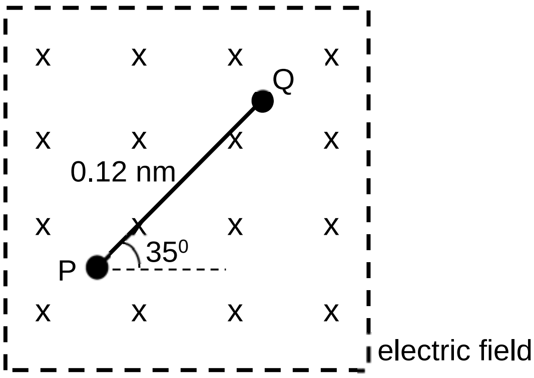
A The air molecules collide with the inner wall of the basketball more frequently.

B Work is done on the air in the basketball and the internal energy remains unchanged.

C The internal energy of air in the basketball increases as work is done on the air and thermal energy is supplied to it.

D Work is done on the air in the basketball and since little thermal energy escapes, the internal energy increases.

19 Two ions P and Q, of charge +*e* and –*e* respectively, are linked to form a molecule and placed in a uniform electric field that is directed into the page. The distance between P and Q is 0.12 nm. The electric field strength is 4200 V m^{-1}.



Which of the following gives the resultant force and initial torque on the molecule?

	resultant force / N	torque / Nm
A	1.3×10^{-15}	4.6×10^{-26}
B	1.3×10^{-15}	8.1×10^{-26}
C	0	4.6×10^{-26}
D	0	8.1×10^{-26}

20 An oil-drop of mass m, carrying a charge q, is in the region between two horizontal plates. When the potential difference between the upper and lower plates is V, the oil-drop is stationary. The potential difference is then increased to $2V$.

What is the initial upward acceleration of the oil-drop? Assume negligible upthrust.

A g **B** $2g$ **C** $\dfrac{2qV}{m} - g$ **D** $\dfrac{2qV}{m}$

21 A potential difference of 6 V is applied across a resistor for a time interval of 10 s. The current flowing through the resistor is 2 A.

Which of the following statements is incorrect?

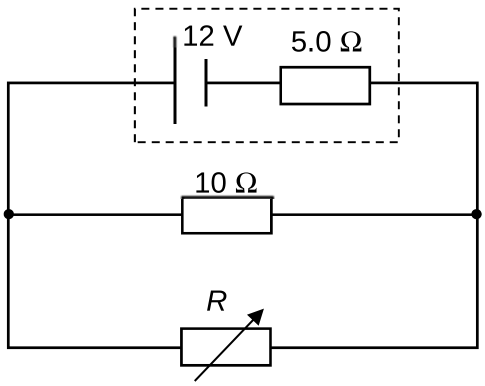
A The resistance of the resistor is 3 Ω.

B The energy dissipated in the resistor is 12 J.

C The charge passing through the resistor is 20 C.

D The potential difference across the resistor is 6 J C^{-1}.

22 A battery of e.m.f. 12 V and internal resistance 5.0 Ω is connected to a fixed resistor of resistance 10 Ω and a variable resistor of resistance R as shown. The battery delivers maximum power to the external resistance when the external resistance is equal to the internal resistance of the battery.



What is the value of R and the power dissipated across the 10 Ω fixed resistor when maximum power is delivered?

	R / Ω	P / W
A	5.0	7.2
B	10	3.6
C	10	14
D	5.0	3.6

23 Fig. (a) shows the top view of two long parallel wires, wire X and wire Y, carrying currents I_X and I_Y respectively in a direction perpendicular to the plane of the paper. The distance between wire X and wire Y is *L*.

Fig. (b) shows the variation of the net magnetic field at distances to the right of wire Y along the line joining wire X and wire Y. At a distance *d* from wire Y, the net magnetic field is zero.

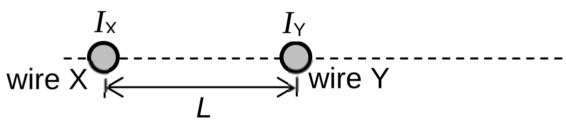


Fig. (a) top view (not to scale)

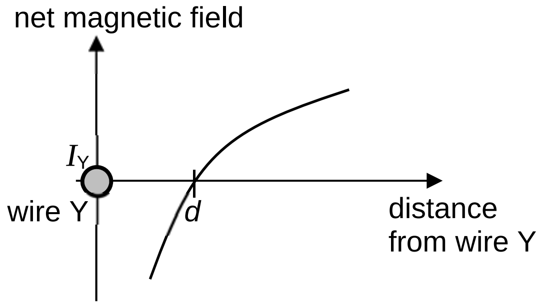


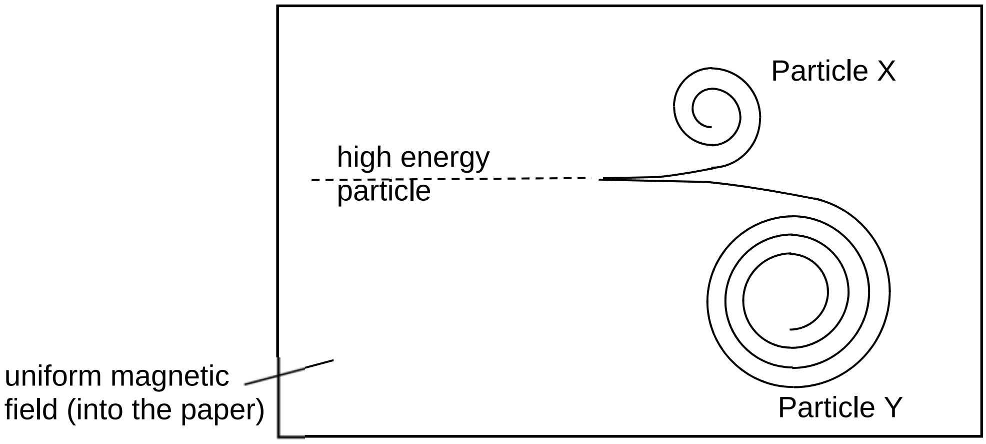
Fig. (b)

Given that the ratio $\frac{I_X}{I_Y}$ is 4.00 and taking the upwards direction to be positive, which of the following gives the relative direction of I_X and I_Y and the value of *L* in terms of *d*?

	relative direction of I_X and I_Y	*L* in terms of *d*
A	I_X and I_Y flow in opposite directions	*d*
B	I_X and I_Y flow in the same direction	*d*
C	I_X and I_Y flow in opposite directions	3*d*
D	I_X and I_Y flow in the same direction	3*d*

24 A high energy particle which carries no charge enters a region of uniform magnetic field directed into the paper. The particle subsequently disintegrates to form two particles X and Y which have the same mass and same magnitude of charge.

The paths of X and Y are shown in the diagram and the initial radius of Y is twice the initial radius of X.



Which of the following statements is correct?

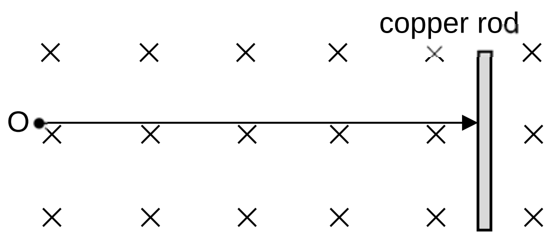
A Particle X is negatively charged, particle Y is positively charged.

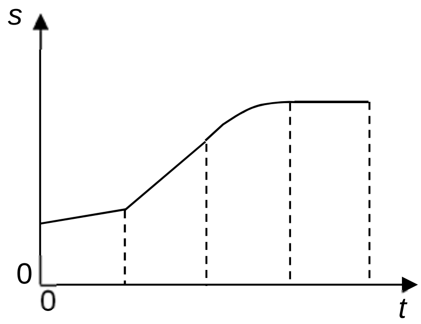
B The ratio of the initial kinetic energy of particle X to particle Y is 0.25.

C The speeds of both particles are increasing steadily.

D Particle X has a larger momentum than particle Y.

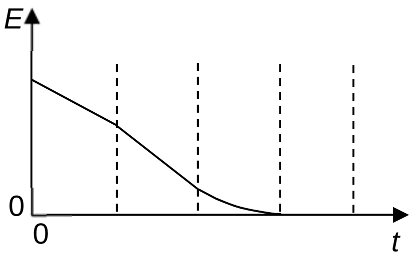
25 A copper rod is moved at right angles to a uniform magnetic field as shown in the diagram. The graph on the right shows the variation with time *t* of the displacement *s* of the copper rod from point O.



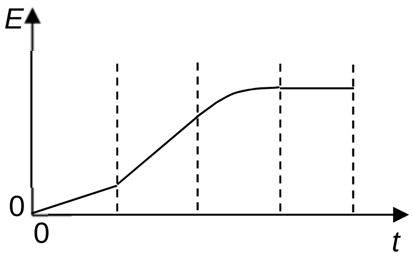


Which graph best shows the variation with time *t* of the e.m.f. *E* induced across the rod?

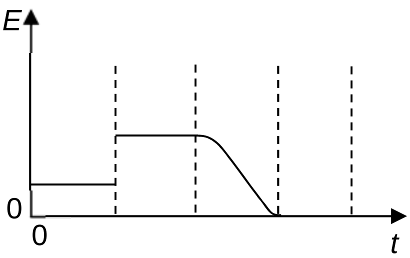
A



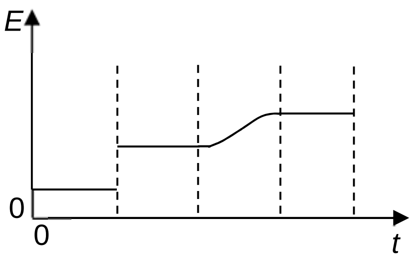
B



C



D



26 A heater is connected to a 110 V sinusoidal alternating current and it dissipates energy at a mean rate of 800 W. The same heater, with its resistance unchanged, is then connected to a 156 V d.c. supply.

At what rate does the heater dissipate energy now?

A 400 W **B** 800 W **C** 1100 W **D** 1600 W

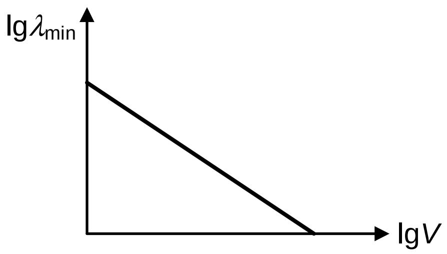
27 Light of wavelength λ strikes a photo-sensitive surface and electrons are ejected with maximum kinetic energy E. If the maximum kinetic energy is to be increased to $2E$, the wavelength must be changed to λ' where

A $\lambda' = \lambda/2$ **B** $\lambda/2 < \lambda' < \lambda$ **C** $\lambda < \lambda' < 2\lambda$ **D** $\lambda' = 2\lambda$

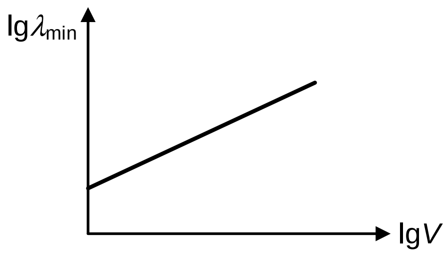
28 Electrons accelerated from rest by a potential difference V are directed to hit a metallic target to produce X-rays. It produces continuous as well as characteristic X-rays.

If λ_{min} is the shortest possible wavelength of X-ray in the spectrum, which of the following shows the variation with $\lg V$ of $\lg \lambda_{min}$?

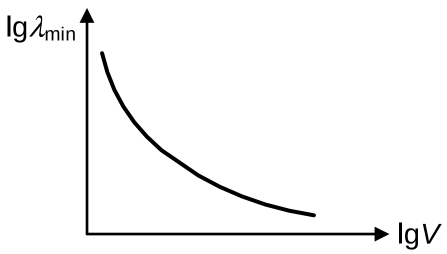
A



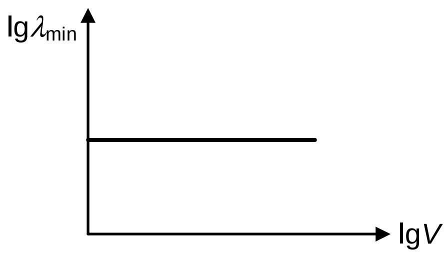
B



C



D



29 1 g of a sample which contains radioactive nuclei is left in the laboratory for 4 days. The radioactive nuclei emit β radiation and have a half-life of 2 days.

What is the mass of the sample at the end of that period?

A $\frac{1}{16}$ g

B $\frac{1}{8}$ g

C $\frac{1}{4}$ g

D slightly less than 1 g

30 The following process shows a stationary isotope of boron when capturing a slow moving neutron, splits to become a lithium isotope and an alpha particle.

$$^{10}_{5}\text{B} + ^{1}_{0}\text{n} \rightarrow ^{7}_{3}\text{Li} + ^{4}_{2}\text{He}$$

γ-ray is emitted in the process.

The nuclear binding energies are:

$^{10}_{5}\text{B}$: 64.94 MeV
$^{7}_{3}\text{Li}$: 39.25 MeV
$^{4}_{2}\text{He}$: 28.48 MeV

What is the energy of the γ-ray emitted, given that the total kinetic energy of $^{7}_{3}\text{Li}$ and $^{4}_{2}\text{He}$ is 2.31 MeV?

A 0.48 MeV

B 2.79 MeV

C 25.69 MeV

D 260.73 MeV

End of Paper 1

2018 Raffles Institution Preliminary Examinations – H2 Physics

Paper 1 Answers

1	C	**6**	B	**11**	C	**16**	D	**21**	B	**26**	D
2	D	**7**	D	**12**	B	**17**	C	**22**	B	**27**	B
3	C	**8**	C	**13**	C	**18**	D	**23**	C	**28**	A
4	A	**9**	A	**14**	A	**19**	D	**24**	B	**29**	D
5	D	**10**	A	**15**	B	**20**	A	**25**	C	**30**	A

Paper 1 Suggested Solutions

1 **C**

$$m_{Liq} = m_{Total} - m_{Beaker} = 70 - 20 = 50 \text{ g}$$

$$\text{V}m_{Liq} = \text{V}m_{Total} + \text{V}m_{Beaker} = 1 + 1 = 2 \text{ g}$$

$$\rho = \frac{m_{Liq}}{V_{Liq}}$$

$$\frac{\Delta\rho}{\rho} = \frac{\Delta m_{Liq}}{m_{Liq}} + \frac{\Delta V_{Liq}}{V_{Liq}} = \frac{2}{50} + \frac{0.6}{10.0}$$

$$\Delta\rho = \left(\frac{2}{50} + \frac{0.6}{10.0}\right)(5.0) = 0.5 \text{ g cm}^{-3} \text{ (1 s.f.)}$$

2 **D**

After first bounce,

$$KE_{left} = \left(1 - \frac{7}{16}\right)KE_{initial} = \frac{9}{16}KE_{initial} = \left(\frac{3}{4}\right)^2 \frac{1}{2}mv_0^2 = \frac{1}{2}m\left(\frac{3}{4}v_0\right)^2$$

where v_0 is the speed just before the ball hits the ground

If the height of the second triangle is now $\frac{3}{4}v_0$, time duration of the second triangle is $\frac{3}{4}t = 0.75t$ (due to similar triangles). Since air resistance is negligible, the time taken by the ball to move up after the first bounce is the same as the time taken to move down to the ground again.

OR

Since air resistance is negligible, the gradient of the velocity-time graphs will all be the same with the value of *g*.

$$\frac{v_0}{t} = g \quad \Rightarrow \quad v_0 = gt$$

$$KE_{left} = \left(1 - \frac{7}{16}\right)KE_{initial} = \frac{9}{16}KE_{initial} = \left(\frac{3}{4}\right)^2 \frac{1}{2}mv_0^2 = \frac{1}{2}m\left(\frac{3}{4}v_0\right)^2$$

speed after bounce, $v_1 = \frac{3}{4}v_0$

$$\text{V}t = \frac{v_1}{g} = \left(\frac{3}{4}v_0\right)\left(\frac{1}{g}\right) = \left(\frac{3}{4}gt\right)\left(\frac{1}{g}\right) = \frac{3}{4}t = 0.75t$$

3 **C** Horizontal motion:

$$s_x = vt$$

$$t = \frac{s_x}{v} = \frac{4.0}{v}$$

Vertical motion:

$$s_y = \frac{1}{2}gt^2$$

$$1.5 - 1.1 = \frac{1}{2}g\left(\frac{4.0}{v}\right)^2$$

$$v = 14 \text{ m s}^{-1}$$

4 **A** This is a completely inelastic collision. Hence, total mechanical energy is **not** conserved.

5 **D** By Newton's second law,

net force, $F - \frac{F}{5} = (m + 3m)a$

$$a = \left(\frac{4}{5}F\right)\left(\frac{1}{4m}\right) = \frac{F}{5m}$$

Consider the forces acting on Y:

$$F_{XY} - \frac{F}{5} = 3m \times \frac{F}{5m}$$

$$F_{XY} = \left(3m \times \frac{F}{5m}\right) + \frac{F}{5} = \frac{4F}{5}$$

6 **B** There cannot be any normal reaction when the sphere is in equilibrium because it will be the only force with a horizontal component that is not balanced.

7 **D** Taking moments about the point on the base of the block through which R acts,

$$(5.0\cos 30^\circ)x = (5.0\sin 30^\circ)\left(10/2 \times 10^{-2}\right) + 1.0\left(8.0 \times 10^{-2}\right)$$

$$x = 0.0473 \text{ m} = 4.7 \text{ cm}$$

8 **C** Work done to stretch it 10 cm:

$$\frac{1}{2}k(0.10)^2 = 4.0$$

$$k = 800 \text{ N m}^{-1}$$

Work done to stretch it 20 cm:

$$\frac{1}{2}(800)(0.20)^2 = 16$$

Additional work required = 16 – 4 = 12 J

9 **A** $T\cos 40^\circ = mg$ --- (1)

$T\sin 40^\circ = \frac{mv^2}{1.2\sin 40^\circ}$ --- (2)

$$\frac{(2)}{(1)} \quad \tan 40^\circ = \frac{v^2}{g \times 1.2\sin 40^\circ} \quad \Rightarrow \quad v = 2.5 \text{ m s}^{-1}$$

10 **A** The equations for potential energy and kinetic energy are given by :

$$E_p = -\frac{GMm}{R} \text{ and } E_k = \frac{GMm}{2R}$$

As R increases, E_p increases (becomes less negative) and E_k decreases.

11 **C** For a body to escape a planet's gravitational influence from its surface:

$$-\frac{GMm}{R} + \frac{1}{2}mv^2 \geq 0 \Rightarrow v_{escape} = \sqrt{\frac{2GM}{R}}$$

and since $M = \frac{4}{3}\rho\pi R^3$

$$v_{escape} = \sqrt{\frac{2G\left(\frac{4}{3}\rho\pi R^3\right)}{R}} = \sqrt{\frac{8G\rho\pi R^2}{3}}$$

$$v_{escape} \propto R\sqrt{\rho}$$

$$\therefore \frac{v_{escape,X}}{v_{escape,Y}} = \frac{R_x\sqrt{\rho_x}}{R_Y\sqrt{\rho_Y}} = \frac{R_x}{R_y}\sqrt{\frac{\rho_x}{\rho_Y}} = \left(\frac{3}{1}\right)\sqrt{\left(\frac{9}{4}\right)} = \frac{9}{2} = 4.50$$

12 **B** The components of the particle's motion in the horizontal x-direction is simple harmonic. Hence $a \propto -x$.

13 **C** Between 2.0 s and 2.5 s, the block is in contact with the spring and its motion is simple harmonic i.e. the graph is ¼ of a cosine graph.

Period when block is in SHM = 4 × 0.5 s = 2.0 s
$\Rightarrow \omega = 2\pi/T = 3.14$ rad s^{-1}

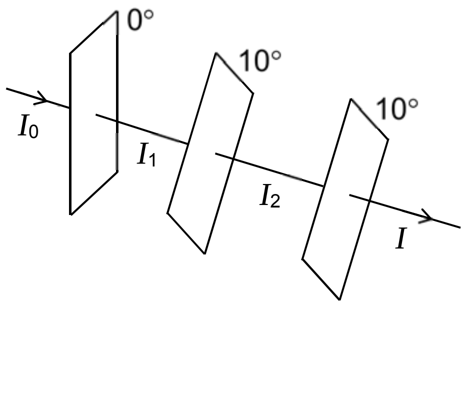
$$x_o = v_o/\omega = 0.30/\pi = 0.095 \text{ m}$$

14 **A** Using Malus' law,

$$I_2 = I_1\cos^2 10° = \frac{1}{2}I_0\cos^2 10°$$

$$I = I_2\cos^2\theta$$

where θ is the angle between the axes of polarisation of the second and third filters



$$I = I_2\cos^2\theta = \frac{1}{2}I_0\cos^2 10°\cos^2\theta$$

$$\frac{1}{3}I_0 = \frac{1}{2}I_0\cos^2 10°\cos^2\theta$$

$$\theta = \cos^{-1}\sqrt{\frac{2}{3\cos^2 10°}} = 33.99 = 34°$$

15 **B**

distance travelled in 1 s = $10\times\frac{1}{2}\lambda$

time taken to travel $\frac{1}{2}\lambda=\frac{1}{10}$ s

distance = speed $\times$ time

$$\frac{1}{2}\lambda=2.0\times\frac{1}{10}$$

$$\lambda=2\left(2.0\times\frac{1}{10}\right)=0.40\text{ m}$$

At initial position M, detector detects maximum intensity (antinode).
Minimum intensity detected will be ¼ wavelength away (node).

$$\text{distance moved}=\frac{1}{4}\lambda=\frac{1}{4}(0.40)=0.10\text{ m}$$

16 **D**

$$\tan\left(\frac{0.40°}{2}\right)=\frac{1.5\times10^{-2}}{2D}$$

$$D=\frac{1.5\times10^{-2}}{2\tan\left(\frac{0.40°}{2}\right)}=2.1\text{ m}$$

$$a\sin\theta=2\lambda$$

$$a=\frac{2\left(600\times10^{-9}\right)}{\sin\left(\frac{0.40°}{2}\right)}=3.44\times10^{-4}=0.34\text{ mm}$$

OR

$$x=\frac{\lambda D}{a}$$

$$a=\frac{\lambda D}{x}=\frac{600\times10^{-9}\times2.1}{\left(1.5\times10^{-2}\right)/4}=0.34\text{ mm}$$

17 **C**

$$\frac{P_1V_1}{T_1}=\frac{P_2V_2}{T_2}$$

$$T_2=P_2V_2\left(\frac{T_1}{P_1V_1}\right)=(1.25P)(0.75V_1)\left(\frac{T_1}{P_1V_1}\right)=0.9375T_1$$

$$E_K=\frac{1}{2}mc^2=\frac{3}{2}kT$$

$$c^2\propto T\quad\Rightarrow\quad c\propto\sqrt{T}$$

$$c_2=\sqrt{\frac{T_2}{T_1}}c=\sqrt{\frac{0.9375T_1}{T_1}}c=0.97c$$

18 **D** For a fixed mass of gas in the pump and basketball,

$$\Delta U=W+Q$$

Compression implies W > 0. Well-insulated pump/basketball implies $Q\approx0$.
Hence, ΔU > 0 (increases) and the temperature of the gas increases.

19 **D** Electric force acting on ion P is eE (in direction of the E field), and that acting on ion Q is also eE (but in the opposite direction to the E field).

Resultant force on the molecule is therefore zero.

$$\begin{aligned}\text{Torque of couple} &= Fd \\ &= qEd \\ &= \left(1.60\times10^{-19}\right)(4200)\left(0.12\times10^{-9}\right) \\ &= 8.1\times10^{-26}\text{ Nm}\end{aligned}$$

20 **A** When oil drop is at equilibrium, $qE = mg$

$$q\frac{V}{d} = mg$$

When p.d. is 2V, net force $= q\dfrac{2V}{d} - mg$

$$\begin{aligned}&= 2mg - mg \\ &= mg \quad \text{(upwards)}\end{aligned}$$

Upward acceleration is thus g.

21 **B** $E = IVt = 2\times6\times10 = 120$ J

22 **B** Effective external resistance for max. power delivered = 5 Ω

$$\frac{1}{R}+\frac{1}{10}=\frac{1}{5}$$

$$\therefore R = 10\ \Omega$$

Potential difference across the 10 Ω resistor

$$= \frac{5}{10}(12) = 6\text{ V}$$

$$P = \frac{V^2}{R} = \frac{6^2}{10} = 3.6\text{ W}$$

23 **C** At d, the net field due to both wires is zero.
Hence the magnetic flux density of each wire is equal in magnitude and opposite in directions. This means I_X and I_Y are in opposite directions.

$$B_X = B_Y$$

$$\frac{\mu_o I_X}{2\pi(L+d)} = \frac{\mu_o I_Y}{2\pi d}$$

$$\frac{I_X}{I_Y} = \frac{L+d}{d} = 4.00$$

$$L = 3d$$

24 **B** Since both X and Y have the same mass to charge ratio,

$$\frac{KE_X}{KE_Y} = \left(\frac{v_X}{v_Y}\right)^2 = \left(\frac{R_X}{R_Y}\right)^2 = \left(\frac{1}{2}\right)^2 = 0.25$$

25 **C** Since $|E| = BLv = BL\dfrac{ds}{dt}$, the magnitude of E can be deduced from the gradient of the s-t graph.

26 **D** Resistance of heater $R = \dfrac{{V_{AC}}^2}{P} = \dfrac{110^2}{800} = 15.125\ \Omega$

Power dissipated when d.c. supply is used $= \dfrac{{V_{DC}}^2}{R} = \dfrac{156^2}{15.125} = 1609\ \text{W}$

27 **B** $\dfrac{hc}{\lambda} = E + \Phi$ and $\dfrac{hc}{\lambda'} = 2E + \Phi$

$\Rightarrow \quad \dfrac{\lambda'}{\lambda} = \dfrac{E+\Phi}{2E+\Phi}$

Since $\dfrac{1}{2} < \dfrac{E+\Phi}{2E+\Phi} < 1 \quad \Rightarrow \quad \lambda/2 < \lambda' < \lambda$

28 **A** Shortest wavelength

$\lambda_{\min} = \dfrac{hc}{eV}$

$\Rightarrow \quad \lg\lambda_{\min} = \lg\left(\dfrac{hc}{e}\right) - \lg V$

Graph of $\lg\lambda_{\min}$ against $\lg V$ is a straight line with negative gradient and positive intercept.

29 **D** The sample consists of the parent as well as the daughter nuclei.
β particles are electrons that have mass much smaller than that of the parent nuclei.
Hence the mass of the sample is only slightly smaller than its initial mass, differing only by the small mass of β particles emitted.

30 **A** energy released = (39.25) + (28.48) – (64.94) = 2.79 MeV
γ-ray energy = 2.79 – 2.31 = 0.48 MeV

Centre Number	Index Number	Name	Class
S3016			

RAFFLES INSTITUTION
2018 Preliminary Examination

PHYSICS **9749/02**
Higher 2

13 September 2018
Paper 2 Structured Questions **2 hours**

Candidates answer on the Question Paper.
No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your index number, name and class in the spaces at the top of this page.
Write in dark blue or black pen in the spaces provided in this booklet.
You may use pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.
The use of an approved scientific calculator is expected, where appropriate.

Answer **all** questions. The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use	
1	/ 15
2	/ 10
3	/ 12
4	/ 11
5	/ 12
6	/ 20
Deduction	
Total	/ 80

This document consists of **20** printed pages and **1** blank page.

Data

speed of light in free space	c	=	3.00×10^{8} m s^{-1}
permeability of free space	μ_0	=	$4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space	ε_0	=	8.85×10^{-12} F m^{-1}
		=	$(1/(36\pi)) \times 10^{-9}$ F m^{-1}
elementary charge	e	=	1.60×10^{-19} C
the Planck constant	h	=	6.63×10^{-34} J s
unified atomic mass constant	u	=	1.66×10^{-27} kg
rest mass of electron	m_e	=	9.11×10^{-31} kg
rest mass of proton	m_p	=	1.67×10^{-27} kg
molar gas constant	R	=	8.31 J K^{-1} mol^{-1}
the Avogadro constant	N_A	=	6.02×10^{23} mol^{-1}
the Boltzmann constant	k	=	1.38×10^{-23} J K^{-1}
gravitational constant	G	=	6.67×10^{-11} N m^{2} kg^{-2}
acceleration of free fall	g	=	9.81 m s^{-2}

Formulae

uniformly accelerated motion	s	=	$ut + \frac{1}{2}at^2$
	v^2	=	$u^2 + 2as$
work done on/by a gas	W	=	$p\Delta V$
hydrostatic pressure	p	=	ρgh
gravitational potential	ϕ	=	$-Gm/r$
temperature	T/K	=	T / °C + 273.15
pressure of an ideal gas	p	=	$\frac{1}{3}\frac{Nm}{V}\langle c^2 \rangle$
mean translational kinetic energy of an ideal gas molecule	E	=	$\frac{3}{2}kT$
displacement of particle in s.h.m.	x	=	$x_0 \sin\omega t$
velocity of particle in s.h.m.	v	=	$v_0 \cos\omega t = \pm\omega\sqrt{x_0^2 - x^2}$
electric current	I	=	$Anvq$
resistors in series	R	=	$R_1 + R_2 + \ldots$
resistors in parallel	$1/R$	=	$1/R_1 + 1/R_2 + \ldots$
electric potential	V	=	$\frac{Q}{4\pi\varepsilon_0 r}$
alternating current/voltage	x	=	$x_0 \sin\omega t$
magnetic flux density due to a long straight wire	B	=	$\frac{\mu_0 I}{2\pi d}$
magnetic flux density due to a flat circular coil	B	=	$\frac{\mu_0 NI}{2r}$
magnetic flux density due to a long solenoid	B	=	$\mu_0 nI$
radioactive decay	x	=	$x_0 \exp(-\lambda t)$
decay constant	λ	=	$\frac{\ln 2}{t_{\frac{1}{2}}}$

Answer **all** the questions in the spaces provided.

1 **(a)** **(i)** State Newton's Second Law of Motion as applied to a *system of bodies*.

....

....

.... [2]

(ii) Explain the implication of Newton's Second Law for a *system of bodies* isolated from all external forces.

....

....

.... [2]

(b) Two blocks A and B are held together with a light spring in between them as shown in Fig. 1.1. The spring has a force constant 80 N m^{-1} and is compressed by 0.060 m.

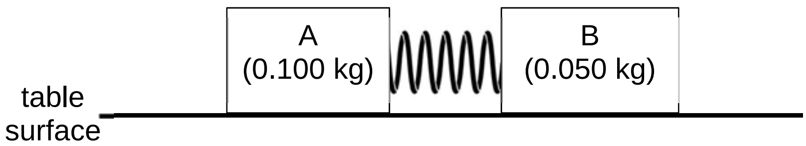


Fig. 1.1

The masses of blocks A and B are 0.100 kg and 0.050 kg respectively. Upon release, the two blocks move off in opposite directions on a smooth table surface and the spring falls off.

(i) On Fig. 1.2, sketch a graph to show the variation with time *t* of the force exerted by the spring on block B during which B is being pushed away from block A.

Fig. 1.2

[2]

(ii) Determine the final speeds of the two blocks.

speed of block A = ... m s^{-1}

speed of block B = ... m s^{-1} [4]

(c) As block B slides forward, it topples over at the edge of the table and lands on a horizontal uniform plank hinged to a wall at O. The centre of block B is at a horizontal distance of 0.15 m from the free end of the plank. The plank is supported by a rope attached to the wall as shown in Fig. 1.3.

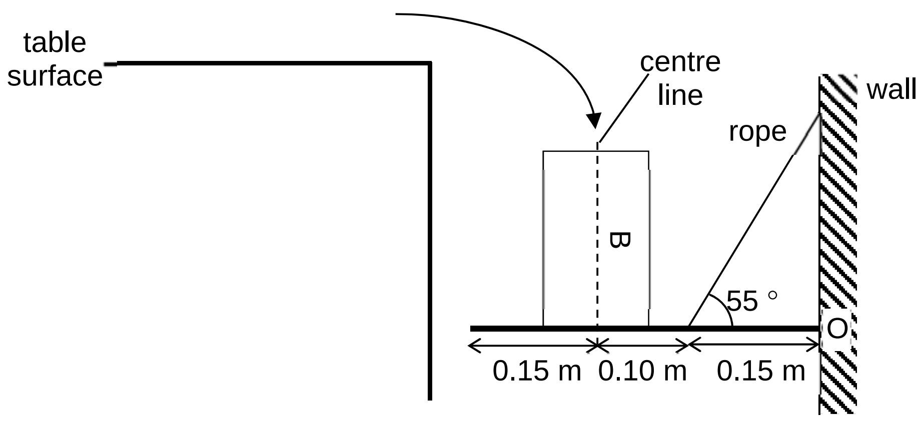


Fig. 1.3

Given that the weight of the plank is 4.0 N, calculate

(i) the tension in the rope after B is at rest on the plank,

tension = ... N [2]

(ii) the magnitude of the horizontal and vertical components of the force exerted by the hinge on the plank,

magnitude of horizontal component = ... N

magnitude of vertical component = ... N [2]

(iii) the angle θ that the force by the hinge on the plank makes with the horizontal.
On Fig. 1.3, draw and label the force *F* by the hinge and indicate the angle θ.

θ = ... ° [1]

2 **(a)** A speaker emits sound waves uniformly in all directions. Fig. 2.1 shows the variation with time t of the displacement x of an air molecule at a point Q that is 120 cm from the speaker.

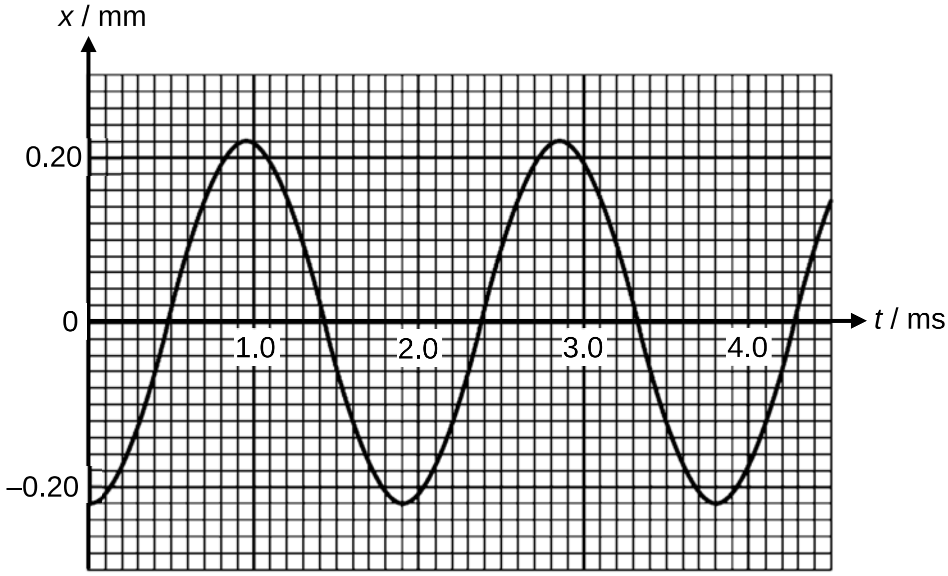


Fig. 2.1

(i) Use Fig. 2.1 to determine the

1. frequency f of the sound waves,

f = ... Hz [1]

2. uncertainty in f calculated in **(a)(i)1.** caused by reading the scale of the graph.

uncertainty in f = ... Hz [3]

(ii) Determine the next earliest time after 1.5 ms when the motion of the air molecule at Q has a phase difference of $\frac{4}{5}\pi$ compared to its phase at 1.5 ms.

time = ... ms [2]

(iii) If the power of the source is reduced to 0.25 of its initial value, calculate the distance from the speaker that will have the same intensity as that at point Q.

distance = ... cm [2]

(b) The wave arriving at point Q is progressive in nature. A stationary wave may be formed when two identical waves travelling in opposite directions superpose.

State the differences between the particles of a progressive wave and particles of a stationary wave in the following aspects:

(i) amplitude,

....

....

.... [1]

(ii) phase difference.

....

....

.... [1]

3 **(a)** Fig. 3.1 shows two chambers, X and Y, connected by a small pipe which is fitted with a valve. Both chambers are filled with ideal gas and the valve was initially closed. The volume of chambers X and Y are 2.5 m^3 and 4.0 m^3 respectively. Chambers X and Y are held at temperatures of 450 K and 300 K respectively.

The valve is then opened and a state of equilibrium is reached with the temperatures in each chamber remaining unchanged.

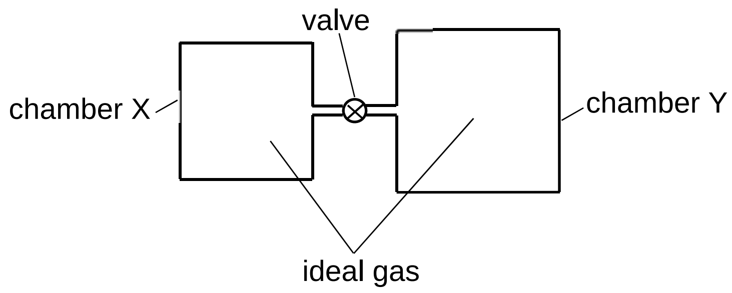


Fig. 3.1

(i) Determine the number of moles of ideal gas in chamber X, given that the number of moles of ideal gas in chamber Y is 1.2 after equilibrium has been reached.

number of moles of ideal gas in X = ... [2]

(ii) Calculate the pressure in both chambers after equilibrium has been reached.

pressure = ... Pa [1]

(iii) The valve is now closed and a pump is used to remove some ideal gas from chamber Y.

State and explain, using the kinetic theory of gas, why the pressure in chamber Y decreases, assuming no change in its temperature.

....

....

....

.... [1]

(b) A system of a fixed mass of ideal gas undergoes a cycle of changes. Fig. 3.2 shows the variation with volume V of the pressure p of the ideal gas as it undergoes the cycle ABCA.

Process A to B is isothermal, process B to C is isovolumetric and process C to A is adiabatic where there is no heat transfer into or out of the system of ideal gas.

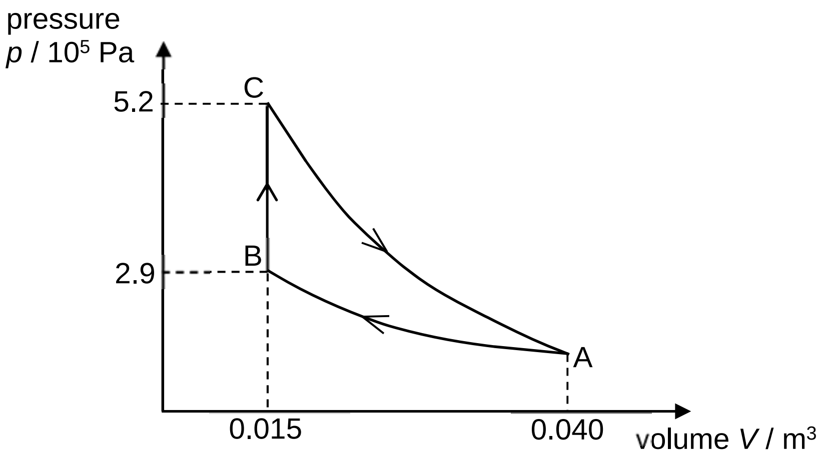


Fig. 3.2

Given that the mass of the ideal gas is 0.060 kg, calculate

(i) the pressure of the ideal gas in state A,

pressure = ... Pa [2]

(ii) the root-mean-square (r.m.s.) speed of the ideal gas molecules in state A,

r.m.s. speed = ... m s^{-1} [2]

(iii) the thermal energy absorbed by the system of ideal gas from B to C.

thermal energy = ... J [3]

(iv) Suggest one other way in which the adiabatic process C to A could be achieved in practice, other than by thermally insulating the system of gas.

....

.... [1]

4 **(a)** State, in words, the relation between the electric field strength E and potential V at a point.

....

.... [1]

(b) Two positively charged metal spheres, P and Q, of diameters 32 cm and 16 cm respectively, each carrying a charge of +7.2 nC, are isolated in space, as shown in Fig. 4.1.

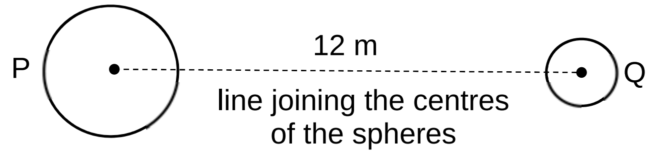


Fig. 4.1

The centres of the spheres are separated by a distance of 12 m. The distance x is measured from the centre of sphere P along the line joining the centres of the two spheres. Assume charges remain uniformly distributed on the surfaces of the spheres.

(i) State the value of x for which a stationary charged particle remains stationary when placed at this distance from the centre of sphere P.

x = ... m [1]

(ii) Calculate the electric potential at the point where the stationary charged particle remains stationary as stated in **(b)(i)**.

electric potential = ... V [1]

(iii) Sketch on Fig. 4.2, the variation with distance x of the electric potential V along the line joining the centres of the two spheres. Indicate on the horizontal axis your value of x in **(b)(i)**.

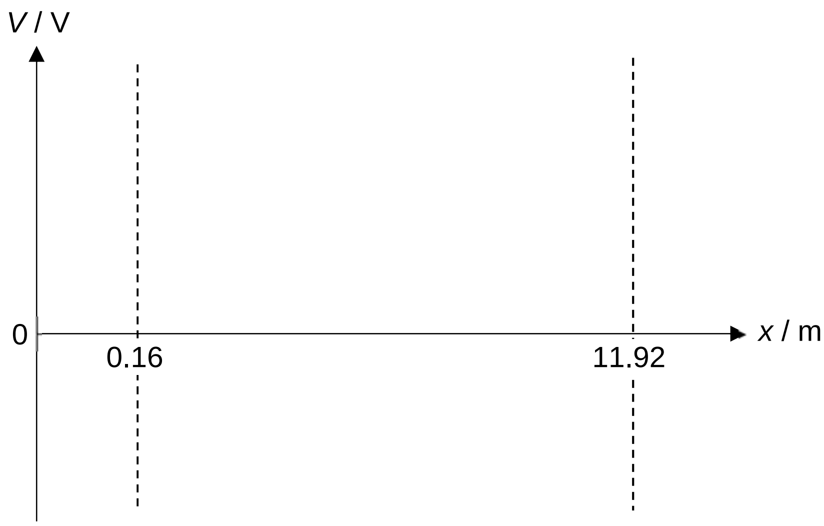


Fig. 4.2 (not to scale)

[3]

(iv) A positively charged particle is released at x = 0.16 m (surface of P).

With reference to your graph in **(b)(iii)**,

1. state and explain whether it will reach x = 11.92 m (surface of Q),

....

....

....

.... [2]

2. describe and explain the entire motion of this particle, using energy considerations or otherwise.

....

....

....

....

....

.... [3]

5 **(a)** **(i)** Distinguish between electrical resistance and resistivity.

....

....

.... [1]

(ii) A metal wire XY of resistance 2.0 Ω has a diameter of 1.0 mm and a resistivity of 1.5×10^{-6} Ω m.

Calculate the length of the wire.

length = ... m [1]

(b) A battery of e.m.f. 6.0 V with negligible internal resistance is connected to the metal wire XY and a light bulb of resistance 4.0 Ω as shown in Fig 5.1. The length of the connecting wire joining the negative terminal of the battery to the lamp is 0.20 m.

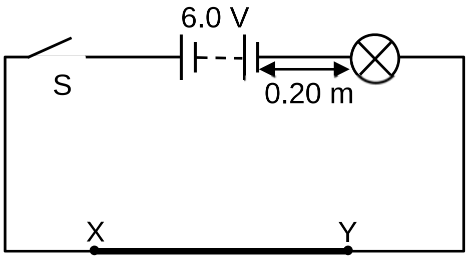


Fig. 5.1

(i) Switch S is closed. Calculate the current in the circuit.

current = ... A [1]

(ii) The connecting wires of diameter 1.0 mm are made of copper.

Given that the density and molar mass of copper are 8.96×10^{3} kg m^{-3} and 64.0 g respectively, calculate the average drift velocity in the copper wires.

Assume that the number of conduction electrons is equal to the number of copper atoms in the wire.

drift velocity = ... m s^{-1} [3]

(iii) Calculate the time it would take for an electron to move from the negative terminal of the battery to the light bulb.

time = ... s [1]

(iv) The light bulb lights up in a time much lesser than the time calculated in **(b)(iii)**. Explain this observation.

....

....

....

.... [2]

(c) The light bulb is removed from the circuit in Fig. 5.1.

A cell with e.m.f. 3.0 V and internal resistance 0.50 Ω and a galvanometer are now connected to the circuit as shown in Fig. 5.2.

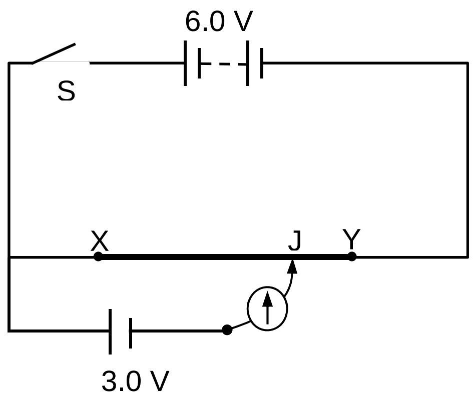


Fig. 5.2

(i) Calculate the length XJ when the galvanometer reads zero.

length XJ = ... m [1]

(ii) A 1.0 Ω resistor is now connected across the 3.0 V cell.

Calculate the new length XJ when the galvanometer reads zero.

length XJ = ... m [2]

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6 The electrical generator in a power station is driven by a steam turbine. The turbine absorbs thermal energy from a boiler and produces useful work. However, thermal energy must also be removed from the turbine by a cooling system as shown in Fig. 6.1.

The operating efficiency e of the turbine is defined by

$$e = \frac{\text{useful work output}}{\text{thermal energy input}}$$

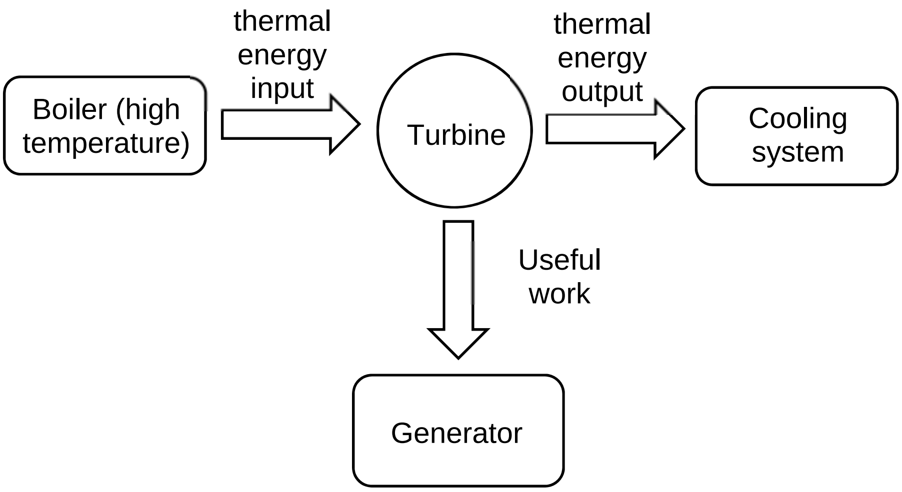


Fig. 6.1

The efficiency of heat engines, of which the turbine is an example, can never exceed a certain value which is fixed by temperatures of the boiler and the cooling system. This ideal efficiency e_{max} is given by the equation

$$e_{max} = \frac{T_2 - T_1}{T_2}$$

where T_2 is the thermodynamic temperature of the boiler and T_1 is the thermodynamic temperature of the cooling system.

Further data for a particular power station situated in Newtown, United Kingdom, are given in Fig. 6.2 below.

Electrical power output	200 MW
Efficiency of electrical generator	100%
Operating efficiency of turbine	31%
Ideal efficiency of turbine	52%
Effective temperature of cooling system (The cooling system uses water which enters at a temperature of 283 K and leaves at 291 K.)	330 K
Specific heat capacity of water in cooling system	4200 J kg^{-1} K^{-1}

Fig. 6.2

(a) Calculate the ideal efficiency e_{max} if the boiler temperature is 100 °C and the cooling system is at 27 °C.

e_{max} = ... [2]

(b) **(i)** Fig. 6.3 shows values of T_2 and e_{max} for a particular value of T_1.

T_2 / K	e_{max}
333	0.048
373	0.15
450	0.30
600	0.47
750	0.58

Fig. 6.3

Plot the variation with T_2 of e_{max} on the axes in Fig. 6.4.

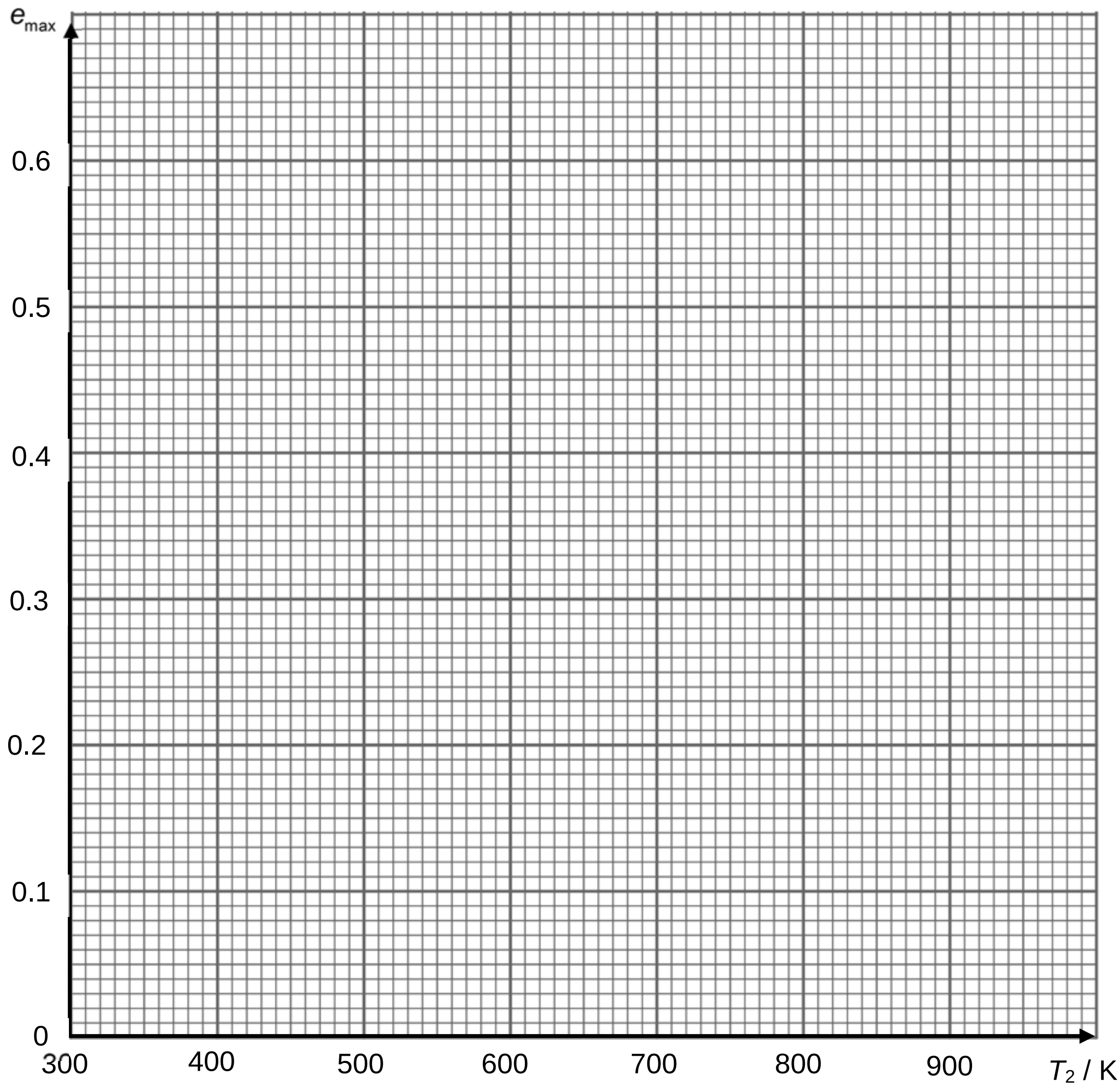


Fig. 6.4

[3]

(ii) From the graph, deduce the value of T_2 for which $e_{max} = 0$.

T_2 = ... K [1]

(iii) Hence, deduce the value of T_1.

T_1 = ... K [1]

(iv) Explain why it is not practical to attain an efficiency of 1.

....

....

....

.... [2]

(c) For the power station in Newtown, calculate

(i) the effective boiler temperature,

effective boiler temperature = ... K [1]

(ii) the rate of input of thermal energy to the turbine,

rate of input of thermal energy = ... W [1]

(iii) the rate at which thermal energy is removed from the turbine,

rate at which thermal energy is removed = ... W [1]

(iv) the required rate of flow of water through the cooling system.

rate of flow of water = ... kg s^{-1} [2]

(d) Suggest a reason for the discrepancy between the ideal efficiency of the turbine and its operating efficiency.

[1]

(e) A significant fraction of the electrical power produced in the UK by burning fossil fuels is used for domestic heating. Two suggestions for improvement are as follows:

(i) Burn the fossil fuel in the home instead of at the power station.

(ii) Cogeneration or combined heat and power (CHP) mechanisms which use the thermal energy output from the turbine for domestic heating.

Comment critically on these suggestions.

[2]

(f) Approximately 95% of Singapore's electricity is produced from fossil fuels (natural gas, coal, petroleum). Due to the lack of natural resources, most of the fossil fuels are imported from neighbouring countries. To enhance the nation's energy security and reduce our carbon footprint, the government has been exploring alternative energy sources.

(i) Suggest, with a reason, the renewable energy source that is the most viable option for Singapore.

[2]

(ii) State and explain a limitation in the deployment of the renewable energy source suggested in **(f)(i)** on a large scale to generate electricity reliably in Singapore.

[1]

End of Paper 2

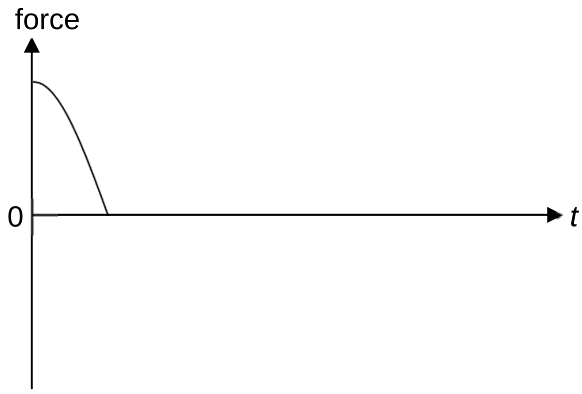
2018 Raffles Institution Preliminary Examinations – H2 Physics

Paper 2 – Solutions

1 **(a)** **(i)** The rate of change of (total) momentum of a system of bodies is directly proportional to the resultant external force acting on the system and the direction of the change is in the direction of the force.

(ii) If the system is isolated from all external forces, then the resultant external force acting on it is zero. By Newton's second law, the total momentum of the system will not change, which means that it is conserved.

(b) **(i)**



One quarter of SHM sinusoidal function

(ii) By conservation of energy,

$$\frac{1}{2}m_A{v_A}^2+\frac{1}{2}m_B{v_B}^2=\frac{1}{2}kx^2$$
$$0.100{v_A}^2+0.050{v_B}^2=80\times(0.060)^2=0.288$$
$$2{v_A}^2+{v_B}^2=5.76 \quad \text{----- (1)}$$

By conservation of momentum,

$$m_Av_A+m_Bv_B=0$$
$$v_B=-2v_A \quad \text{----- (2)}$$

Substitute (2) into (1),

$$2{v_A}^2+4{v_A}^2=5.76$$
$$v_A=0.98\text{ m s}^{-1}$$

Hence, $v_B=1.96\text{ m s}^{-1}$

(c) **(i)** Taking moments about O,

$$T\sin 55^\circ\times 0.15=(0.050\times 9.81\times 0.25)+(4.0\times 0.20)$$
$$T=7.509=7.51\text{ N}$$

(ii) Resolving the forces horizontally,

$$F_x=T\cos 55^\circ=7.509\times\cos 55^\circ=4.307=4.31\text{ N}$$

Horizontal component is 4.31 N

(Direction is leftward.)

Resolving the forces vertically,

$F_y + T\sin 55^\circ = (0.050 \times 9.81) + 4.0$

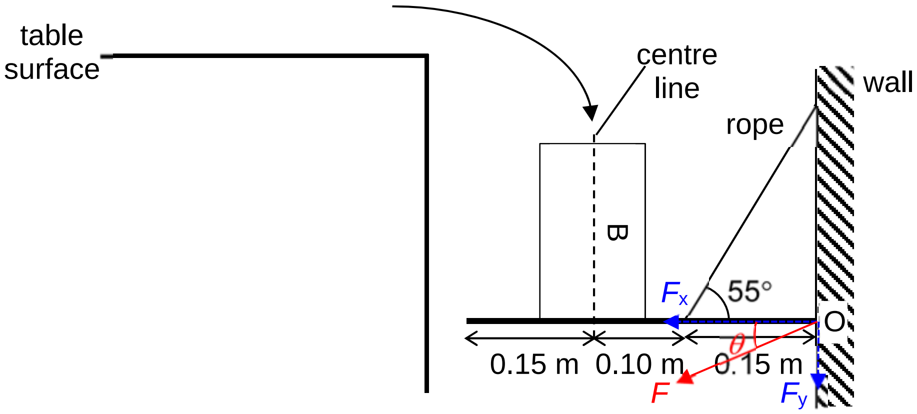
$F_y = (0.050 \times 9.81) + 4.0 - (7.509 \times \sin 55^\circ) = -1.661 = -1.66$ N

Vertical component is 1.66 N

(Direction is downward.)

(iii) $\tan\theta = \dfrac{F_y}{F_x} = \dfrac{1.661}{4.307}$

$\theta = 21.09^\circ = 21.1^\circ$



2 **(a)** **(i)** **1.** 1 cycle

$T = 1.90$ ms

$f = \dfrac{1}{T} = \dfrac{1}{(1.90 \times 10^{-3})} = 526.3 = 526$ Hz

(Students are allowed to use one or more cycles.)

2. uncertainty in the time scale is the smallest division: 0.1 ms

If used one period in (a)(i)1., $\Delta T = 0.1\,\text{ms}$

$\dfrac{Vf}{f} = \dfrac{VT}{T}$

$Vf = \dfrac{VT}{T} \times f$

$= \dfrac{0.1}{1.9} \times 526.3$

$= 27.7 = 30$ Hz (1 s.f.)

Absolute uncertainty given to 1 s.f.

OR

If used two periods in (a)(i)1., $2\Delta T = 0.1\,\text{ms}$

$VT = \dfrac{1}{2}(0.1) = 0.05$ ms

$$\frac{\Delta f}{f} = \frac{\Delta T}{T}$$
$$\Delta f = \frac{\Delta T}{T} \times f$$
$$= \frac{0.05}{1.90} \times 526.3$$
$$= 13.85 = 10 \text{ Hz (1 s.f.)}$$

Absolute uncertainty given to 1 s.f.

(ii)
$$\phi = \frac{\Delta t}{T} \times 2\pi$$
$$\frac{4}{5}\pi = \frac{\Delta t}{T} \times 2\pi$$
$$\Delta t = \left(\frac{4\pi}{5}\right)\left(\frac{T}{2\pi}\right) = \frac{2}{5}(1.90) = 0.76 \text{ ms}$$

$$1.50 + 0.76 = 2.26 \text{ ms}$$

(iii)
$$I = \frac{P}{4\pi r^2} \quad \Rightarrow \quad I \propto \frac{P}{r^2}$$
$$\frac{I_1}{I} = \frac{P_1}{r_1^2} \times \frac{r^2}{P}$$
for $I_1 = I$
$$r_1^2 = \frac{P_1}{P} r^2$$
$$r_1 = \sqrt{\frac{0.25P}{P}}r = \sqrt{0.25}(120) = 60 \text{ cm}$$

(b) (i) All the particles in a progressive wave oscillate with the same amplitude.
The particles in a stationary wave oscillate with amplitudes that range from zero at the nodes to a maximum at the antinodes.

(ii) All the particles within a wavelength of a progressive wave have different phases.
All the particles between two adjacent nodes of a stationary wave have the same phase. Particles in adjacent segments have a phase difference of π radians.

3 (a) (i) At equilibrium, pressures in both chambers are the same.

Using $pV = nRT$
$$\frac{n_X R T_X}{V_X} = \frac{n_Y R T_Y}{V_Y}$$
$$n_X = n_Y \frac{T_Y}{T_X}\frac{V_X}{V_Y} = (1.2)\left(\frac{300}{450}\right)\left(\frac{2.5}{4.0}\right)$$
$$= 0.50 \text{ mol}$$

(ii)
$$p = \frac{nRT}{V}$$
$$p_X = \frac{1.2 \times 8.31 \times 300}{4.0} \quad \text{OR} \quad p_Y = \frac{0.50 \times 8.31 \times 450}{2.5}$$

$p_X = p_Y = 747.9 = 750$ Pa

(iii) With some gas removed, there are <u>fewer gas molecules</u> in Y which results in a <u>smaller overall rate of change of momentum</u> of molecules as they collide with the walls of the chamber. Hence the <u>average force</u> on the walls <u>decreases</u> which implies gas pressure is reduced.

(b) **(i)** Since process A to B is isothermal $\therefore$ $T_A = T_B$

$\therefore\ p_A V_A = p_B V_B$

$$p_A = \frac{(2.9\times10^5)(0.015)}{0.040}$$
$$= 1.09\times10^5 = 1.1\times10^5 \text{ Pa}$$

(ii) Using $p = \frac{1}{3}\frac{Nm}{V}\langle c^2\rangle$

$$\langle c^2\rangle = \frac{3pV}{Nm} = \frac{3(1.09\times10^5)(0.040)}{0.060}$$
$$c_{rms} = \sqrt{\langle c^2\rangle} = 466.9 = 470 \text{ m s}^{-1}$$

(iii)
$$\Delta U = \frac{3}{2}nR\Delta T = \frac{3}{2}\Delta(pV)$$
$$\Delta U = \frac{3}{2}(p_C V_C - p_B V_B)$$
$$= \frac{3}{2}\left[0.015(5.2\times10^5 - 2.9\times10^5)\right]$$
$$= 5175 = 5200 \text{ J}$$

Using the First Law of Thermodynamics,

$\nabla U = W + Q = 0 + Q$

$Q = 5200$ J

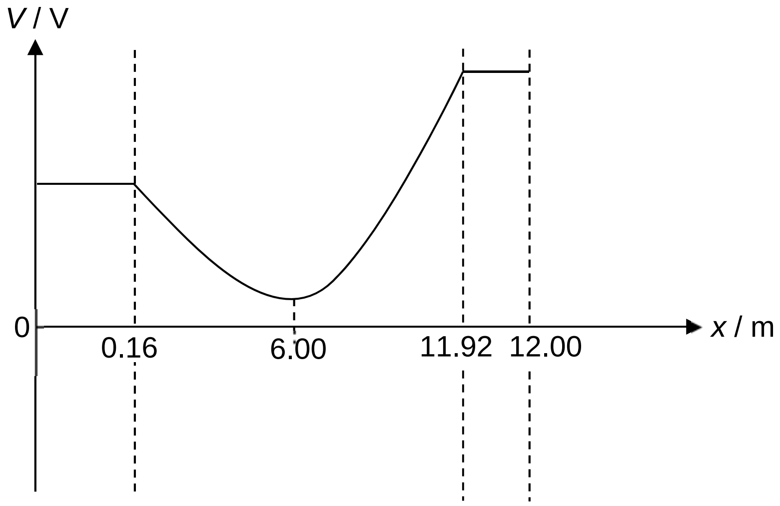
(iv) By ensuring that the process from C to A takes place <u>rapidly</u> such that there is <u>insufficient time for any heat transfer</u> to take place between the system and its surroundings.

4 **(a)** Electric field strength is numerically equal to the potential gradient at that point.
OR
Electric field strength is the negative of the potential gradient.

(b) **(i)** 6.0 m

(ii)
$$\frac{Q}{4\pi\varepsilon_0 r}\times 2=\frac{7.2\times10^{-9}}{4\pi\times8.85\times10^{-12}\times6.0}\times 2$$
$$=21.6=22\text{ V}$$

(iii)



(iv) **1.** No it will not reach the surface of Q.
It does not have sufficient kinetic energy to reach Q, as the electric potential at the surface of Q is higher than the electric potential at the surface of P.

2. Being positively charged, it will be repelled by sphere P's electric field and moves with increasing kinetic energy as the electric potential decreases towards x = 6.0 m / mid-point.
After passing x = 0.60 m, it moves towards sphere Q with decreasing kinetic energy as the electric potential increases, but it does not have sufficient energy to reach Q.
Its kinetic energy drops to zero somewhere before 11.92 m and it returns to sphere P with its kinetic energy increasing towards x = 0.60 m then decreasing after x = 0.60 m, and the cycle repeats again.

OR

Being positively charged, it will be repelled by sphere P's electric field and accelerates towards the point x = 0.60 m as the resultant electric field is in the positive x-direction, as shown by the negative of the potential gradient.
After passing x = 0.60 m, it decelerates towards sphere Q as the resultant electric field direction is in the negative x-direction, and its velocity reaches zero before reaching Q.
It will then return to sphere P, accelerating towards x = 0.60 m, then decelerating after the mid-point, and the cycle repeats again.

5 **(a)** **(i)** Resistance of a conductor is defined as the ratio of the potential difference across it to the current flowing through it i.e. $R = \dfrac{V}{I}$

Resistivity is the constant of proportionality for the relationship between a conductor's resistance and its length and cross-sectional area i.e. $R = \rho\dfrac{l}{A}$

OR

Resistance of a conductor is dependent on the length and cross-sectional area (i.e. $R = \rho\dfrac{l}{A}$) of the conductor whereas resistivity is a characteristic of the conductor's material which is independent of length and cross-sectional area.

(ii)

$$R = \frac{\rho L}{A}$$

$$L = \frac{RA}{\rho}$$

$$= \frac{(2.0)\left[\pi\left(1.0\times10^{-3}/2\right)^2\right]}{1.5\times10^{-6}}$$

$$= 1.047 = 1.0 \text{ m}$$

(b) **(i)**

$$V = RI$$

$$I = \frac{V}{R}$$

$$= \frac{6.0}{2.0+4.0}$$

$$= 1.0 \text{ A}$$

(ii) number density of conduction electrons,

$$n = \frac{\text{no. of mol}\times N_A}{\text{volume}}$$

$$= \frac{\text{density}}{\text{molar mass}}\times N_A$$

$$= \frac{8.96\times10^3}{0.064}\times\left(6.02\times10^{23}\right)$$

$$= 8.428\times10^{28} = 8.4\times10^{28} \text{ m}^{-3}$$

$$I = nAv_dq$$

$$v_d = \frac{I}{nAq}$$

$$= \frac{1.0}{\left(8.43\times10^{28}\right)\left[\pi(1.0\times10^{-3}/2)^2\right]\left(1.60\times10^{-19}\right)}$$

$$= 9.440\times10^{-5} = 9.4\times10^{-5} \text{ ms}^{-1}$$

(iii)

$$t = \frac{d}{v_d}$$

$$= \frac{0.20}{9.44 \times 10^{-5}}$$

$$= 2.119 \times 10^{3} = 2.1 \times 10^{3} \text{ s}$$

(iv) When the switch is closed, the <u>electric field is established in the circuit almost instantaneously</u>.
Hence, <u>all free electrons including those in the lamp filament present in the circuit will start to drift at the same time</u>.

(c) **(i)**

$$\text{L}_{\text{XJ}} = \frac{V_{XJ}}{V_{XY}} \text{L}_{\text{XY}}$$

$$= \frac{3.0}{6.0}(1.0)$$

$$= 0.50 \text{ m}$$

(ii)

$$\text{L}_{\text{XJ}} = \frac{V_{XJ}}{V_{XY}} \text{L}_{\text{XY}}$$

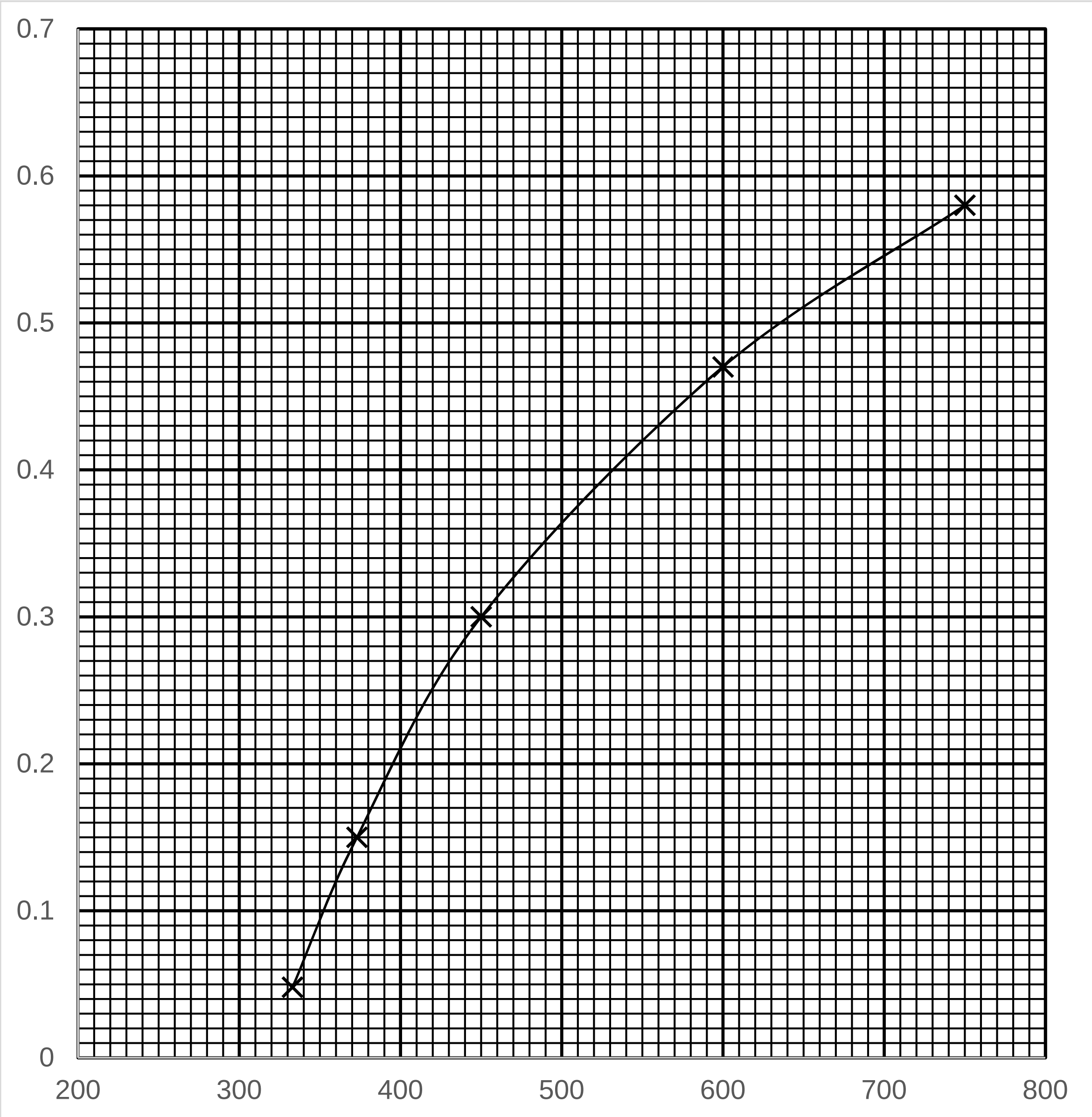
$$= \left(\frac{\frac{1.0}{1.0 + 0.5}(3.0)}{6.0} \right)(1.0)$$

$$= 0.333 = 0.30 \text{ m}$$

6 **(a)**

$$e_{max} = \frac{373 - 300}{373}$$
$$= 0.196$$

(b) **(i)**



(ii) 320 K

(iii)

$$e_{max} = \frac{T_2 - T_1}{T_2} = 1 - \frac{T_1}{T_2}$$

When $e_{max} = 0$,

$$1 - \frac{T_1}{T_2} = 0$$

$$T_1 = T_2 = 320 \text{ K}$$

(iv) To obtain ideal efficiency close to 1, <u>either T_2 would have to be very high or T_1 would have to be very low</u>.
The <u>components of the heat engine may not be able to withstand the high temperature</u>.
At very low temperatures, <u>water used in the cooling system may freeze</u>.

(c) **(i)** $0.52 = \dfrac{T_2 - 330}{T_2}$

$T_2 = 688$ K

(ii) $0.31 = \dfrac{200}{\text{rate of thermal energy input}}$

rate of thermal energy input $= 6.45 \times 10^8$ W

(iii) Rate of thermal energy output

$= (6.45 - 2.00) \times 10^8$

$= 4.45 \times 10^8$ W

<u>Alternative:</u>

$= 0.69 \times (6.45 \times 10^8)$

$= 4.45 \times 10^8$ W

(iv) $4.45 \times 10^8 = \dfrac{m}{t} c \Delta T$

$\dfrac{m}{t} = \dfrac{4.45 \times 10^8}{(4200)(291 - 283)}$

$= 13200$ kg s^{-1}

(d) There could be <u>energy lost due to friction between moving parts</u> of the turbine **or** <u>heat loss to the surroundings</u>.

(e) The efficiency of the turbine is low (31% from from Fig. 6.2). <u>Burning fossil fuel at home may be more efficient</u>. However, there will be a lot of <u>harmful emissions</u> which would not be contained.
There is a <u>large percentage of thermal energy</u> (69%) which would be used in cogeneration plants. This energy would otherwise be wasted.

(f) **(i)** <u>Solar power</u>.
Singapore is situated at the equator and <u>receives sunshine almost all year round</u>.

OR Singapore receives more solar radiation than temperate countries.

(ii) Singapore's small physical size, high population density and land scarcity <u>limit the amount of available space to install solar panels</u>.
OR
The <u>output of a solar cell is variable and dependent on weather conditions</u> compared with a conventional generator that produces a stable output. As such, output from solar cell is largely dependent on environmental factors and weather conditions such as the amount of sunlight, cloud cover and shadow. This can result in imbalances between supply and demand.

Centre Number	Index Number	Name	Class
S3016			

RAFFLES INSTITUTION
2018 Preliminary Examination

PHYSICS **9749/03**
Higher 2

18 September 2018
Paper 3 Longer Structured Questions **2 hours**

Candidates answer on the Question Paper.
No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your index number, name and class in the spaces at the top of this page.
Write in dark blue or black pen in the spaces provided in this booklet.
You may use pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.
The use of an approved scientific calculator is expected, where appropriate.

Section A
Answer **all** questions.

Section B
Answer **one** question only and **circle the question number** on the cover page.

You are advised to spend one and half hours on Section A and half an hour on Section B.
The number of marks is given in brackets [ ] at the end of each question or part question.

***This booklet only contains Section A.**

For Examiner's Use		
Section A	1	/ 10
	2	/ 12
	3	/ 12
	4	/ 13
	5	/ 13
Section B (circle 1 question)	6	/ 20
	7	/ 20
Deduction		
Total		/ 80

This document consists of **15** printed pages.

Data

speed of light in free space	c	=	3.00×10^{8} m s^{-1}
permeability of free space	μ_0	=	$4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space	ε_0	=	8.85×10^{-12} F m^{-1}
		=	$(1/(36\pi)) \times 10^{-9}$ F m^{-1}
elementary charge	e	=	1.60×10^{-19} C
the Planck constant	h	=	6.63×10^{-34} J s
unified atomic mass constant	u	=	1.66×10^{-27} kg
rest mass of electron	m_e	=	9.11×10^{-31} kg
rest mass of proton	m_p	=	1.67×10^{-27} kg
molar gas constant	R	=	8.31 J K^{-1} mol^{-1}
the Avogadro constant	N_A	=	6.02×10^{23} mol^{-1}
the Boltzmann constant	k	=	1.38×10^{-23} J K^{-1}
gravitational constant	G	=	6.67×10^{-11} N m^2 kg^{-2}
acceleration of free fall	g	=	9.81 m s^{-2}

Formulae

uniformly accelerated motion	s	=	$ut + \frac{1}{2}at^2$
	v^2	=	$u^2 + 2as$
work done on/by a gas	W	=	$p\Delta V$
hydrostatic pressure	p	=	ρgh
gravitational potential	ϕ	=	$-Gm/r$
temperature	T/K	=	T / °C + 273.15
pressure of an ideal gas	p	=	$\frac{1}{3}\frac{Nm}{V}\langle c^2 \rangle$
mean translational kinetic energy of an ideal gas molecule	E	=	$\frac{3}{2}kT$
displacement of particle in s.h.m.	x	=	$x_0 \sin \omega t$
velocity of particle in s.h.m.	v	=	$v_0 \cos \omega t = \pm \omega \sqrt{x_0^2 - x^2}$
electric current	I	=	$Anvq$
resistors in series	R	=	$R_1 + R_2 + \ldots$
resistors in parallel	$1/R$	=	$1/R_1 + 1/R_2 + \ldots$
electric potential	V	=	$\frac{Q}{4\pi\varepsilon_0 r}$
alternating current/voltage	x	=	$x_0 \sin \omega t$
magnetic flux density due to a long straight wire	B	=	$\frac{\mu_0 I}{2\pi d}$
magnetic flux density due to a flat circular coil	B	=	$\frac{\mu_0 NI}{2r}$
magnetic flux density due to a long solenoid	B	=	$\mu_0 nI$
radioactive decay	x	=	$x_0 \exp(-\lambda t)$
decay constant	λ	=	$\frac{\ln 2}{t_{\frac{1}{2}}}$

Section A

Answer **all** the questions in this Section in the spaces provided.

1 During a space expedition on the Moon, a table tennis ball is dropped in a large, enclosed container on the surface of the Moon. The container contains air from the Earth. Special arrangements are made to ensure that the pressure of the air is maintained at the Earth's atmospheric pressure. The variation with time *t* of the speed *v* of the table tennis ball is shown in Fig. 1.1.

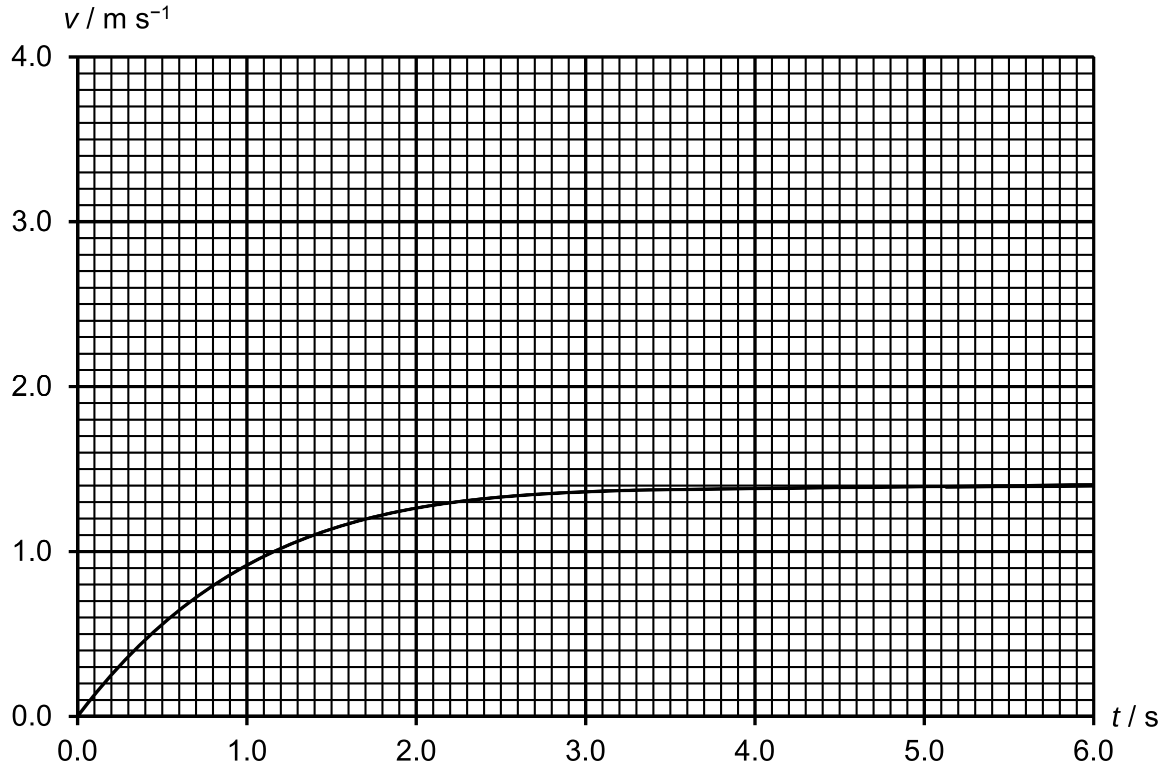


Fig. 1.1

The mass of the table tennis ball is 2.7 g.

(a) (i) Use Fig. 1.1 to determine the acceleration of free fall *g* of the ball on the surface of the Moon. Show your construction on Fig. 1.1.

g = ... m s^{-2} [2]

(ii) If the table tennis ball were dropped *outside* the container, determine the time taken for it to reach the value of the constant speed in Fig. 1.1.

time = ... s [1]

(b) The resistive force F acting on the table tennis ball is related to its speed v by the equation

$$F = kv$$

where k is a constant.

(i) Calculate the maximum resistive force experienced by the ball as it falls inside the container.

maximum resistive force = ... N [1]

(ii) Using your answer in **(b)(i)**, deduce the value of k.

k = ... kg s^{-1} [1]

(iii) Determine the maximum speed of the table tennis ball if this experiment is conducted on the surface of the Earth.

maximum speed = ... m s^{-1} [2]

(iv) Sketch, on Fig. 1.1, a new graph showing the variation with time t of the speed v of the table tennis ball when the experiment is repeated with the following changes made independently:

1. Liquid nitrogen of 1.5 times the mass of the ball is injected into the ball. Label this graph P.

2. The ball is thrown vertically downwards with an initial speed of 4.0 m s^{-1}. Label this graph Q.

[3]

2 **(a)** **(i)** Define gravitational field strength.

....

.... [1]

(ii) Hence, state with a reason, if gravitational field strength is a scalar or vector quantity.

....

.... [1]

(iii) State Newton's law of gravitation and use your definition in **(a)(i)** to write down an expression for the gravitational field strength *g* at a distance *R* from a point mass *M*.

....

....

....

....

.... [2]

(b) The mass of planet Jupiter is 1.90×10^{27} kg and its radius is 7.14×10^{7} m. The radius of Jupiter's orbit around the Sun is 7.79×10^{11} m. The mass of the Sun is 1.99×10^{30} kg.

(i) Calculate the ratio

$$\frac{\text{gravitational field strength on the surface of Jupiter due to the Sun}}{\text{gravitational field strength on the surface of Jupiter due to the mass of Jupiter}}.$$

ratio = ... [2]

(ii) Hence explain if the gravitational field strength due to the Sun on the surface of Jupiter can be neglected.

....

.... [1]

(c) The Galilean moons are the largest moons of Jupiter which were first discovered by Galileo in January 1610. Some of the data of the 3 Galilean moons closest to Jupiter are given in Fig. 2.1.

Name of moon	Io	Europa	Ganymede
Average orbital radius / m	4.22×10^8	6.71×10^8	1.07×10^9

Fig. 2.1

(i) For moons revolving around a planet in circular orbits, determine that the orbital period T of a moon is given by

$$T^2 = KR^3$$

where R is the radius of the orbit and K is a constant. Explain your working clearly.

[3]

(ii) Hence, show that the orbital period of Io : Europa : Ganymede is 1 : 2 : 4 approximately.

[2]

3 A test-tube is partially loaded with small ball bearings such that it is able to float upright in water of density ρ as shown in Fig. 3.1. The bottom of the test-tube is a distance H below the water surface.

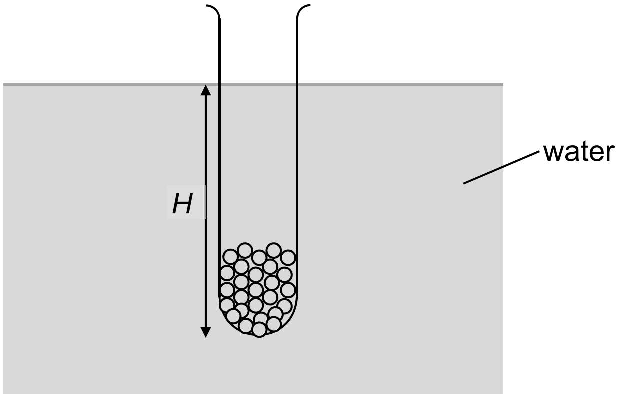


Fig. 3.1

Ignoring its rounded bottom, the test-tube may be regarded as a cylinder of cross sectional area A and mass m. The mass of the ball bearings added is M.

(a) Derive an expression that relates H to A, ρ, M and m.

[2]

(b) The test-tube is displaced vertically by displacement y and then released. Ignoring dissipative forces,

(i) write down, in terms of ρ, A, g and y, an expression for the net force acting on the loaded test-tube,

.... [1]

(ii) show that the acceleration of the test-tube is given by

$$a = -\left(\frac{\rho A g}{M + m}\right) y$$

where g is the acceleration of free fall.

[1]

(c) It is given that $\rho = 1.00 \times 10^{3}\ \text{kg m}^{-3}$
$A = 6.0 \times 10^{-4}\ \text{m}^{2}$
$M = 0.012\ \text{kg}$
$m = 0.025\ \text{kg}$

Show that the period of oscillation of the test-tube is 0.50 s.

[3]

(d) In practice, it is observed that the variation with time t of the vertical displacement y of the test-tube is as shown in Fig. 3.2.

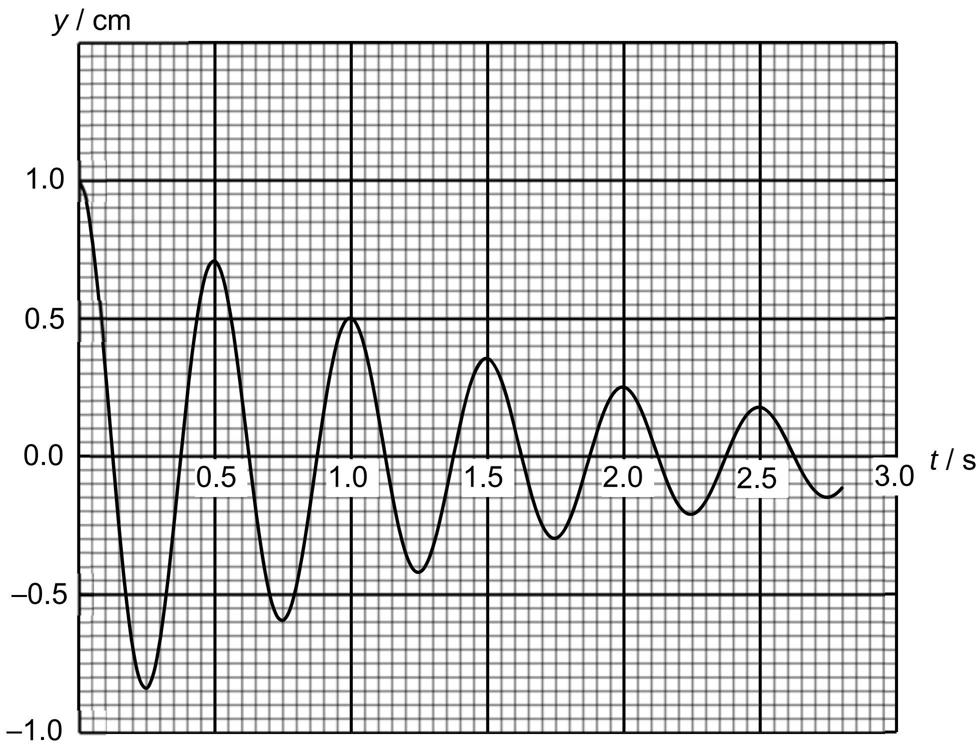


Fig. 3.2

Explain why the amplitude of the oscillations decreases gradually over time.

....

....

.... [2]

(e) To sustain the oscillations of the test-tube, low-amplitude water waves of frequency 0.30 Hz are generated on the surface of the water.

(i) Sketch a graph to show the variation with time *t* of the vertical displacement *y* of the test-tube when it is oscillating steadily. Numerical values are not required for the graph.

[1]

(ii) It is observed that the amplitude of the vertical oscillations of this test-tube is rather small. Without changing the water waves, suggest with reasoning how the amplitude of the oscillations of this test-tube may be increased.

....

....

....

.... [2]

4 **(a)** **(i)** State the principle of superposition.

....

....

.... [2]

(ii) Use Huygen's principle to explain the interference pattern formed when waves of a single wavelength pass through a single slit.

....

.... [1]

(b) A parallel beam of light of wavelength 600 nm from a point source is incident normally on a rectangular slit of width 0.30 mm as shown in Fig. 4.1. Light passing through the slit is incident on a screen placed a distance *D* from the slit.

The centre of the interference pattern formed on the screen is at O. The angle a light ray emerging from the slit makes with the normal line between the slit and the screen is θ.

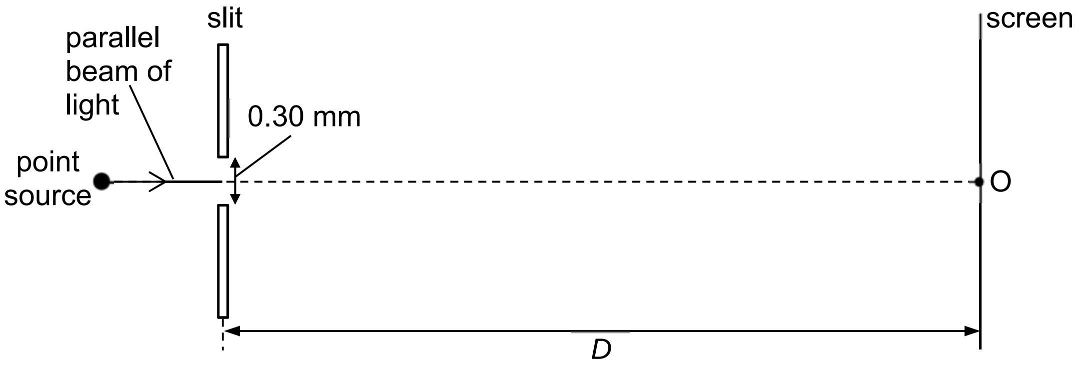


Fig. 4.1 (not to scale)

(i) On the axes in Fig. 4.2, sketch a graph to show the variation with $\sin\theta$ of the intensity I of the light on the screen. Include appropriate values along the $\sin\theta$ axis.

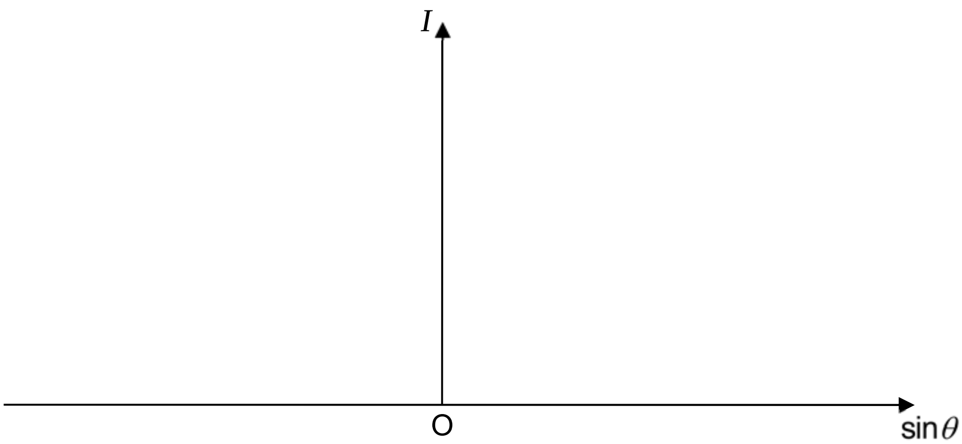


Fig. 4.2

[3]

(ii) Another identical point source of light is placed at a distance of 1.0 mm from the first point source as shown in Fig. 4.3. Both sources are 0.25 m from the slit. Light from each source forms a separate interference pattern on the screen.

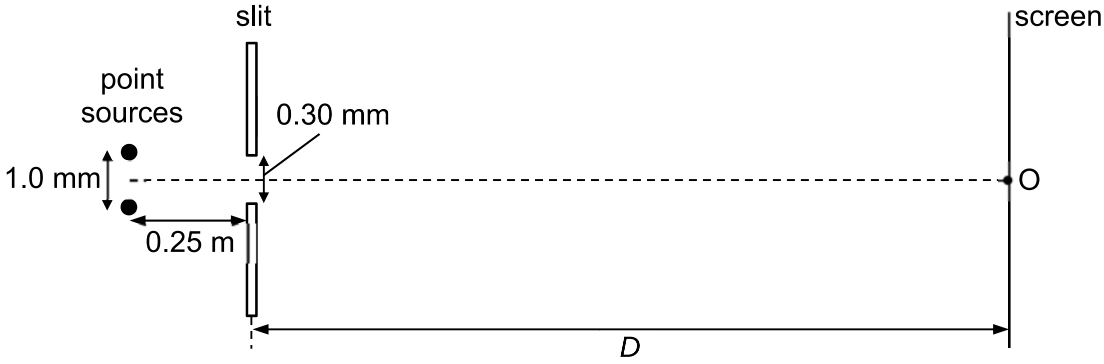


Fig. 4.3 (not to scale)

Determine, with appropriate calculations, if it is possible to resolve the images of the two sources on the screen.

The two interference patterns can / cannot be resolved. [2]

(c) The single slit in Fig. 4.1 is replaced with double slits each with the same slit width of 0.30 mm and with a slit separation of 1.2 mm. There is only one point source and light from the point source is incident normally on the slits.

(i) Determine the number of maxima observed within the central fringe of the single slit interference pattern. Explain your working clearly.

number of maxima = ... [3]

(ii) If the width of the central fringe is 12 mm, calculate the perpendicular distance *D* between the double slits and the screen.

D = ... m [2]

5 **(a)** State Faraday's law of electromagnetic induction.

....

....

.... [1]

(b) Fig. 5.1 shows a coil of 400 turns and cross-sectional area of 4.2×10^{-4} m^2 placed in the middle of a long solenoid. The coil is connected to a sensitive ammeter. The solenoid is connected to a variable resistor and a sinusoidally-alternating voltage supply.

The variation with time t of the magnetic flux density B in the solenoid is shown in Fig. 5.2.

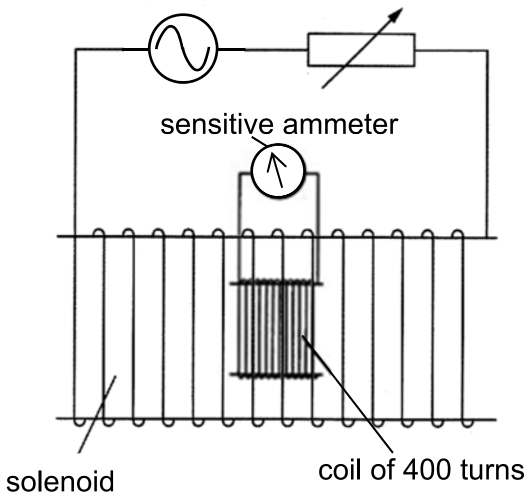


Fig. 5.1

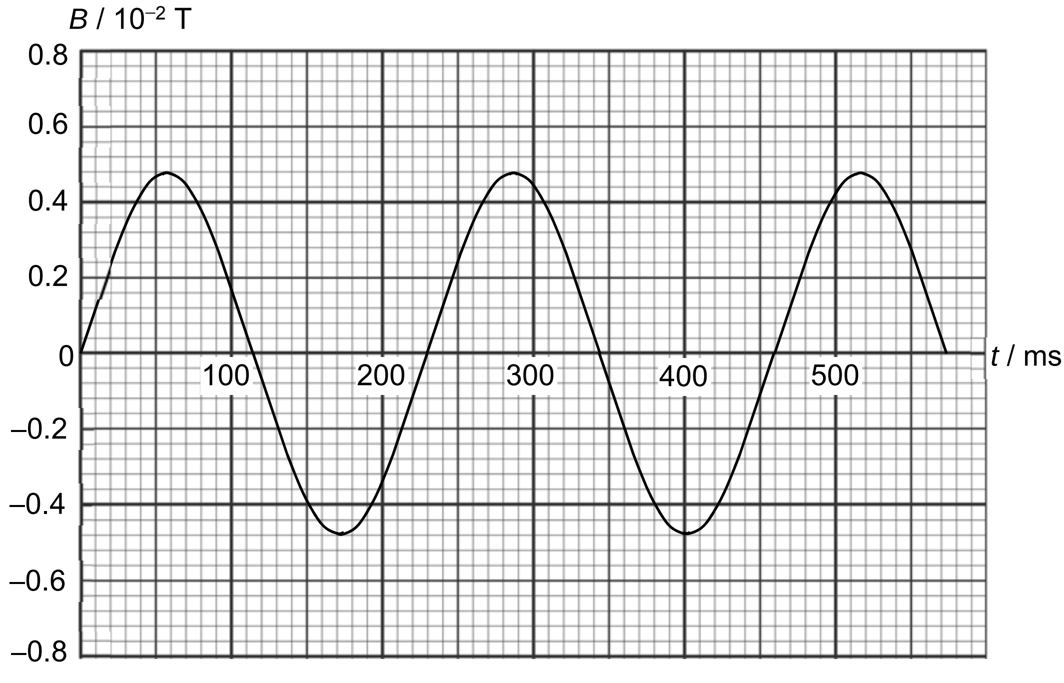


Fig. 5.2

(i) Explain, with reference to the magnetic field in the solenoid, why the sensitive ammeter deflects in opposite directions.

....

....

....

....

.... [2]

(ii) Using Fig. 5.2,

1. state a value of t when the magnitude of the induced e.m.f. is maximum,

t = ... s [1]

2. hence determine the maximum induced current in the coil given that the resistance of the coil is 5.0 Ω,

maximum induced current = ... A [3]

3. calculate the mean power dissipated by the coil.

mean power dissipated = ... W [2]

(iii) Sketch on Fig. 5.3, a graph to show the variation with time t of the induced current i in the coil from t = 0 ms to t = 460 ms. Include appropriate scale markings on the vertical axis.

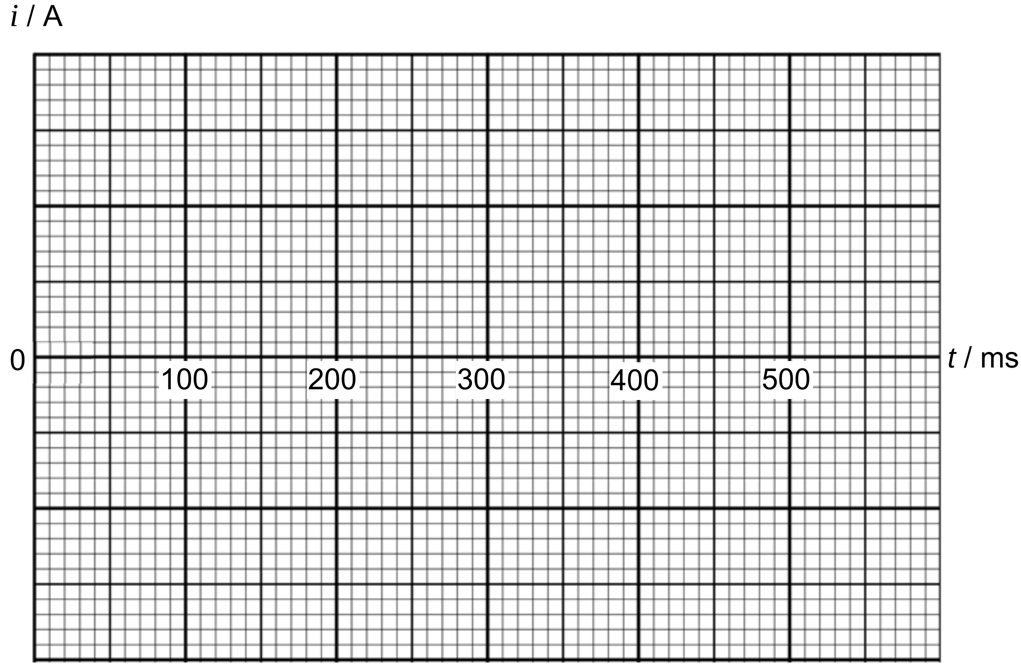


Fig. 5.3

[2]

(iv) Sketch on Fig. 5.4, a graph to show the variation with time t of the power P dissipated in the coil from t = 0 ms to t = 460 ms. Include appropriate scale markings on the vertical axis.

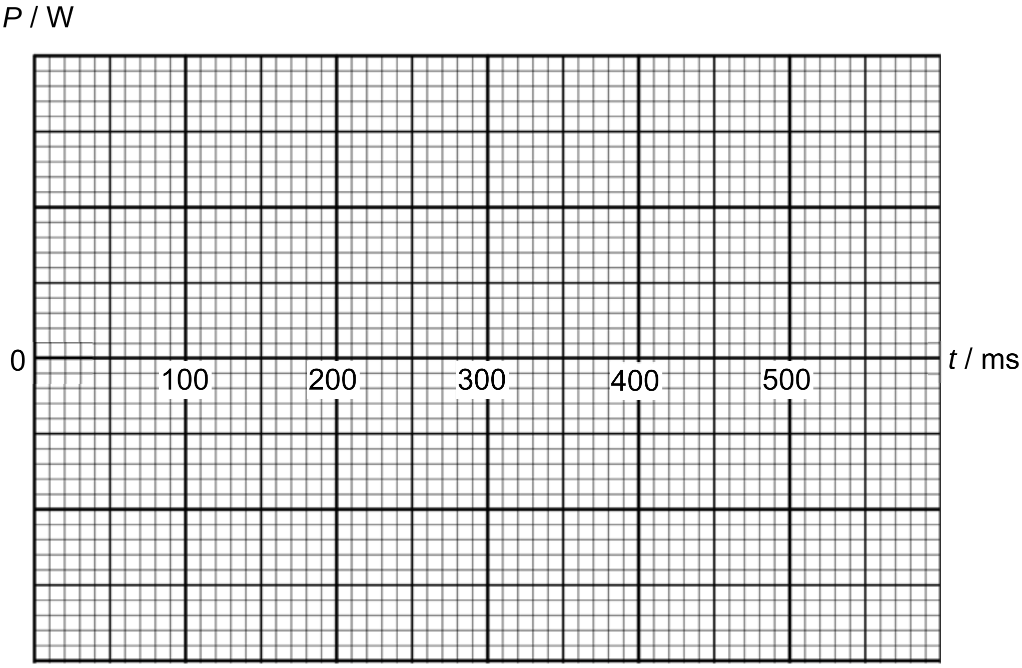


Fig. 5.4

[2]

End of Paper 3 Section A

Centre Number	Index Number	Name	Class
S3016			

RAFFLES INSTITUTION
2018 Preliminary Examination

PHYSICS **9749/03**
Higher 2

18 September 2018
Paper 3 Longer Structured Questions **2 hours**

Candidates answer on the Question Paper.
No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your index number, name and class in the spaces at the top of this page.
Write in dark blue or black pen in the spaces provided in this booklet.
You may use pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.
The use of an approved scientific calculator is expected, where appropriate.

Section A
Answer **all** questions.

Section B
Answer **one** question only and **circle the question number** on the cover page.

You are advised to spend one and half hours on Section A and half an hour on Section B.
The number of marks is given in brackets [ ] at the end of each question or part question.

***This booklet only contains Section B.**

For Examiner's Use		
Section B (circle 1 question)	**6**	/ 20
	7	/ 20
Deduction		

This document consists of **9** printed pages.

Section B

Answer **one** question from this Section in the spaces provided.

6 **(a)** The energy levels of a hypothetical one-electron atom are given by

$$E_n = -\frac{27.90}{n^2}\ \text{eV}$$

where $n = 1, 2, 3, \ldots$

(i) Calculate the energies of the four lowest energy levels and construct a clearly labelled energy level diagram.

[3]

(ii) If the atoms are in the ground state and are bombarded by electrons of kinetic energy 26.5 eV, determine the highest energy level that an atom can reach. Show your working clearly.

highest energy level = ... [3]

(iii) Indicate, with arrows, in your energy level diagram in **(a)(i)** all the possible transitions that produce emission lines when these atoms de-excite.

[2]

(iv) Calculate the longest and the shortest wavelengths of the photons emitted during these transitions.

longest wavelength = ... nm

shortest wavelength = ... nm [2]

(b) In a modern X-ray tube, electrons are accelerated through a large potential difference and the X-rays are produced when electrons strike a metal target embedded in a large piece of copper.

Fig. 6.1 shows an energy level diagram of an atom of a hypothetical metal.

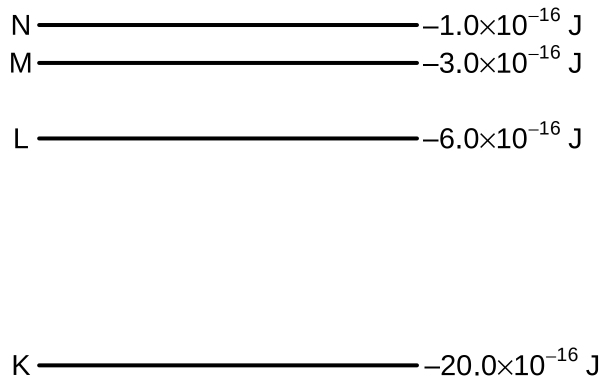


Fig. 6.1

The emission spectrum of the metal when it is bombarded by a beam of fast-moving electrons is shown in Fig. 6.2.

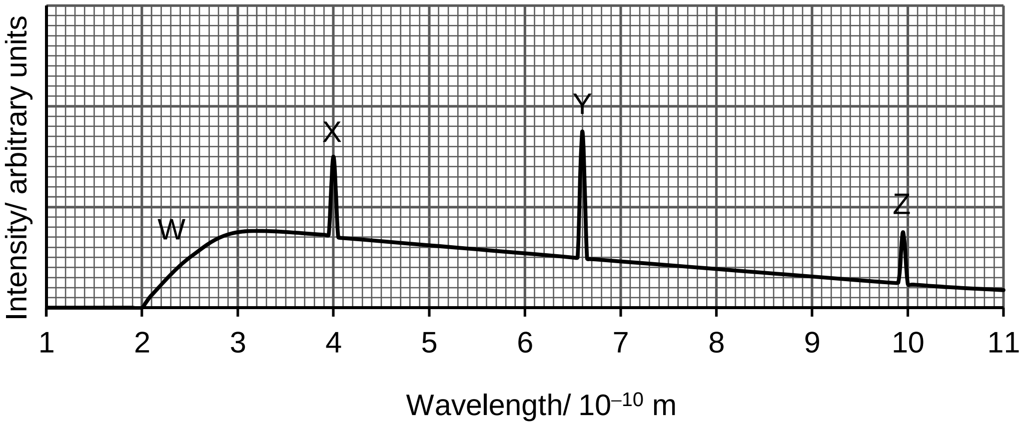


Fig. 6.2

(i) Describe the processes that occur at the target which produce the continuous spectrum W.

....

....

....

....

....

....

....

....

.... [4]

(ii) Calculate the accelerating potential of the X-ray tube.

accelerating potential = ... V [3]

(iii) Using Fig. 6.1, deduce which of the lines X, Y and Z in Fig. 6.2 correspond to L_α, L_β and M_α lines.

L_α = ...

L_β = ...

M_α = ... [2]

(iv) Explain why the K spectral lines are missing from Fig. 6.2.

....

.... [1]

7 The count rate C of a mixture of two radioactive nuclides X and Y is measured and the variation with time t of ln C is plotted and shown in Fig. 7.1. The readings show the count rate after the background count rate has been subtracted from it.

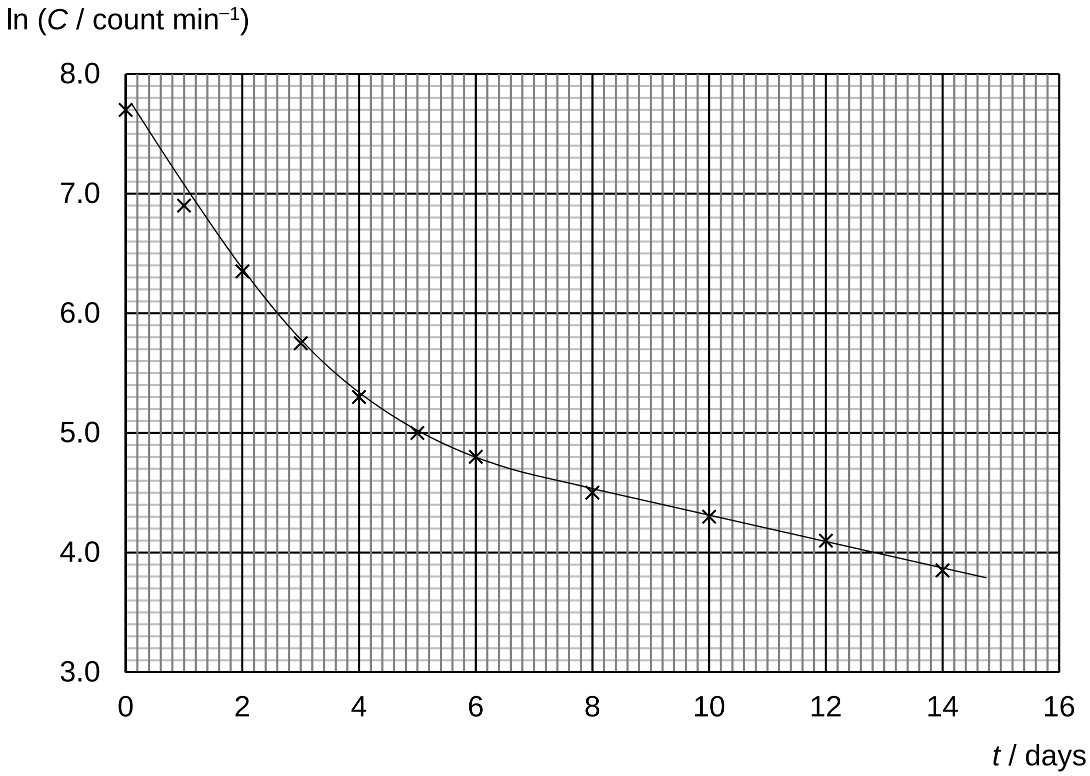


Fig. 7.1

It is known that the half-life of X is much longer than that of Y. The graph approaches a straight line eventually.

(a) By using an equation with the symbols defined below, explain why the graph approaches a straight line eventually.

Given C_X : count rate of X at time t,

C_{X_0} : initial count rate of X,

λ_X : decay constant of X.

....

....

....

....

.... [3]

(b) **(i)** Determine the initial count rate of X and its half-life using information from Fig. 7.1.

initial count rate = ... count min^{-1}

half-life = ... days [5]

(ii) Estimate the count rate of the mixture at t = 19 days.

count rate = ... count min^{-1} [2]

(c) One of the radioactive nuclides in the mixture can be used as a tracer to check whether the thyroid gland is absorbing iodine normally from the blood in a human body. The tracer nuclei decay by emitting beta particles and gamma rays, and the gamma rays are monitored from outside the body close to the thyroid using a detector.

A dose of iodine with the tracer is injected into a patient's blood, and 20% of that dose is absorbed by the thyroid gland. The detector records 0.40% of the gamma rays emitted.

(i) Suggest a reason why the beta particles are not monitored.

....

.... [1]

(ii) Suggest a reason why the detector records only 0.40% of the gamma rays emitted from the radioactive nuclei inside the thyroid.

....

.... [1]

(iii) In administering radioactive nuclides for medical applications, factors such as the half-life of the source must be considered.

Suggest two other significant factors that should be considered.

....

....

....

....

.... [2]

(d) Source Y has a half-life of 20 hours. In the absence of source Y, a constant average count-rate of 15 s^{-1} is recorded by a radiation detector.

Immediately after source Y is placed 30 cm from the detector, the average count-rate rises to 100 s^{-1}.

Determine the distance the detector should be placed from source Y in order to detect the same average count-rate of 100 s^{-1} 60 hours later.

Assume that source Y is a point source emitting radiation in all direction.

(Sample X is not present in this part of the experiment.)

distance = ... cm [4]

(e) Fig. 7.2 shows the variation with time of the cumulative counts (total count) of a small sample of X and of the background radiation.

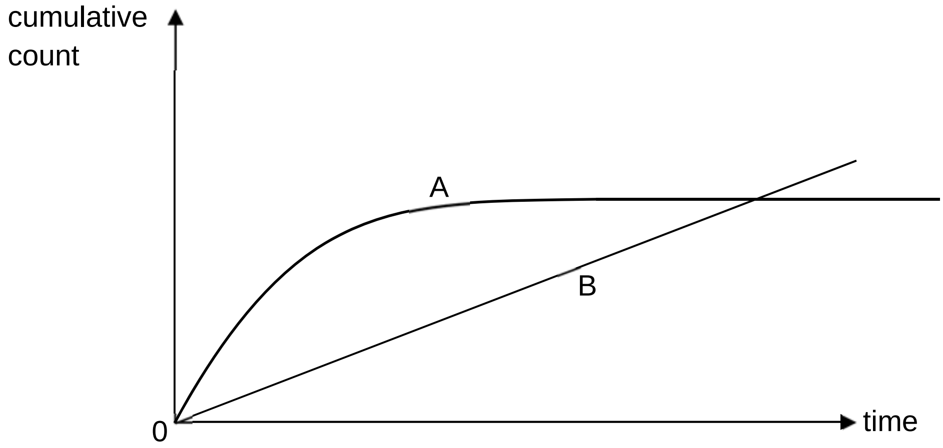


Fig. 7.2

(i) State and explain which graph, A or B, in Fig. 7.2 represents the cumulative count of the background radiation.

....

.... [1]

(ii) Sketch and label on Fig. 7.2, a graph that represents the cumulative count of a sample of Y that has half the initial number of nuclei as that of sample X.

[1]

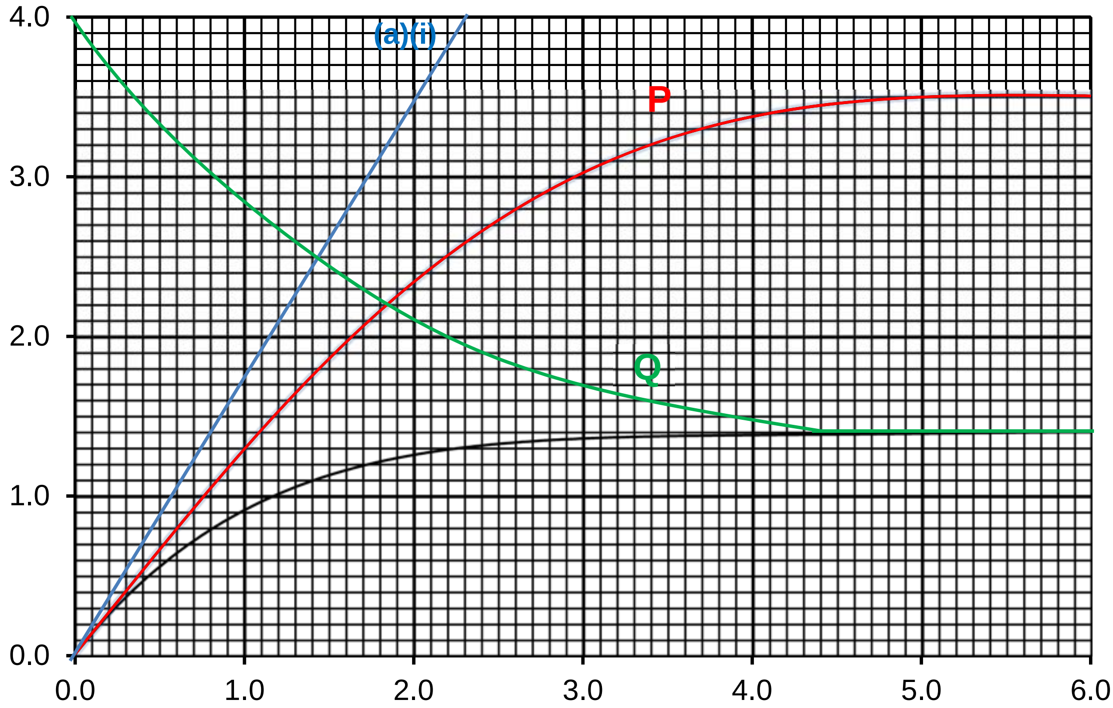
End of Paper 3 Section B

2018 Raffles Institution Preliminary Examinations – H2 Physics

Paper 3 – Solutions

Section A

1



(a) **(i)** (The graph is a curve. This implies there is non-constant acceleration due to effect of air resistance. Only at t = 0 is the acceleration equal to g)

Draw tangent at t = 0

acceleration = gradient $= \dfrac{4.00}{2.30} = 1.74 \text{ m s}^{-2}$

(ii) The Moon's surface has no atmosphere (very negligible compared to Earth). There is no air resistance outside the container.

Read off from tangent (as this is the v-t graph for no air resistance):
v = 1.4 m s^{-1}, t = <u>0.80 s</u>

or use equation: $v = u + at$
(substitute value of a from (a)(i), v = 1.4, u = 0)

(b) **(i)** At terminal velocity, resistive force F reaches its maximum value.

$$\begin{aligned} F_{\text{max}} &= mg \\ &= 0.0027(1.74) \\ &= 4.70 \times 10^{-3} \text{ N} \end{aligned}$$

(ii) $kv_T = mg$ (v_T is terminal velocity on Moon)

$$k(1.40) = 4.70 \times 10^{-3}$$

$$k = 3.36 \times 10^{-3} \text{ kg s}^{-1}$$

(iii) $kv_T^{'} = mg$ ($v_T^{'}$ is terminal velocity on Earth)

$$3.36\times10^{-3}v_T^{'} = 0.0027(9.81)$$

$$v_T^{'} = 7.89 \text{ m s}^{-1}$$

(iv) **1.** Total mass is 2.5 x initial mass.

$kv_T = mg$

$$v_T = \frac{mg}{k} = \frac{2.5\left(4.70\times10^{-3}\right)}{3.36\times10^{-3}} = 3.50 \text{ m s}^{-1}$$

Initial gradient is the same, and graph always above the original (but below the tangent) – B1

Curve reaches terminal velocity 3.5 m s^{-1} – B1

(time it reaches terminal velocity is later – not marking pt)

2. Starts from 4.0 m s^{-1}

Curve must show speed decreasing to v_T – B1

2 **(a)** **(i)** The gravitational field strength at a point in space is defined as the gravitational force experienced per unit mass at that point.

(ii) Gravitational field strength is a vector since it is defined using gravitational force which is a vector.

(iii) Newton's law of gravitation states that two point masses attract each other with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

Since gravitational field strength g is defined as the gravitational force acting per unit mass:

$$g = \frac{F_G}{m} = \frac{GMm}{r^2 m} = \frac{GM}{r^2}$$

(b) **(i)**

$$\frac{g_{\text{Sun}}}{g_{\text{Jupiter}}} = \frac{\left(\frac{GM_{Sun}}{r_{sun}{}^2}\right)}{\left(\frac{GM_{Jupiter}}{r_{Jupiter}{}^2}\right)} = \frac{M_{Sun}}{M_{Jupiter}}\left(\frac{r_{Jupiter}}{r_{Sun}}\right)^2$$

$$= \left(\frac{1.99\times10^{30}}{1.90\times10^{27}}\right)\left(\frac{7.14\times10^{7}}{7.79\times10^{11}}\right)^2$$

$$= 8.80\times10^{-6}$$

(ii) Since the gravitation field strength due to the Sun on the surface of Jupiter is only ~10^{-6} (< 0.001%) that of the gravitational field strength on the surface of Jupiter due to its mass, it can be neglected.

(c) **(i)** For a moon in circular orbit about its planet, the centripetal force is provided by the gravitational force acting on the moon by the planet:

$$\frac{GM_pM_m}{R^2} = M_mR\omega^2$$

Since $T = \dfrac{2\pi}{\omega}$, *we have* $\omega = \dfrac{2\pi}{T}$

$$GM_p = R^3\omega^2 = R^3\left(\frac{2\pi}{T}\right)^2$$

Rearranging, we have:

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

Since M_p *is the mass of the planet,* $\dfrac{4\pi^2}{GM_p}$ *is a constant*

$$\therefore\ T^2 = KR^3 \text{ where } K = \frac{4\pi^2}{GM_p}$$

(ii) Since $T^2 \propto R^3$

$$\frac{T_E}{T_I} = \sqrt{\left(\frac{R_E}{R_I}\right)^3} = \sqrt{\left(\frac{R_E}{R_I}\right)^3} = \sqrt{\left(\frac{6.71\times10^8}{4.22\times10^9}\right)^3} = 2.01 \approx 2$$

$$\frac{T_G}{T_I} = \sqrt{\left(\frac{R_G}{R_I}\right)^3} = \sqrt{\left(\frac{R_G}{R_I}\right)^3} = \sqrt{\left(\frac{1.07\times10^9}{4.22\times10^8}\right)^3} = 4.04 \approx 4$$

Hence, the ratio of the orbital period of Io: Europa: Ganymede is 1: 2: 4

3 **(a)** Since the test-tube is in equilibrium, $F_{net} = (M+m)g - \rho(AH)g = 0$

$$(M+m)g = \rho(AH)g$$

$$H = \frac{(M+m)}{\rho A}$$

(b) **(i)** $-\rho Agy$

(ii) $-\rho Agy = (M+m)a$

$$a = -\frac{\rho Ag}{M+m}y$$

(c) By comparing with $a = -\omega^2 x$,

$$\omega^2 = \frac{\rho Ag}{M+m}$$

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

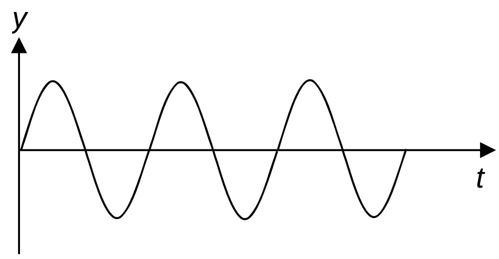
$$= 2\pi\sqrt{\frac{M+m}{\rho Ag}}$$

$$= 2\pi\sqrt{\frac{0.012+0.025}{1000\times6.0\times10^{-4}\times9.81}}$$

$$= 0.498 \approx 0.50 \text{ s}$$

(d) As the test-tube oscillates, it experiences drag force exerted by the water . This results in light damping and energy is gradually lost as heat.

(e) **(i)**



(ii) The amplitude of oscillation is small because the frequency of the driving force (the waves) is too low (0.30 Hz) compared to the natural frequency of the test-tube (2 Hz).

The amplitude of the oscillations can be increased by adding ball bearings to the test-tube to decrease the natural frequency so that it is closer to the frequency of the driving force.

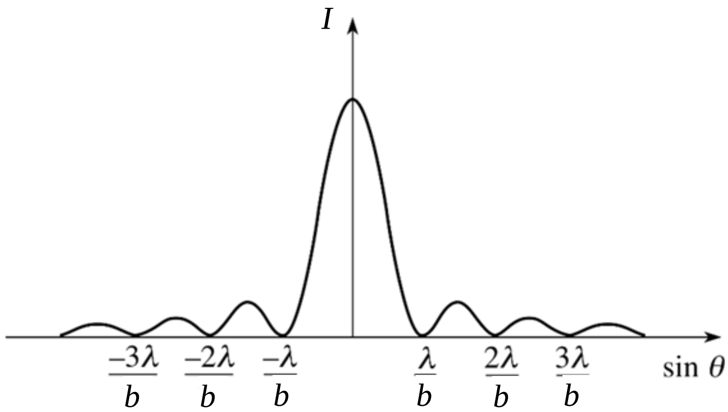
4 **(a)** **(i)** The principle of superposition states that when two or more waves of the same kind meet at a point in space, the resultant displacement at that point is equal to the vector sum of the displacements of the individual waves at that point.

(ii) According to Huygen's principle, all the points on the wavefronts that pass through the single slit are individual sources of circular wavelets which interfere with one another by the principle of superposition to form the interference pattern.

(b) **(i)** For single slit diffraction, $b\sin\theta = m\lambda$

Positions of minima, $\sin\theta = \dfrac{\lambda}{b}m = \dfrac{600\times10^{-9}}{0.30\times10^{-3}}m = \left(2.0\times10^{-3}\right)m$

where $\dfrac{\lambda}{b} = 2.0\times10^{-3}$



(ii) limiting angle of resolution for the single slit, $\theta_{\text{min}} \approx \dfrac{\lambda}{b} = 2.0\times10^{-3}$ rad

$\theta \approx \dfrac{s}{r} = \dfrac{1.0\times10^{-3}}{0.25} = 4.0\times10^{-3}$ rad

Since $\theta > \theta_{\text{min}}$, the interference patterns due to the two point sources of light can be resolved.

(c) (i) Position of first minima of the single slit diffraction envelope is given by:
$b\sin\theta = \lambda$ ----- (1)
where b is the slit width

Positions of maxima of the double slit interference pattern is given by:
$a\sin\theta = n\lambda$ ----- (2)
where a is the slit separation

Where the first minima of the single slit diffraction envelope coincide with a double slit maxima, θ is the same in equations (1) and (2).

$$\frac{(2)}{(1)}: \quad n = \frac{a}{b} = \frac{1.2}{0.30} = 4$$

Hence the 4th orders will be missing from the double slit interference pattern.

Number of maxima in the central region / within the diffraction envelope
= 3 + 3 + 1 = 7
(3 maxima on either side of the principle axis and the central maximum)

(ii)

$$\tan\theta = \frac{12\times10^{-3}}{2}\times\frac{1}{D}$$

$$D \approx \frac{12\times10^{-3}}{2\theta}$$

$$= \frac{12\times10^{-3}}{2\left(2.0\times10^{-3}\right)}$$

$$= 3.0 \text{ m}$$

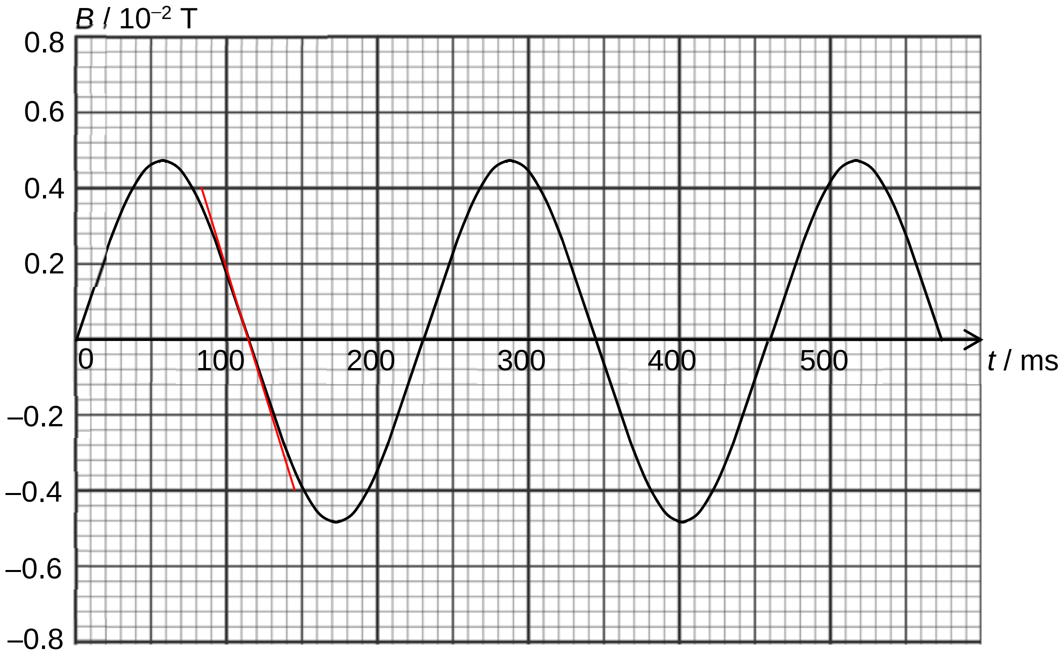
5 **(a)** Faraday's law of electromagnetic induction states that the induced e.m.f. is proportional to the rate of change of magnetic flux linkage.

(b) **(i)** When magnetic field increases in the positive direction, induced current decreases in the negative direction. When magnetic field reaches maximum, induced current becomes zero. As magnetic field decreases in the positive direction, induced current increases in the positive direction until it reaches a minimum value when B = 0.

This corresponds to Lenz's law as induced current flows in a direction to produce effects that opposes the change producing it. Hence sensitive ammeter deflects in opposite directions.

(ii) **1.** Accept t = 115, 230, 345 or 450 $\times 10^{-3}$ s

2.



Using (85×10^{-3}, 0.40×10^{-2}) and (145×10^{-3}, -0.40×10^{-2}),

$$\left|\frac{dB}{dt}\right|_{max} = \frac{\left(-0.40\times10^{-2} - \left(-0.40\times10^{-2}\right)\right)}{\left(145\times10^{-3} - 85\times10^{-3}\right)} = 0.1333$$

$$i_{max} = \frac{E_{max}}{R} = \frac{AN}{R}\left|\frac{dB}{dt}\right|_{max} = \frac{4.2\times10^{-4}\times400\times0.1333}{5.0}$$

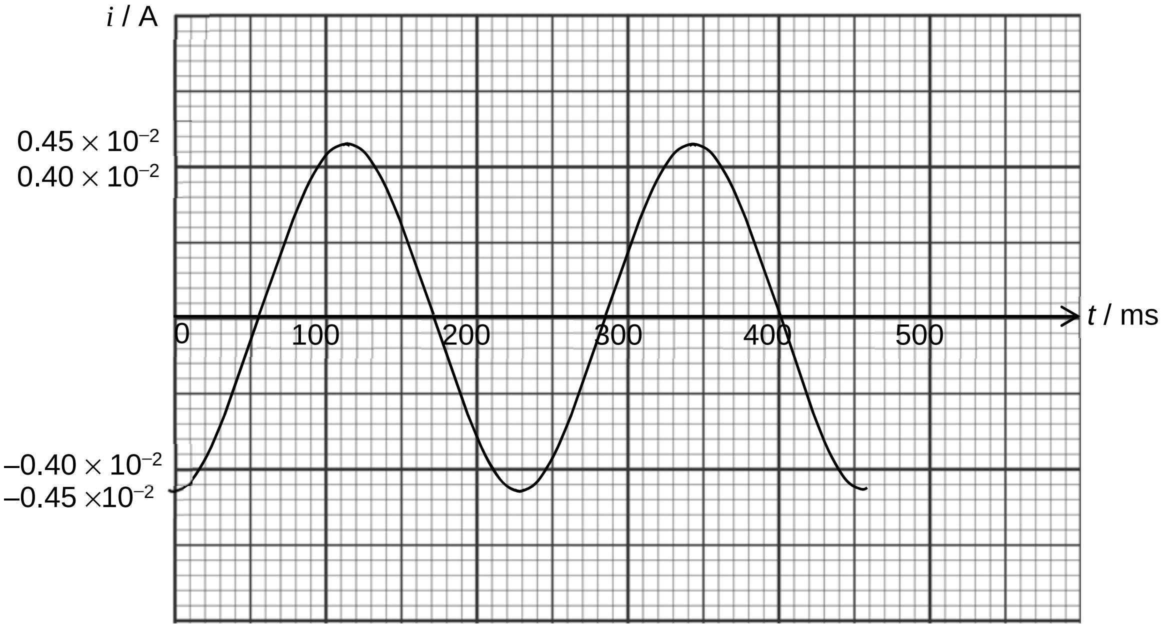
$$\therefore i_{max} = 4.5\times10^{-3}\text{ A}$$

3.

$$\langle P\rangle = \frac{P_o}{2} = \frac{i_{max}^2 R}{2} = \frac{\left(4.479\times10^{-3}\right)^2\times5.0}{2}$$

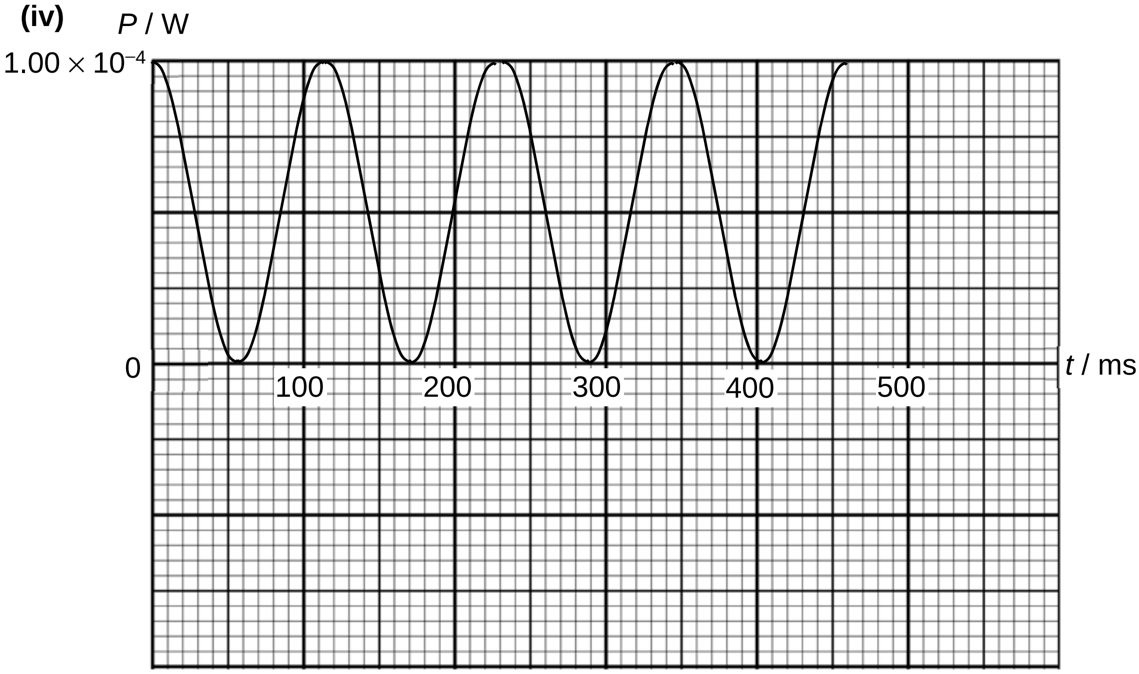
$$\therefore \langle P\rangle = 5.0\times10^{-5}\text{ W}$$

(iii)



i / A
0.45 × 10⁻²
0.40 × 10⁻²
–0.40 × 10⁻²
–0.45 ×10⁻²
0
100
200
300
400
500
t / ms

(iv)

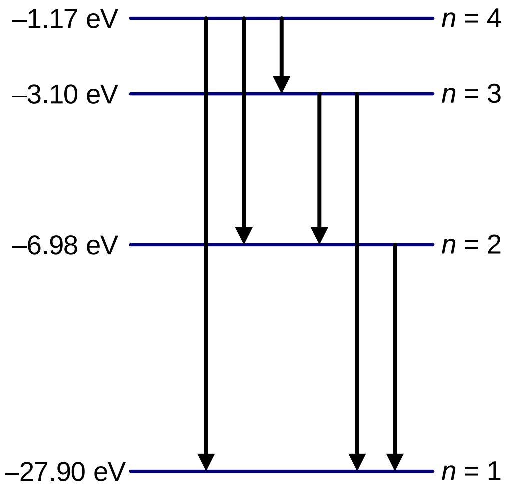


P / W
1.00 × 10⁻⁴
0
100
200
300
400
500
t / ms

Section B

6 **(a)** **(i)**

n	E_n / eV
1	–27.90
2	–6.975
3	–3.100
4	–1.744



(ii)

n	ΔE / eV
$1 \rightarrow 2$	20.92
$1 \rightarrow 3$	24.80
$1 \rightarrow 4$	26.16
$1 \rightarrow 5$	26.78

(iii) Refer to diagram above.

(iv) To calculate wavelength, we use

$$\Delta E = \frac{hc}{\lambda} \qquad \Rightarrow \qquad \lambda = \frac{hc}{\Delta E}$$

Longest wavelength

$$\lambda = \frac{hc}{\Delta E_{4\rightarrow 3}} = \frac{6.63\times10^{-34}\times3.00\times10^{8}}{1.36\times1.60\times10^{-19}} = 914 \text{ nm}$$

Shortest wavelength

$$\lambda = \frac{hc}{\Delta E_{4\rightarrow 1}} = \frac{6.63\times10^{-34}\times3.00\times10^{8}}{26.16\times1.60\times10^{-19}} = 47.5 \text{ nm}$$

(b) **(i)** Bombarding electrons experience (rapid) deceleration when they are deflected by or collide/interact with the nuclei/atoms in the target metal.
During each of these interactions, an electron loses a fraction of its K.E. and emit a photon with energy equals the loss in K.E.
Since an electron can loses varying amount of its K.E. (due to different degree of deceleration), emitted X-ray photons will have a continuous range of energy up to the entire K.E. of the bombarding electrons. Hence the continuous spectrum W.
The most energetic X-ray photon with the minimum wavelength has energy equals to K.E. of bombarding electron.

(ii) Maximum energy of electron is equal to energy of photon with shortest wavelength.

$$E_{\max} = \frac{hc}{\lambda_{\min}}$$

Accelerating potential

$$V = \frac{hc}{e\lambda_{\min}} = \frac{6.63\times10^{-34}\times3.00\times10^{8}}{1.60\times10^{-19}\times2.00\times10^{-10}}$$
$$= 6220 \text{ V}$$

(iii) L_α = Y
L_β = X
M_α = Z

(iv) The energy of the bombarding electron is insufficient to knock out an electron from the K-shell of the atom.

7 **(a)** (total count rate $C = C_x + C_y$)
As half-life of X is much longer than Y, after about 8 days, the activity (or count-rate) of Y becomes negligible, hence the total count rate is only given by X.
($C \approx C_x$)

As the count rate of X obeys the exponential decay law

$$C_X = C_{X_0} e^{-\lambda_X t}$$
$$\ln C_X = \ln C_{X_0} - \lambda_X t$$

A graph of ln C_X against t is a straight line (with gradient $-\lambda_X$ and vertical intercept $\ln C_{X_0}$).

(b) **(i)** Extrapolate the straight line portion to find y–intercept, to get the initial count rate of X.

Value of y–intercept = 5.4

$$\ln C_{X_0} = 5.4$$
$$C_{X_0} = e^{5.4}$$
$$= 221 = 220 \text{ counts per minuite (2 or 3 s.f.)}$$

Slope of the straight line = – λ_X = (3.90 – 4.50) / (14.0 – 8.0) = – 0.10 day^{-1}

OR

Taking coordinates of the extrapolated line
Slope of the straight line = – λ_X = (3.90 – 5.40) / (14.0 – 0) = – 0.11 day^{-1}

$$t_{1/2} = \frac{\ln 2}{\lambda_X} = \frac{\ln 2}{0.11}$$
$$= 6.3 \text{ days (or 6.9 days)}$$

(ii) After 19 days, the count rate is nearly all due to X.

$$C_X = C_{X_0} e^{-\lambda t}$$
$$= 220\, e^{-0.11(19)}$$
$$= 27 \text{ counts per minute}$$

(c) **(i)** The range of beta particles through the human body is short.
OR
The penetrative power of beta particles is weak.

(ii) The gamma rays are emitted in all directions (and the detector is small and only measures the rays at a point).

(iii)
- The physical state of the source (solid, liquid, or in solution) as it affects the way the source is administrated into the body.
- The nuclide used should decay to a stable product (so that it no longer emits radioactive substance longer than it should).
- If the nuclide is introduced to the human body, it must be able to be removed naturally e.g. in urine, exhaled or excreted.
- The source should not be carcinogenic or toxic.

(d) Background count = 15 s^{-1}
Corrected initial count-rate (due to Y alone) = 100 – 15 = 85 s^{-1}

Count-rate after 3 $t_{1/2}$ is $85 \times \left(\frac{1}{2}\right)^3 = 10.625\ s^{-1}$

Assuming emission is in all direction hence count-rate $\propto 1/r^2$

$$\frac{C_2}{C_1} = \left(\frac{r_1}{r_2}\right)^2$$
$$\frac{85}{10.625} = \left(\frac{30}{r}\right)^2$$
$$r = 10.6 \text{ cm}$$

Note:
The correct answer can also be obtained even if background is not accounted for :

$$C_2 = C_1 \times \left(\frac{1}{2}\right)^3 = \frac{C_1}{8}$$

Hence

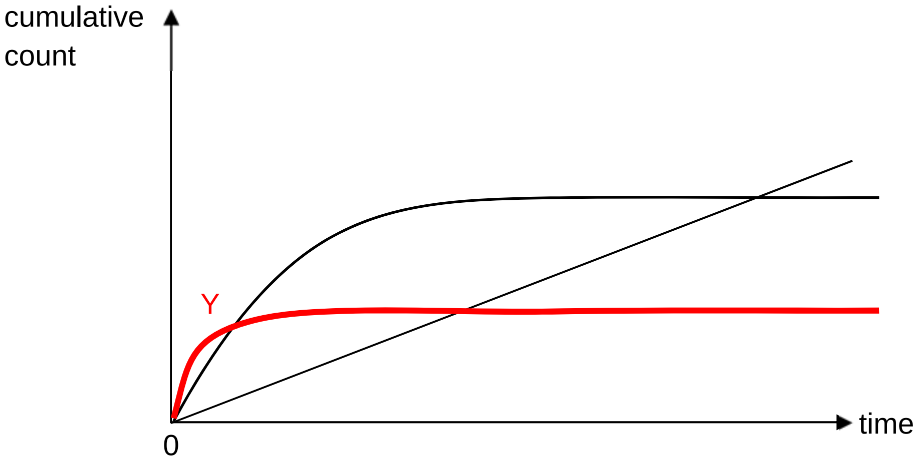
$$\frac{C_2}{C_1} = \left(\frac{r_1}{r_2}\right)^2$$
$$\frac{C_1/8}{C_1} = \left(\frac{30}{r}\right)^2$$
$$\frac{1}{8} = \left(\frac{30}{r}\right)^2$$
$$r = 10.6 \text{ cm}$$

which is independent of what C_1 is (whether background is considered or not).

This is unique in this context. Students should still be aware that in general, background count needs to be subtracted when accounting for radioactivity of the nuclides.

(e) **(i)** Graph B
Since count rate (of background) is constant, the total count increases at a constant rate.

(ii)



*Initial increase is greater than X, reaches plateau sooner than X. Lower final total count.

The following workings are for infor only:

X's half-life = 6.9 days
Y's half-life = 20 hours

$$A_0 = \frac{\ln 2}{t_{1/2}} N_0$$

For X: $A_0 = \dfrac{\ln 2}{6.9 \times 24} N_0 = 0.004 N_0$

For Y: $A_0 = \dfrac{\ln 2}{20} \dfrac{N_0}{2} = 0.017 N_0$

$$A = -\frac{dN}{dt}$$

Graph is equivalent to ($N_0 - N$) against time.
Hence gradient of graph is proportional to A.
Since initial activity of Y > X, hence initial gradient of Y > X