NANYANG JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 2

PHYSICS 9749/01

Paper 1 Multiple Choice **25 September 2018**

1 hour

Additional Materials: Multiple Choice Answer Sheet

READ THESE INSTRUCTIONS FIRST

Write in soft pencil.
Do not use staples, paper clips, highlighters, glue or correction fluid.
Write your name, class and tutor's name on the Answer Sheet in the spaces provided unless this has been done for you.

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 separate Answer Sheet.

Read the instructions on the Answer Sheet 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.

This document consists of **13** printed pages.

Data

speed of light in free space	c	=	3.00×10^{8} m s^{-1}
permeability of free space	μ_o	=	$4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space	ε_o	=	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 molecule	E	=	$\frac{3}{2}kT$
displacement of particle in s.h.m.	x	=	$x_o \sin \omega t$
velocity of particle in s.h.m.	v	=	$v_o \cos \omega t$
		=	$\pm \omega\sqrt{(x_o^2 - x^2)}$
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	=	$Q / 4\pi\varepsilon_o r$
alternating current/voltage	x	=	$x_o \sin \omega t$
magnetic flux density due to a long straight wire	B	=	$\mu_o I / 2\pi d$
magnetic flux density due to a flat circular coil	B	=	$\mu_o NI / 2r$
magnetic flux density due to a long solenoid	B	=	$\mu_o nI$
radioactive decay	x	=	$x_o \exp(-\lambda t)$
decay constant	λ	=	$\ln 2 / t_{1/2}$

1 Which of the following statements is not always true?

A The total mass of two 1 kg masses is 2 kg.

B The total charge of a +1 C charge and a –1 C charge is zero.

C The resultant of two 1 N forces is 2 N.

D The total energy of 1 J of kinetic energy and 1 J of potential energy is 2 J.

2 The following are the results obtained by two students P and Q in the determination of the mass of an object.

Student P	1.05 kg	0.96 kg	1.01 kg	0.97 kg
Student Q	1.08 kg	1.07 kg	1.08 kg	1.06 kg

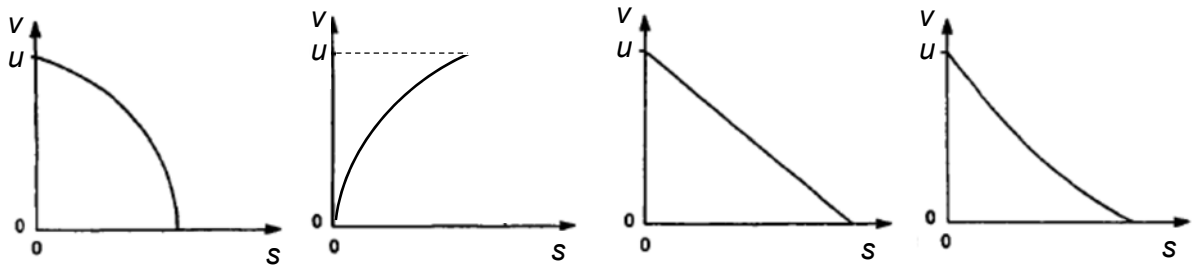
Which of the following most appropriately describes the results obtained by students P and Q?

	more accurate	more precise
A	Q	*cannot be determined*
B	P	Q
C	Q	P
D	*cannot be determined*	Q

3 A train initially at rest accelerates at a constant rate of 1.4 m s^{-2} for 10 s and then slows down at a constant rate of 0.20 m s^{-2} until it comes to a rest. The total distance travelled by the train is

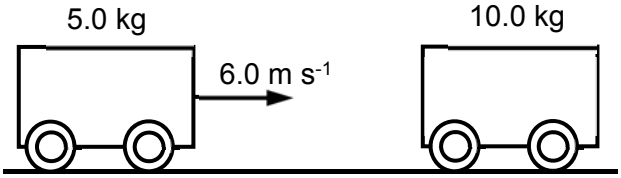
A 80 m **B** 220 m **C** 560 m **D** 1120 m

4 A falling stone strikes some soft ground at speed *u* and suffers a constant deceleration until it stops. Which one of the following graphs best represents the variation of the stone's speed, *v*, with distance, *s*, measured downwards, from the surface of the ground?



A **B** **C** **D**

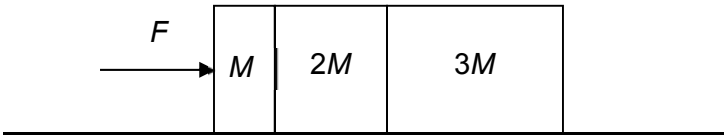
5 A trolley of mass 5.0 kg travelling at a speed of 6.0 m s^{-1} collides head-on and locks together with another trolley of mass 10.0 kg which is initially at rest. The collision lasts for 0.20 s.



What is the total kinetic energy of the two trolleys after the collision and the average force acting on each trolley during this collision?

	Total kinetic energy after the collision / J	Average force on each trolley / N
A	30	150
B	75	150
C	30	100
D	75	100

6 Three blocks with masses *M,* 2*M* and 3*M* are pushed along a rough surface by a horizontal force *F* as shown.



The frictional force between a block and the rough surface is directly proportional to the weight of the block. Given that the frictional force between the block with mass *M* and the rough surface is *f,* what is the magnitude of the force mass 3*M* exerts on mass 2*M*?

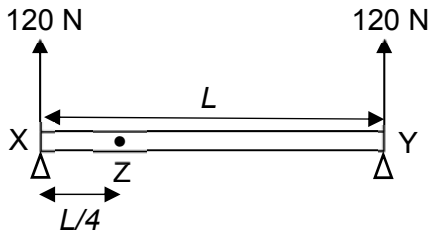
A $\frac{F}{2}$

B $\frac{F}{2} + 3f$

C $\frac{F}{3} + f$

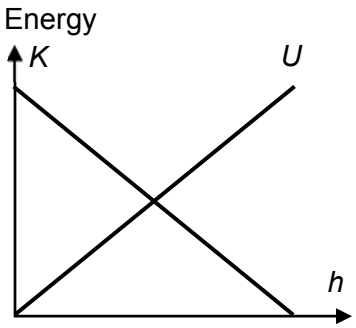
D $\frac{F}{3} + 3f$

7 A uniform plank of length *L* is supported by initially equal forces of 120 N at X and Y. If the force at X is now moved to Z such that the plank is kept horizontal, what is the magnitude of the force at Y?

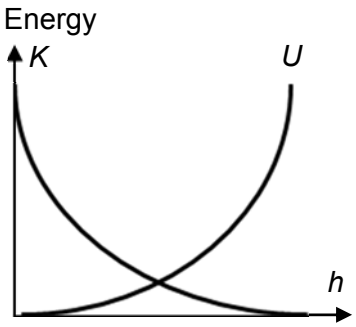


A 60 N **B** 80 N **C** 120 N **D** 160 N

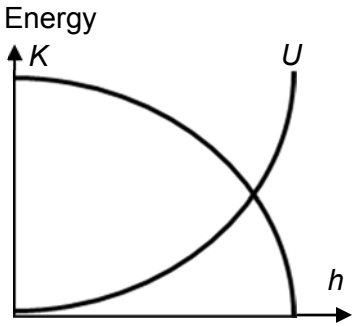
8 A ball is projected vertically upwards. At a height *h*, the kinetic energy of the ball is *K* and its potential energy is *U*. Taking air resistance to be negligible, which graph correctly shows the variations of *K* and *U* with *h*?



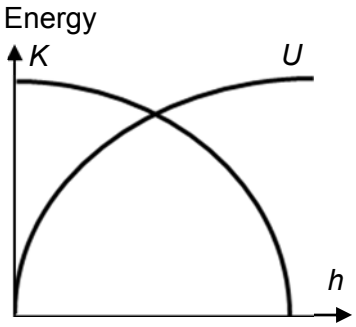
A



B



C

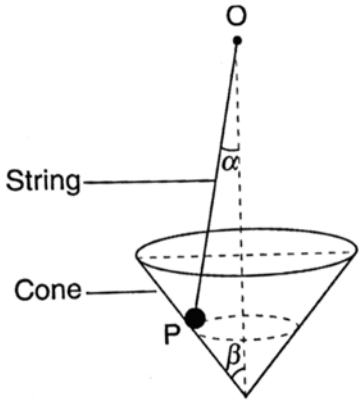


D

9 The engine of a car has maximum output power of 54 kW. The air resistance acting on the car when it is moving with speed *v* is cv^2, where *c* is 2.0 kg m^{-1}. What is the maximum speed that can be achieved by the car on level road?

A 3.0 m s^{-1} **B** 5.0 m s^{-1} **C** 30 m s^{-1} **D** 160 m s^{-1}

10 A pendulum bob at the end of the string which is fixed at O moves in a horizontal circle on the inside of a cone as shown.



If the tension in the string is T and the normal contact force by the cone is R, which of the following gives the centripetal force on the bob?

A $T \sin \alpha + R \cos \beta$

B $T \sin \alpha - R \cos \beta$

C $T \cos \alpha + R \sin \beta$

D $T \cos \alpha - R \sin \beta$

11 Two satellites X and Y are orbiting at heights of $5R$ and $9R$ above the surface of the Earth respectively, where R is the radius of the Earth.

What is the ratio of their orbital speeds v_X/v_Y ?

A 1.29 **B** 1.34 **C** 1.67 **D** 1.80

12 The gravitational potentials on the surface of a planet P and on the surface of its moon Q are -120 MJ kg^{-1} and -20 MJ kg^{-1} respectively.

The minimum amount of energy required to project a 1 kg mass from the surface of Q to the surface of P is E.

Which of the following correctly describes the value of E?

A $E < 20$ MJ

B $E = 20$ MJ

C 20 MJ $< E <$ 100 MJ

D 100 MJ $< E <$ 120 MJ

13 Which of the statements about damped oscillations is not true?

A The period of the oscillation increases with time.

B The amplitude of the oscillation decreases with time.

C The energy of the oscillation decreases with time.

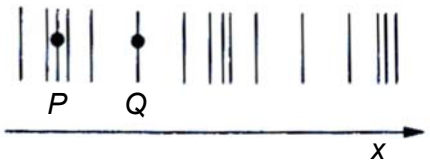
D The frequency of the oscillation is lower compared to that of an undamped oscillation.

14 In a heating experiment, energy is supplied at a constant rate to a liquid in a beaker of negligible heat capacity. The temperature of the liquid rises by 4.0 K per minute just before it begins to boil. After 40 minutes, all the liquid has boiled away.

For this liquid, what is the ratio $\frac{\text{specific heat capacity}}{\text{specific latent heat of vapourisation}}$?

A $\frac{1}{10}\ \text{K}^{-1}$ **B** $\frac{1}{40}\ \text{K}^{-1}$ **C** $\frac{1}{160}\ \text{K}^{-1}$ **D** $\frac{1}{640}\ \text{K}^{-1}$

15 The compressions and rarefactions of a sound wave travelling in air in the positive *x*-direction are shown below.



Which statement is true about the diagram?

A At *P*, the air pressure is minimum.

B At *Q*, it is a position of antinode.

C At *Q*, the air molecule is momentarily at rest.

D At *P*, the air molecule is moving in the positive *x*-direction.

16 The two lowest frequencies at which an open narrow tube resonates are 256 Hz and 512 Hz. If one of the ends is closed, what are the two lowest frequencies at which it would now resonate?

A 128 Hz and 256 Hz

B 128 Hz and 384 Hz

C 384 Hz and 640 Hz

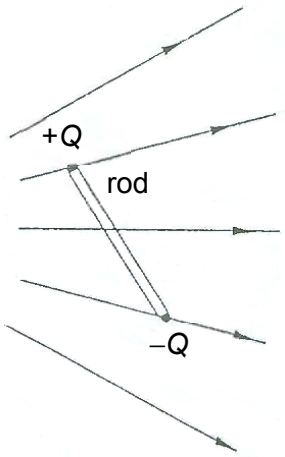
D 768 Hz and 1536 Hz

17 A beam of light that consists of all wavelengths between 480 nm and 600 nm is projected on a diffraction grating that contains 500 lines per millimeter.

What is the maximum number of complete continuous spectra that can be observed emerging from the grating?

A 6 **B** 7 **C** 8 **D** 9

18 An insulated rod with equal and opposite charges at its ends is placed in a non-uniform electric field with field lines as shown below.



The rod experiences

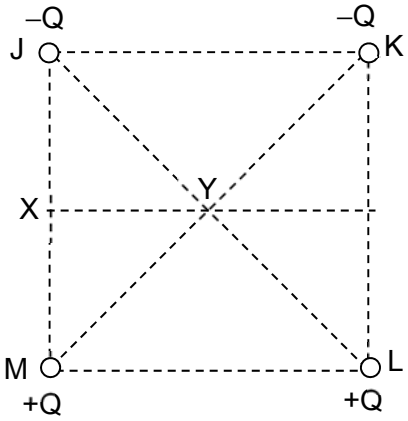
A a resultant force in the plane of the paper and a torque.

B a resultant force in the plane of the paper but no torque.

C a resultant force normal to the plane of the paper and a torque.

D a resultant force normal to the plane of the paper but no torque.

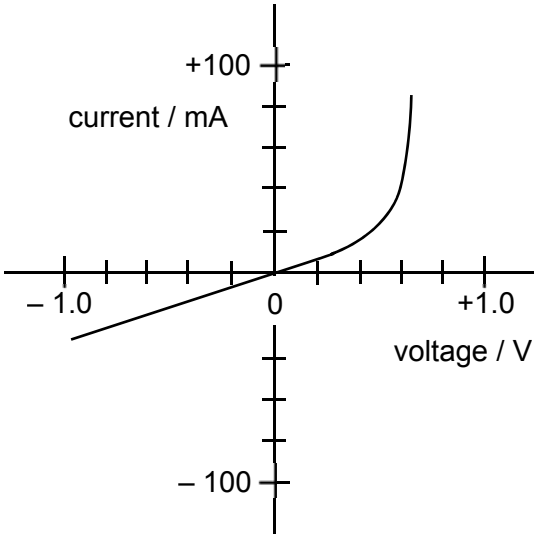
19 Four point charges are at the corners of a square JKLM. The point charges at J and K have a charge of –*Q* and the point charges at L and M have a charge of +*Q*.



An electron is brought from point X to point Y in a straight line by an external force without any change in its speed. Which of the following is correct about the change in electric potential energy of the system and work done by the external force?

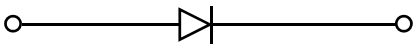
	change in electric potential energy	work done by the external force
A	positive	positive
B	negative	negative
C	negative	positive
D	zero	zero

20 A student is given a sealed box containing a concealed electrical circuit. The student plots the current-voltage characteristics below.

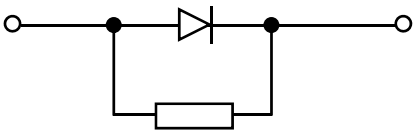


Which circuit is most likely to be enclosed within the box?

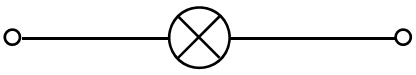
A



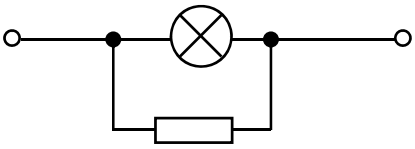
B



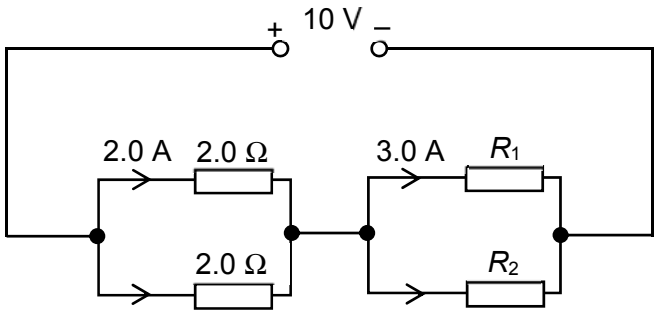
C



D



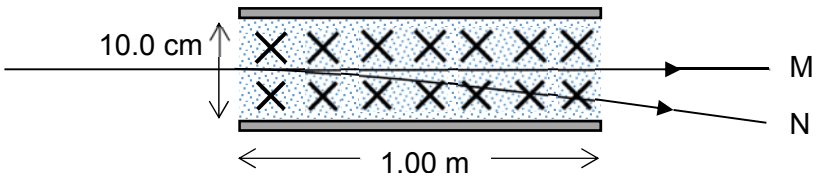
21 Four resistors are connected across a 10 V supply as shown in the circuit below.



What are the resistances R_1 and R_2?

	R_1	R_2
A	1.0 Ω	3.0 Ω
B	2.0 Ω	2.0 Ω
C	2.0 Ω	6.0 Ω
D	3.0 Ω	3.0 Ω

22 In the region of dimensions 10.0 cm by 1.00 m between two charged plates with a p.d. of 100 V, there is a uniform magnetic field of strength 100 mT directed into the page.



M and N are the paths made by electrons of different speeds.

Which of the following correctly describes the speed of the electron that made N?

A slightly smaller than 1.00×10^4 m s^{-1}

B slightly greater than 1.00×10^4 m s^{-1}

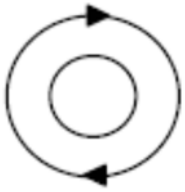
C slightly smaller than 1.00×10^5 m s^{-1}

D slightly greater than 1.00×10^5 m s^{-1}

23 A circular loop of wire with radius of 0.20 m is placed in a uniform magnetic field of 1.2 T that is normal to the plane of the loop. The loop is rotated about an axis along a diameter at a rate of 50 revolutions per minute. What is the maximum instantaneous e.m.f. induced?

A 0.13 V **B** 0.15 V **C** 0.79 V **D** 47 V

24 A small circular coil lies inside a large coil. The two coils are horizontal and concentric. The large coil carries a constant clockwise current.



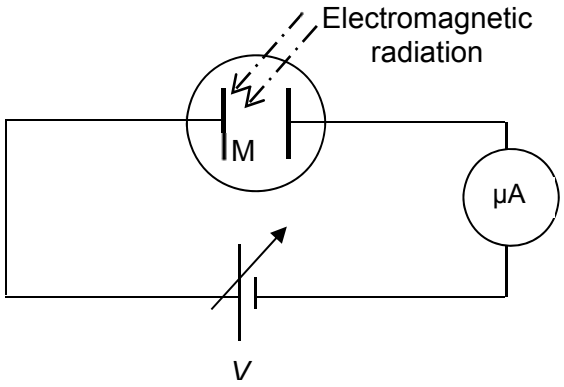
The smaller coil is pulled perpendicular out of the plane of the paper. Which of the following describes the direction of the induced current in the smaller coil and the resultant force between the coils?

	Induced current	Force between coils
A	Clockwise	Attraction
B	Clockwise	Repulsion
C	Anticlockwise	Attraction
D	Anticlockwise	Repulsion

25 An alternating voltage of 230 kV is supplied to a transformer, which steps the voltage down to a number of streetlamps with a rating of 230 V 150 W. If the maximum allowable current through the primary coil is 10 A, what is the maximum number of streetlamps that can be connected in parallel?

A 1500 **B** 6500 **C** 10000 **D** 15000

26 A 0.31 mW beam of photons with energy 3.11 eV each is incident on a clean metal plate M. The potential difference V is varied until the microammeter gives a maximum reading of 2.0 μA.



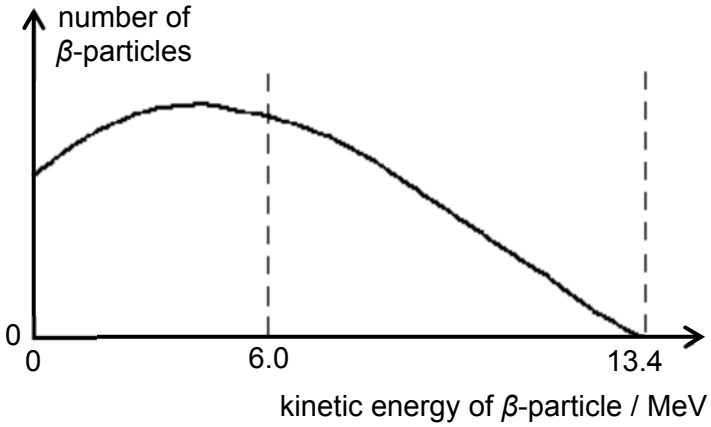
What is the ratio $\frac{\text{electrons emitted per unit time}}{\text{photons incident per unit time}}$?

A 3.2×10^{-21} **B** 2.0×10^{-2} **C** 1.0 **D** 1.3×10^{17}

27 What is the de Broglie wavelength of an alpha particle of kinetic energy E, given that u is the unified atomic mass unit?

A $\frac{h}{2\sqrt{uE}}$ **B** $\frac{2\sqrt{uE}}{h}$ **C** $\frac{h}{2\sqrt{2uE}}$ **D** $\frac{2\sqrt{2uE}}{h}$

28 The beta spectrum for ^{12}B decay is as shown below.



The kinetic energy of an emitted β-particle is 6.0 MeV. What is the approximate energy of the associated neutrino?

A 4.0 MeV **B** 6.0 MeV **C** 7.4 MeV **D** 13.4 MeV

29 Two radioactive isotopes P and Q have half-lives of 10 minutes and 15 minutes respectively. A sample initially contains the same number of atoms of each isotope. After 30 minutes, the ratio of the number of atoms of P to the number of atoms of Q will be

A 0.25 **B** 0.50 **C** 1.0 **D** 2.0

30 At time t, a sample of a radioactive substance contains N atoms of a particular nuclide.

At time $(t + \Delta t)$, where Δt is a short period of time, the number of atoms of the nuclide is $(N - \Delta N)$.

Which of the following expressions gives the decay constant of the nuclide?

A $\frac{\Delta N}{N}$ **B** $\frac{N - \Delta N}{t + \Delta t}$ **C** $\frac{\Delta N}{N\Delta t}$ **D** $\frac{N\Delta N}{\Delta t}$

End of Paper

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elementary charge	e	=	1.60×10^{-19} C
the Planck constant	h	=	6.63×10^{-34} J s
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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 molecule	E	=	$\frac{3}{2}kT$
displacement of particle in s.h.m.	x	=	$x_o \sin \omega t$
velocity of particle in s.h.m.	v	=	$v_o \cos \omega t$
		=	$\pm \omega\sqrt{(x_o^2 - x^2)}$
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	=	$Q / 4\pi\varepsilon_o r$
alternating current/voltage	x	=	$x_o \sin \omega t$
magnetic flux density due to a long straight wire	B	=	$\mu_o I / 2\pi d$
magnetic flux density due to a flat circular coil	B	=	$\mu_o NI / 2r$
magnetic flux density due to a long solenoid	B	=	$\mu_o nI$
radioactive decay	x	=	$x_o \exp(-\lambda t)$
decay constant	λ	=	$\ln 2 / t_{1/2}$

1 Which of the following statements is not always true?

A The total mass of two 1 kg masses is 2 kg.

B The total charge of a +1 C charge and a –1 C charge is zero.

C The resultant of two 1 N forces is 2 N.

D The total energy of 1 J of kinetic energy and 1 J of potential energy is 2 J.

Vector addition takes into consideration direction.

2 The following are the results obtained by two students P and Q in the determination of the mass of an object.

Student P	1.05 kg	0.96 kg	1.01 kg	0.97 kg
Student Q	1.08 kg	1.07 kg	1.08 kg	1.06 kg

Which of the following most appropriately describes the results obtained by students P and Q?

	more accurate	more precise
A	Q	*cannot be determined*
B	P	Q
C	Q	P
D	*cannot be determined*	Q

True value is not known.

3 A train initially at rest accelerates at a constant rate of 1.4 m s^{-2} for 10 s and then slows down at a constant rate of 0.20 m s^{-2} until it comes to a rest. The total distance travelled by the train is

A 80 m **B** 220 m **C** 560 m **D** 1120 m

$$s_1 = u_1 t_1 + \frac{1}{2} a_1 t_1^2 = \frac{1}{2} x1.4 x10^2 = 70\text{m}$$

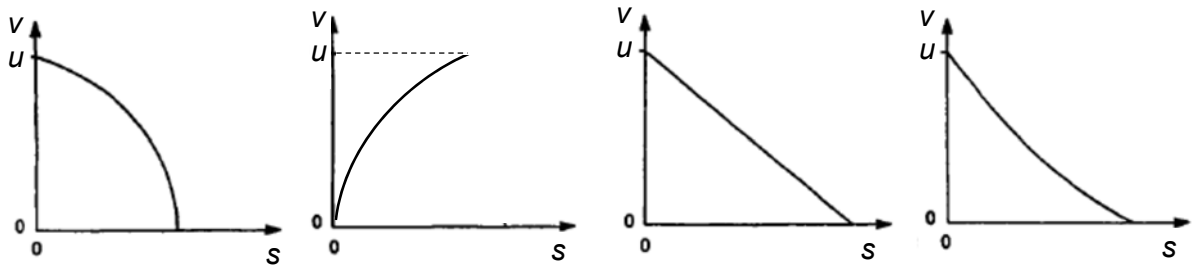
$$v_1 = u_1 + a_1 t_1 = 1.4 x10 = 14 = u_2$$

$$v_2^2 = u_2^2 + 2a_2 s_2$$

$$s_2 = \frac{u_2^2}{2a_2} = \frac{14^2}{2x0.2} = 490\text{m}$$

$$s = s_1 + s_2 = 70 + 490 = 560m$$

4 A falling stone strikes some soft ground at speed *u* and suffers a constant deceleration until it stops. Which one of the following graphs best represents the variation of the stone's speed, *v*, with distance, *s*, measured downwards, from the surface of the ground?



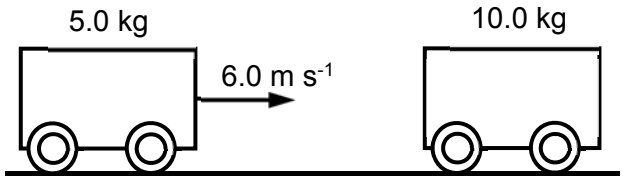
A **B** **C** **D**

$v^2 = u^2 + 2as$ where a is negative.

$$\frac{dv}{ds} = \frac{dv}{dt} \times \frac{dt}{ds} = \frac{a}{v}$$

As v decrease, gradient of v-s graph becomes increasingly negative.

5 A trolley of mass 5.0 kg travelling at a speed of 6.0 m s^{-1} collides head-on and locks together with another trolley of mass 10.0 kg which is initially at rest. The collision lasts for 0.20 s.



What is the total kinetic energy of the two trolleys after the collision and the average force acting on each trolley during this collision?

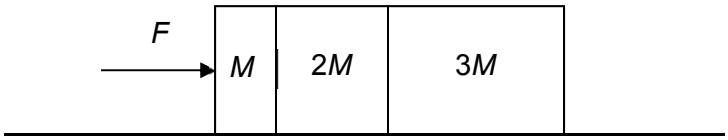
	Total kinetic energy after the collision / J	Average force on each trolley / N
A	30	150
B	75	150
C	30	100
D	75	100

Applying conservation of linear momentum, the speed after the collision is 2.0 m s^{-1}.

Hence, the total kinetic energy after the collision is ½ m_{total} v^2 = ½ x 15 x 2.0^2 = 30 J.

The force on either trolley is $\Delta p/\Delta t$ = 20/0.20 = 100 N.

6 Three blocks with masses *M,* 2*M* and 3*M* are pushed along a rough surface by a horizontal force *F* as shown.



The frictional force between a block and the rough surface is directly proportional to the weight of the block. Given that the frictional force between the block with mass *M* and the rough surface is *f,* what is the magnitude of the force mass 3*M* exerts on mass 2*M*?

A $\frac{F}{2}$

B $\frac{F}{2} + 3f$

C $\frac{F}{3} + f$

D $\frac{F}{3} + 3f$

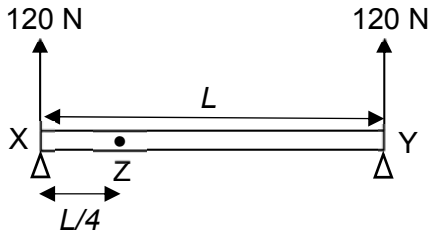
Consider the whole system,
$F - 6f = 6Ma$

$$a = \frac{F - 6f}{6M}$$

Let the force that 3M acts on 2M be F_1.
Consider Newton's 2nd law on 3M,
$F_1 - 3f = 3Ma$

$$F_1 = 3M\left(\frac{F - 6f}{6M}\right) + 3f = \frac{F}{2}$$

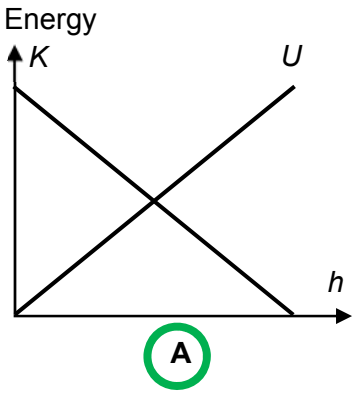
7 A uniform plank of length *L* is supported by initially equal forces of 120 N at X and Y. If the force at X is now moved to Z such that the plank is kept horizontal, what is the magnitude of the force at Y?



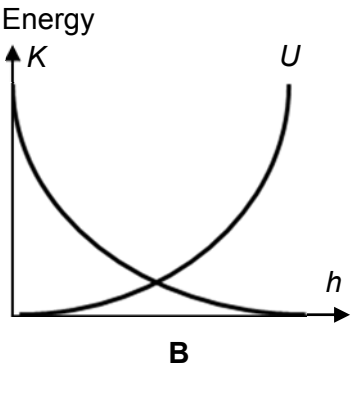
A 60 N **B** 80 N **C** 120 N **D** 160 N

Weight of plank is 240 N acting through the centre.
When force is moved to point Z, taking moment about point Z,
240 x L/4 = Force at Y x 3L/4
Force at Y = 80 N

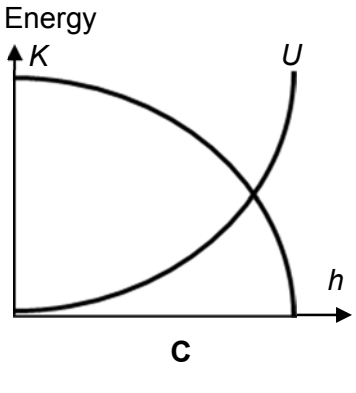
8 A ball is projected vertically upwards. At a height h, the kinetic energy of the ball is K and its potential energy is U. Taking air resistance to be negligible, which graph correctly shows the variations of K and U with h?



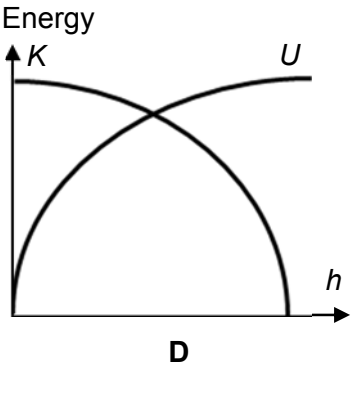
A



B



C



D

U = m g h → U varies linearly with h.

K + U = Total energy (constant)

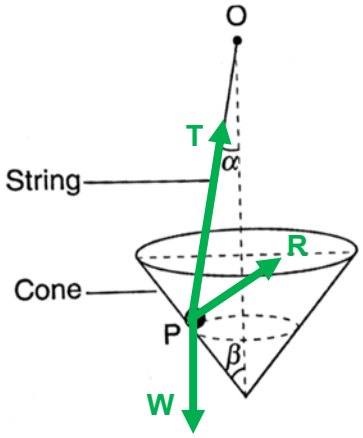
9 The engine of a car has maximum output power of 54 kW. The air resistance acting on the car when it is moving with speed v is cv^2, where c is 2.0 kg m^{-1}. What is the maximum speed that can be achieved by the car on level road?

A 3.0 m s^{-1} **B** 5.0 m s^{-1} **C** 30 m s^{-1} **D** 160 m s^{-1}

At max speed, rate of work done against air resistance = 54×10^3 W

F v = $cv^2 \times v = 54\times10^3$ → v = 30 m s^{-1}

10 A pendulum bob at the end of the string which is fixed at O moves in a horizontal circle on the inside of a cone as shown.



If the tension in the string is T and the normal contact force by the cone is R, which of the following gives the centripetal force on the bob?

A $T \sin \alpha + R \cos \beta$

B $T \sin \alpha - R \cos \beta$

C $T \cos \alpha + R \sin \beta$

D $T \cos \alpha - R \sin \beta$

11 Two satellites X and Y are orbiting at heights of $5R$ and $9R$ above the surface of the Earth respectively, where R is the radius of the Earth.

What is the ratio of their orbital speeds v_X/v_Y ?

A 1.29 **B** 1.34 **C** 1.67 **D** 1.80

$G M m / r^2 = m v^2 / r \rightarrow G M / r = v^2$

$\rightarrow v_X / v_Y = (r_Y / r_X)^{1/2} = (10R / 6R)^{1/2} = 1.29$

12 The gravitational potentials on the surface of a planet P and on the surface of its moon Q are -120 MJ kg^{-1} and -20 MJ kg^{-1} respectively.

The minimum amount of energy required to project a 1 kg mass from the surface of Q to the surface of P is E.

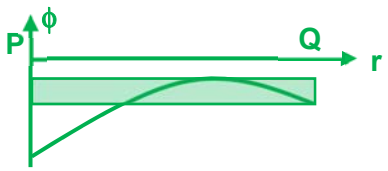
Which of the following correctly describes the value of E?

A $E < 20$ MJ

B $E = 20$ MJ

C $20 \text{ MJ} < E < 100$ MJ

D $100 \text{ MJ} < E < 120$ MJ



The highest potential between P and Q is greater than –20 MJ kg^{-1} and less than 0.

13 Which of the statements about damped oscillations is not true?

A The period of the oscillation increases with time.

B The amplitude of the oscillation decreases with time.

C The energy of the oscillation decreases with time.

D The frequency of the oscillation is lower compared to that of an undamped oscillation.

14 In a heating experiment, energy is supplied at a constant rate to a liquid in a beaker of negligible heat capacity. The temperature of the liquid rises by 4.0 K per minute just before it begins to boil. After 40 minutes, all the liquid has boiled away.

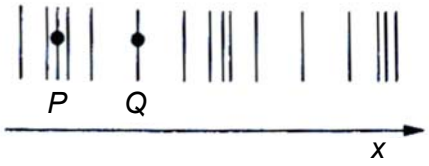
For this liquid, what is the ratio $\frac{\text{specific heat capacity}}{\text{specific latent heat of vapourisation}}$?

A $\frac{1}{10}\ \text{K}^{-1}$ **B** $\frac{1}{40}\ \text{K}^{-1}$ **C** $\frac{1}{160}\ \text{K}^{-1}$ **D** $\frac{1}{640}\ \text{K}^{-1}$

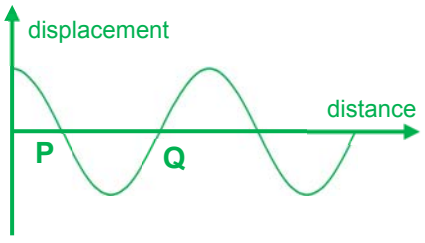
$P = m\,c\,d\theta/dt = dm/dt\,L$

$c / L = (m/40) / (m \times 4.0) = 1/160$

15 The compressions and rarefactions of a sound wave travelling in air in the positive x-direction are shown below.



Which statement is true about the diagram?



A At P, the air pressure is minimum.

B At Q, it is a position of antinode.

C At Q, the air molecule is momentarily at rest.

D At P, the air molecule is moving in the positive x-direction.

16 The two lowest frequencies at which an open narrow tube resonates are 256 Hz and 512 Hz. If one of the ends is closed, what are the two lowest frequencies at which it would now resonate?

A 128 Hz and 256 Hz

B 128 Hz and 384 Hz

C 384 Hz and 640 Hz

D 768 Hz and 1536 Hz

Length of tube L = ½ × v / 256 = v / 512

Closed tube: f_0 = v / (4L) = 512 / 4 = 128 Hz

f_1 = v / (4L/3) = ¾ × 512 = 384 Hz

17 A beam of light that consists of all wavelengths between 480 nm and 600 nm is projected on a diffraction grating that contains 500 lines per millimeter.

What is the maximum number of complete continuous spectra that can be observed emerging from the grating?

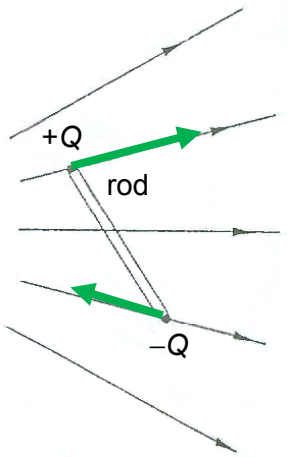
A 6 **B** 7 **C** 8 **D** 9

For longest wavelength: $n \lambda / d \leq 1 \rightarrow n \leq (1.0 \times 10^{-3} / 500) / 600 \times 10^{-9} = 3.3$

max n = 3

Thus there will be 6 spectra observed. (Zeroth order maximum is not a spectrum.)

18 An insulated rod with equal and opposite charges at its ends is placed in a non-uniform electric field with field lines as shown below.



The rod experiences

A a resultant force in the plane of the paper and a torque.

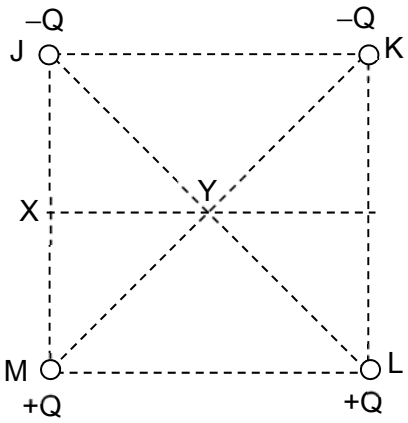
B a resultant force in the plane of the paper but no torque.

C a resultant force normal to the plane of the paper and a torque.

D a resultant force normal to the plane of the paper but no torque.

The resultant force can be seen from the diagram that it lies in the plane of the paper. The forces will produce a clockwise torque and cause the rod to rotate.

19 Four point charges are at the corners of a square JKLM. The point charges at J and K have a charge of –Q and the point charges at L and M have a charge of +Q.



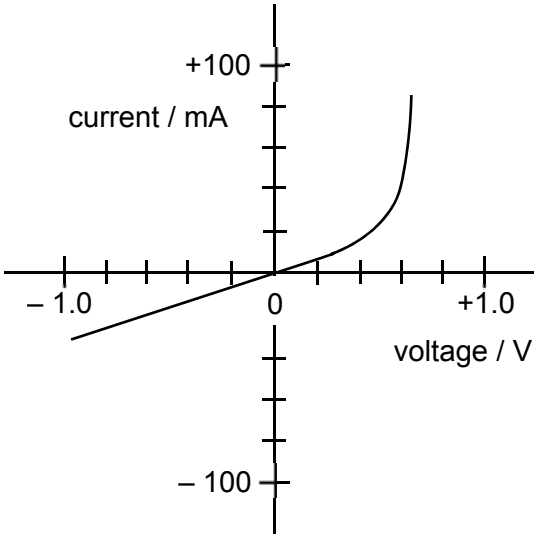
An electron is brought from point X to point Y in a straight line by an external force without any change in its speed. Which of the following is correct about the change in electric potential energy of the system and work done by the external force?

	change in electric potential energy	work done by the external force
A	positive	positive
B	negative	negative
C	negative	positive
D	zero	zero

The potentials at points X and Y are both zero, because they are each equidistant from the charges at J and M, and also equidistant from the charges at K and L.

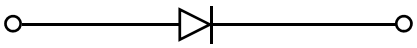
Since there is no change in the electrical potential energy from X to Y, no work is done by the external force.

20 A student is given a sealed box containing a concealed electrical circuit. The student plots the current-voltage characteristics below.

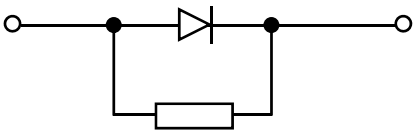


Which circuit is most likely to be enclosed within the box?

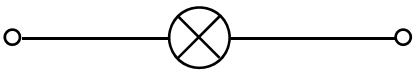
A



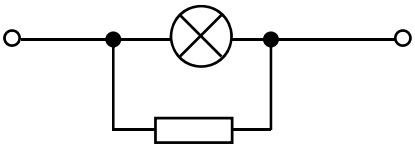
B



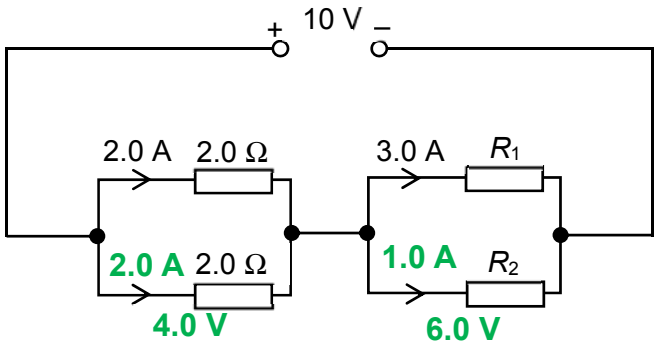
C



D



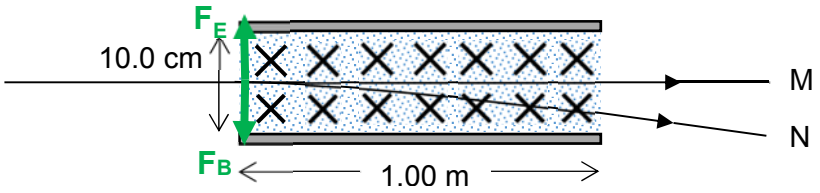
21 Four resistors are connected across a 10 V supply as shown in the circuit below.



What are the resistances R_1 and R_2?

	R_1	R_2
A	1.0 Ω	3.0 Ω
B	2.0 Ω	2.0 Ω
C	2.0 Ω	6.0 Ω
D	3.0 Ω	3.0 Ω

22 In the region of dimensions 10.0 cm by 1.00 m between two charged plates with a p.d. of 100 V, there is a uniform magnetic field of strength 100 mT directed into the page.



M and N are the paths made by electrons of different speeds.

Which of the following correctly describes the speed of the electron that made N?

A slightly smaller than 1.00×10^4 m s^{-1}

B slightly greater than 1.00×10^4 m s^{-1}

C slightly smaller than 1.00×10^5 m s^{-1}

D slightly greater than 1.00×10^5 m s^{-1}

M: $F_B = F_E \rightarrow B q v = q E$

$v = E / B = V / d B = 1.00 \times 10^4$ m s^{-1}

N: $F_B > F_E$

$v > 1.00 \times 10^4$ m s^{-1}

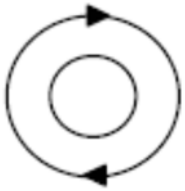
23 A circular loop of wire with radius of 0.20 m is placed in a uniform magnetic field of 1.2 T that is normal to the plane of the loop. The loop is rotated about an axis along a diameter at a rate of 50 revolutions per minute. What is the maximum instantaneous e.m.f. induced?

A 0.13 V **B** 0.15 V **C** 0.79 V **D** 47 V

$$\varepsilon = -\frac{d\phi}{dt} = -\frac{d(BA\cos\omega t)}{dt} = \omega BA\sin\omega t$$

$$\varepsilon_{max} = \omega BA = \frac{50x2\pi}{60}x1.2x\pi x0.20^2 = 0.79V$$

24 A small circular coil lies inside a large coil. The two coils are horizontal and concentric. The large coil carries a constant clockwise current.



The smaller coil is pulled perpendicular out of the plane of the paper. Which of the following describes the direction of the induced current in the smaller coil and the resultant force between the coils?

	Induced current	Force between coils
A	Clockwise	Attraction
B	Clockwise	Repulsion
C	Anticlockwise	Attraction
D	Anticlockwise	Repulsion

25 An alternating voltage of 230 kV is supplied to a transformer, which steps the voltage down to a number of streetlamps with a rating of 230 V 150 W. If the maximum allowable current through the primary coil is 10 A, what is the maximum number of streetlamps that can be connected in parallel?

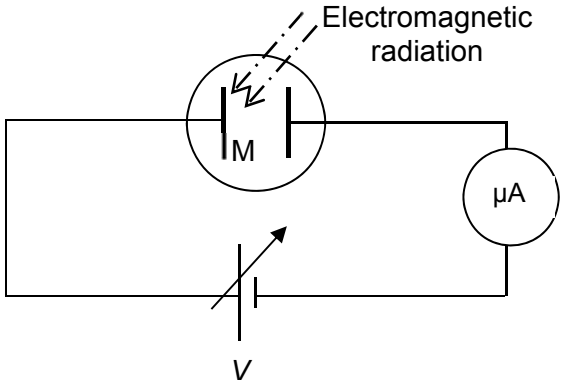
A 1500 **B** 6500 **C** 10000 **D** 15000

$N_P/N_S = V_P/V_S = 1000 = I_S/I_P$ → $I_S = 1000 \times 10 = 1\times10^4$ A

Current in each lamp = P / V = 150 / 230 = 0.65 A

No of lamps = 1×10^4 / 0.65 = 1.5×10^4

26 A 0.31 mW beam of photons with energy 3.11 eV each is incident on a clean metal plate M. The potential difference V is varied until the microammeter gives a maximum reading of 2.0 μA.



What is the ratio $\frac{\text{electrons emitted per unit time}}{\text{photons incident per unit time}}$?

A 3.2×10^{-21} **B** 2.0×10^{-2} **C** 1.0 **D** 1.3×10^{17}

Electrons: $dN_e/dt = I / e = 2.0\times10^{-6} / 1.6\times10^{-19}$

Photons: $dN_p/dt = P / E = 0.31\times10^{-3} / 3.11\times1.6\times10^{-19}$

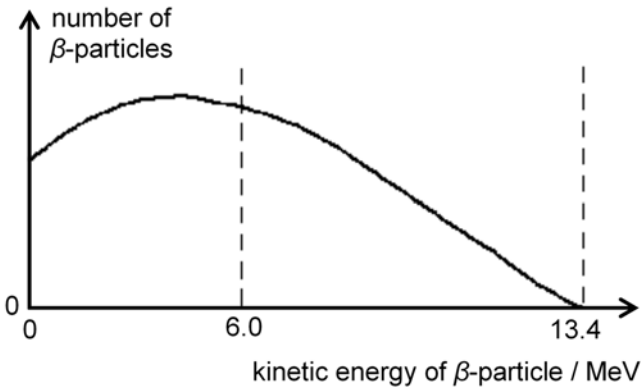
27 What is the de Broglie wavelength of an alpha particle of kinetic energy E, given that u is the unified atomic mass unit?

A $\frac{h}{2\sqrt{uE}}$ **B** $\frac{2\sqrt{uE}}{h}$ **C** $\frac{h}{2\sqrt{2uE}}$ **D** $\frac{2\sqrt{2uE}}{h}$

$E = ½ m v^2 = p^2/ 2m \rightarrow p = (2mE)^{1/2} = (8uE)^{1/2}$

$\lambda = h / p = h / (8uE)^{1/2}$

28 The beta spectrum for ^{12}B decay is as shown below.



The kinetic energy of an emitted β-particle is 6.0 MeV. What is the approximate energy of the associated neutrino?

A 4.0 MeV **B** 6.0 MeV **C** 7.4 MeV **D** 13.4 MeV

Based on COE and COM, the kinetic energy of the daughter nuclei is negligible hence the total energy released is shared between β particle and neutrino. Since the highest possible KE of β particle is 13.4 MeV, i.e. when neutrino has zero KE, hence the total energy released by the reaction is also 13.4 MeV, and this value is fixed for this particular reaction. Thus, when an emitted β particle has KE of 6.0 MeV, the associated neutrino must have 13.4 – 6.0 = 7.4 MeV of energy.

29 Two radioactive isotopes P and Q have half-lives of 10 minutes and 15 minutes respectively. A sample initially contains the same number of atoms of each isotope. After 30 minutes, the ratio of the number of atoms of P to the number of atoms of Q will be

A 0.25 **B** 0.50 **C** 1.0 **D** 2.0

$$\frac{\text{the number of atoms of P}}{\text{the number of atoms of Q}} = \frac{\left(\frac{1}{2}\right)^{30/10}}{\left(\frac{1}{2}\right)^{30/15}} = \frac{\left(\frac{1}{2}\right)^{3}}{\left(\frac{1}{2}\right)^{2}} = \tfrac{1}{2} = 0.5$$

30 At time *t,* a sample of a radioactive substance contains *N* atoms of a particular nuclide.

At time $(t + \Delta t)$, where Δt is a short period of time, the number of atoms of the nuclide is $(N - \Delta N)$.

Which of the following expressions gives the decay constant of the nuclide?

A $\frac{\Delta N}{N}$ **B** $\frac{N - \Delta N}{t + \Delta t}$ **C** $\frac{\Delta N}{N \Delta t}$ **D** $\frac{N \Delta N}{\Delta t}$

Decay constant is the fraction of the total number of undecayed nuclei present which decays per unit time. Suppose *N* is the size of a population of radioactive atoms at a given time *t*, and *dN* is the amount by which the population decreases in time *dt*; then the rate of change is given by the equation $\frac{dN}{dt} = -\lambda N$, where λ is the decay constant.

$$\frac{dN}{dt} = -\lambda N \rightarrow \lambda = -\frac{1}{N}\frac{dN}{dt} = \frac{\Delta N}{N \Delta t}$$

End of Paper

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

H

NANYANG JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 2

CANDIDATE NAME			
CLASS		TUTOR'S NAME	
CENTRE NUMBER	S	INDEX NUMBER	

PHYSICS 9749/02

Structured Questions **12 September 2018**

2 hours

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your name, class, Centre number and index number on all the work you hand in.
Write in dark blue or black pen on both sides of the paper.
You may use a soft pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, highlighters, glue or correction fluid.

Answer **all** questions.

At the end of the examination, fasten all your work securely together.
The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use	
1	/ 8
2	/ 6
3	/ 8
4	/ 6
5	/ 9
6	/ 8
7	/ 8
8	/ 8
9	/ 19
Total	/ 80

This document consists of **19** printed pages.

Data

speed of light in free space	c	=	3.00×10^{8} m s^{-1}
permeability of free space	μ_o	=	$4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space	ε_o	=	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/^{o}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 molecule	E	=	$\frac{3}{2}kT$
displacement of particle in s.h.m.	x	=	$x_o \sin \omega t$
velocity of particle in s.h.m.	v	=	$v_o \cos \omega t$
		=	$\pm \omega\sqrt{(x_o^2 - x^2)}$
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	=	$Q / 4\pi\varepsilon_o r$
alternating current/voltage	x	=	$x_o \sin \omega t$
magnetic flux density due to a long straight wire	B	=	$\mu_o I / 2\pi d$
magnetic flux density due to a flat circular coil	B	=	$\mu_o NI / 2r$
magnetic flux density due to a long solenoid	B	=	$\mu_o nI$
radioactive decay	x	=	$x_o \exp(-\lambda t)$
decay constant	λ	=	$\ln 2 / t_{1/2}$

For Examiner's Use

1 In 2018, the Singapore government announced that personal mobility devices (PMDs) such as e-scooters used on public paths must not have a device speed exceeding 25 km h^{-1} or weigh more than 20 kg.

(a) Suggest why there is a need to set a speed limit and weight limit on PMDs.

……..

……..

……..

…….. [2]

(b) Given that a typical e-scooter with rider has a total mass of 100 kg and that the time of impact is 0.20 s, determine the average force this scooter could cause. Assume that the e-scooter comes to rest after impact.

average force = ……. N [2]

(c) Other than the speed and weight of PMDs, state and explain one other factor that can contribute to the magnitude of the force of impact caused in an accident involving PMDs.

……..

……..

……..

…….. [2]

(d) It is suggested that an infra-red sensor can be fixed at the front end of a PMD such that once an obstacle is detected within 30 cm, the PMD will decelerate to a stop. By reference to the maximum allowable speed of 25 km h^{-1}, explain whether this is feasible.

……..

…….. [2]

For Examiner's Use

2 A grenade is launched at ground level with velocity of 75 m s^{-1} and angle 20^0 from the horizontal to hit a sniper on top of a 30 m tall building at a position 245 m from the foot of the building. The sniper is standing at a distance *x* from the edge of the building.

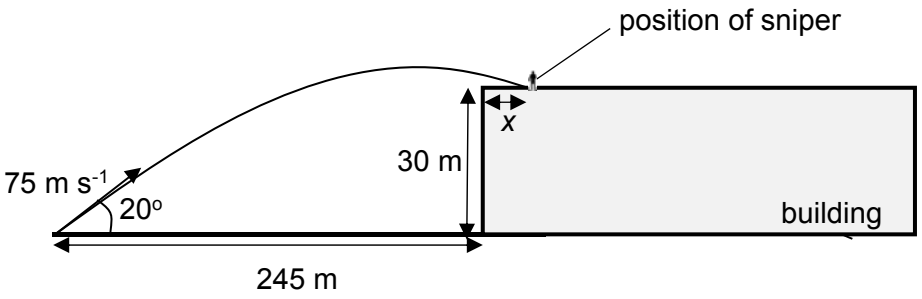


Fig. 2.1

(a) Show that the time for the grenade to reach the sniper is 3.5 s.

[1]

(b) Calculate the speed of the grenade just before impact.

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

(c) Determine the distance, *x*, of the sniper from the edge of the building.

x = ... m [2]

(d) The sniper runs away immediately from the edge of the building when the grenade is launched. Given that the grenade has a 'kill radius' of 10 m, calculate the minimum constant acceleration at which the sniper should run in order to escape.

minimum acceleration = ... m s^{-2} [1]

For Examiner's Use

3 A peg is fixed to the rim of a vertical turntable of radius r, rotating with a constant angular speed ω, as shown below.

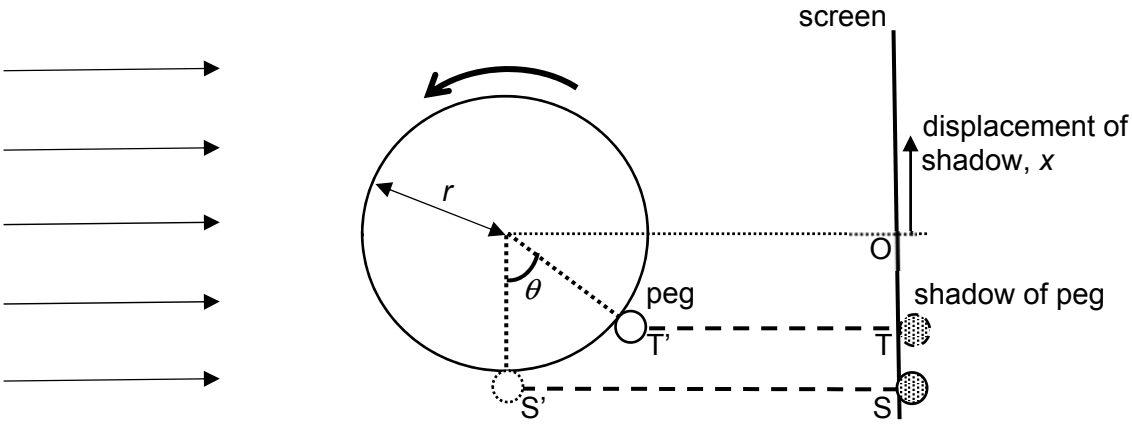


Fig. 3.1

A parallel beam of light is incident on the turntable such that the shadow of the peg is observed on the screen. Initially, the peg is at position S' and its shadow is at S. After time t, the peg moves through an angle of θ and it is positioned at T' while its shadow is at T. The displacement of the shadow, x, from O is shown in Fig. 3.1 where the upward direction is taken to be positive.

(a) **(i)** Express the angular displacement of the peg, θ, in terms of ω and t.

[1]

(ii) Write down an expression for the displacement, x, of the shadow on the screen in terms of ω, t and r.

[1]

(iii) Hence, prove that the shadow of the peg is moving in simple harmonic motion. Explain your working.

[2]

(b) The turntable has a radius of 20.0 cm and angular speed of 3.5 rad s^{-1}. For the motion of the shadow on the screen,

(i) calculate the acceleration of the shadow when the shadow is instantaneously at rest,

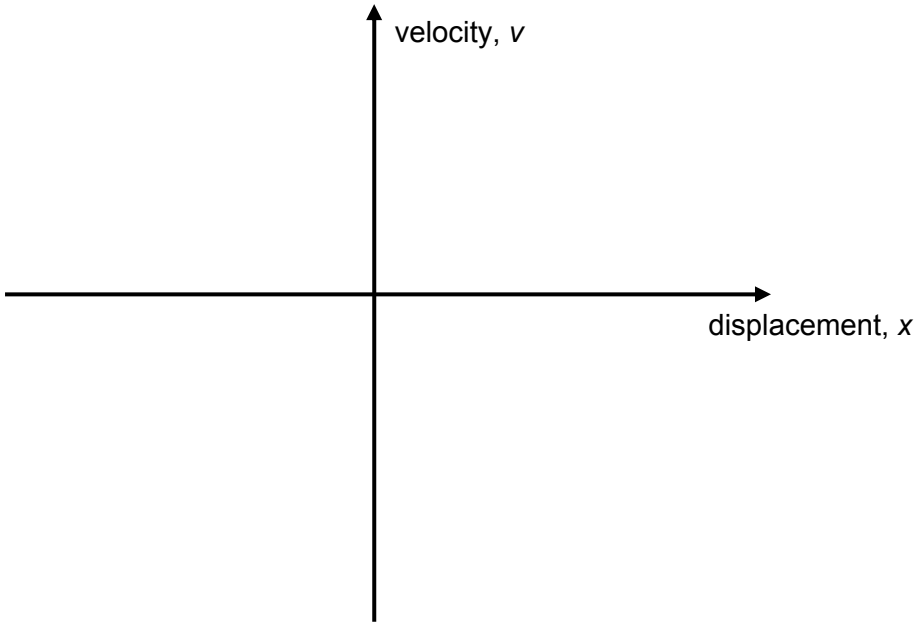
acceleration = ... m s^{-2} [1]

For Examiner's Use

(ii) determine the velocity of the shadow as it passes through S,

velocity = …….. m s^{-1} [1]

(iii) sketch the variation of the velocity, *v*, of the shadow with its displacement, *x*.



[2]

For Examiner's Use

4 **(a)** Explain what is meant by *polarised* light.

……..

……..…….. [1]

(b) Explain why two coherent sources of light that are polarised in planes perpendicular to each other will not produce interference fringes.

……...

……..…….. [1]

(c) Fig. 4.1 shows the setup for a Young's double slit experiment. The polarisers are initially aligned such that the light from the slits are polarised in parallel planes. The slit separation of the double slit is 0.10 mm, the distance between the double slit and the screen is 1.50 m and the separation of the fringes produced is 0.90 cm.

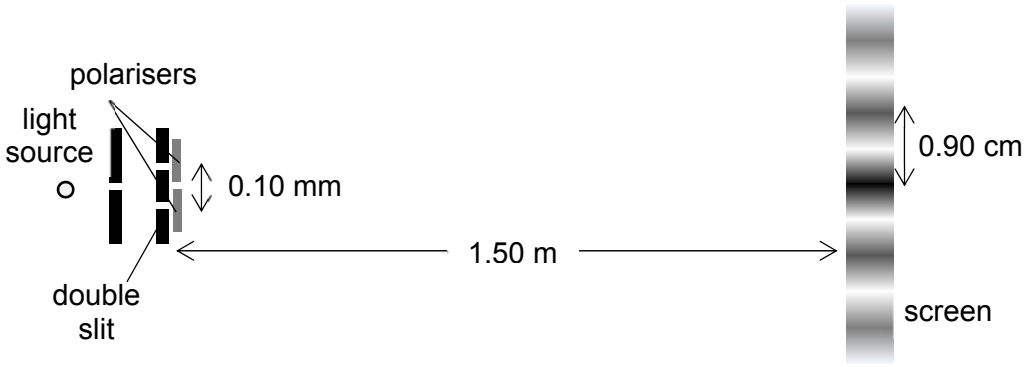


Fig. 4.1

(i) Calculate the wavelength of the light source.

wavelength = ……. m [2]

(ii) One of the polarisers is rotated by an angle of 45° about an axis parallel to the incident light. Describe the appearance of the fringes with reference to its original appearance.

……...

……...

……...

…..…….. [2]

For Examiner's Use

5 A stationary copper-64 nucleus undergoes a nuclear reaction to form a zinc-64 nucleus and a beta-particle. After the reaction, the zinc-64 nucleus moves off with negligible speed, while the beta-particle moves off with high speed.

(a) Explain qualitatively why the beta-particle moves off with a much higher speed than the zinc-64 nucleus.

……

……

……

…….. [2]

(b) The kinetic energy E_K and the distance r of the beta-particle from the centre of nucleus of zinc-64 nucleus' centre are monitored. Fig. 5.2 shows how the values of E_K varies with $\frac{1}{r}$.

Assume that the beta-particle and zinc-64 nucleus form an isolated system.

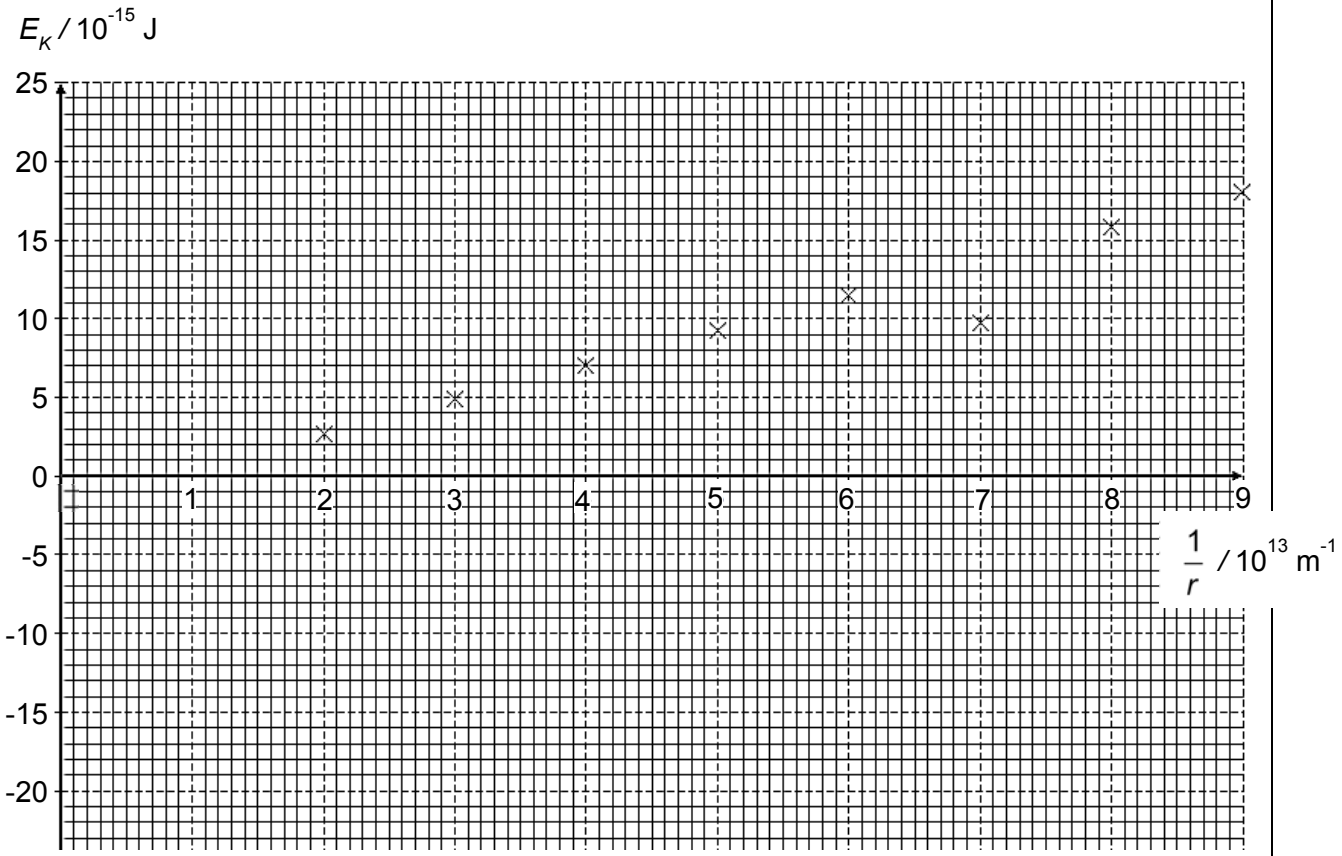


Fig. 5.2

(i) By drawing an appropriate line on Fig. 5.2, determine the y-intercept, E_o, of the graph.

vertical intercept, E_o = ... J [2]

For Examiner's Use

(ii) Explain the physical significance of the value of E_o found in **(b)(i)**.

……...

……...

…….. [2]

(iii) Assuming that total energy of the beta-particle remains constant during its motion, sketch labelled graphs on the axes in Fig. 5.2 to represent

1. the variation of the total energy E_T .

2. the variation of the electric potential energy E_P. [3]

For Examiner's Use

6 Fig. 6.1 shows a circuit consisting of two resistors connected in series to a d.c. supply.

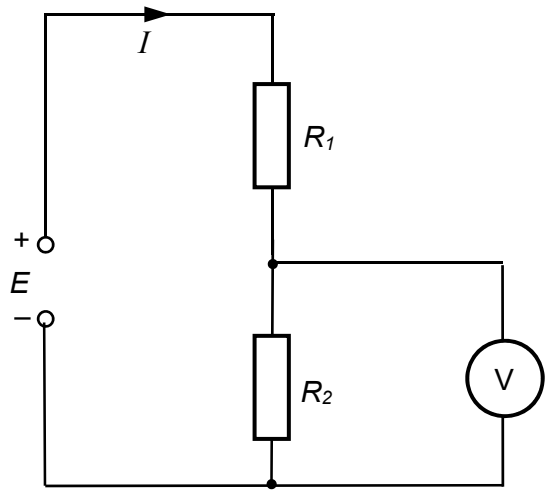


Fig. 6.1

The resistors have resistances R_1 and R_2. The supply has e.m.f. E and negligible internal resistance. The current from the supply is I. The voltmeter has an infinite resistance.

(a) By reference to Ohm's Law, show that the voltmeter reading V is given by the relation

$$V = \left(\frac{R_2}{R_1 + R_2} \right) E.$$

[2]

(b) Fig. 6.2 shows a circuit that includes a thermistor.

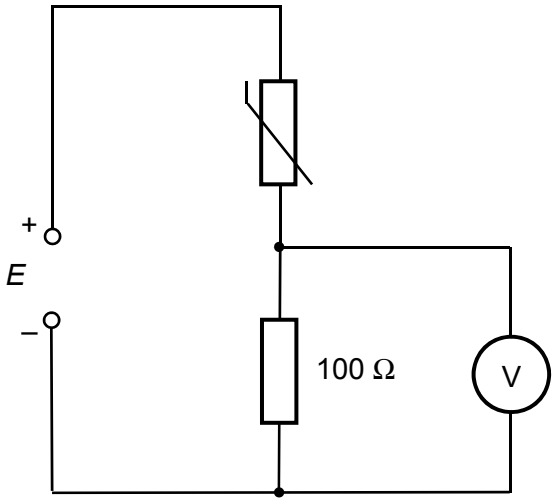


Fig. 6.2

For Examiner's Use

Describe and explain how the voltmeter reading changes as the temperature of the thermistor is increased.

……..

……...

……...

…….. [2]

(c) Fig. 6.3 shows a circuit that includes a potentiometer wire. It is used to test E_T, the e.m.f. of the test cell and the balance length is found to be b.

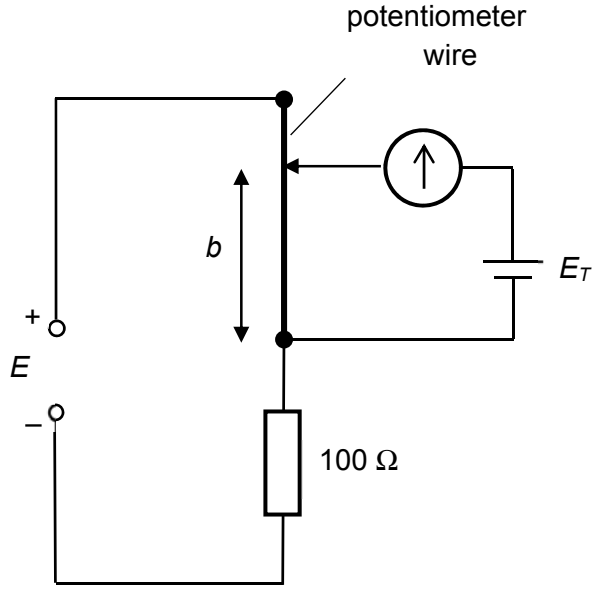


Fig. 6.3

(i) The potentiometer wire, of 1.00 m long, is made of nichrome wire of resistivity 1.57×10^{-6} Ω m and has a uniform radius of 0.10 mm. Determine the resistance of the potentiometer wire.

resistance = ... Ω [2]

(ii) Given that the ratio of $\frac{E_T}{E} = 0.20$, determine the balance length b.

b = ... m [2]

For Examiner's Use

7 **(a)** Define *magnetic flux density*.

……

…….. [1]

(b) A 1.0 m long wire carrying a current of 2.0 A is placed in a magnetic field. When it is aligned with XX' as shown in Fig. 7.1A, it experiences a force of 0.50 N that is directed into the page. When it is aligned with YY' as shown in Fig. 7.1B, it experiences a force of 0.80 N that is directed out of the page.

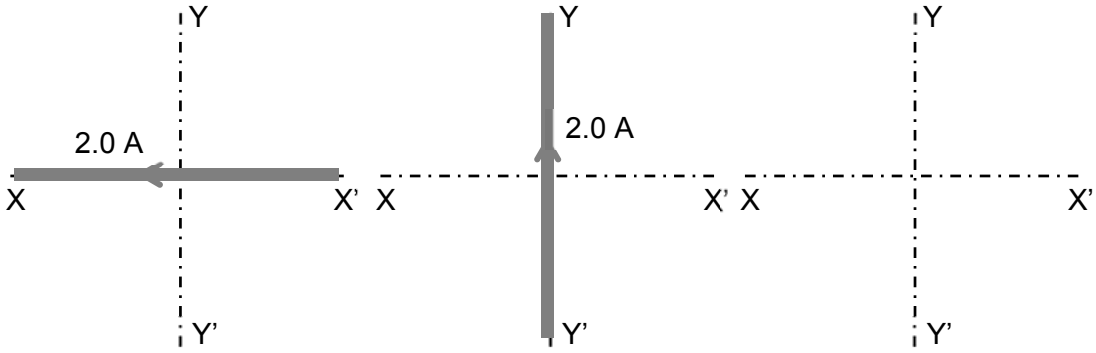


Fig. 7.1A **Fig. 7.1B** **Fig. 7.1C**

(i) Calculate the magnetic flux density of the field present.

magnetic flux density = ……. T [3]

(ii) Determine the position of the wire such that it experiences a force of the maximum magnitude. Draw <u>accurately</u> the position of the wire in Fig. 7.1C.

[2]

(c) The current-carrying wire in **(b)** has a magnetic field of its own. Show, by calculation, that it is impossible to find a point near the wire such that its magnetic flux density at that point has the same magnitude as the field present.

[2]

For Examiner's Use

8 In Singapore, the power stations are situated near the coast because sea water is used to condense steam into water. The transmission of electric power over long distances from the power stations to homes would not be feasible without transformers.

A step-up transformer near the power station boosts the station's output root-mean-square (r.m.s.) voltage from 12.0 kV to 240 kV and a series of step-down transformers near the homes reduces the r.m.s. voltage to a final value of 240 V at the homes. The transmission voltage has a frequency of 50 Hz.

(a) For the transformer located near the power station, determine the ratio

$$\frac{N_p}{N_s} = \frac{\text{number of turns of primary coil}}{\text{number of turns of secondary coil}}.$$

ratio = ... [1]

(b) Explain why

(i) the voltage is stepped up near the power plant,

……...

……...

……...

…….. [2]

(ii) an alternating voltage is used instead of direct voltage to transmit electrical energy.

……...

……...

…….. [1]

(c) **(i)** Determine the r.m.s. current delivered to an electric kettle rated at 700 W when it is connected to a power socket in the house.

r.m.s. current = ... A [1]

(ii) Calculate the peak output voltage to the electric kettle.

V_o = ... V [1]

(d) On Fig. 8.1 below, sketch a labelled graph for the variation with time t of the thermal power P dissipated by the electric kettle.

For Examiner's Use

Fig. 8.1

[2]

For Examiner's Use

9 The use of satellites for communication using microwaves is relatively commonplace, for example in telephone links. The most useful sort of satellite orbit is a geostationary or geosynchronous one. It orbits the Earth which has a radius of 6.4×10^3 km. The microwave transmitting and receiving dishes do not have to constantly change their orientation, but can constantly point in the same direction.

One disadvantage, however, in the use of the geostationary satellite is that there will be regions on Earth where the satellite will appear to be below the horizon and cannot be seen at all. As shown in Fig. 9.1, there will be an angle, θ, above the equator, beyond which an observer on Earth cannot see the geostationary satellite.

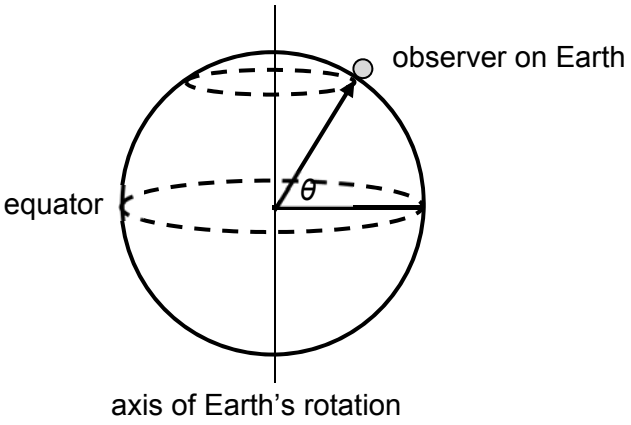


Fig. 9.1

Communication to and from moving ships and aircraft over long distances is obviously more difficult, even with geostationary satellites. Large ships move relatively slowly, and can carry a transmitting dish and the tracking equipment to keep it pointing in the right direction (assuming they know where they are on the Earth's surface accurately enough). However, small boats and aircraft have a weight and size problem; aircraft have the added complication of high speeds.

A type of microwave transmitter (and receiver) has been developed which can transmit in almost any carefully controlled direction without any moving parts, making it lighter and less vulnerable to mechanical damage than a conventional dish. The working principle is shown in Fig. 9.2.

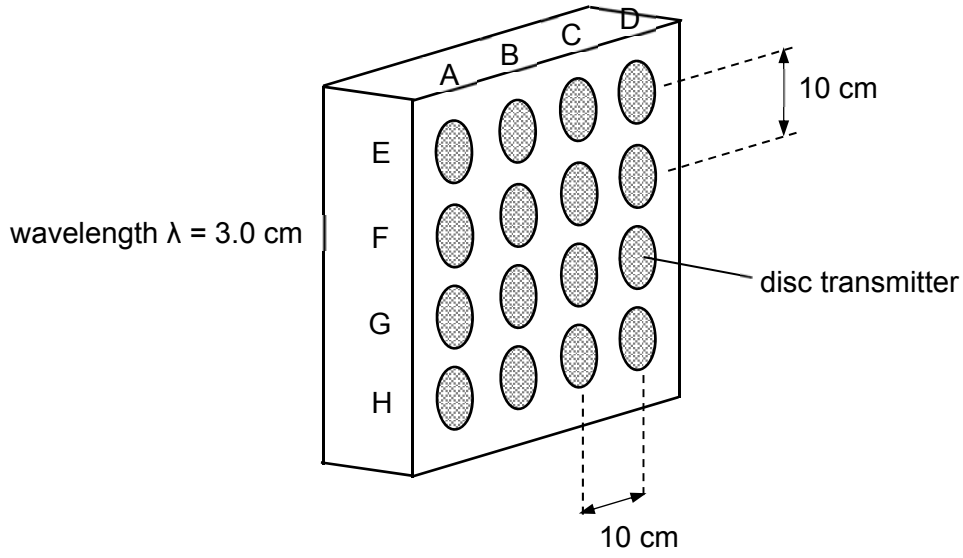


Fig. 9.2

For Examiner's Use

Fig. 9.2 shows a microwave transmitter which consists of 4 columns of discs, column A, B, C and D, and four rows of discs, row E, F, G and H. Each disc can have a different phase difference introduced into the signal before it is transmitted. For instance, if all the signals are in phase, there will be a strong signal sent directly in front of the array, but if row G is 1 cycle behind row H, row F 2 cycles behind row H and row E 3 cycles behind row H, a strong signal is sent upwards at an angle of about 17°. This is very similar to the way in which a diffraction grating works for light. Care has to be taken in choosing the spacing in the array, otherwise there could be very little signal in some directions.

(a) Calculate the time it takes a geostationary satellite to orbit the Earth once.

time = ... s [1]

(b) A geostationary satellite must be positioned directly above the Equator. Explain why this is so.

.....

.....

.....

.....

..... [3]

(c) Using the data provided and your answer in **(a)**, show that the radius of a geostationary orbit is 4.2×10^4 km. Explain your working.

[3]

(d) Estimate, by scale drawing or otherwise, the angle θ above the Equator at which a receiving dish can be and still "see" the satellite.

For Examiner's Use

angle = ... ° [3]

For Examiner's Use

(e) Show that the angle of 17° given in the passage is correct.

[1]

(f) A strong signal can be sent out if the phase relationships were as follows; vertical column A all in phase, column B all 1/3 of a cycle later, column C all 2/3 of a cycle later and column D all 1 cycle later.

(i) Calculate the path difference of the waves between adjacent column.

path difference = ... m [1]

(ii) Hence, determine the angle and direction, of this strong signal.

angle = ... °

direction = ... [2]

(g) Suggest, in principle, and without technical details, how a ship's communication with satellites could be used as a navigation aid, so that it can know accurately where its position is.

.....

.....

.....

..... [3]

For Examiner's Use

(h) "Care has to be taken in choosing the spacing in the array". In this "phased array" setup, it is essential that each disc is only a few wavelengths apart from its neighbouring discs. Suggest why the discs cannot be positioned too close together or too far apart.

.....

.....

..... [2]

End of Paper

H

NANYANG JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 2

CANDIDATE NAME			
CLASS		TUTOR'S NAME	
CENTRE NUMBER	S	INDEX NUMBER	

PHYSICS 9749/02

Structured Questions **12 September 2018**

2 hours

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hydrostatic pressure	p	=	ρgh
gravitational potential	ϕ	=	$-Gm / r$
temperature	T/K	=	T/^{o}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 molecule	E	=	$\frac{3}{2}kT$
displacement of particle in s.h.m.	x	=	$x_o \sin \omega t$
velocity of particle in s.h.m.	v	=	$v_o \cos \omega t$
		=	$\pm \omega\sqrt{(x_o^2 - x^2)}$
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	=	$Q / 4\pi\varepsilon_o r$
alternating current/voltage	x	=	$x_o \sin \omega t$
magnetic flux density due to a long straight wire	B	=	$\mu_o I / 2\pi d$
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decay constant	λ	=	$\ln 2 / t_{1/2}$

1 In 2018, the Singapore government announced that personal mobility devices (PMDs) such as e-scooters used on public paths must not have a device speed exceeding 25 km h^{-1} or weigh more than 20 kg.

(a) Suggest why there is a need to set a speed limit and weight limit on PMDs. [2]

Momentum is the product of mass and velocity, which are related to weight and speed of PMD. [1] As force is proportional to rate of change of momentum, the amount of force a PMD can inflict is controlled. [1]
Note: award one mark only answer only state 'Setting speed limit so that rider will not be thrown outward due to sudden stop/deceleration' [1]

(b) Given that a typical e-scooter with rider has a total mass of 100 kg and that the time of impact is 0.20 s, determine the average force this scooter could cause. Assume that the e-scooter comes to rest after impact. [2]

$$F = \frac{\Delta P}{t} = \frac{(100)(0 - \frac{25\times10^3}{60\times60})}{0.20} = 3472 = 3500 \text{ N}$$

(c) Other than the speed and weight of PMDs, state and explain one other factor that can contribute to the magnitude of the force of impact caused in an accident involving PMDs. [2]

- mass of the load on the PMD. A greater load increases the momentum of the PMD/load system, contributing to a large force.

Or

- material of PMD (Hardness of material): Harder material causes shorter time of impact and by N2L, larger force.

(Area of contact is not accepted as it affects the pressure, but not the force)

(d) It is suggested that an infra-red sensor can be fixed at the front end of a PMD such that once an obstacle is detected within 30 cm, the PMD will decelerate to a stop. By reference to the maximum allowable speed of 25 km h^{-1}, explain whether this is feasible. [2]

$v^2 = u^2 + 2as$

$0 = (\frac{25\times10^3}{60\times60})^2 + 2a(0.30)$

$a = -80 \text{ m s}^{-2} \approx -8g$ [1]

Not feasible as the deceleration is several times that of *g*/deceleration is too large. [1]

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2 A grenade is launched at ground level with velocity of 75 m s^{-1} and angle 20^0 from the horizontal to hit a sniper on top of a 30 m tall building at a position 245 m from the foot of the building. The sniper is standing at a distance *x* from the edge of the building.

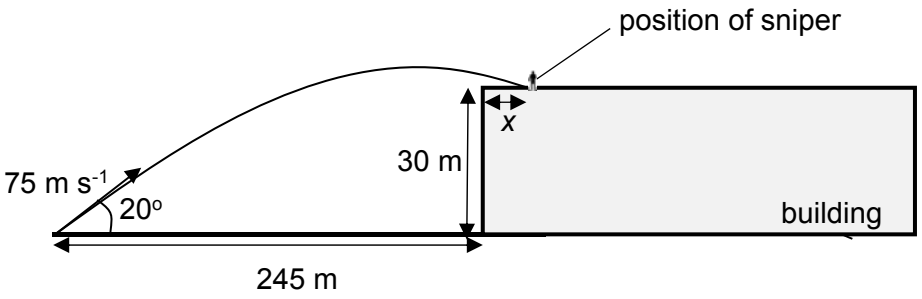

Fig. 2.1

(a) Show that the time for the grenade to reach the sniper is 3.5 s. [1]

$$s_y = u_y t + \frac{1}{2}gt^2$$

$$30 = 75\sin 20^\circ t - \frac{1}{2}x9.81t^2$$

$$t = 3.5\ s$$

(b) Calculate the speed of the grenade just before impact. [2]

$$v_y = u_y + at$$

$$= 75\sin 20^\circ - \frac{1}{2}x9.81x3.5$$

$$= 8.5\ ms^{-1}$$

$$v_x = 75\cos 20^\circ = 70.5\ ms^{-1}$$

$$v = \sqrt{8.5^2 + 70.5^2} = 71\ ms^{-1}$$

(c) Determine the distance, *x*, of the sniper from the edge of the building. [2]

$$u_x t = 245 + x$$

$$75\cos 20^\circ x3.5 = 245 + x$$

$$x = 1.7\ m$$

(d) The sniper runs away immediately from the edge of the building when the grenade is launched. Given that the grenade has a 'kill radius' of 10 m, calculate the minimum constant acceleration at which the sniper should run in order to escape. [1]

$$s = u\,t + \frac{1}{2}at^2$$

$$10 = \frac{1}{2}a.(3.5)^2$$

$$a = 1.6\ ms^{-2}$$

For Examiner's Use

3 A peg is fixed to the rim of a vertical turntable of radius r, rotating with a constant angular speed ω, as shown below.

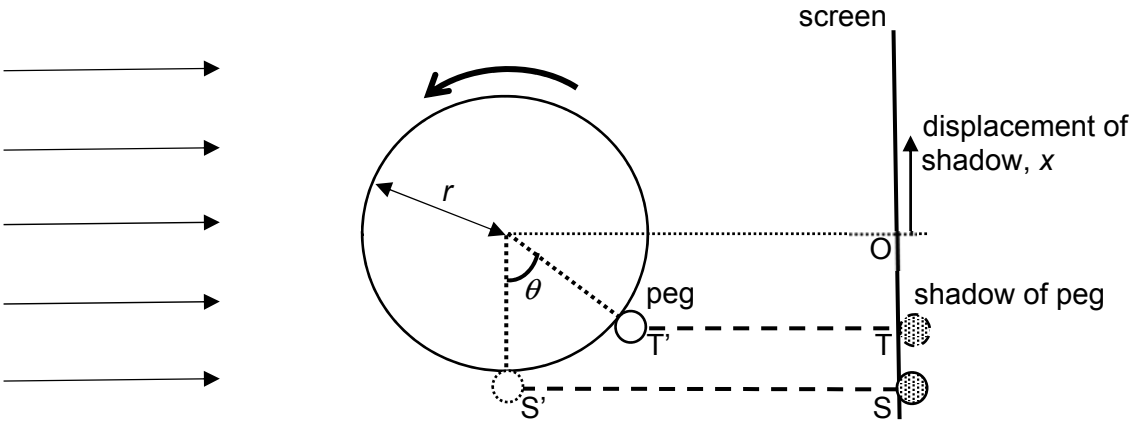

Fig. 3.1

A parallel beam of light is incident on the turntable such that the shadow of the peg is observed on the screen. Initially, the peg is at position S' and its shadow is at S. After time t, the peg moves through an angle of θ and it is positioned at T' while its shadow is at T. The displacement of the shadow, x, from O is shown in Fig. 3.1 where the upward direction is taken to be positive.

(a) (i) Express the angular displacement of the peg, θ, in terms of ω and t. [1]

$\theta = \omega t$

(ii) Write down an expression for the displacement, x, of the shadow on the screen in terms of ω, t and r. [1]

$x = -r\cos\omega t$

(iii) Hence, prove that the shadow of the peg is moving in simple harmonic motion. Explain your working. [2]

Since velocity is the rate of change of displacement,

$$v = \frac{dx}{dt} = -\omega(-r\sin\omega t) = \omega r\sin\omega t$$

Since acceleration is the rate of change of velocity,

$$a = \frac{dv}{dt} = \omega(r\omega\cos\omega t) = \omega^2(r\cos\omega t) = -\omega^2(-r\cos\omega t) = -\omega^2 x$$

Since acceleration of the shadow *a* is directly proportional to its displacement x, and is in the opposite direction to displacement, $a = -\omega^2 x$ is the defining equation of a simple harmonic equation.

(b) The turntable has a radius of 20.0 cm and angular speed of 3.5 rad s^{-1}. For the motion of the shadow on the screen,

(i) calculate the acceleration of the shadow when the shadow is instantaneously at rest, [1]

$$a = -\omega^2 x$$
$$= -(3.5)^2(0.200)$$
$$= -2.45\, m\, s^{-2}$$

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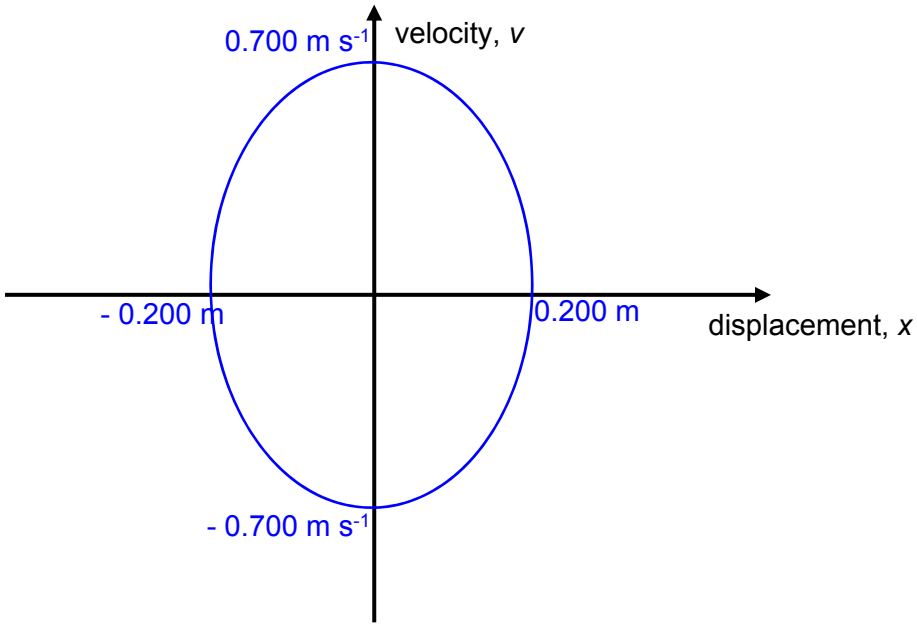
(ii) determine the velocity of the shadow as it passes through S, [1]

As the shadow passes through S, its amplitude position, it is instantaneously at rest.

$$v = \pm\omega\sqrt{x^2 - x_o^{\ 2}}$$
$$= \pm\omega\sqrt{0.200^2 - 0.200^2}$$
$$= 0.00\, m\, s^{-1}$$

(iii) sketch the variation of the velocity, *v*, of the shadow with its displacement, *x*.



[2]

$$v_{max} = \pm\omega\sqrt{x^2 - x_o^{\ 2}}$$
$$= \pm 3.5\sqrt{0.200^2 - 0^2}$$
$$= \pm 0.700\, m\, s^{-1}$$

Elliptical shape with max *v* (y-intercept) = 0.700 m s^{-1};
max *x* (x-intercept) = 0.200 m

4 **(a)** Explain what is meant by *polarised* light. [1]

Light in which the oscillations of the electromagnetic fields are all in a single plane

(b) Explain why two coherent sources of light that are polarised in planes perpendicular to each other will not produce interference fringes. [1]

The displacements due to the two waves are in perpendicular axes, thus their vector sum will not be able to produce maxima and minima, since they can never be in the same or in opposite directions.

(c) Fig. 4.1 shows the setup for a Young's double slit experiment. The polarisers are initially aligned such that the light from the slits are polarised in parallel planes. The slit separation of the double slit is 0.10 mm, the distance between the double slit and the screen is 1.50 m and the separation of the fringes produced is 0.90 cm.

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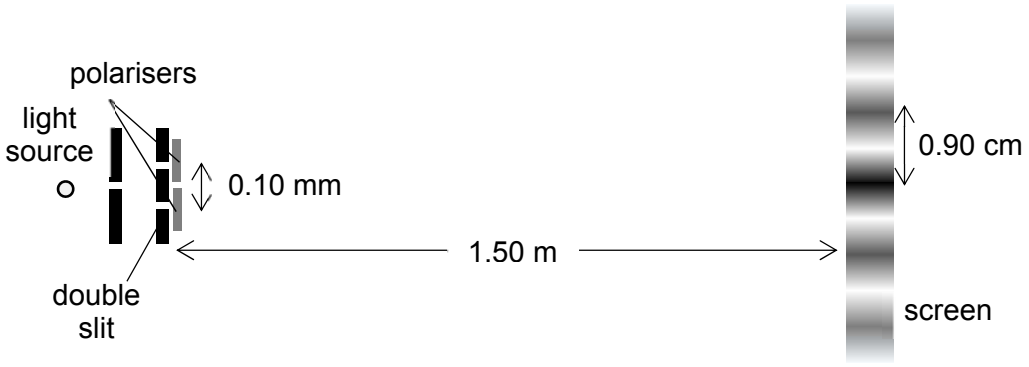

Fig. 4.1

(i) Calculate the wavelength of the light source. [2]

$\lambda = a\,x / D = 0.10\times10^{-3} \times 0.90\times10^{-2} / 1.50 = 6.00\times10^{-7}$ m

(ii) One of the polarisers is rotated by an angle of 45° about an axis parallel to the incident light. Describe the appearance of the fringes with reference to its original appearance. [2]

Only the components of the light waves that are oscillating in parallel planes will interfere to form maxima and minima. The components that are oscillating in perpendicular planes will not be affected by each other. Thus the maxima will be less bright and the minima will be brighter.

5 A stationary copper-64 nucleus undergoes a nuclear reaction to form a zinc-64 nucleus and a beta-particle. After the reaction, the zinc-64 nucleus moves off with negligible speed, while the beta-particle moves off with high speed.

(a) Explain qualitatively why the beta-particle moves off with a much higher speed than the zinc-64 nucleus. [2]

By Conservation of Momentum, the **final total momentum of Zinc-64 nucleus and beta-particle must be equal to the initial momentum of Copper-64 which is zero**. [1] As the **beta-particle is much light** than Zinc-64 nucleus, the beta-particle will have much **larger speed** in order to have a momentum equal in **magnitude** but **opposite** in direction to that of Zinc-64 nucleus. [1]

(b) The kinetic energy E_K and the distance r of the beta-particle from the centre of nucleus of zinc-64 nucleus' centre are monitored. Fig. 5.2 shows how the values of E_K varies with $\frac{1}{r}$.

Assume that the beta-particle and zinc-64 nucleus form an isolated system.

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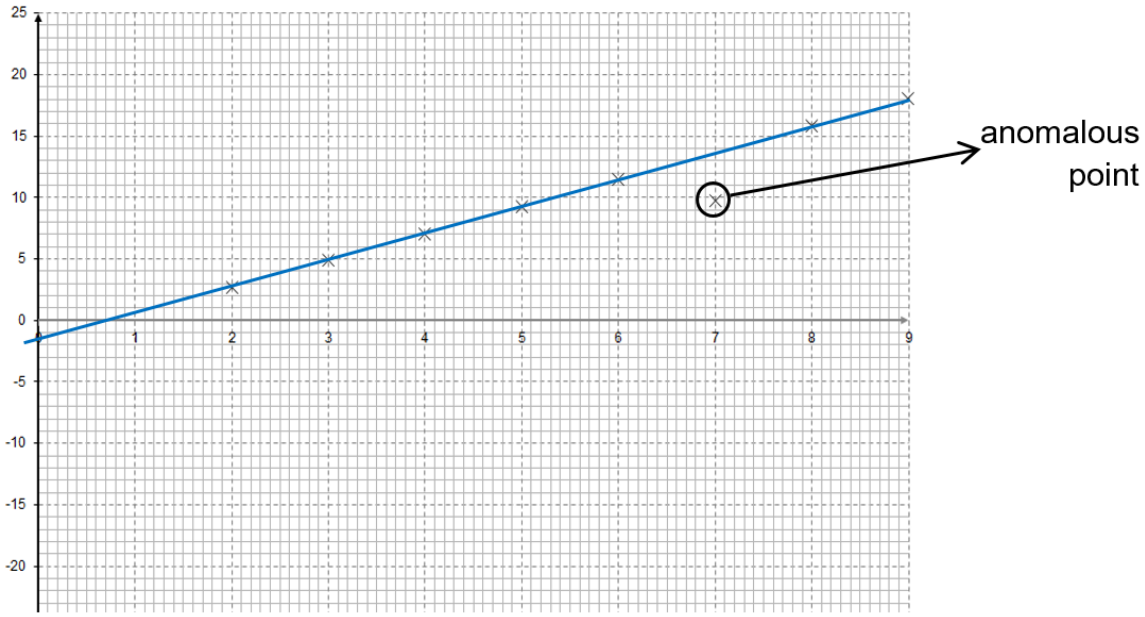

Identifying the anomalous point (circled and labelled) **and** sketching an appropriate BFL
Or
A BFL without anomalous point.

(i) By drawing an appropriate line on Fig. 5.2, determine the *y*-intercept, E_o, of the graph. [2]

Reading correctly the *y*-intercept: E_o = -2.0 x 10^{15} J

(ii) Explain the physical significance of the value of E_o found in **(b)(i)**. [2]

At $\frac{1}{r} = 0 \Rightarrow r \to \infty$. The vertical intercept represents the kinetic energy of the beta-particle when it is at an infinite distance from the Zinc-64 nucleus.

Since E_o is negative, it means that the beta-particle cannot escape from the Zinc nucleus' electric field / it requires additional k.e. to escape from the Zinc nucleus electric field.

(iii) Assuming that total energy of the beta-particle remains constant during its motion, sketch labelled graphs on the axes in Fig. 5.2 to represent

1. the variation of the total energy E_T.

2. the variation of the electric potential energy E_P. [3]

1. Total Energy : E_T – a horizontal straight line passing through E_o.

2. EPE:

Treating the beta-particle and the Zinc-64 nucleus as an isolated system, the electric potential energy of the system $E_p = -\frac{1}{4\pi\varepsilon_0}\frac{Q_{Zn}q_\beta}{r} \propto -\frac{1}{r}$

When $r \to \infty \Rightarrow \frac{1}{r} = 0$, $E_p = 0$.

When $\frac{1}{r} = 9 \times 10^{13}\ m^{-1}$, $E_K = 18.0 \times 10^{-15}$ J,

$\Rightarrow$ Therefore $E_P = E_T - E_K = (-2-18) \times 10^{-15}$ J $= -20.0 \times 10^{-15}$ J

Hence, E_p graph is a straight line graph with negative gradient, passing through (0,0) and (9, -20).

[1]: a negative gradient straight line graph passing through (0,0)

[1]: The line passes through (9, -20.5) – note that shape of line must be correct first for the second mark to be awarded.

6 Fig. 6.1 shows a circuit consisting of two resistors connected in series to a d.c. supply.

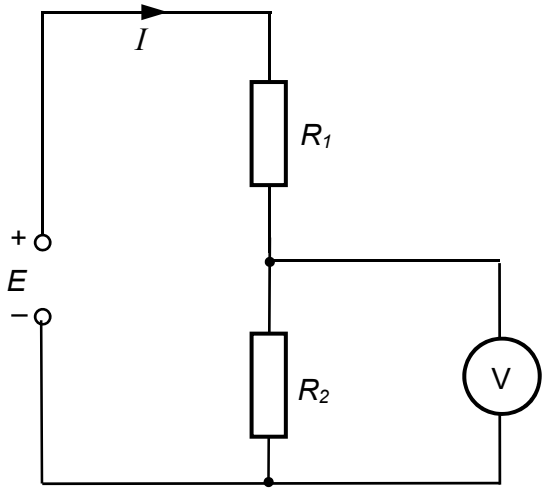

Fig. 6.1

The resistors have resistances R_1 and R_2. The supply has e.m.f. E and negligible internal resistance. The current from the supply is I. The voltmeter has an infinite resistance.

(a) By reference to Ohm's Law, show that the voltmeter reading V is given by the relation

$$V = \left(\frac{R_2}{R_1 + R_2} \right) E.$$

[2]

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By Ohm's Law, $E = IR_{tot}$

$$I = \frac{E}{R_{tot}}$$

$$= \frac{E}{R_1 + R_2}$$

Potential difference across R_2, $V = IR_2$

$$= \left(\frac{E}{R_1 + R_2}\right) R_2$$

$$= \left(\frac{R_2}{R_1 + R_2}\right) E \quad \text{[shown]}$$

(b) Fig. 6.2 shows a circuit that includes a thermistor.

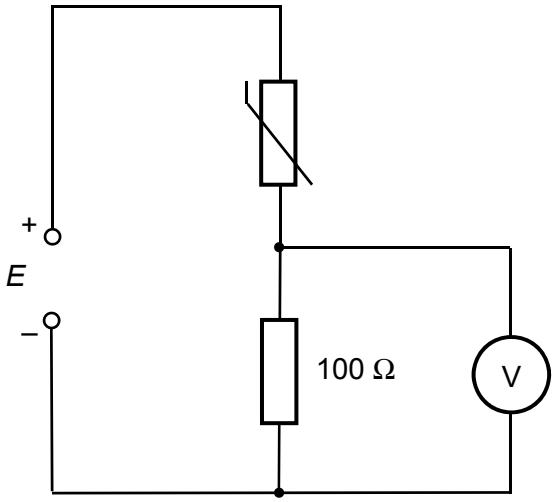

Fig. 6.2

Describe and explain how the voltmeter reading changes as the temperature of the thermistor is increased. [2]

As the temperature of the thermistor is increased, the resistance of the thermistor will decrease (R_1 decreases). As the resistance of the 100 Ω resistor remains constant, the ratio of its resistance to the total resistance will increase, i.e. $R_2/(R_1$

+ R_2) will increase. As such the potential difference across the 100 Ω resistor increases and the voltmeter will register a higher reading.

(c) Fig. 6.3 shows a circuit that includes a potentiometer wire. It is used to test E_T, the e.m.f. of the test cell and the balance length is found to be b.

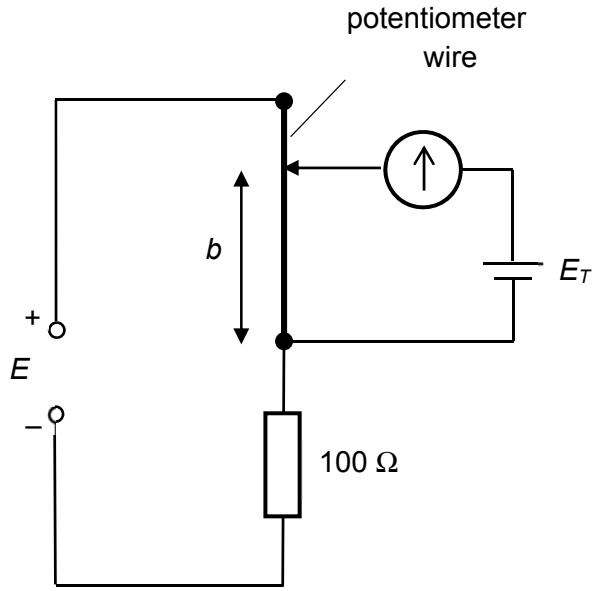

Fig. 6.3

(i) The potentiometer wire, of 1.00 m long, is made of nichrome wire of resistivity 1.57×10^{-6} Ω m and has a uniform radius of 0.10 mm. Determine the resistance of the potentiometer wire. [2]

$$R = \frac{\rho l}{A}$$
$$= \frac{\rho l}{\pi r^2}$$
$$= \frac{1.57 \times 10^{-6}(1.00)}{\pi(0.10 \times 10^{-3})^2}$$
$$= 50\ \Omega$$

(ii) Given that the ratio of $\frac{E_T}{E} = 0.20$, determine the balance length b. [2]

Potential across potentiometer wire $= \frac{50}{50+100} \times E = 0.333\ E$

balance length $b = \frac{0.20}{0.333} \times 1.00 = 0.60$ m

7 (a) Define *magnetic flux density*. [1]

Magnetic flux density is defined as the force acting per unit length per unit current on a conductor carrying current placed at right angles to the magnetic field.

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(b) A 1.0 m long wire carrying a current of 2.0 A is placed in a magnetic field. When it is aligned with XX' as shown in Fig. 7.1A, it experiences a force of 0.50 N that is directed into the page. When it is aligned with YY' as shown in Fig. 7.1B, it experiences a force of 0.80 N that is directed out of the page.

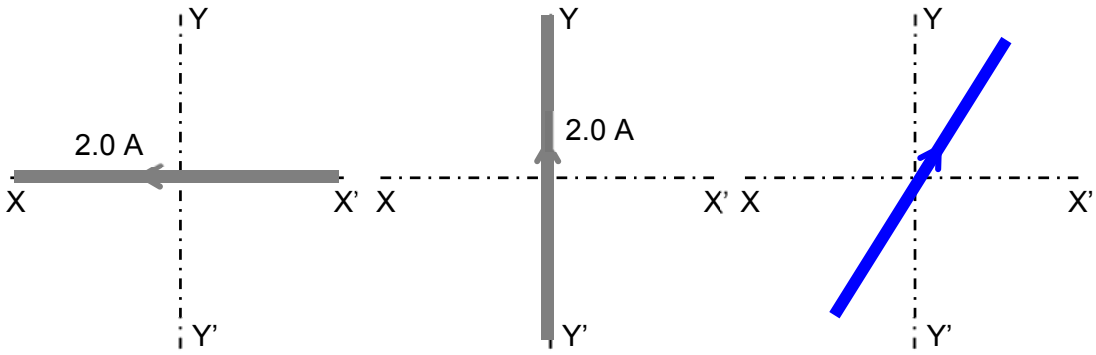

Fig. 7.1A **Fig. 7.1B** **Fig. 7.1C**

(i) Calculate the magnetic flux density of the field present. [3]

$(F/L)_x = B_y I \rightarrow B_y = 0.50 / 2.0 = 0.25$ T ↑
$(F/L)_y = B_x I \rightarrow B_x = 0.80 / 2.0 = 0.40$ T ←
$B = \sqrt{(0.25^2 + 0.40^2)} = 0.47$ T

(ii) Determine the position of the wire such that it experiences a force of the maximum magnitude. Draw accurately the position of the wire in Fig. 7.1C. [2]

$\theta = \tan^{-1}(0.25 / 0.40) = 32^o$
Direction of B is $\perp$ 32^{o-} → Alignment of wire for maximum force is $\angle$ 58^o

(c) The current-carrying wire in **(b)** has a magnetic field of its own. Show, by calculation, that it is impossible to find a point near the wire such that its magnetic flux density at that point has the same magnitude as the field present. [2]

$B = \mu_0 I / 2\pi d \rightarrow 0.47 = 2\times10^{-7} \times 2.0 / d$
$d = 8.5\times10^{-7}$ m
distance is much smaller than thickness of wire → not possible

8 In Singapore, the power stations are situated near the coast because sea water is used to condense steam into water. The transmission of electric power over long distances from the power stations to homes would not be feasible without transformers.

A step-up transformer near the power station boosts the station's output root-mean-square (r.m.s.) voltage from 12.0 kV to 240 kV and a series of step-down transformers near the homes reduces the r.m.s. voltage to a final value of 240 V at the homes. The transmission voltage has a frequency of 50 Hz.

(a) For the transformer located near the power station, determine the ratio

$$\frac{N_p}{N_s} = \frac{\text{number of turns of primary coil}}{\text{number of turns of secondary coil}}.$$

[1]

$$\frac{N_p}{N_s} = \frac{V_p}{V_s}$$
$$= \frac{12000}{240000}$$
$$= 0.05$$

(b) Explain why

(i) the voltage is stepped up near the power plant, [2]

The same power delivered at **higher transmission voltage** would result in a **lower transmission current**.
Lower current results in **lower power loss/dissipated in the power cables**.

(ii) an alternating voltage is used instead of direct voltage to transmit electrical energy. [1]

Alternating voltage can set up a **changing magnetic flux linkage** in a transformer which can be used to step the transmission voltage up or down.

(c) **(i)** Determine the r.m.s. current delivered to an electric kettle rated at 700 W when it is connected to a power socket in the house. [1]

Kettle power rating = P_{avg}
$P_{avg} = V_{rms}I_{rms}$
I_{rms} = 700/240 = 2.92 A

(ii) Calculate the peak output voltage to the electric kettle. [1]

$V_0 = \sqrt{2} \times V_{rms} = \sqrt{2} \times 240$
= 339 V

(d) On Fig. 8.1 below, sketch a labelled graph for the variation with time *t* of the thermal power *P* dissipated by the electric kettle.

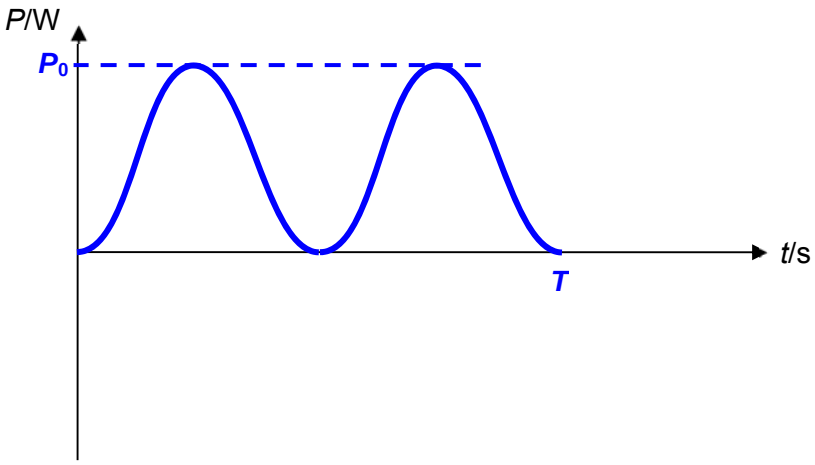

Fig. 8.1

[2]

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9 The use of satellites for communication using microwaves is relatively commonplace, for example in telephone links. The most useful sort of satellite orbit is a geostationary or geosynchronous one. It orbits the Earth which has a radius of 6.4×10^3 km. The microwave transmitting and receiving dishes do not have to constantly change their orientation, but can constantly point in the same direction.

One disadvantage, however, in the use of the geostationary satellite is that there will be regions on Earth where the satellite will appear to be below the horizon and cannot be seen at all. As shown in Fig. 9.1, there will be an angle, θ, above the equator, beyond which an observer on Earth cannot see the geostationary satellite.

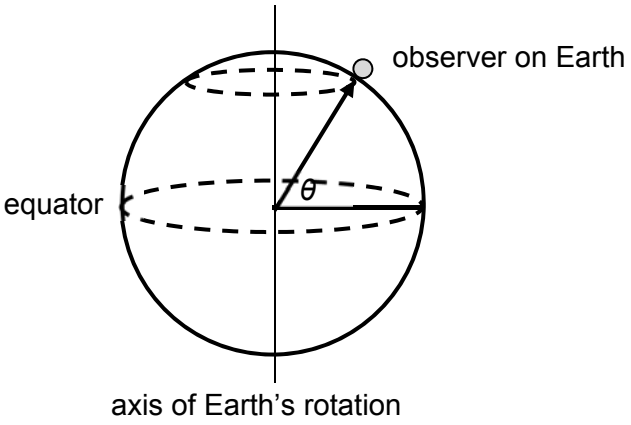


Fig. 9.1

Communication to and from moving ships and aircraft over long distances is obviously more difficult, even with geostationary satellites. Large ships move relatively slowly, and can carry a transmitting dish and the tracking equipment to keep it pointing in the right direction (assuming they know where they are on the Earth's surface accurately enough). However, small boats and aircraft have a weight and size problem; aircraft have the added complication of high speeds.

A type of microwave transmitter (and receiver) has been developed which can transmit in almost any carefully controlled direction without any moving parts, making it lighter and less vulnerable to mechanical damage than a conventional dish. The working principle is shown in Fig. 9.2.

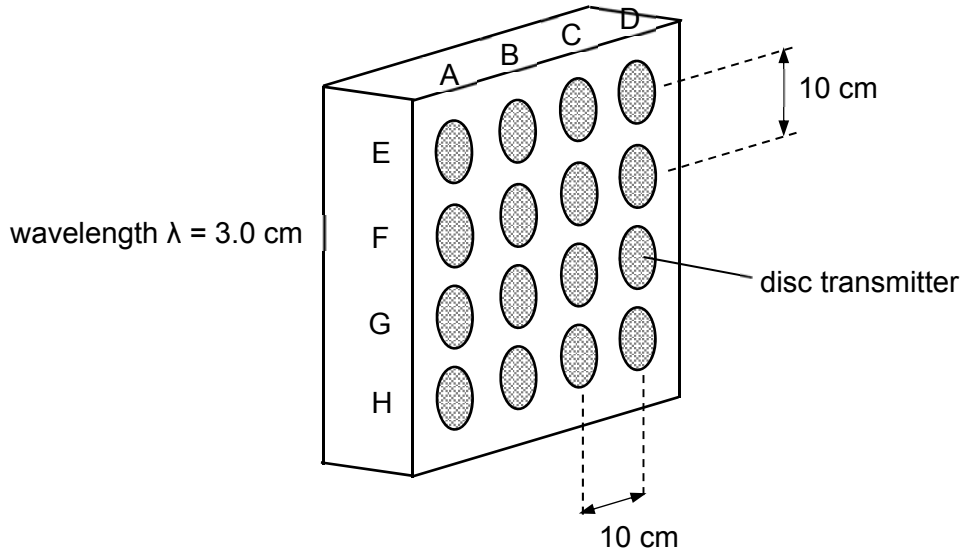


Fig. 9.2

Fig. 9.2 shows a microwave transmitter which consists of 4 columns of discs, column A, B, C and D, and four rows of discs, row E, F, G and H. Each disc can have a different phase difference introduced into the signal before it is transmitted. For instance, if all the signals are in phase, there will be a strong signal sent directly in front of the array, but if row G is 1 cycle behind row H, row F 2 cycles behind row H and row E 3 cycles behind row H, a strong signal is sent upwards at an angle of about 17°. This is very similar to the way in which a diffraction grating works for light. Care has to be taken in choosing the spacing in the array, otherwise there could be very little signal in some directions.

(a) Calculate the time it takes a geostationary satellite to orbit the Earth once. [1]

time = $24.0 \times 3600 = 8.64 \times 10^4$ s

(b) A geostationary satellite must be positioned directly above the Equator. Explain why this is so. [3]

This is to ensure that the satellite rotates about the same axis as the Earth. The line joining the object and the centre of Earth (which the gravitational force acts along) has to pass through the Equator and rests along the plane perpendicular to the Earth's axis of rotation.
If the object lies above other latitudes besides the equator, its axis of rotation will not coincide with that of the Earth's. As such it will be above different latitudes as it rotates and will not be geostationary.

(c) Using the data provided and your answer in **(a)**, show that the radius of a geostationary orbit is 4.2×10^4 km. Explain your working. [3]

The gravitational force on the satellite by Earth provides the centripetal force for it to orbit the Earth.
By Newton's 2nd Law of motion,

$$\Sigma F = ma$$

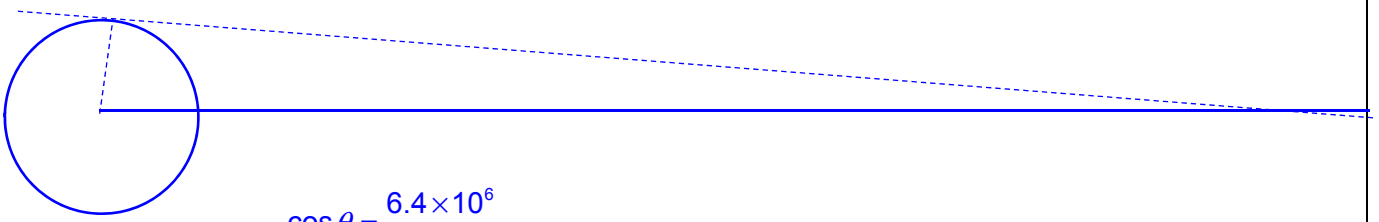
$$\frac{GM_E m}{r^2} = mr\omega^2$$

$$\frac{GM_E m}{r^2} = mr\left(\frac{4\pi^2}{T^2}\right)$$

$$r = \sqrt[3]{\frac{GM_E T^2}{4\pi^2}} = \sqrt[3]{\frac{gR_E{}^2 T^2}{4\pi^2}} = \sqrt[3]{\frac{(9.81)(6.4\times10^6)^2(86400)^2}{4\pi^2}} = 4.2\times10^7 \text{ m}$$

(Near the Earth's surface, $g = \frac{GM_E}{R_E{}^2} \Rightarrow GM_E = gR_E{}^2$)

(d) Estimate, by scale drawing or otherwise, the angle θ above the Equator at which a receiving dish can be and still "see" the satellite. [3]



$$\cos\theta = \frac{6.4\times10^6}{4.2\times10^7}$$

$$\theta = 81°$$

accept 75° to 85° for scale drawing; 81° for exact calculation

(e) Show that the angle of 17° given in the passage is correct. [1]

$$d\sin\theta = n\lambda$$
$$\theta = \sin^{-1}\left(\frac{n\lambda}{d}\right)$$
$$= \sin^{-1}\left(\frac{1\times 0.030}{0.10}\right)$$
$$= 17°$$

(f) A strong signal can be sent out if the phase relationships were as follows; vertical column A all in phase, column B all 1/3 of a cycle later, column C all 2/3 of a cycle later and column D all 1 cycle later.

(i) Calculate the path difference of the waves between adjacent column. [1]

Path difference = 1/3 × 0.03. = 0.010 m

(ii) Hence, determine the angle and direction, of this strong signal. [2]

$$d\sin\theta = n\lambda$$
$$\theta = \sin^{-1}\left(\frac{n\lambda}{d}\right)$$
$$= \sin^{-1}\left(\frac{\frac{1}{3}\times 0.030}{0.10}\right)$$
$$= 5.7°$$

Direction to towards column D.

(g) Suggest, in principle, and without technical details, how a ship's communication with satellites could be used as a navigation aid, so that it can know accurately where its position is. [3]

The ship can transmit signals in all directions by varying the phase difference between the columns as well as the rows of transmitters. When the signal is received by a satellite in a known position, the satellite can transmit a signal back to notify the ship. The ship can then use its own orientation on Earth (using a compass) and the phase differences between the columns and rows to calculate the exact location it is on the Earth's surface.

(h) "Care has to be taken in choosing the spacing in the array". In this "phased array" setup, it is essential that each disc is only a few wavelengths apart from its neighbouring discs. Suggest why the discs cannot be positioned too close together or too far apart. [2]

If the discs are positioned too close together (much less than 1 wavelength), signals can only be detected at certain angles.
If the discs are positioned too far apart, a small phase difference between the discs will not change the angle of the signal significantly.

End of Paper

H

NANYANG JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 2

CANDIDATE NAME			
CLASS		TUTOR'S NAME	
CENTRE NUMBER	S	INDEX NUMBER	

PHYSICS 9749/03

Paper 3 Longer Structured Questions **20 September 2018**

2 hours

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your name, class, Centre number and index number on all the work you hand in.
Write in dark blue or black pen on both sides of the paper.
You may use a soft pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, highlighters, glue or correction fluid.

Section A
Answer **all** questions.

Section B
Answer any **one** question.

You are advised to spend about one and a half hours on Section A, and about thirty minutes on Section B.

At the end of the examination, fasten all your work securely together.
The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use	
Section A	
1	**/ 7**
2	**/ 6**
3	**/ 8**
4	**/ 10**
5	**/ 10**
6	**/ 7**
7	**/ 12**
Section B	
8	**/ 20**
9	**/ 20**
Total	**/ 80**

This document consists of **21** printed pages.

Data

speed of light in free space	c	=	3.00×10^{8} m s^{-1}
permeability of free space	μ_o	=	$4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space	ε_o	=	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 molecule	E	=	$\frac{3}{2}kT$
displacement of particle in s.h.m.	x	=	$x_o \sin \omega t$
velocity of particle in s.h.m.	v	=	$v_o \cos \omega t$
		=	$\pm \omega\sqrt{(x_o^2 - x^2)}$
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	=	$Q / 4\pi\varepsilon_o r$
alternating current/voltage	x	=	$x_o \sin \omega t$
magnetic flux density due to a long straight wire	B	=	$\mu_o I / 2\pi d$
magnetic flux density due to a flat circular coil	B	=	$\mu_o NI / 2r$
magnetic flux density due to a long solenoid	B	=	$\mu_o nI$
radioactive decay	x	=	$x_o \exp(-\lambda t)$
decay constant	λ	=	$\ln 2 / t_{1/2}$

For Examiner's Use

Section A

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

1 Capacitance measures the ability of an electrical component to store charge and is defined as the ratio of charge stored in a capacitor to the potential difference across it.

(a) The S.I. unit for capacitance is the farad (F). Express F in S.I. base units.

F = ... [3]

(b) A capacitor of capacitance 50 μF is charged using a cell in the circuit shown in Fig. 1.1.

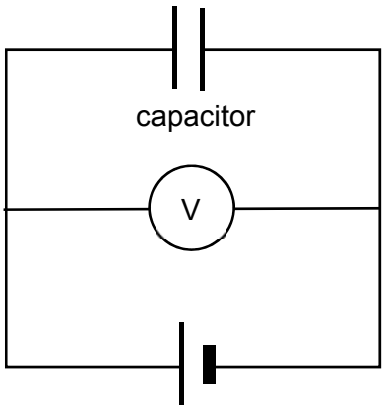


Fig. 1.1

(i) The voltmeter reads 2.20 V. By applying the given definition of capacitance, calculate the charge stored in the capacitor to 3 significant figures.

charge = ... C [1]

For Examiner's Use

(ii) The uncertainty of the voltmeter reading is ±0.05 V, and the capacitance of the capacitor has a tolerance of ±10%.

Express the charge stored in the capacitor in the form of $(Q \pm \Delta Q)$.

$(Q \pm \Delta Q)$ = ... C [3]

2 A person supports a load of 20 N in his hand as shown in Fig. 2.1. The system consisting of the arm and load is equivalent to the system shown in Fig. 2.2. The rod represents the forearm, and *T* represents the tension exerted in the biceps. The forearm weighs 65 N.

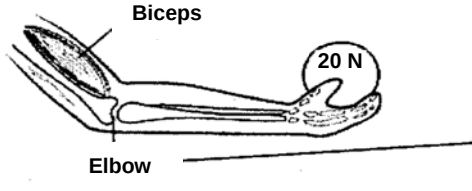


Fig. 2.1

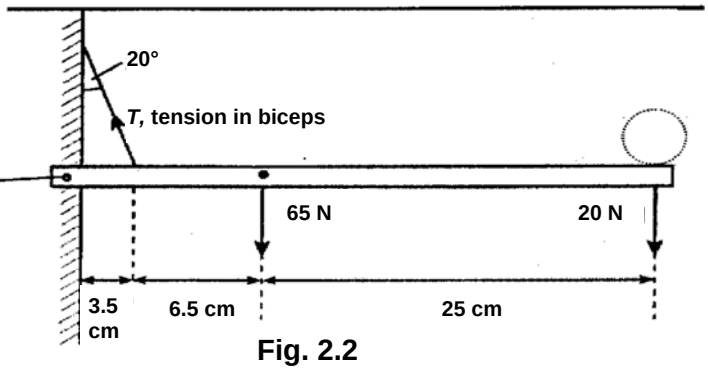


Fig. 2.2

(i) Show that the tension *T* in the biceps is 410 N.

[2]

(ii) Hence, determine the magnitude and direction of the force acting at the elbow.

For Examiner's Use

force = ... N [3]

direction = ... [1]

3 At Luna Amusement Park in Sydney, Australia, the Rotor and Big Dipper Rollercoaster are the most exciting rides.

(a) The popular Rotor ride consists of a large vertical cylinder, which spins about its axis so quickly that any person standing inside is held against the wall when the floor drops away. The passengers maintain horizontal circular motion at constant speed within the cylinder. The normal contact force N acting on each passenger is related to the frictional force f on the passenger by a constant μ as given by the expression $f = \mu N$.

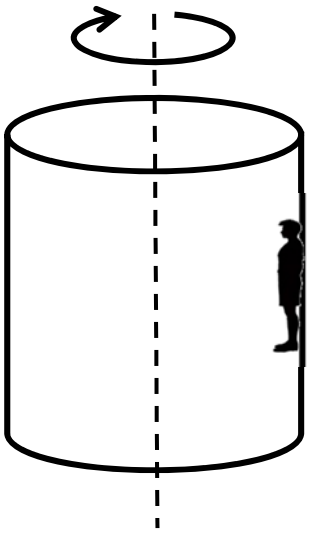


Fig. 3.1

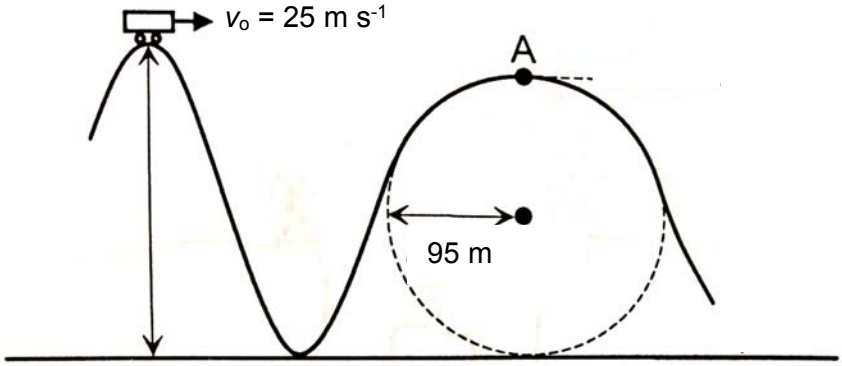
(i) Draw and label, on Fig. 3.1, the forces acting on the passenger. [1]

For Examiner's Use

(ii) Show that the linear velocity v at which the cylinder of radius R must rotate is independent of the mass of the passenger, m.

[3]

(b) The cart on the exhilarating Big Dipper Rollercoaster moves with negligible friction along the track as shown. The cart travels with an initial speed v_o of 25 m s^{-1} at the top of one hill, of height h, before reaching the top of a second hill, which forms a circular arc of radius 95 m.



(i) Calculate the maximum speed at which the cart can travel without leaving the track at the top of the second hill at point A.

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

(ii) Hence, determine the maximum height, h, of the first hill for the condition in **(b)(i)** to hold.

h = ... m [2]

For Examiner's Use

4 **(a)** "The magnitude of *gravitational field strength* at a point is proportional to the *gravitational potential gradient* at that point."

Explain the terms in italics.

gravitational field strength: .....

.....

gravitational potential gradient: .....

..... [2]

(b) Fig. 4.1 shows four equipotential lines at 1000-km intervals in a non-uniform gravitational field.

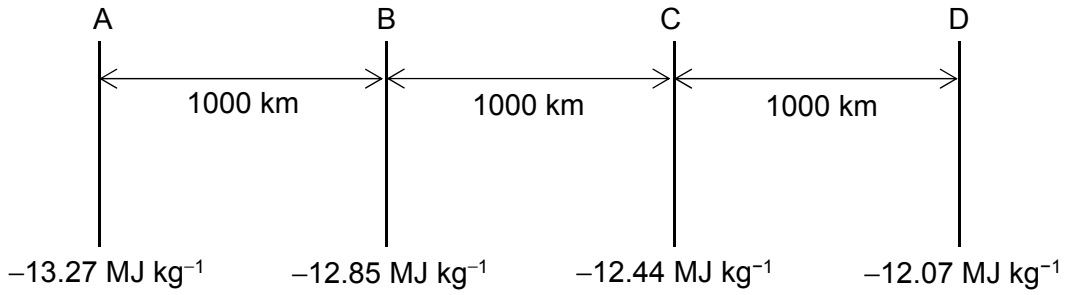


Fig. 4.1

(i) Draw an arrow on Fig. 4.1 to indicate the direction of the gravitational field. [1]

(ii) Calculate the ratio of

$$\frac{\text{field strength at B}}{\text{field strength at C}}.$$

ratio = ... [3]

For Examiner's Use

(c) A theoretical long open tube is placed in the gravitational field as shown in Fig. 4.2. An object is released from rest at B.

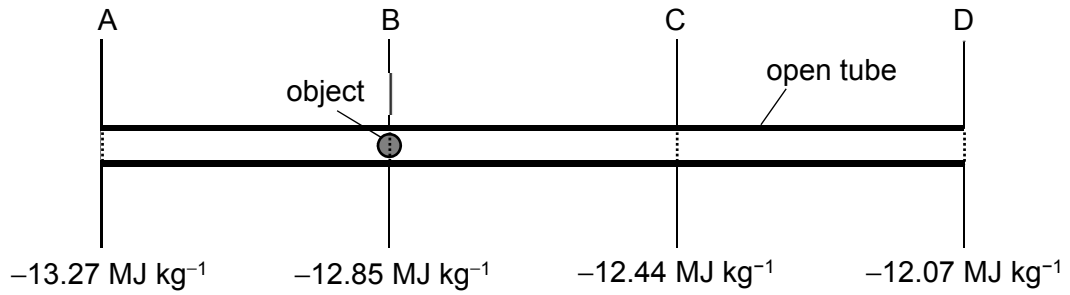


Fig. 4.2

Determine the speed with which the object leaves the tube.

speed = …… m s^{-1} [4]

5 **(a)** State what is meant by the term *internal energy of an ideal gas*.

.....

..... [1]

(b) The pressure p exerted by an ideal gas is given by the equation

$$p = \frac{1}{3}\rho < c^2 >$$

State what the symbols ρ and $<c^2>$ represent.

ρ: .....

$<c^2>$: ..... [2]

For Examiner's Use

(c) Use the equation given in **(b)** to show that the total kinetic energy of the molecules of an ideal gas of volume V and pressure p is given by $\frac{3}{2}pV$.

[2]

(d) **(i)** Calculate the internal energy of an ideal gas of volume 3.4×10^{-4} m^3 when its pressure is 100 kPa.

internal energy = …… J [1]

(ii) Calculate the increase in internal energy when the gas expands at constant pressure to a volume of 8.8×10^{-4} m^3.

increase in internal energy = …… J [2]

(iii) Determine the heat supplied to the gas so as to enable the expansion at constant pressure to take place.

energy supplied = …… J [2]

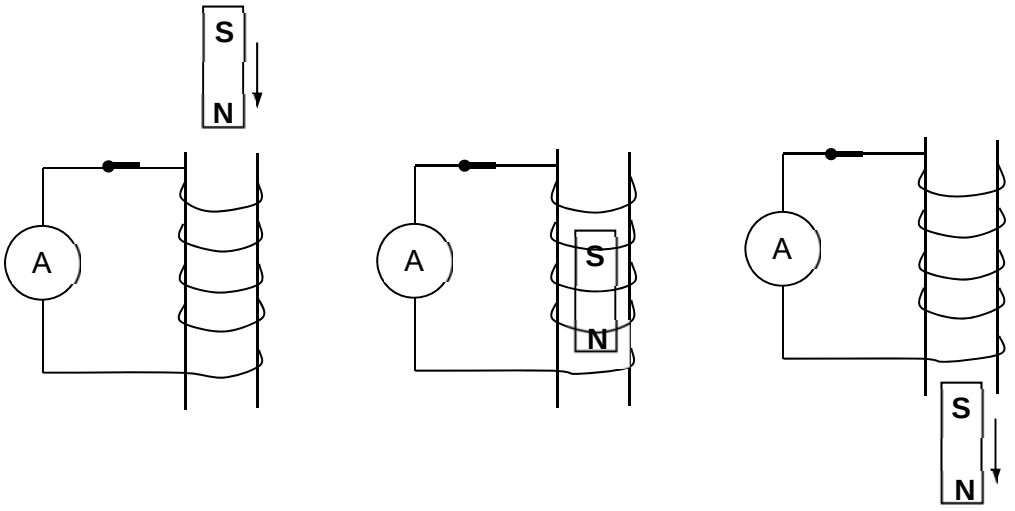
For Examiner's Use

6 **(a)** State Lenz's Law.

.....

..... [1]

A strong magnet is allowed to drop through a solenoid which is wound around a cardboard tube. The solenoid is connected to a switch and an ammeter.



Magnet approaching solenoid
Fig. 6.1A

Magnet in the middle of solenoid
Fig. 6.1B

Magnet leaving solenoid
Fig. 6.1C

(b) Indicate, with arrows on the winding of the solenoid in Fig. 6.1A, Fig. 6.1B and Fig. 6.1C, the direction of any induced current. [2]

(c) Hence, sketch on Fig. 6.2 a labelled graph showing the variation with time of the current induced in the solenoid as the magnet falls through it. [2]

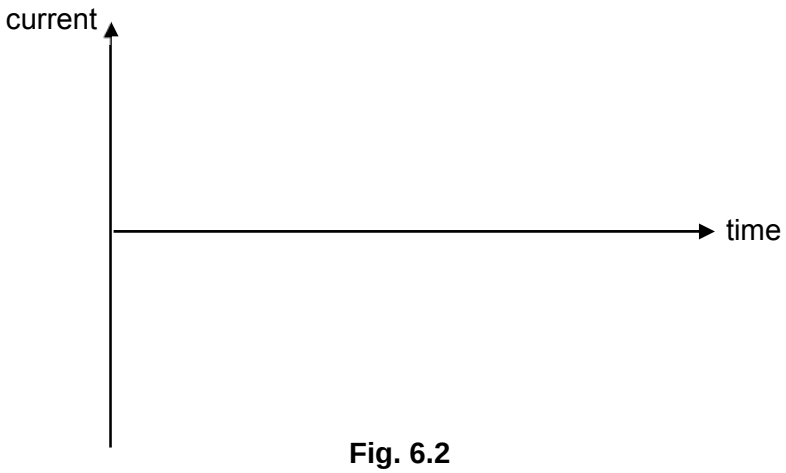


Fig. 6.2

For Examiner's Use

(d) The switch connected to the solenoid is now opened, and the same magnet is allowed to drop through the solenoid again.

State and explain any change in the speed of the magnet as it leaves the solenoid.

.....

.....

.....

..... [2]

7 **(a)** Tungsten, a transition metal, is commonly used as a target metal for the production of X-rays. The energy levels of the K- to M-shells for tungsten are shown in Fig. 7.1 below.

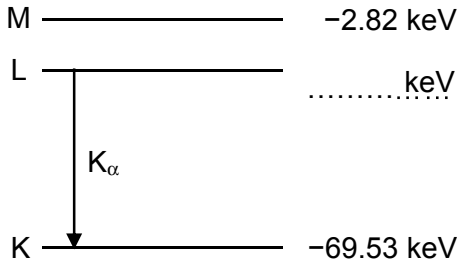


Fig. 7.1

The wavelength of the photon produced by the K_α transition is 21.65 pm.

(i) Complete Fig. 7.1 by filling in the energy level of the L-shell for tungsten.

[2]

(ii) Determine the wavelength of the photon produced by L_α transition.

wavelength = …… pm [1]

For Examiner's Use

The intensity of various photon wavelengths from electron bombardment of a tungsten target metal is shown in Fig. 7.2 below.

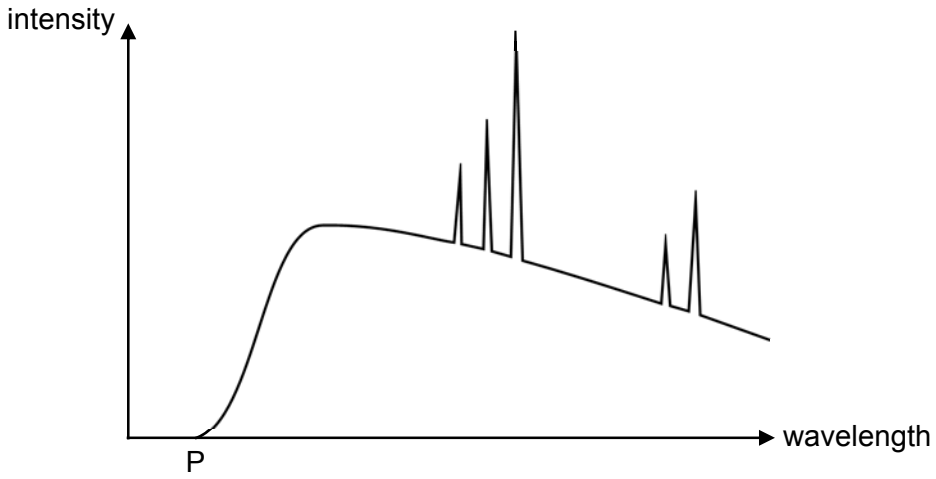


Fig. 7.2

(iii) On Fig. 7.2, label the peaks for K_α and L_α transitions. [2]

(iv) State the significance of the value of P.

.....

..... [1]

(v) With reference to Fig. 7.1, explain why the electrons bombarding the target metal must have a minimum energy of 69.53 keV to produce the spectrum shown in Fig. 7.2.

.....

.....

.....

.....

..... [3]

For Examiner's Use

(b) Fig. 7.3 below shows a typical setup for producing such X-ray beams.

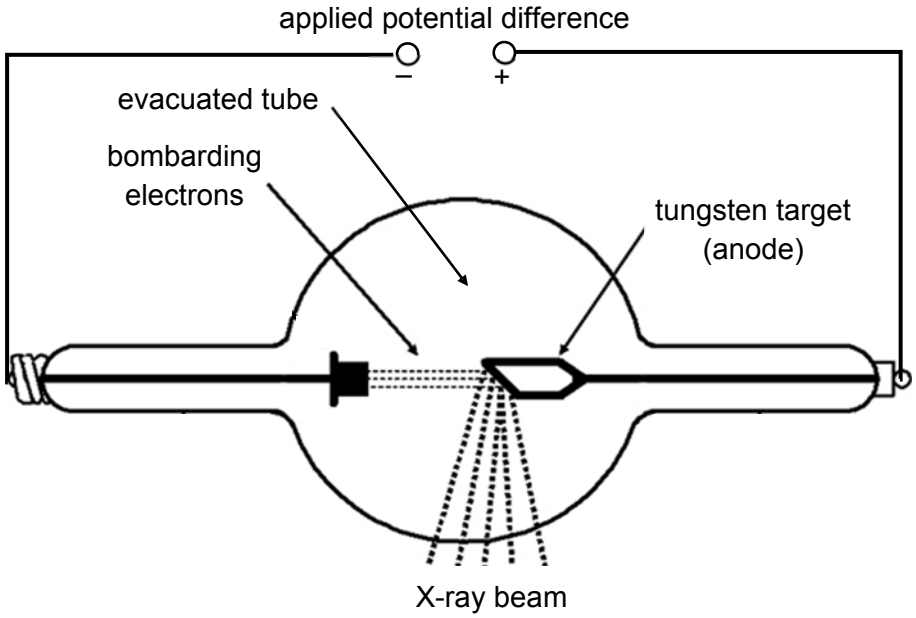


Fig. 7.3

For safety reasons, the wavelength of radiation used for medical X-rays is no shorter than 50 pm. Explain, with calculation, how the setup in Fig. 7.3 can be adjusted to ensure that the wavelength of the X-rays produced does not fall below 50 pm.

.....

.....

.....

..... [3]

For Examiner's Use

Section B

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

8 **(a)** Point source P, consisting of light with wavelength 630 nm, passes through a narrow slit and is incident on a screen at a distance of 2.4 m from the slit. Fig. 8.1 below shows the variation of intensity I of the light on the screen with distance x along the screen.

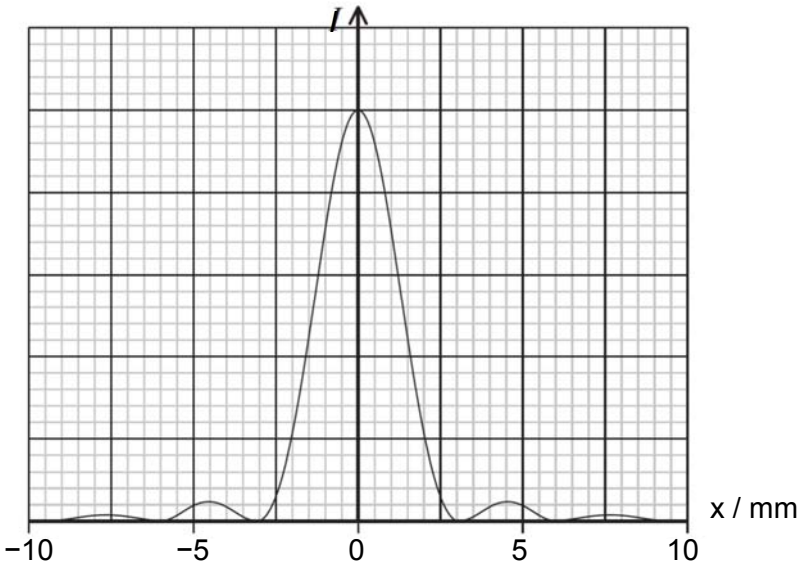


Fig. 8.1

(i) Use Fig. 8.1 to determine the width of the slit.

width = …… mm [2]

(ii) State the effect on the pattern on the screen if each of the following changes is made separately:

1. the width of the single slit is reduced,

.....

.....

..... [2]

For Examiner's Use

2. the red source is replaced with another source of violet light.

.....

.....

..... [2]

(b) Another point source Q, emitting light of the same wavelength as P, is placed 5.0 mm from P, and the two sources are arranged as shown in Fig. 8.2. The slit is now replaced with another slit of width *b*.

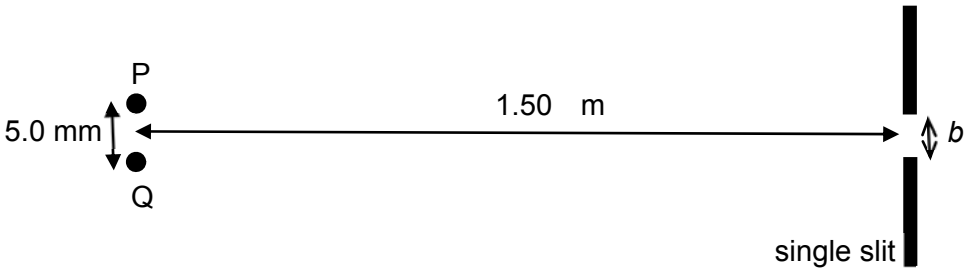


Fig. 8.2

(i) State the condition for the image of P and the image of Q formed on the screen to be just resolved.

.....

..... [1]

(ii) Sketch, on Fig. 8.1, the graph for point source Q when the condition in **(b)(i)** is met. [1]

(iii) Calculate the minimum width *b* of the slit for the two images to be just resolved.

b = …… mm [3]

For Examiner's Use

(c) Two microwave transmitters, A and B, are separated by a distance of 0.80 m. They each transmit a microwave of frequency 3.00 GHz.

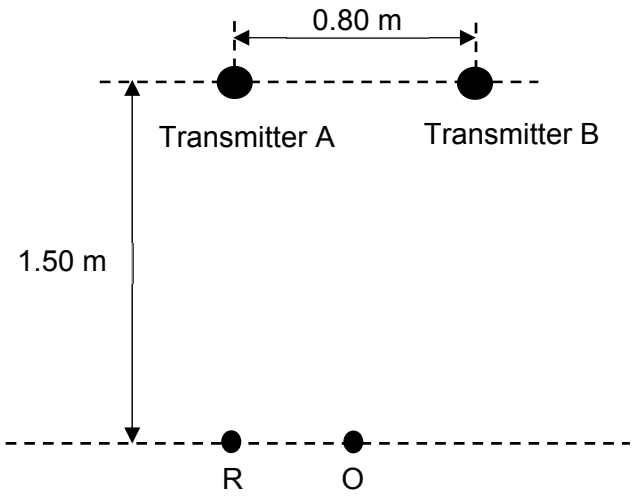


Fig. 8.3

A microwave receiver is moved along a line parallel to, and 1.50 m from, the line joining the two transmitters, as shown in Fig. 8.3. Point O lies on the line where it is equidistant from both transmitters, while point R is at a distance 1.50 m from transmitter A. As the receiver moves from O to R, a minimum signal is detected at R.

(i) Determine the path difference between the two waves arriving at R.

path difference = …… m [2]

(ii) Show that the two waves are emitted in antiphase at the transmitters.

[4]

Fig. 8.4 below shows the displacement-time graph of the waves arriving at R when only transmitter A is switched on and when both transmitters A and B are switched on.

For Examiner's Use

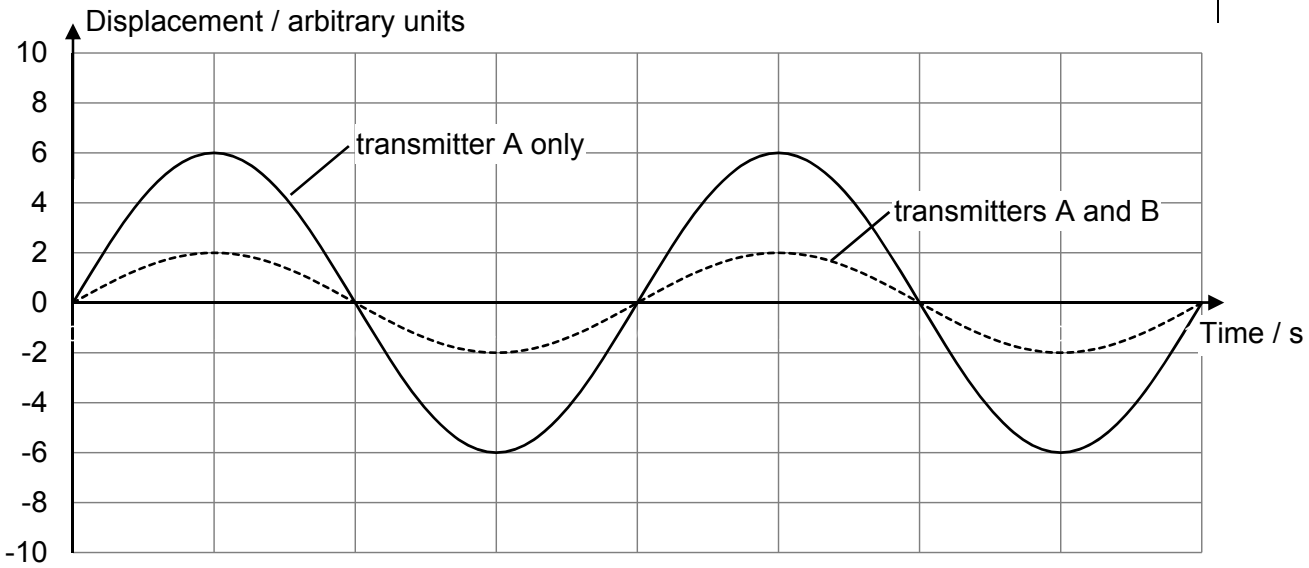


Fig. 8.4

(iii) Sketch, on Fig. 8.4, the displacement-time graph of the waves arriving at R when only transmitter B is switched on. [1]

(iv) Determine the ratio, at point R, of $\frac{\text{intensity of microwave due to transmitter A}}{\text{intensity of microwave due to transmitter B}}$.

ratio = …… [2]

For Examiner's Use

9 **(a)** Fig. 9.1 below shows a Rutherford scattering experiment in which α-particles are directed at a gold foil. The detector is shown in two positions in the evacuated chamber.

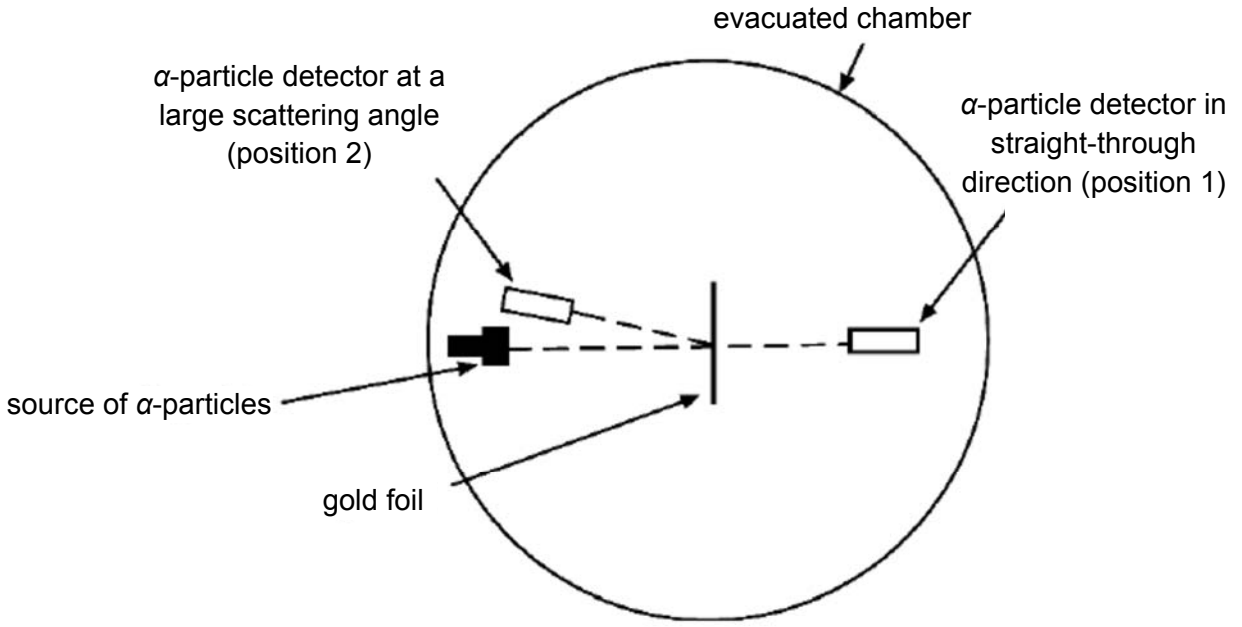


Fig. 9.1

(i) Explain why air needs to be removed from the apparatus.

.....

..... [1]

(ii) Explain why the gold foil should be very thin.

.....

..... [1]

(iii) State what can be deduced, from the following observations, about the structure of the atom and the properties of the gold nucleus:

1. A high count rate is detected by the α-particle detector in position 1.

.....

..... [1]

2. A low count rate is detected by the α-particle detector in position 2.

.....

.....

..... [2]

For Examiner's Use

(b) Fig. 9.2 illustrates the variation with nucleon number of the binding energy per nucleon of nuclei.

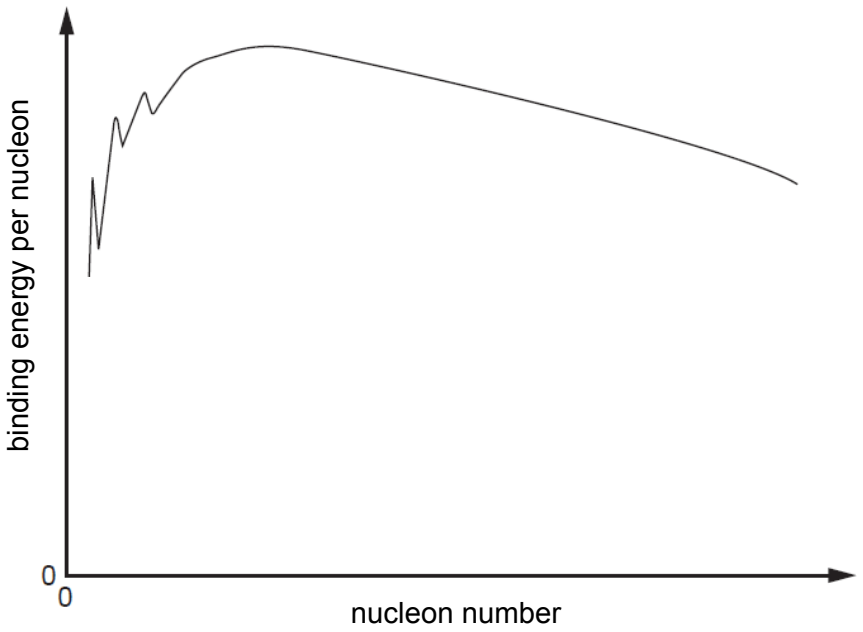


Fig. 9.2

(i) Explain what is meant by the *binding energy* of a nucleus.

.....

.....

..... [2]

(ii) With the aid of Fig. 9.2, explain why more energy per nucleon is released in fusion than in fission.

.....

.....

.....

.....

..... [3]

(iii) On Fig. 9.2, mark with the letter **S** the region of the graph representing nuclei having the greatest stability. [1]

(iv) On Fig. 9.2, complete the graph for elements of low nucleon numbers. [1]

For Examiner's Use

(c) Uranium-235 may undergo fission when bombarded by a slow-moving neutron to produce xenon-142 and strontium-90 as shown below.

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{142}_{54}Xe + ^{90}_{39}Sr + \text{neutrons} + ^{0}_{-1}e$$

(i) Determine the number of neutrons produced in this fission reaction.

number = ... [1]

(ii) State the role of these neutrons in the fission reaction.

.....

..... [1]

(iii) Data on binding energy per nucleon for some nuclides is given in Fig. 9.3.

isotope	binding energy per nucleon / MeV
Uranium-235	7.59
Xenon-142	8.23
Strontium-90	8.70

Fig. 9.3

Calculate

1. the energy released in this fission reaction,

energy = ... J [2]

2. the mass equivalent of this energy.

mass = ... kg [1]

For Examiner's Use

(iv) A nuclear power station supplies 100 MW of electrical power to a town for one year at an efficiency of 35%.

Calculate the mass of uranium needed to operate the power station for one year.

mass = …… kg [3]

End of Paper

H

NANYANG JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 2

CANDIDATE NAME			
CLASS		TUTOR'S NAME	

PHYSICS 9749/03

Paper 3 Longer Structured Questions **20 September 2018**

2 hours

Candidates answer on the Question Paper.

No Additional Materials are required

READ THESE INSTRUCTIONS FIRST

Write your name, class, Centre number and index number on all the work you hand in.
Write in dark blue or black pen on both sides of the paper.
You may use a soft pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, highlighters, glue or correction fluid.

Section A
Answer **all** questions.

Section B
Answer any **one** question.

You are advised to spend about one and a half hours on Section A, and about thirty minutes on Section B.

At the end of the examination, fasten all your work securely together.
The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use	
Section A	
1	**/ 7**
2	**/ 6**
3	**/ 8**
4	**/ 10**
5	**/ 10**
6	**/ 7**
7	**/ 12**
Section B	
8	**/ 20**
9	**/ 20**
Total	

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Data

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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 molecule	E	=	$\frac{3}{2}kT$
displacement of particle in s.h.m.	x	=	$x_o \sin \omega t$
velocity of particle in s.h.m.	v	=	$v_o \cos \omega t$
		=	$\pm \omega\sqrt{(x_o^2 - x^2)}$
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	=	$Q / 4\pi\varepsilon_o r$
alternating current/voltage	x	=	$x_o \sin \omega t$
magnetic flux density due to a long straight wire	B	=	$\mu_o I / 2\pi d$
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radioactive decay	x	=	$x_o \exp(-\lambda t)$
decay constant	λ	=	$\ln 2 / t_{1/2}$

Section A

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

1 Capacitance measures the ability of an electrical component to store charge and is defined as the ratio of charge stored in a capacitor to the potential difference across it.

(a) The S.I. unit for capacitance is the farad (F). Express F in S.I. base units.

$F = C\ V^{-1}$

$C = A\ s$ and $V = [W/q] = kg\ m^2\ s^{-2}\ A^{-1}\ s^{-1} = kg\ m^2\ s^{-3}\ A^{-1}$

$F = kg^{-1}\ m^{-2}\ s^4\ A^2$

F = ... [3]

(b) A capacitor of capacitance 50 μF is charged using a cell in the circuit shown in Fig. 1.1.

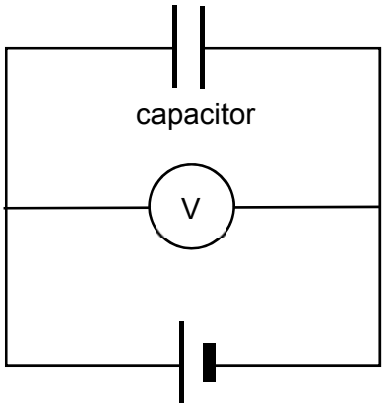


Fig. 1.1

(i) The voltmeter reads 2.20 V. By applying the given definition of capacitance, calculate the charge stored in the capacitor to 3 significant figures.

$C = Q / V \rightarrow Q = 50\times10^{-6} \times 2.20 = 1.10 \times10^{-4}$ C

(ii) The uncertainty of the voltmeter reading is ±0.05 V, and the capacitance of the capacitor has a tolerance of ±10%.

Express the charge stored in the capacitor in the form of $(Q \pm \Delta Q)$.

$Q = C\ V$

$\Delta Q/Q = \Delta C/C + \Delta V/V = 0.10 + 0.05/2.20 = 0.12$

$\Delta Q = 0.1\times10^{-4}$ C

$Q \pm \Delta Q = (1.1 \pm 0.1) \times10^{-4}$ C

2 A person supports a load of 20 N in his hand as shown in Fig. 2.1. The system consisting of the arm and load is equivalent to the system shown in Fig. 2.2. The rod represents the forearm, and *T* represents the tension exerted in the biceps. The forearm weighs 65 N.

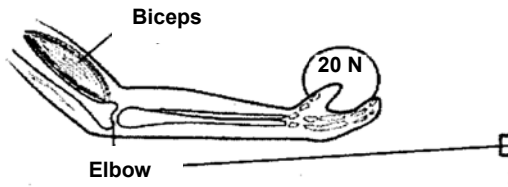


Fig. 2.1

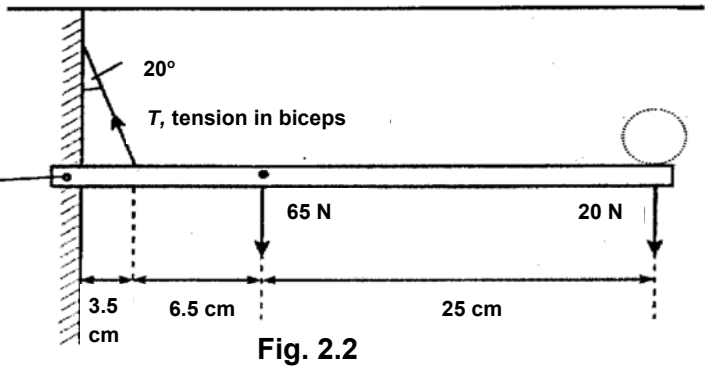


Fig. 2.2

(i) Show that the tension T in the biceps is 410 N. [2]

Taking moments about elbow

$T\cos 20^{o} \times 0.035 = [20 \times (0.250+0.065+ 0.035)] + [65 \times (0.065+ 0.035)]$

$T = 410$ N

(ii) Hence, determine the magnitude and direction of the force acting at the elbow.

Let the force acting on the elbow be F.

Horizontal component of $F = 410 \times \sin 20^{o} = 140.2$ N right

Vertical component of $F = (410 \times \cos 20^{o}) - 65 - 20 = 300.3$ N downwards

$F = \sqrt{(300.3^2 + 140.2^2)} = 331$ N

$\theta = \tan^{-1}(300.3/140.2) = 65^{o}$ below forearm

3 At Luna Amusement Park in Sydney, Australia, the Rotor and Big Dipper Rollercoaster are the most exciting rides.

(a) The popular Rotor ride consists of a large vertical cylinder, which spins about its axis so quickly that any person standing inside is held against the wall when the floor drops away. The passengers maintain horizontal circular motion at constant speed within the cylinder. The normal contact force *N* acting on each passenger is related to the frictional force *f* on the passenger by a constant μ as given by the expression $f = \mu N$.

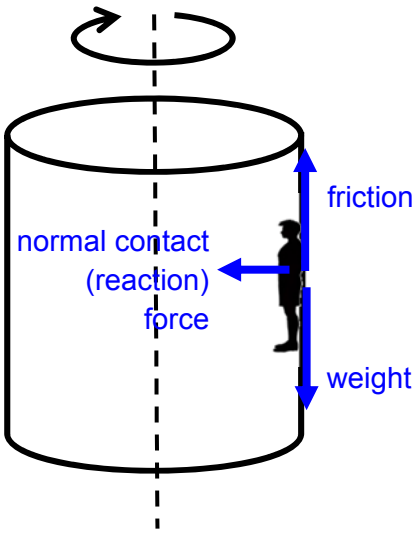


Fig. 3.1

(i) Draw and label, on Fig. 3.1, the forces acting on the passenger. [1]

All forces spelled out in full and in the correct direction

(ii) Show that the linear velocity *v* at which the cylinder of radius *R* must rotate is independent of the mass of the passenger, m.

By Newton's First Law,

$$\sum F_y = ma = 0$$
$$f - W = 0$$
$$f = mg \text{ L } (1)$$

Normal contact force provides the centripetal force for the passenger to be in circular motion.

$$\sum F_c = ma_c$$
$$N = \frac{mv^2}{R} \text{ where } f = \mu N$$
$$\frac{f}{\mu} = \frac{mv^2}{R} \text{ L } (2)$$

Taking (2) / (1):

$$\frac{f}{\mu} = \frac{\frac{mv^2}{R}}{mg}$$

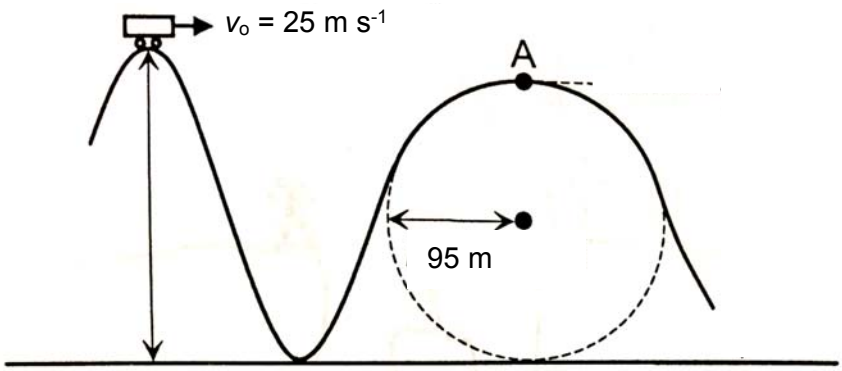
$$\frac{1}{\mu} = \frac{v^2}{Rg}$$

$$v = \sqrt{\frac{Rg}{\mu}}$$

where velocity v is independent of mass m.

[3]

(b) The cart on the exhilarating Big Dipper Rollercoaster moves with negligible friction along the track as shown. The cart travels with an initial speed v_o of 25 m s^{-1} at the top of one hill, of height h, before reaching the top of a second hill, which forms a circular arc of radius 95 m.



(i) Calculate the maximum speed at which the cart can travel without leaving the track at the top of the second hill at point A.

$$\sum F_c = ma_c$$

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

Upon losing contact, $N = 0$

$$W = \frac{mv^2}{r}$$

$$mg = \frac{mv^2}{r}$$

$$v = \sqrt{rg}$$

$$= \sqrt{95 \times 9.81}$$

$$= 30.528$$

$$= 30.5\, m\, s^{-1}$$

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

(ii) Hence, determine the maximum height, *h*, of the first hill for the condition in **(b)(i)** to hold. [2]

By Principle of Conservation of Energy,

$$GPE_{top\ of\ hill} + KE_{top\ of\ hill} = GPE_{At\ A} + KE_{At\ A}$$

$$mgh + \frac{1}{2}m(25)^2 = mg(95\times 2) + \frac{1}{2}m(30.528)^2$$

$$h = 206\,m$$

h = ... m [2]

4 **(a)** "The magnitude of *gravitational field strength* at a point is proportional to the *gravitational potential gradient* at that point."

Explain the terms in italics.

gravitational field strength: gravitational force per unit mass

gravitational potential gradient: change in gravitational potential energy per unit mass per unit distance, *or* work done per unit mass against gravitational force per unit distance

(b) Fig. 4.1 shows four equipotential lines at 1000-km intervals in a non-uniform gravitational field.

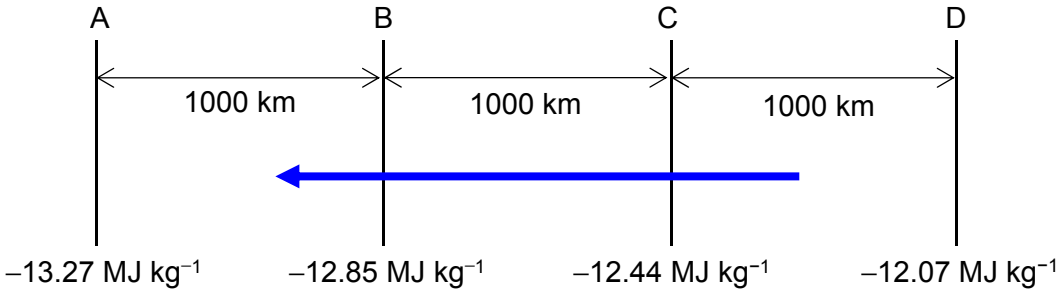


Fig. 4.1

(i) Draw an arrow on Fig 4.1 to indicate the direction of the gravitational field. [1]

(ii) Calculate the ratio of

$$\frac{\text{field strength at B}}{\text{field strength at C}}$$

Field strength at B = $(13.27 - 12.44)\times 10^6 / 2000\times 10^3 = 0.415$ N kg^{-1}

Field strength at C = $(12.85 - 12.07)\times 10^6 / 2000\times 10^3 = 0.390$ N kg^{-1}

Ratio = 0.415 / 0.390 = 1.06

ratio = ... [3]

(c) A theoretical long open tube is placed in the gravitational field as shown in Fig. 4.2. An object is released from rest at B.

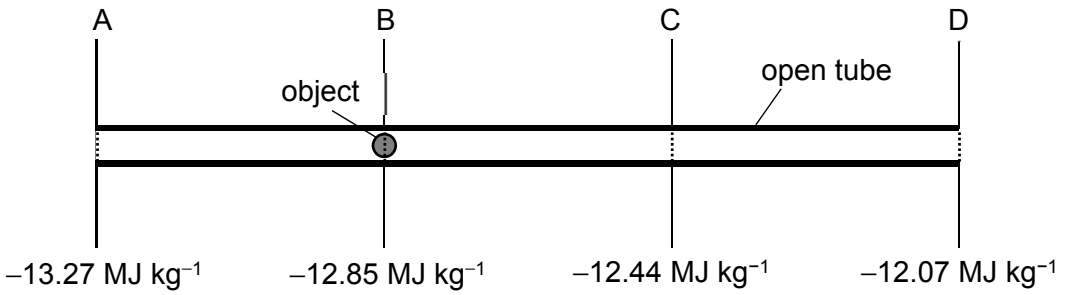


Fig. 4.2

Determine the speed with which the object leaves the tube.

object will accelerate to the left

Loss in GPE = m (13.27 – 12.85)×10^6 = 0.42×10^6 m

Gain in KE = ½ m v^2 – 0 = 0.42×10^6 m

v = 917 m s^{-1}

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

5 **(a)** State what is meant by the term *internal energy of an ideal gas*.

The internal energy of an ideal gas is the sum of the microscopic kinetic energy due to random motion of all the atoms/molecules of the gas.

(b) The pressure p exerted by an ideal gas is given by the equation

$$p = \frac{1}{3}\rho < c^2 >$$

State what the symbols ρ and $<c^2>$ represent.

ρ: density of the gas

$<c^2>$: mean-square speed of the atoms/molecules in the gas

(c) Use the equation given in **(b)** to show that the total kinetic energy of the molecules of an ideal gas of volume V and pressure p is given by $\frac{3}{2}pV$.

$$p = \frac{1}{3}\rho < c^2 > = \frac{1}{3}\frac{Nm}{V} < c^2 >$$

where N is the number of molecules in the gas; m the mass of each molecule and V the volume of the gas. Therefore,

$$pV = \frac{1}{3}Nm < c^2 >$$

$$\frac{1}{2}Nm < c^2 > = \frac{3}{2}pV$$

(d) **(i)** Calculate the internal energy of an ideal gas of volume 3.4×10^{-4} m^3 when its pressure is 100 kPa.

$$\text{Internal Energy} = \frac{3}{2}pV$$
$$= \frac{3}{2}(100\times10^3)(3.4\times10^{-4})$$
$$= 51 \text{ J}$$

(ii) Calculate the increase in internal energy when the gas expands at constant pressure to a volume of 8.8×10^{-4} m^3.

$$\text{Increase in internal Energy} = \frac{3}{2}p\Delta V$$
$$= \frac{3}{2}(100\times10^3)(8.8\times10^{-4} - 3.4\times10^{-4})$$
$$= 81 \text{ J}$$

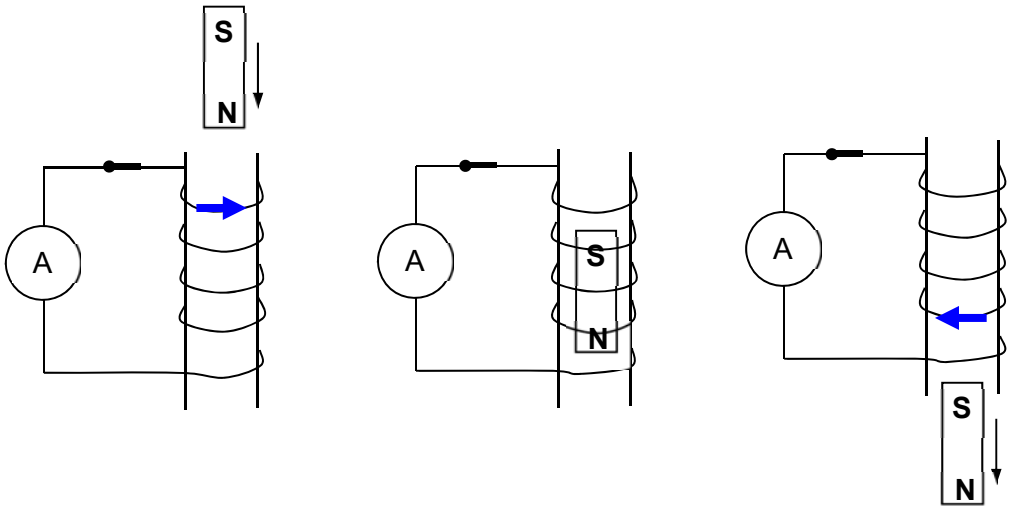
(iii) Determine the heat supplied to the gas so as to enable the expansion at constant pressure to take place.

$$\text{Work done by gas} = p\Delta V$$
$$= (100\times10^3)(8.8\times10^{-4} - 3.4\times10^{-4})$$
$$= 54 \text{ J}$$
$$\Delta U = Q + W$$
$$81 = Q - 54$$
$$Q = 135 \text{ J}$$

6 **(a)** State Lenz's Law.

Lenz's law states that the e.m.f. is induced in the direction such that its effects oppose the change in the magnetic flux linkage that is inducing it. [1]

A strong magnet is allowed to drop through a solenoid which is wound around a cardboard tube. The solenoid is connected to a switch and an ammeter.



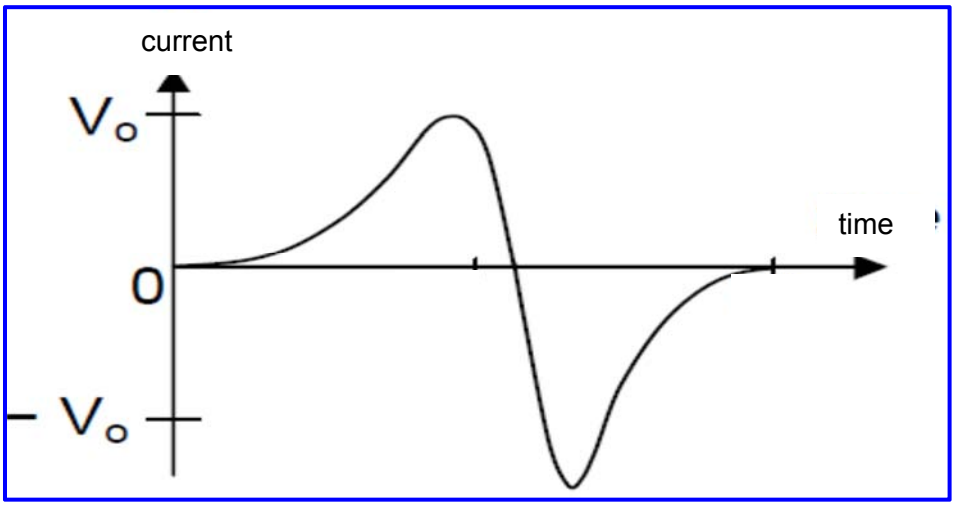
Magnet approaching solenoid Fig. 6.1A

Magnet in the middle of solenoid Fig. 6.1B

Magnet leaving solenoid Fig. 6.1C

(b) Indicate, with arrows on the winding of the solenoid in Fig. 6.1A, Fig. 6.1B and Fig. 6.1C, the direction of any induced current. [2]

(c) Hence, sketch on Fig. 6.2 a labelled graph showing the variation with time of the current induced in the solenoid as the magnet falls through it. [2]



Correct shape/positive & negative current. [1]

Peak of current for retreating magnet is greater. [1]

(d) The switch connected to the solenoid is now opened, and the same magnet is allowed to drop through the solenoid again.

State and explain any change in the speed of the magnet as it leaves the solenoid.

The speed of the magnet increases. [1]

Since the switch is opened; there is no induced current in the solenoid to produce an opposing induced magnetic field to oppose the motion of the magnet. [1]

7 **(a)** Tungsten, a transition metal, is commonly used as a target metal for the production of X-rays. The energy levels of the K- and M-shells for tungsten are shown in Fig. 7.1 below.

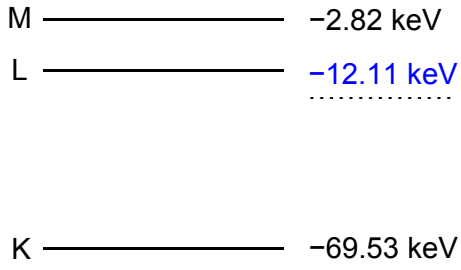


Fig. 7.1

The wavelength of the photon produced by the K_α transition is 21.65 pm.

(i) Complete Fig. 7.1 by filling in the energy level of the L-shell for tungsten.

$$E = \frac{h\,c}{\lambda} = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{21.65 \times 10^{-12}}$$

$= 9.187 \times 10^{-15}$ J = 57.42 keV

$E_2 = -69.53 + 57.42 = -12.11$ keV

Examiner's comments:
A number of students rounded values prematurely, resulting in inaccurate final values.

[2]

(ii) Determine the wavelength of the photon produced by L_α transition.

−2.82−(−12.11) = 9.29 keV

$$\lambda = \frac{h\,c}{E} = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{9.29 \times 10^{3} \times 1.6 \times 10^{-19}}$$

= 134 pm

wavelength = ... pm [1]

The intensity of various photon wavelengths from electron bombardment of a tungsten target metal is shown in Fig. 7.2 below.

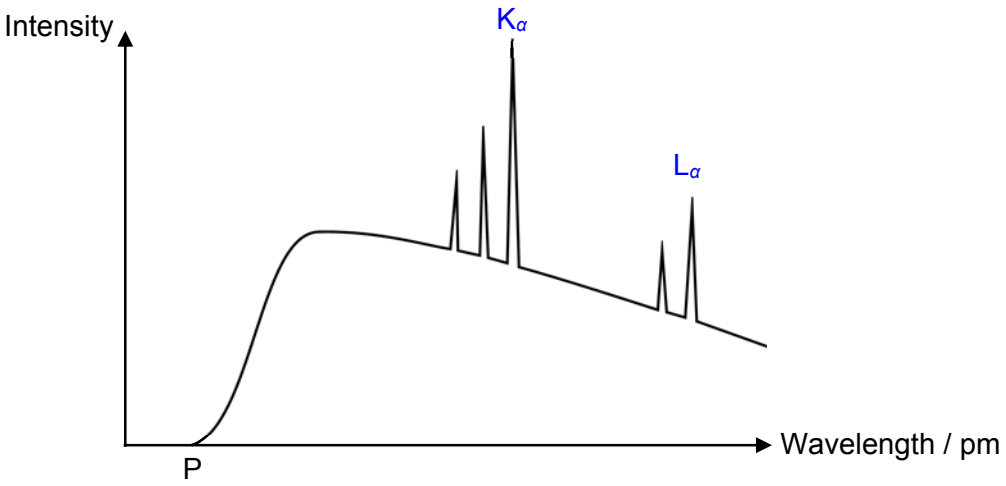


Fig. 7.2

(iii) On Fig. 7.2, label the peaks for K_α and L_α transitions. [2]

(iv) State the significance of the value of P.

indicates highest energy photons / KE of electrons [1]

no marks for "minimum wavelength" only

[1]

Examiner's comments

An alarming number of students used phrasing that indicates a concept error. Photons do not have KE, nor is KE "transferred" from electrons to photons.

(v) With reference to Fig. 7.1, explain why the electrons bombarding the target metal must have a minimum energy of 69.53 keV to produce the spectrum shown in Fig. 7.2.

To produce the characteristic lines in the spectrum, [1]

electrons must have sufficient energy to knock out / remove K-shell electrons.[1]

The amount of energy required to bring the electron from K-shell to ionized state is 69.53 keV / the energy level of the K-shell is −69.53 eV. [1]

Examiner's comments:

Some students are still labouring under the misconception that electrons can deexcite from "infinity energy level" to ground state and produce a photon. E_∞ indicates the electron has escaped the atom (free electron) and has a minimum energy of 0 eV

[3]

(b) Fig. 7.3 below shows a typical setup for producing such X-ray beams.

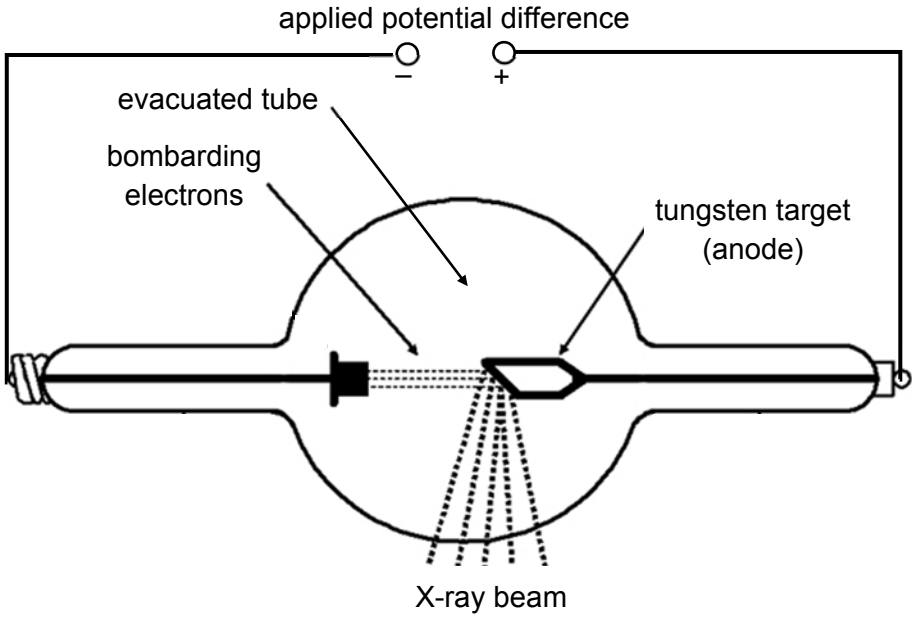


Fig. 7.3

For safety reasons, the wavelength of radiation used for medical X-rays is no shorter than 50 pm. Explain, with calculation, how the setup in Fig. 7.3 can be adjusted to ensure that the wavelength of the X-rays produced does not fall below 50 pm.

Minimum wavelength of X-rays produced is determined by KE of electrons which is, in turn, determined by the accelerating p.d. [1]

$$eV = \frac{hc}{\lambda}$$

$$= \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{50 \times 10^{-12}}$$

V = 2.5×10⁴ V = 25 kV [1] for working to show value of V

The accelerating p.d. is to be kept under 25 kV. [1]

[3]

Section B

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

8 **(a)** Point source P, consisting of light with wavelength 630 nm, passes through a narrow slit and is incident on a screen at a distance of 2.4 m from the slit. Fig. 8.1 below shows the variation of intensity I of the light on the screen with distance x along the screen.

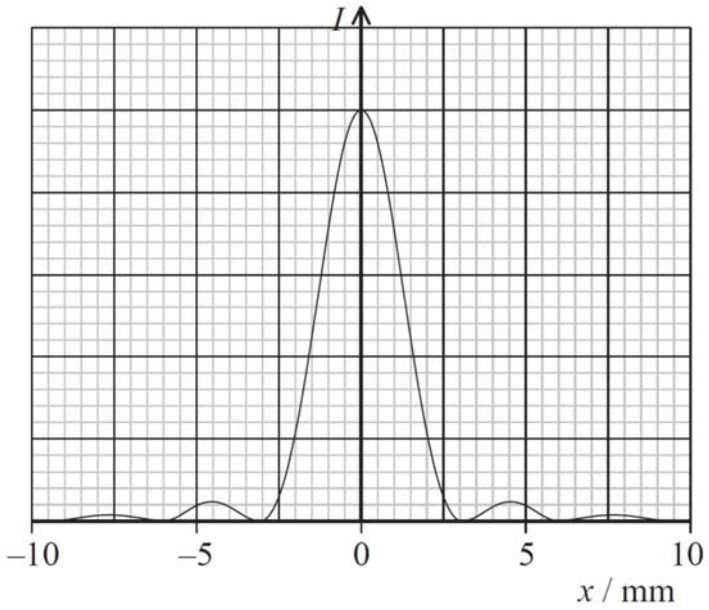


Fig. 8.1

(i) Use Fig. 8.1 to determine the width of the slit.

sin θ = λ/b

$sin\theta = \frac{0.003}{2.4} = \frac{\lambda}{b}$

$b = 5.04 \times 10^{-4}\ m$

(ii) State the effect on the pattern on the screen if each of the following changes is made separately:

1. the width of the single slit is reduced,

b↓ , sinθ↑, θ↑ → increase in width of central maximum, maxima are further lower intensity

2. the red source is replaced with another source of violet light.

λ↓, sinθ↓, θ↓ → reduced width of central maximum, maxima are closer

green and dark regions

(b) Another point source Q emitting light of the same wavelength as P is placed 5.0 mm from P, and the two sources are arranged as shown in Fig. 8.2. The slit is now replaced with another slit of width *b*.

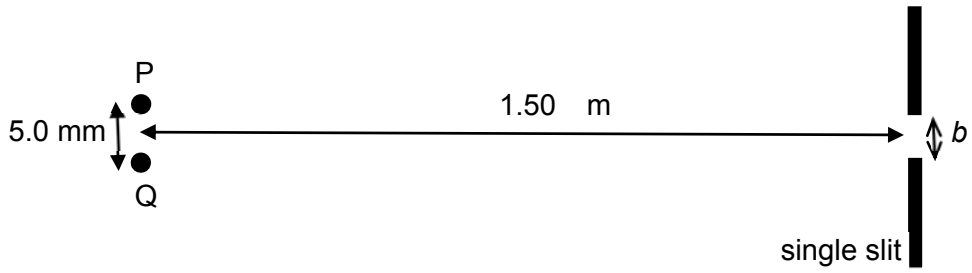


Fig. 8.2

(i) State the condition for the image of P and the image of Q formed on the screen to be just resolved.

Rayleigh's criterion states that two images are just distinguishable if the central maximum of one diffraction pattern falls on the first minimum of the diffraction pattern of the other.

(ii) Sketch, on Fig. 8.1, the graph for point source Q when the condition in **(b)(i)** is met. [1]

(iii) Calculate the minimum width *b* of the slit for the two images to be just resolved. **[3]**

$$tan\theta = \frac{0.0025}{1.50} = 1.6667 \times 10^{-3}$$

$$By\ small\ angle\ approximation, \theta res = 2tan\theta$$

$$\theta res = \frac{\lambda}{b}$$

$$b = \frac{630 \times 10^{-9}}{2 \times 1.6667 \times 10^{-3}} = 1.89 \times 10^{-4}\ m$$

b = ... mm [2]

(c) Two microwave transmitters, A and B, are separated by a distance of 0.80 m. They each transmit a microwave of frequency 3.00 GHz.

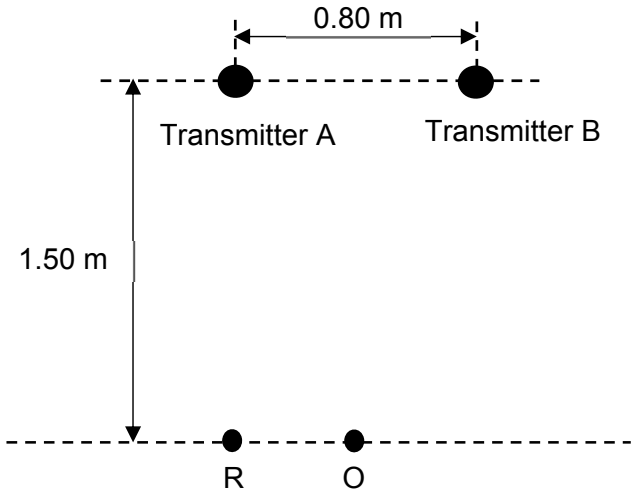


Fig. 8.3

A microwave receiver is moved along a line parallel to, and 1.50 m from, the line joining the two transmitters, as shown in Fig. 8.3. Point O lies on the line where it is equidistant from both transmitters, while point R is at a distance 1.50 m from transmitter A. As the receiver moves from O to R, a minimum signal is detected at R.

(i) Determine the path difference between the two waves arriving at R.

$S_2R = (0.80^2 + 1.50^2)^{½} = 1.70$ m

Path difference = 1.70 – 1.50 = 0.20 m

(ii) Show that the two waves are emitted in antiphase at the transmitters. [4]

Wavelength of microwave = c / f = $(3.00 \times 10^8) / (3.00 \times 10^9) = 0.100$ m

Path difference = 0.20 m = 2 x wavelengths

Phase difference due to path difference = $(2\lambda / \lambda) \times 2\pi = 4\pi$

Total phase difference = 3π or 5π

Since the signal received at R is a minimum, destructive interference must have occurred where the waves met in antiphase. Therefore, a phase difference of π must have been introduced at the sources.

i.e. Phase difference due sources = π

Fig. 8.4 below shows the displacement-time graph of the waves arriving at R when only transmitter A is switched on and when both transmitters A and B are switched on.

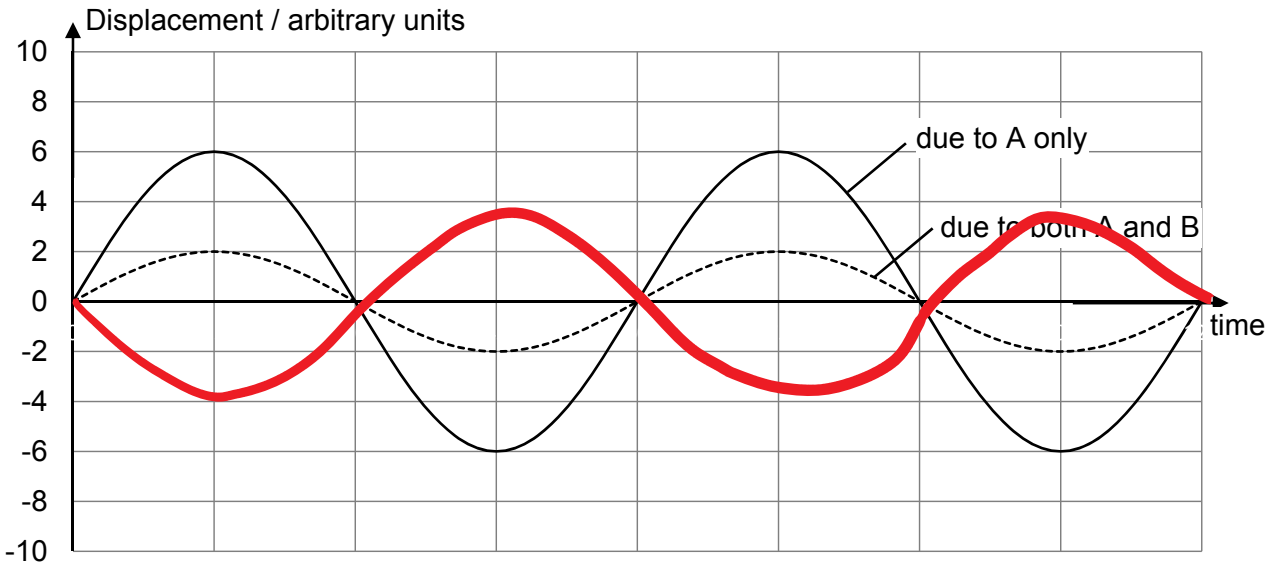


Fig. 8.4

(iii) Sketch, on Fig. 8.4, the displacement-time graph of the waves arriving at R when only transmitter B is switched on. [1]

(iv) Determine the ratio, at point R, $\frac{\text{intensity of microwave due to transmitter A}}{\text{intensity of microwave due to transmitter B}}$.

$$\frac{Amplitude\ due\ to\ A}{Amplitude\ due\ to\ A\ and\ B} = \frac{9}{3}$$

$$\frac{Amplitude\ due\ to\ A}{Amplitude\ due\ to\ B} = \frac{9}{6}$$

$$\frac{Intensity\ due\ to\ A}{Intensity\ due\ to\ A\ and\ B} = \left(\frac{9}{6}\right)^2 = 2.25$$

9 **(a)** Fig. 9.1 below shows a Rutherford scattering experiment in which *α*-particles are directed at a gold foil. The detector is shown in two positions in the evacuated chamber.

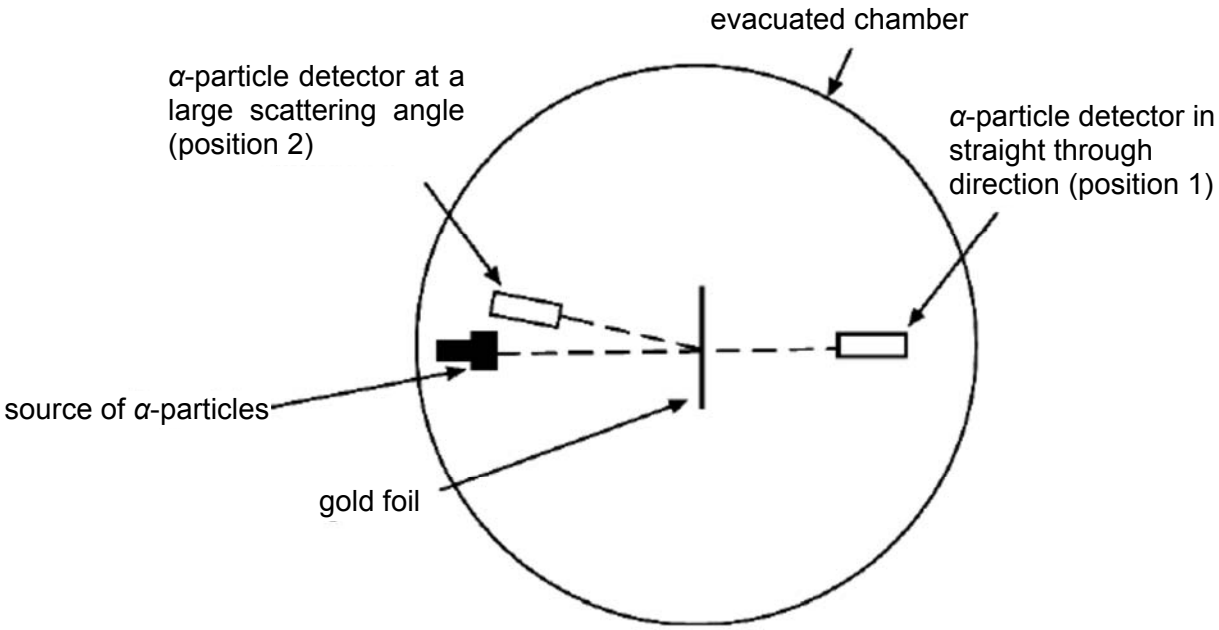


Fig. 9.1

(i) Explain why air needs to be removed from the apparatus.

to minimise collisions between α particles and air molecules) **B1**
Or
α particles have a short range in air (3–5 cm) **B1**
(or any answer to the same effect)

(ii) Explain why the gold foil should be very thin.

the α particles must only be scattered at most once **B1**
Or
- the α particles must not be absorbed/stopped/blocked by the foil **B1**
("to allow the alpha particle to emerge from the gold foil" is not accepted)

(iii) **1.** Explain why a high count rate is detected by the *α*-particle detector in position 1.

Most of the **α** particles pass straight through as the atom consists mainly of open space **B1**
(do not accept small nucleus)

2. A low count rate is detected by the *α*-particle detector in position 2. State what can be deduced from this observation about the structure of the atom and the properties of the gold nucleus.

- the nucleus is positively charged
- the nucleus is **very** small **in comparison to the size of an atom**
- the nucleus is very massive
(any two answers)

(b) Fig. 9.2 illustrates the variation with nucleon number A of the binding energy per nucleon *E* of nuclei.

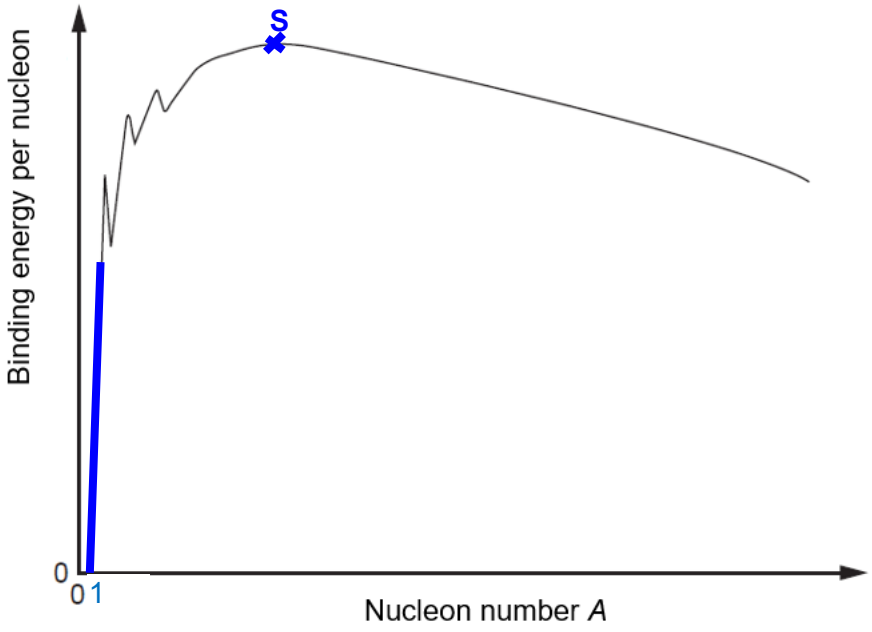


Fig. 9.2

(i) Explain what is meant by the *binding energy* of a nucleus.

Binding energy of a nucleus refers to the amount of energy required to break it apart into its separate constituents of protons and neutrons. **B1**

nucleons separated to infinity / completely …….. **B1**

(ii) With the aid of Fig. 9.2, explain why more energy per nucleon is released in fusion than in fission.

- Energy released in a nuclear reaction is equal to the difference in binding energies between the products and the original reactants. …….. **B1**

- Fusion occurs for reactants and products that have nucleon numbers less than 56 while fission occurs for reactants and products that have nucleon numbers greater than 56. …… **B1**
Or
- Fusion reaction is one in which two light nuclei combine to form a heavier nucleus, while in fission a heavy nucleus splits into two lighter nuclei. …….. **B1**

- From graph, the steeper slope of the binding energy curve for lighter nuclei indicates that the change in binding energy in fusion is larger, compared to that for fission reactions. …….. **B1**
- Hence, more energy is released in a fusion reaction.

(iii) On Fig. 9.2, mark with the letter **S** the region of the graph representing nuclei having the greatest stability. [1]

(iv) On Fig. 9.2, complete the graph for elements of low nucleon numbers. [1]

(c) Uranium-235 may undergo fission when bombarded by a slow moving neutron to produce Xenon-142 and Strontium-90 as shown below.

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{142}_{54}\text{Xe} + ^{90}_{39}\text{Sr} + \text{neutrons} + ^{0}_{-1}\beta$$

(i) Determine the number of neutrons produced in this fission reaction.

No of neutrons = 4 …….. **A1**

(ii) State the role of these neutrons in the fission reaction.

The role of neutrons is to initiate more nuclear fission reactions by bombarding other $^{236}_{92}U$ nuclei such that a chain reaction results.

(iii) Data on binding energy per nucleon for some nuclides are given in Fig. 9.3.

isotope	binding energy per nucleon / MeV
Uranium-235	7.59
Xenon-142	8.23
Strontium-90	8.70

Fig. 9.3

Calculate

1. the energy released in this fission reaction,

energy released = (8.23 × 142 **+** 8.70 × 90) **–** 235 × 7.59 …….. **C1**

= 168 MeV

= 2.69 x 10^{-11} J …….. **A1**

2. the mass equivalent of this energy.

mass equivalent = (2.69 x 10^{-11}) / $(3.0 \times 10^{8})^2$

= 2.99 × 10^{-28} kg …….. **A1**

(iv) A nuclear power station supplies 100 MW of electrical power to a town for one year at an efficiency of 35%.

Calculate the mass of uranium needed to operate the power station for one year.

Useful output Power = 100 x 10^6 W at 35% efficiency

In a year, total energy required = 100 x 10^6 x 365 x 24 x 60 x 60/0.35

= 9.01 x 10^{15} J …….. **C1**

Energy released in 1 reaction = 2.69×10^{-11} J

No of reactions required = $9.01 \times 10^{15} / 2.69 \times 10^{-11}$

= 3.35×10^{26} …….. **C1**

= N, number of uranium atoms required.

Mass required = $3.35 \times 10^{26} \times 235 \times 1.66 \times 10^{-27}$

= 1.3×10^{2} kg …….. **A1**