Anglo-Chinese Junior College

Physics Preliminary Examination
Higher 2

A Methodist Institution
(Founded 1886)

CANDIDATE NAME		CLASS	
CENTRE NUMBER	S 3 0 0 4	INDEX NUMBER	

PHYSICS **9749/03**

Paper 3 Longer Structured Questions

30 August 2022

2 hours

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

READ THESE INSTRUCTIONS FIRST

Write your name, class and index number in the spaces at the top of this page.
Write in dark blue or black pen on both sides of the paper.
You may use an HB pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, glue or correction fluid.

The use of an approved scientific calculator is expected, where appropriate.

Section A
Answer **all** questions.

Section B
Answer **one** question only.

You are advised to spend one and a half hours on Section A and half an hour 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 Examiners' use only	
Section A	
1	/ 12
2	/ 10
3	/ 12
4	/ 12
5	/ 14
Total	/ 60
Section B	
6	/ 20
7	/ 20
Grand Total	/ 80

DATA AND FORMULAE

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	=	$\rho g h$
gravitational potential,	ϕ	=	$-\dfrac{Gm}{r}$
temperature	T/K	=	T/°C + 273.15
pressure of an ideal gas	p	=	$\dfrac{1}{3}\dfrac{Nm}{V}\langle c^2 \rangle$
mean translational kinetic energy of an ideal gas molecule,	E	=	$\dfrac{3}{2}kT$
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	=	$\dfrac{Q}{4\pi\varepsilon_o r}$
alternating current/voltage,	x	=	$x_o \sin \omega t$
magnetic flux density due to a long straight wire	B	=	$\dfrac{\mu_o I}{2\pi d}$
magnetic flux density due to a flat circular coil	B	=	$\dfrac{\mu_o N I}{2r}$
magnetic flux density due to a long solenoid	B	=	$\mu_0 n I$
radioactive decay,	x	=	$x_o \exp(-\lambda t)$
decay constant,	λ	=	$\dfrac{\ln 2}{t_{1/2}}$

[Turn over

For Examiner's Use

Section A

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

1 A student is exploring Physics principles with wooden blocks and some Physics activities.

(a) Fig. 1.1 shows the first experiment with block A attached to a frictionless pulley using an inelastic massless string. Block A accelerates up a frictionless inclined plane of angle 50°. Block B of mass 8.3 kg is attached to the string on the opposite end of the pulley.

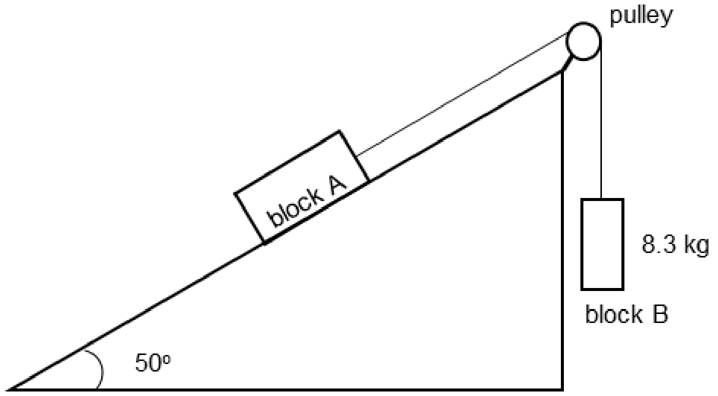


Fig. 1.1

(i) On Fig. 1.2, label the forces acting on block A.

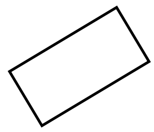


Fig. 1.2

[1]

For Examiner's Use

(ii) The tension of the string is 54 N.

Show that the mass of block A is 5.0 kg.

[3]

(b) Fig. 1.3 shows another experiment with block A from **(a).** Block A moves along a frictionless horizontal plane towards a stationary block C of mass 10 kg at a constant speed. Block A collides with block C at t = 0 s.

Fig. 1.3

The variation with time t of the momentum p of block A is shown in Fig. 1.4.

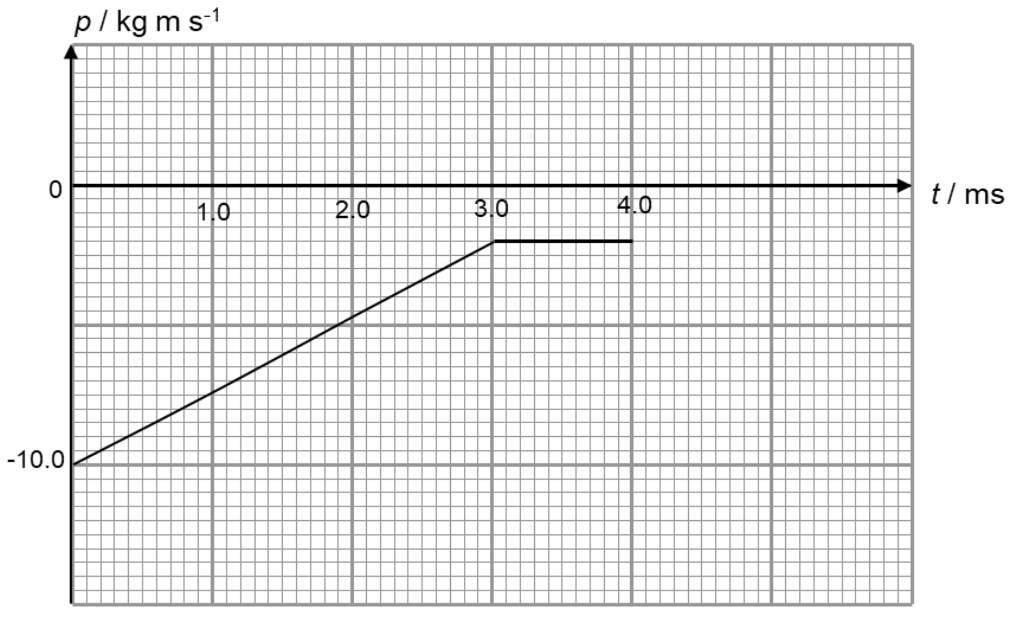


Fig. 1.4

For Examiner's Use

(i) Determine the force acting on block C during the collision.

force = ……………………… N [2]

(ii) Calculate the velocity of block A after the collision.

velocity = ……………………… m s^{-1} [2]

(iii) Deduce whether the collision between the two blocks is elastic or inelastic.

Show your working.

………………………………………………………………………………………

……………………………………………………………………………….… [4]

[Total: 12]

For Examiner's Use

2 **(a)** Define *electric potential* at a point.

…………………………………………………………………………………………………..

…………………………………………………………………………………………………..

…………………………………………………………………………………………………..

……………………………………………………………………………………….... [2]

(b) A thin hollow conducting sphere A of radius 0.050 m has an electric potential V of 400 V and an electric field strength E of 8000 N C^{-1} at its surface as shown in Fig. 2.1.

distance from centre of A / m	V / V	E / N C^{-1}
0.050	400	8000
0.200		

Fig. 2.1

Complete Fig. 2.1 for the electric potential V and electric field strength E at 0.200 m from the centre of sphere A.

[2]

(c) Sphere A is placed inside a second thin hollow conducting sphere B of radius 0.200 m carrying a charge of the same magnitude but opposite sign as the charge on A. The spheres have a common centre as shown in Fig. 2.2(a) and Fig. 2.3(a).

Without further calculations, use values in **(b)** to sketch graphs of the variation with distance r from the common centre for **(c)(i)** and **(c)(ii)** below.

Take the positive direction of electric field strength E to be in the positive horizontal axis.

(i) When only sphere A is present.

1. electric potential on Fig. 2.2(b). Label $\boldsymbol{V_A}$. [2]

2. electric field strength on Fig. 2.2(c). Label $\boldsymbol{E_A}$. [2]

(ii) When both spheres A and B are present.

1. electric potential on Fig. 2.3(b). Label $\boldsymbol{V_R}$. [1]

2. electric field strength on Fig. 2.3(c). Label $\boldsymbol{E_R}$. [1]

[Total: 10]

For Examiner's Use

Fig. 2.2(a)

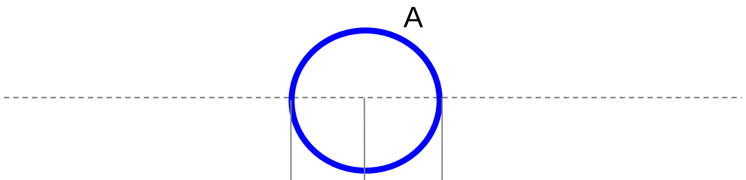


Fig. 2.2(b)

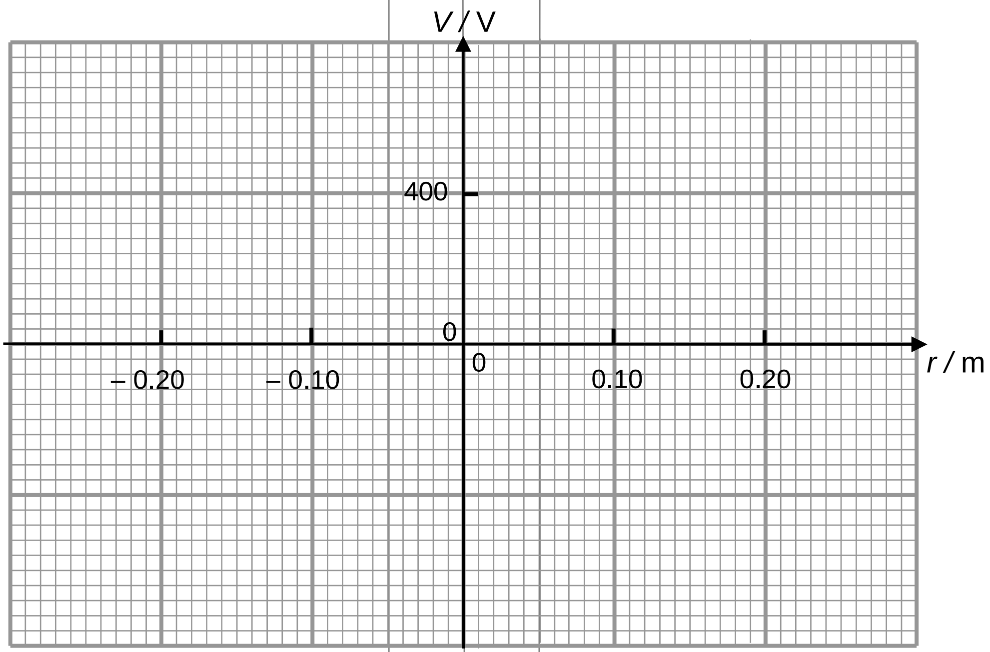


Fig. 2.2(c)

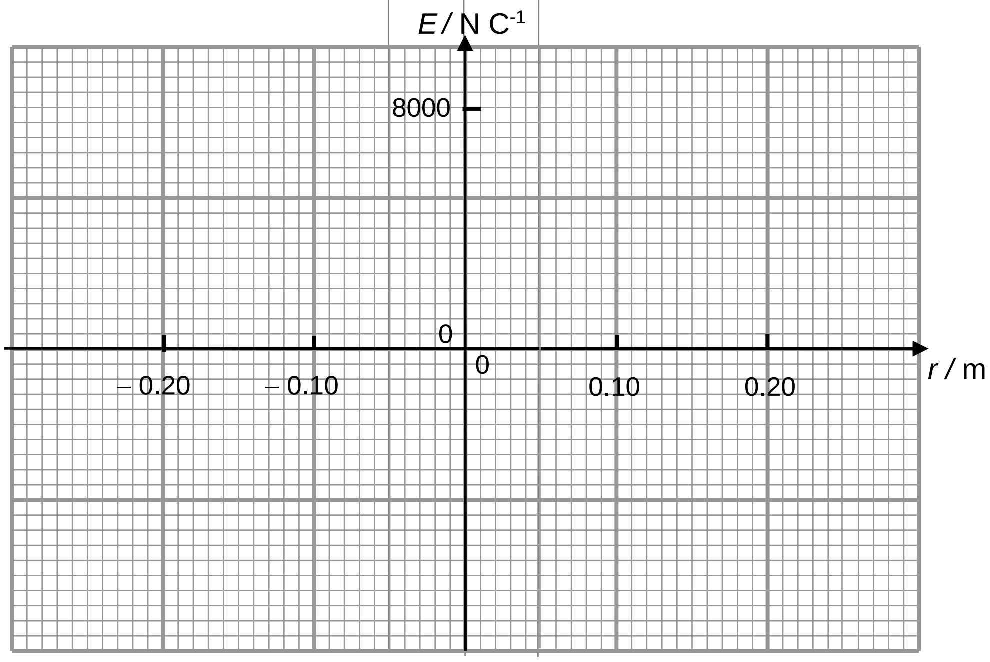


Fig. 2.3(a)

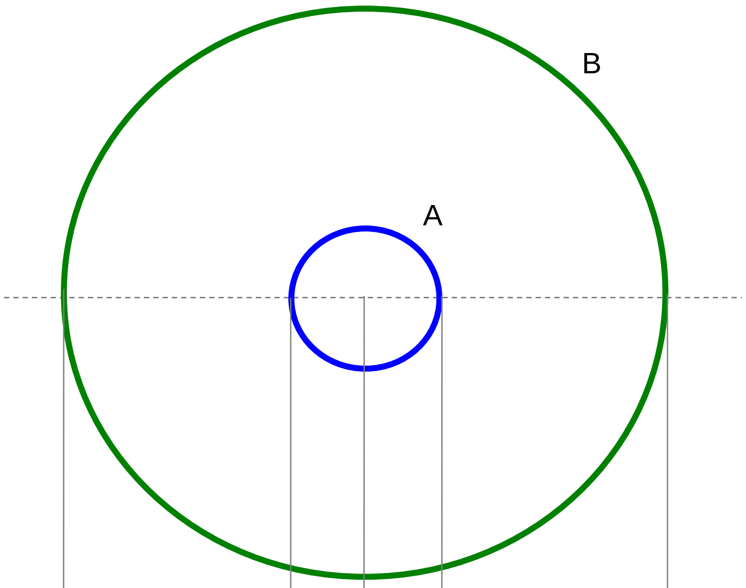


Fig. 2.3(b)

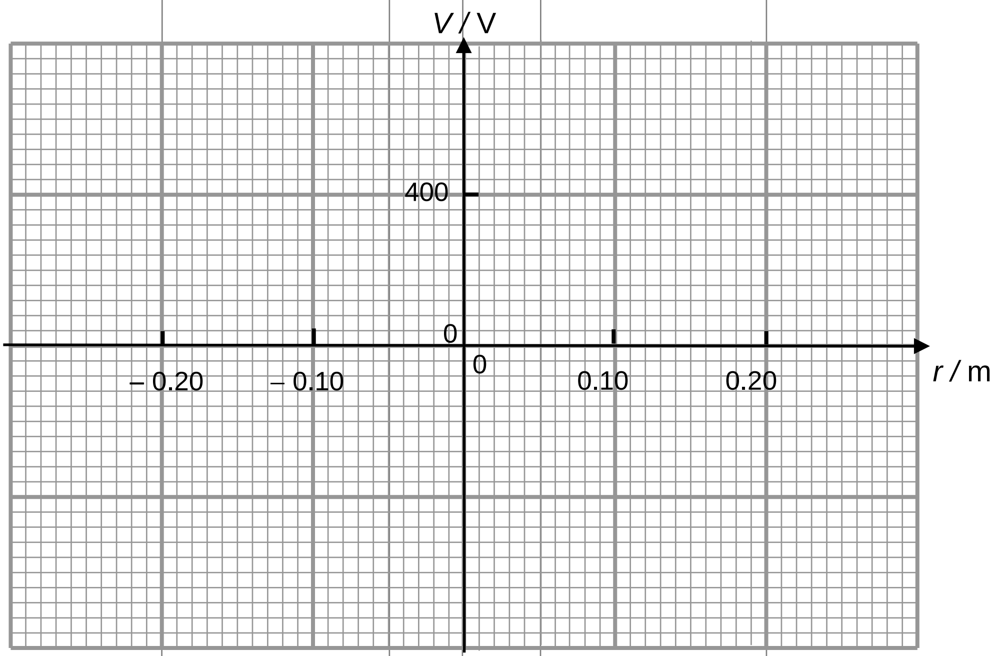
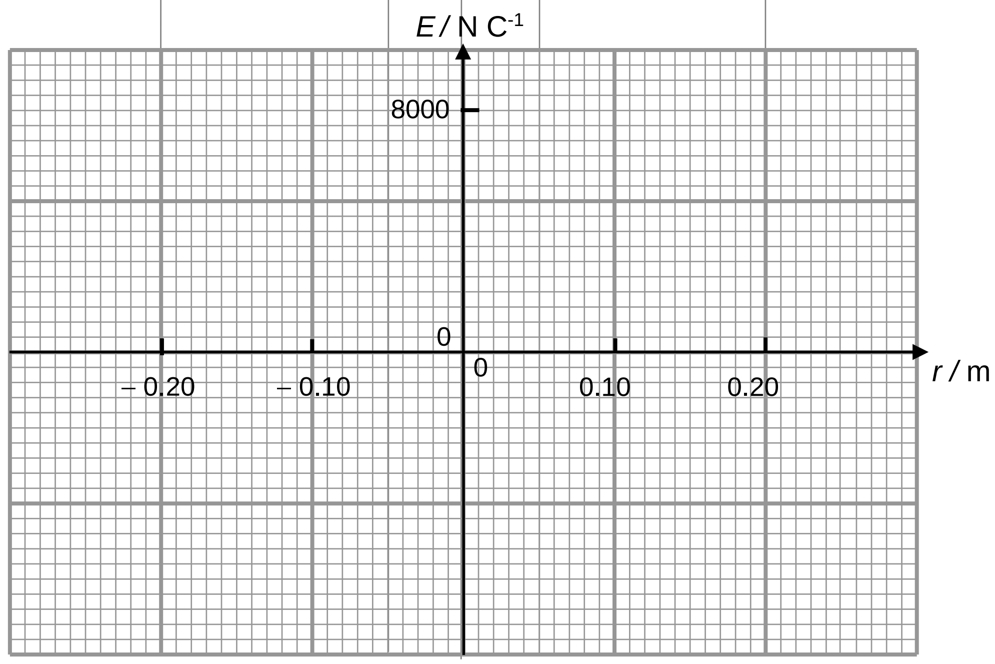


Fig. 2.3(c)



For Examiner's Use

3 **(a)** State the *first law of thermodynamics*.

…………………………………………………………………………………………………..

…………………………………………………………………………………………………..

…………………………………………………………………………………………………..

………………………………………………………………………………………… [2]

(b) Use the first law of thermodynamics to calculate the gain in internal energy when 5.0 kg of water at 100 °C is transformed into 5.0 kg of steam at 100 °C at a constant pressure of 1.01×10^5 Pa.

density of steam = 0.598 kg m^{-3}
density of water = 1000 kg m^{-3}
specific latent heat of vaporisation of water = 2.26×10^6 J kg^{-1}

gain in internal energy = ……………………… J [4]

For Examiner's Use

(c) A fixed mass of ideal gas undergoes a cycle of changes as shown in Fig. 3.1. No thermal energy was transferred during the processes from A to B and C to D.

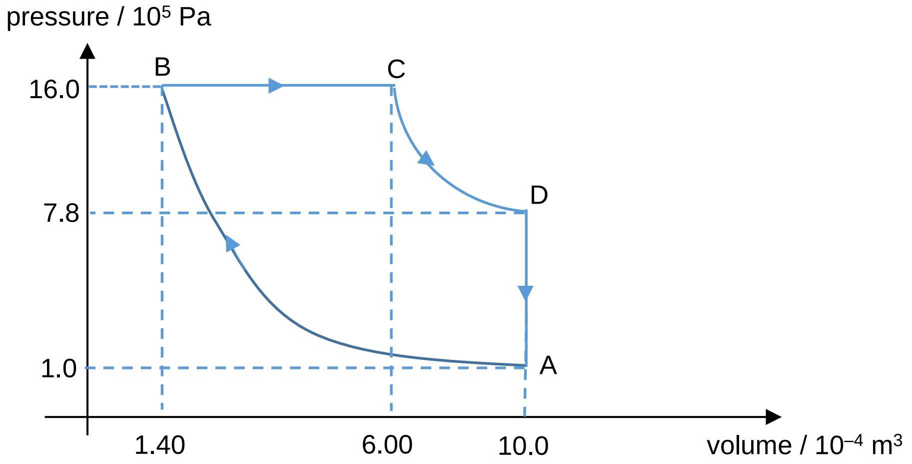


Fig 3.1

(i) State and explain whether the gas is at a higher temperature at C or D.

....

....

....

.... [2]

(ii) Fig. 3.2 shows the energy changes during one complete cycle. Complete the table.

Section of cycle	heat supplied to gas / J	work done on gas / J	increase in internal energy of gas / J
A to B			300
B to C		–740	1840
C to D			
D to A	–1700		

Fig. 3.2

[4]

[Total: 12]

[Turn over

For Examiner's Use

4 A ball of mass *m* is hung on a spring of spring constant *k* as shown in Fig. 4.1 below. The ball is in equilibrium and the spring is extended by a length of *d*.

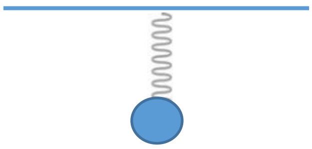


Fig. 4.1

The ball is displaced vertically downwards from its equilibrium position and then released. The acceleration of the ball is *a* and the vertical displacement of the ball from its equilibrium position is *x*.

(a) **(i)** By considering the resultant force acting on the ball, show that $a = -\frac{k}{m}x$.

[2]

(ii) Explain why the expression in **(a)(i)** leads to the conclusion that the ball is performing simple harmonic motion.

…………………………………………………………………………………………..

…………………………………………………………………………………………..

…………………………………………………………………………………………..

………………………………………………………………………………………… [2]

For Examiner's Use

(iii) The spring and ball system is now attached to an oscillator. The mass of the ball is 50 g and the spring constant is 1.2 N m^{-1}.

With reference to the expression in **(a)(i)**, determine the natural frequency of the system.

frequency = ……………………… Hz [2]

(iv) On Fig. 4.2, sketch a graph showing the variation with frequency *f* of the oscillator of the amplitude *A* of the ball. Air resistance is not negligible.

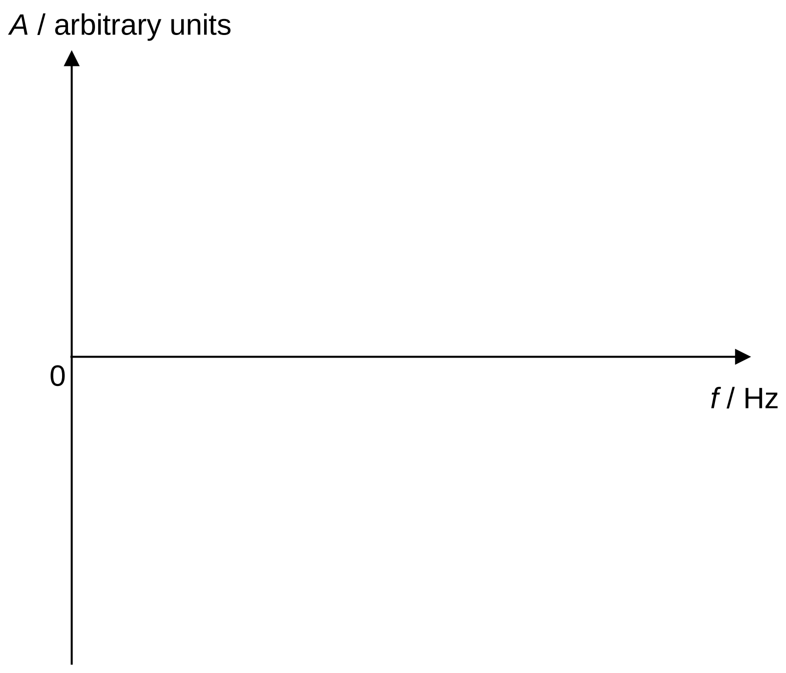


Fig. 4.2

[2]

For Examiner's Use

(b) The spring is now cut into two equal segments.

(i) Determine the natural frequency of the system if only one segment of the spring is used to support the ball.

frequency = ……………………… Hz [2]

(ii) A piece of cardboard with negligible mass is then attached to the ball and the ball is made to oscillate with an initial displacement x_o.

On Fig. 4.3, sketch a graph showing the variation with time t of the displacement x of the ball.

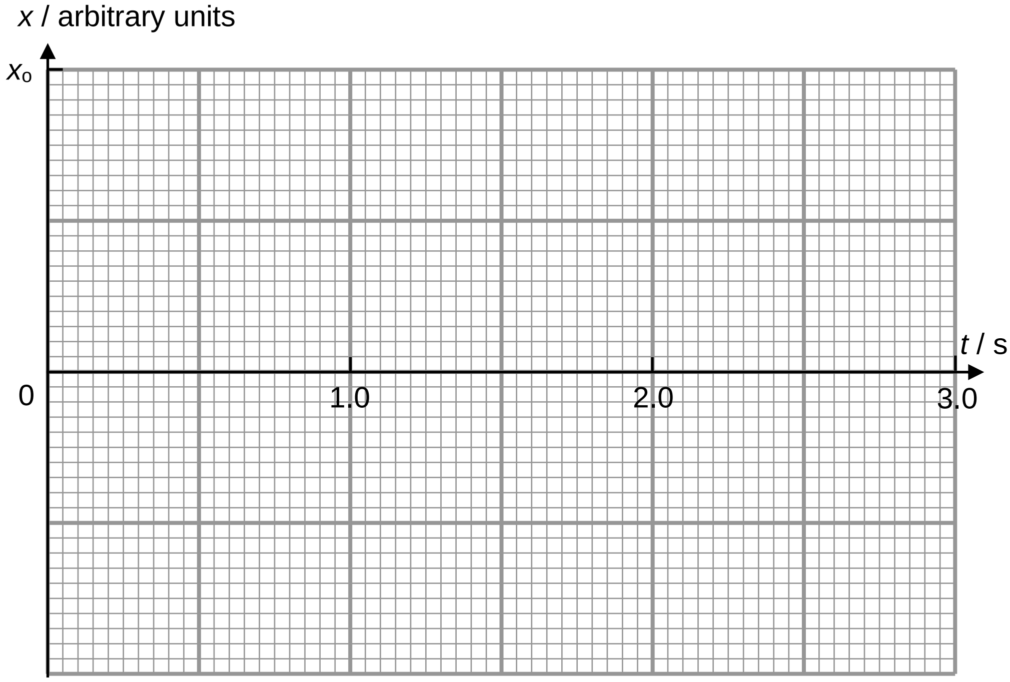


Fig. 4.3

[2]

[Total: 12]

For Examiner's Use

5 **(a)** Fig. 5.1 shows the schematic diagram of an experimental setup to study the photoelectric effect. Photons of wavelength 390 nm are incident on the emitter.

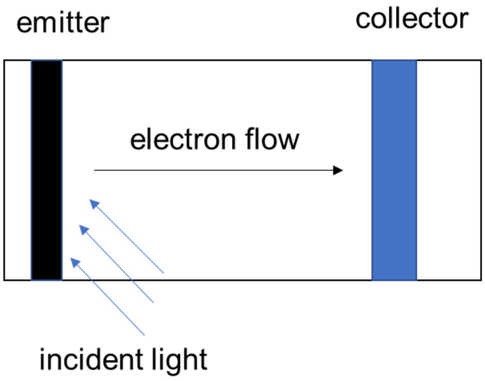


Fig. 5.1

(i) Explain what is meant by a *photon*.

…………………………………………………………………………………...

…………………………………………………………………………………...

…………………………………………………………………………………...

………………………………………………………………………….… [2]

(ii) Show that the energy of the photon is 3.19 eV.

[2]

(iii) Sodium and iron are used to investigate the photoelectric effect. The emitter and collector are made of the same metals for two set of experiments. For each metal tested, the photons incident on the emitter results in photocurrent detected. Fig. 5.2 shows the work functions of the metals.

metal	work function/ eV
sodium	2.46
iron	4.50

Fig. 5.2

[Turn over

For Examiner's Use

1. On Fig. 5.3, sketch the variation with frequency f of the maximum kinetic energy E_k of electrons emitted from both metals.

Label **Na** for the graph of sodium and **Fe** for the graph of iron.

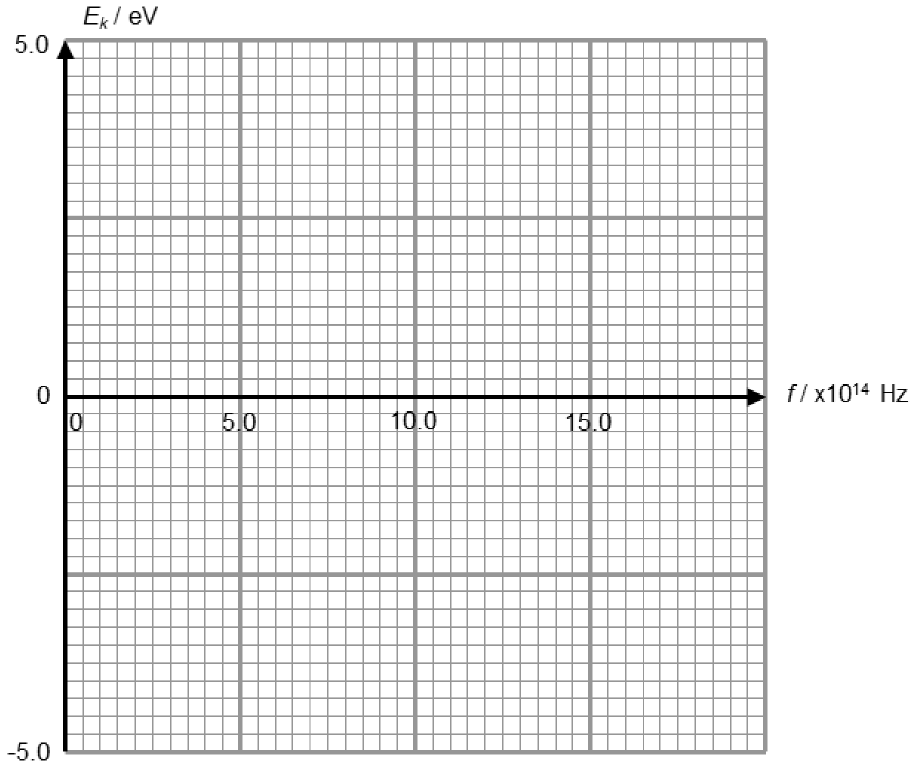


Fig. 5.3

[3]

2. The intensity of light incident on both metals is doubled while the wavelength remains constant.

State and explain the changes, if any, to the gradient and vertical intercept in Fig. 5.3.

gradient: ……………………………………………………………………………

……………………………………………………………………………………

vertical intercept: ……………………………………………………………

……………………………………………………………………………………

[2]

For Examiner's Use

(b) Fig. 5.4 shows some values of the energy levels of the hydrogen atom.

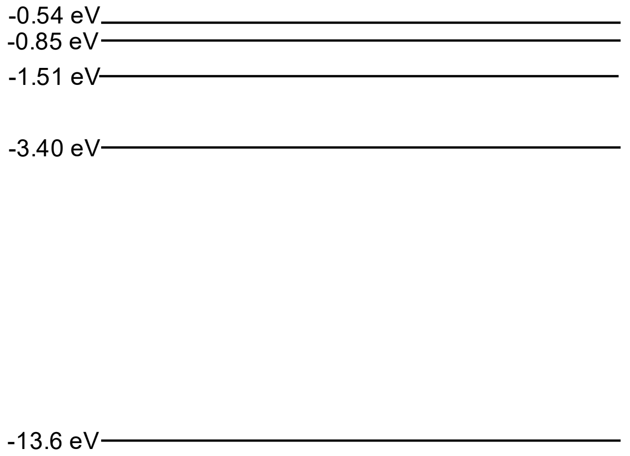


Fig. 5.4

(i) Using Fig. 5.4, state the ionisation energy of hydrogen atom.

ionisation energy = ……………………… eV [1]

(ii) Explain why the energy level values in Fig. 5.4 are negative.

…………………………………………………………………………………………

………………………………………………………………………………………… [1]

(iii) A beam of white light passes through a cloud of hydrogen gas and is observed on a screen. The spectrum of the transmitted light contains a few dark lines.

Explain why the dark lines occur.

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

………………………………………………………………………………………… [3]

[Total: 14]

[Turn over

Section B

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

6 **(a)** Fig. 6.1 shows a six-string electric guitar. The sounds are amplified by electronic pickups (microphones), and an amplifier to convert the vibration of its strings into electrical signals and ultimately reproduced by loudspeakers as sound.

Fig. 6.1

(i) State the conditions required for the formation of stationary waves.

....

....

....

....

.... [2]

(ii) A guitar string produces a note of fundamental frequency 622 Hz. The velocity of wave travelling along the guitar string is 405 m s^{-1}.

1. Determine the effective length of the string.

length = ... m [2]

For Examiner's Use

2. The amplitude of the vibrating guitar string is 3.3 mm.

Determine the maximum velocity of the vibrating string when the whole string is momentarily at the equilibrium position.

maximum velocity = ……………………… m s^{-1} [2]

(iii) The output of the electric guitar is fed into a loudspeaker. The loudspeaker emits hemispherical sound waves of mean power 200 W. A small microphone is placed at a distance 10.0 m from the loudspeaker.

1. Determine the mean intensity I of the sound wave detected by the microphone.

I = ……………………… W m^{-2} [2]

2. Two identical loudspeakers are connected to an electric guitar playing a note of a single frequency. The loudspeakers are then placed a distance apart and facing each other.

State two reasons why a stationary wave may not be formed between the two loudspeakers.

1. ………………………………………………………………………………

………………………………………………………………………………

………………………………………………………………………………

2. ………………………………………………………………………………

………………………………………………………………………………

……………………………………………………………………………… [2]

[Turn over

For Examiner's Use

(b) Fig. 6.2 shows a human eye. To see an object, light from the object enters the eye through a small aperture known as the pupil and forms an image at the retina. The average diameter of the pupil is 3.00 mm and the distance between the pupil and the position of image at the retina is 17.0 mm.

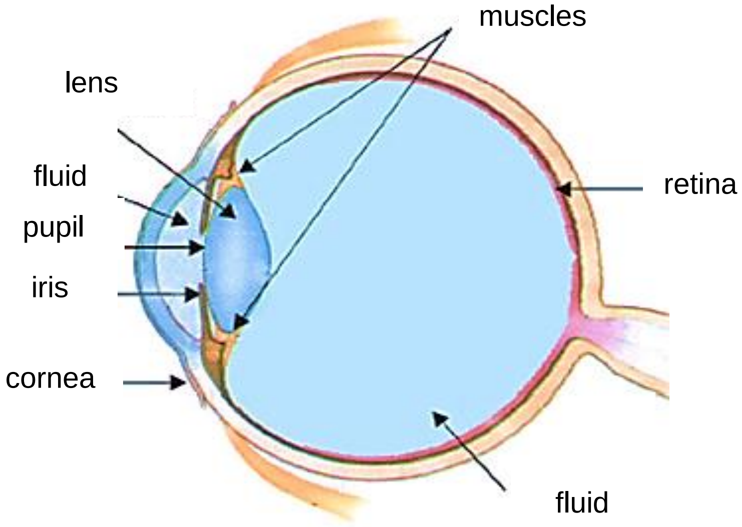


Fig. 6.2

(i) A beam of blue light passes through the pupil. The distance between the positions of zero intensity on both sides of the central bright fringe of the image is 4.80 μm on the retina.

Determine the wavelength of the blue light.

wavelength = ……………………… nm [3]

For Examiner's Use

(ii) The Dutch artist Vincent van Gogh painted the *Irises* in 1889.

Fig. 6.3(a) shows an image of the actual painting.

Fig. 6.3(b) shows a pixelated poster of the *Irises*. The pixels have varying colours, shades or light intensities.

The wavelength of blue light ranges from 380 nm to 500 nm.

Fig. 6.3(a)

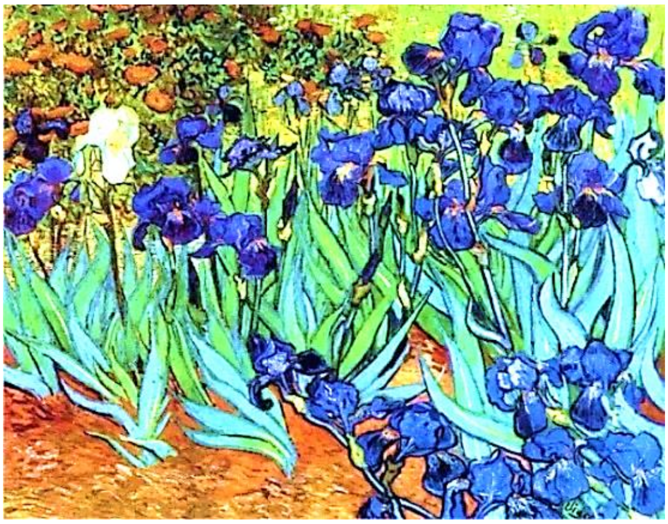
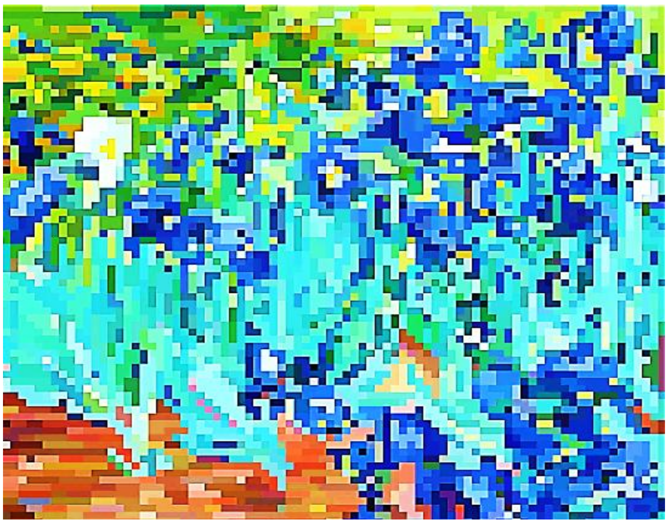


Fig. 6.3(b)



1. Explain the *Rayleigh criterion* for the optical resolution of two images.

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

…………………………………………………………………………………………… [2]

For Examiner's Use

2. Determine the minimum angular resolution for the human eye to distinguish two adjacent pixels of blue light according to the *Rayleigh criterion*.

minimum angular resolution = ……………………… rad [1]

3. In the pixelated poster of *Iris*es, there are 710 pixels within 72 cm vertically, and 820 pixels within 93 cm horizontally. The pixels of the flowers and majority of the leaves are in blue.

In practice, the angular resolution of a human eye is about 2.91×10^{-4} rad.

Determine if an observer can distinguish two adjacent blue pixels of the same wavelength in all directions if the distance between his eye and the poster is 1.5 m.

……………………………………………………………………………………

…………………………………………………………………………………… [3]

4. In dimmer lighting, the pupil diameter will increase to allow more light to enter the eye. For the observer in **(b)(ii)3.**, state and explain the change, if any, to the minimum distance between his eye and the poster to distinguish two adjacent blue pixels.

……………………………………………………………………………………

……………………………………………………………………………………

…………………………………………………………………………………… [1]

[Total: 20]

7 **(a)** Flat coils are commonly used as metal detectors to detect mines buried underground and concealed metal objects at access points in airports, prisons and military bases.

Fig. 7.1 shows a flat circular coil P carrying a current of 2.0 A. The coil has 300 turns and a mean diameter of 0.10 m.

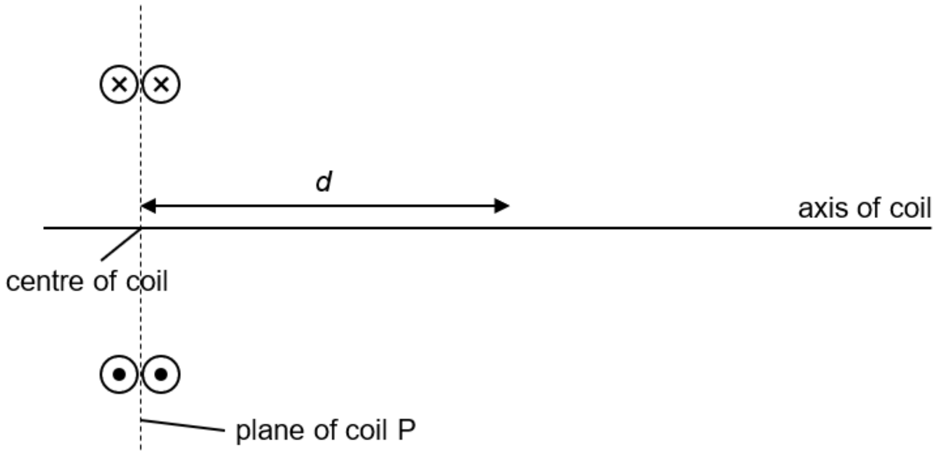


Fig. 7.1

The variation with distance *d* from the centre of the coil along its axis of the magnitude of the magnetic flux density *B* produced by the coil is shown in Fig. 7.2.

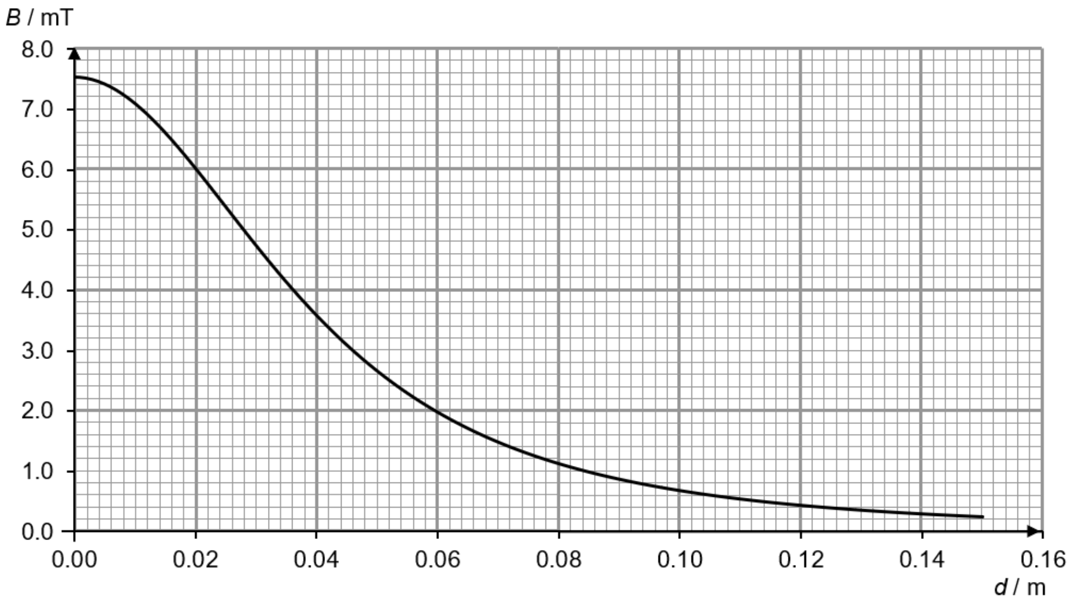


Fig. 7.2

(i) State the magnetic flux density at the centre of the coil B_C.

B_C = ……………………… T [1]

For Examiner's Use

(ii) Hence determine a value for the permeability of free space μ_o.

μ_o = ……………………… H m^{-1} [2]

(b) A smaller coil Q is placed with its axis aligned to coil P as shown in Fig. 7.3. Coil Q is moved away from coil P along the axis of the coils at a steady speed. The magnetic flux is always perpendicular to coil Q.

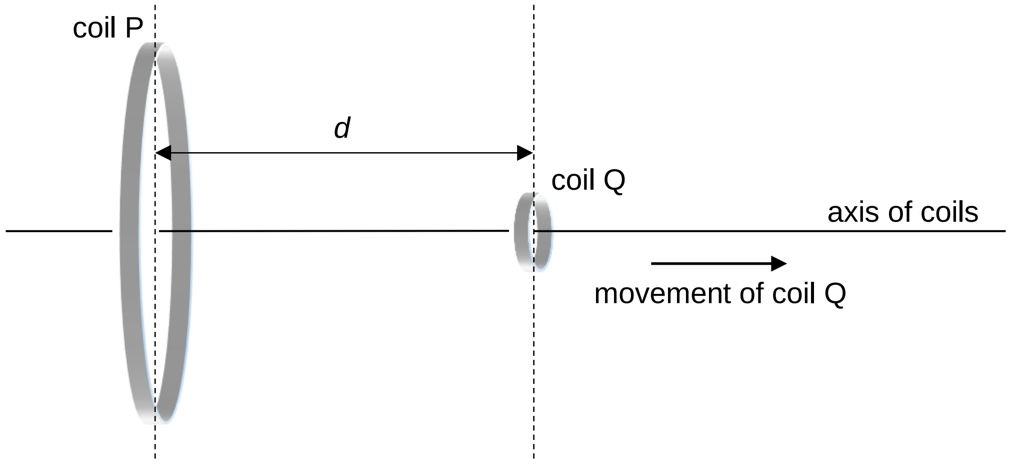


Fig. 7.3

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

…………………………………………………………………………………………..

…………………………………………………………………………………………..

………………………………………………………………………………………… [1]

For Examiner's Use

(ii) Estimate the value of *d* where the induced e.m.f. in coil Q is a maximum.

d = ……………………… m [1]

(iii) With reference to Fig. 7.2, explain why the value of *d* in **(b)(ii)** results in maximum induced e.m.f in coil Q.

…………………………………………………………………………………….

…………………………………………………………………………………….

…………………………………………………………………………………….

…………………………………………………………………………………….

……………………………………………………………………………….…. [2]

(iv) State and explain the direction of induced current in coil Q as it is moved along the axis of the coils.

…………………………………………………………………………………….

…………………………………………………………………………………….

…………………………………………………………………………………….

…………………………………………………………………………………….

……………………………………………………………………………….…. [2]

(v) Coil Q is moved from the centre of coil P to a position 0.040 m along the axis of the coils in 0.25 s.

1. Determine the change in magnetic flux density ΔB during this time interval.

ΔB = ……………………… T [1]

For Examiner's Use

2. Coil Q has 5000 turns, each of effective area 1.5×10^{-4} m^2.

Hence determine the magnitude of the average induced e.m.f. ε_{ave} in coil Q during this time interval.

ε_{ave} = ………………………. V [3]

For Examiner's Use

(c) **(i)** Explain what is meant by the *root-mean-square* value of an alternating current.

…………………………………………………………………………………………..

…………………………………………………………………………………………..

…………………………………………………………………………………..… [1]

(ii) The input voltage to an ideal transformer is as shown in Fig. 7.4. The turns ratio of the primary coil to the secondary coil is 50:1 and the mean input power is 20 W.

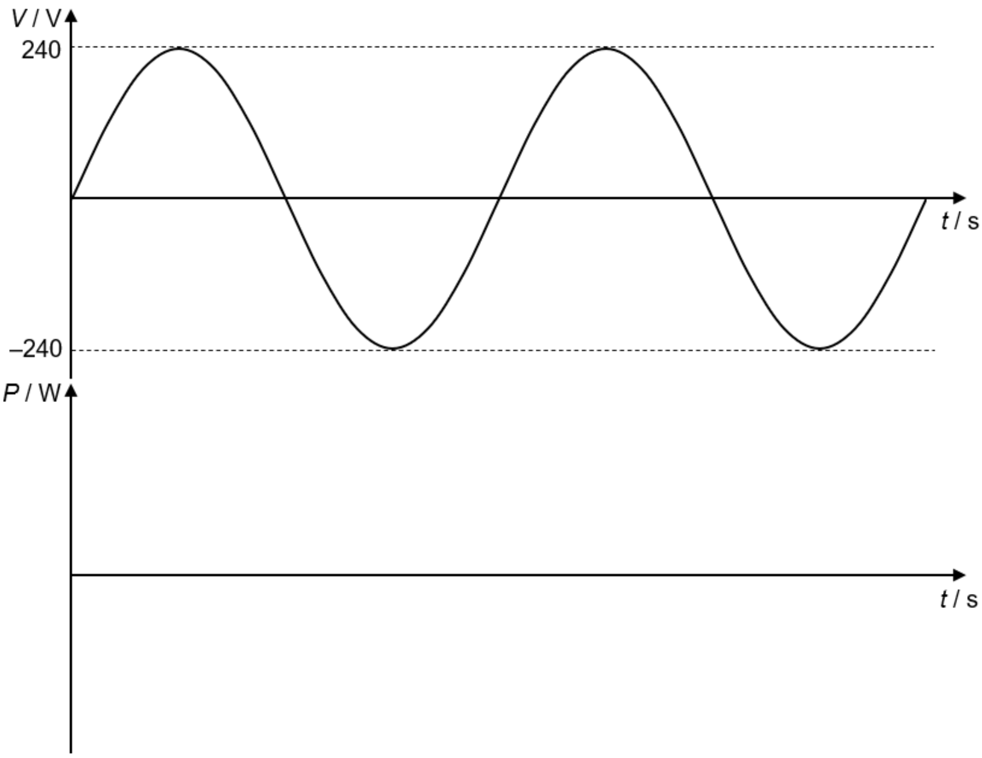


Fig. 7.4

1. On Fig. 7.4, sketch the variation with time t of the input power P to the transformer for two complete cycles. [2]

2. Determine the r.m.s. value of the output voltage.

r.m.s. output voltage = ……………………… V [2]

[Turn over

For Examiner's Use

(iii) Draw a labeled circuit diagram to show how a sinusoidal voltage V_{in} can be converted into half-wave rectified voltage V_{out}.

[1]

(iv) If the output voltage of **(c)(ii)** was half-wave rectified by the circuit in **(c)(iii)**, determine the value of the r.m.s. output voltage.

r.m.s. output voltage = ……………………… V [1]

[Total: 20]

End of Paper