Class	Adm No

Candidate Name: ______________________________

H

millennia institute

2024 Preliminary Exams

Pre-University 3

H2 PHYSICS **9749/02**

Paper 2 Structured Questions **12 September**

2 hours

Candidates answer on the Question Paper

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Do not turn over this page until you are told to do so.

Write your full name, class and Adm number in the spaces at the top of this page.

Write in dark blue or black pen on both sides of this booklet.
You may use an HB pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.

The use of an approved scientific calculator is expected, where appropriate.
Answer **all** questions.

The number of marks is given in brackets [ ] at the end of each question or part question

.

For Examiner's Use		
1		/ 12
2		/ 11
3		/ 13
4		/ 7
5		/ 10
6		/ 7
7		/ 20
Presentation		
Total		/ 80

Data

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

Formulae

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

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

1 A ball is thrown from the ground and follows the path shown in Fig. 1.1. The ground is horizontal. The effect of air resistance is negligible.

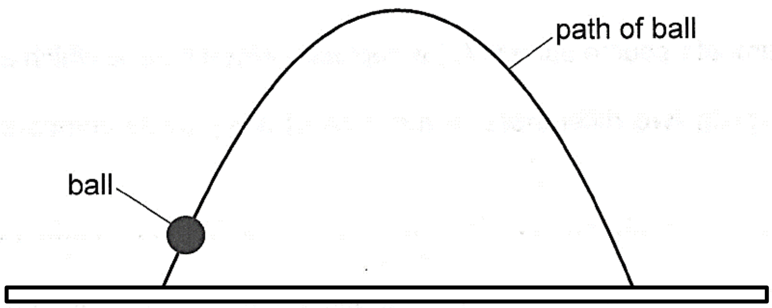

Fig. 1.1 (not to scale)

(a) **(i)** Describe the variation in the vertical velocity and the vertical acceleration of the ball throughout the path.

....

....

....

....

....

....

....

....[3]

(ii) Describe the variation in the horizontal velocity and the horizontal acceleration of the ball throughout the path.

....

....

....

....[2]

(b) **(i)** The initial velocity of the ball is 15 m s^{-1} at an angle of 20^{o} to the horizontal.

Calculate the horizontal distance travelled by the ball before hitting the ground.

horizontal distance = ... m [3]

(ii) The ball is now thrown at the same speed and angle from a cliff edge. The cliff height is 70 m.

Calculate the extra horizontal distance travelled by the ball before hitting the ground when thrown from the cliff edge.

extra horizontal distance = ... m [4]

[Total: 12]

2 This question is about the gravitational field around Mars.

Fig. 2.1 shows some equipotential lines around Mars. The mass of Mars is 6.4×10^{23} kg and the radius of Mars is 3.4×10^{6} m.

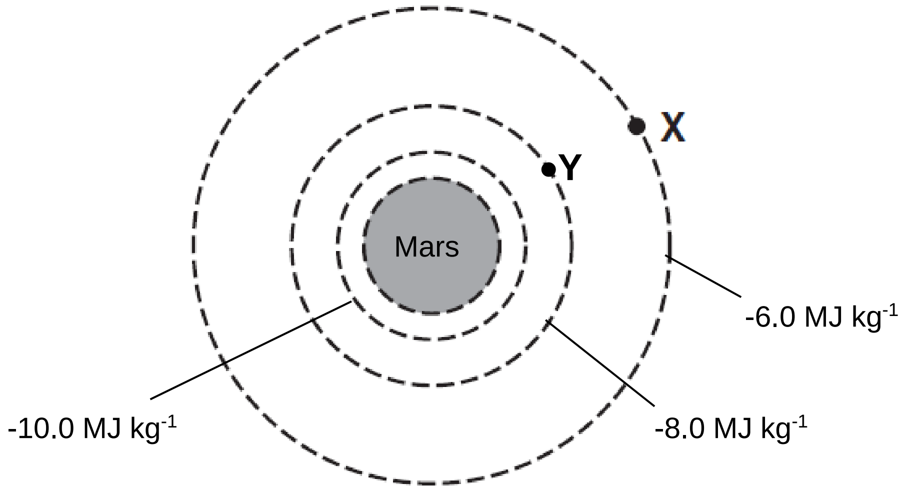

Fig. 2.1

(a) Define *gravitational field strength* at a point.

....

.... [1]

(b) State how Fig. 2.1 shows that the gravitational field strength decreases as the distance from the surface of the Mars increases.

....

.... [1]

(c) A spacecraft at point X drops a satellite, of mass 90 kg, from rest onto the surface of Mars.

Calculate the velocity of the satellite when it reaches point Y.

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

(d) The satellite reaches the geostationary orbit of Mars. Fig. 2.2 shows this satellite orbiting at a height of 1.7×10^7 m above the surface of Mars.

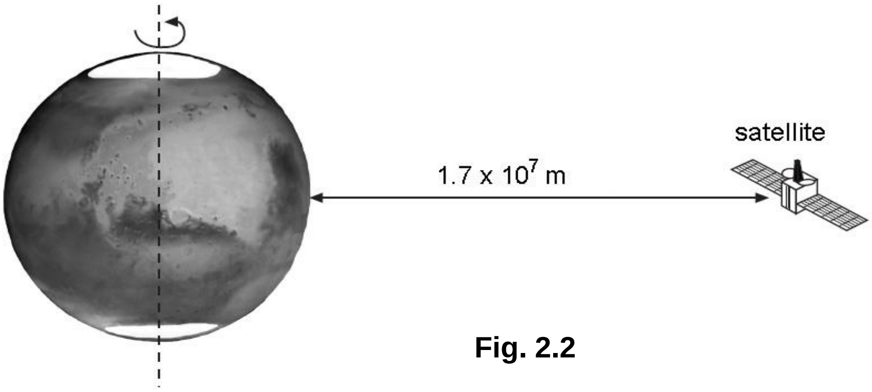

Fig. 2.2

(i) Calculate the period of the satellite in the geostationary orbit.

period = ... h [3]

(ii) Calculate the kinetic energy of the satellite in this orbit.

kinetic energy = ... J [2]

(iii) Assuming that the satellite experiences friction as it orbits around Mars, explain in terms of conservation of energy, what happens to the kinetic energy of the satellite.

....

....

....[2]

[Total: 11]

3 **(a)** Explain why steam at $100\ ^{\circ}\mathrm{C}$ causes a more severe burn than the same mass of boiling water at $100\ ^{\circ}\mathrm{C}$.

....

....

....[2]

(b) A fixed mass of monoatomic ideal gas undergoes a cycle of changes in pressure, volume and temperature, as shown in Fig. 3.1. The temperatures of the gas at A and D are 800 K and 226 K respectively.

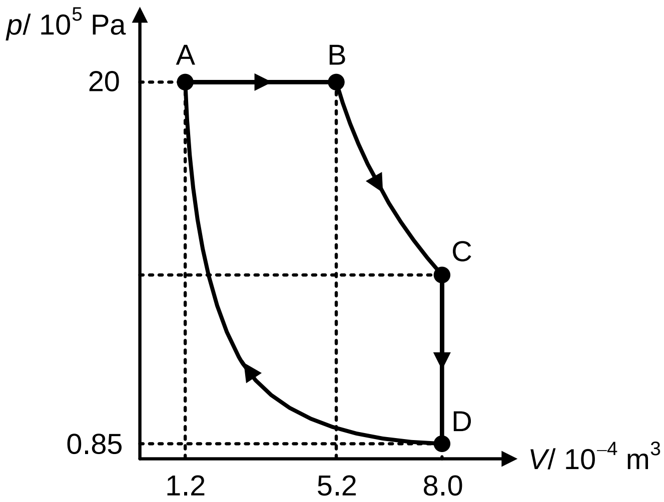

Fig. 3.1

(i) Calculate the amount of gas, in moles.

amount of gas = ... mol [2]

(ii) For the constant-pressure expansion from A to B, calculate

1. the temperature at B,

temperature = ... K [1]

2. the increase in internal energy,

increase in internal energy = ... J [2]

3. the work done on the gas,

work done on gas = ... J [2]

4. the heat supplied to the gas,

heat supplied to gas = ... J [1]

(iii) For each of the changes from B to C and from D to A, there is no heat exchange with the surrounding. The work done by the gas from B to C is 390 J. Calculate the net work done by the gas in one cycle.

net work done by the gas = ... J [3]

[Total: 13]

[Turn over

4 **(a)** State how a *polarised* transverse wave differs from an *unpolarised* transverse wave.

....

....

....[1]

(b) Light is polarised when it passes through a sheet material known as a polaroid. Three polaroids are stacked, with the polarising axis of the second and third polaroids at θ and 62° respectively, to that of the first, as shown in Fig. 4.1.

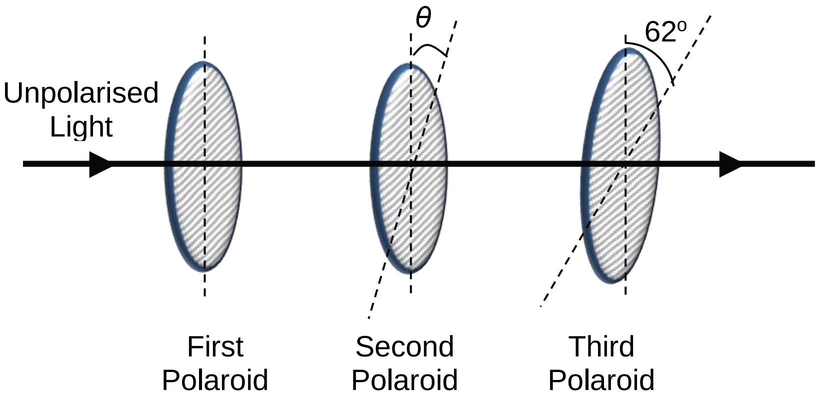

Fig. 4.1

When an unpolarised light of amplitude A_0 is incident on the stack of polaroids, the light has amplitude of A_1 after it passes through the first polaroid, A_2 after it passes through the second polaroid and A_3 after it passes through the third polaroid.

(i) If θ = 90°, determine A_3 in terms of A_1.

A_3 = ... [1]

(ii) If the second polaroid is rotated such that $\theta = 23°$

1. Show that $A_3 = 0.715\ A_1$.

[2]

2. The intensity of the unpolarised light after it passes through the first polaroid is reduced to half.

Determine the percentage reduction of the intensity after the unpolarised light passes through the stack of three polaroids.

percentage reduction = ... % [3]

[Total: 7]

5 **(a)** The graph Fig. 5.1 shows how the resistance, R_R, of a metal resistor and the resistance, R_{Th}, of a thermistor change with temperature.

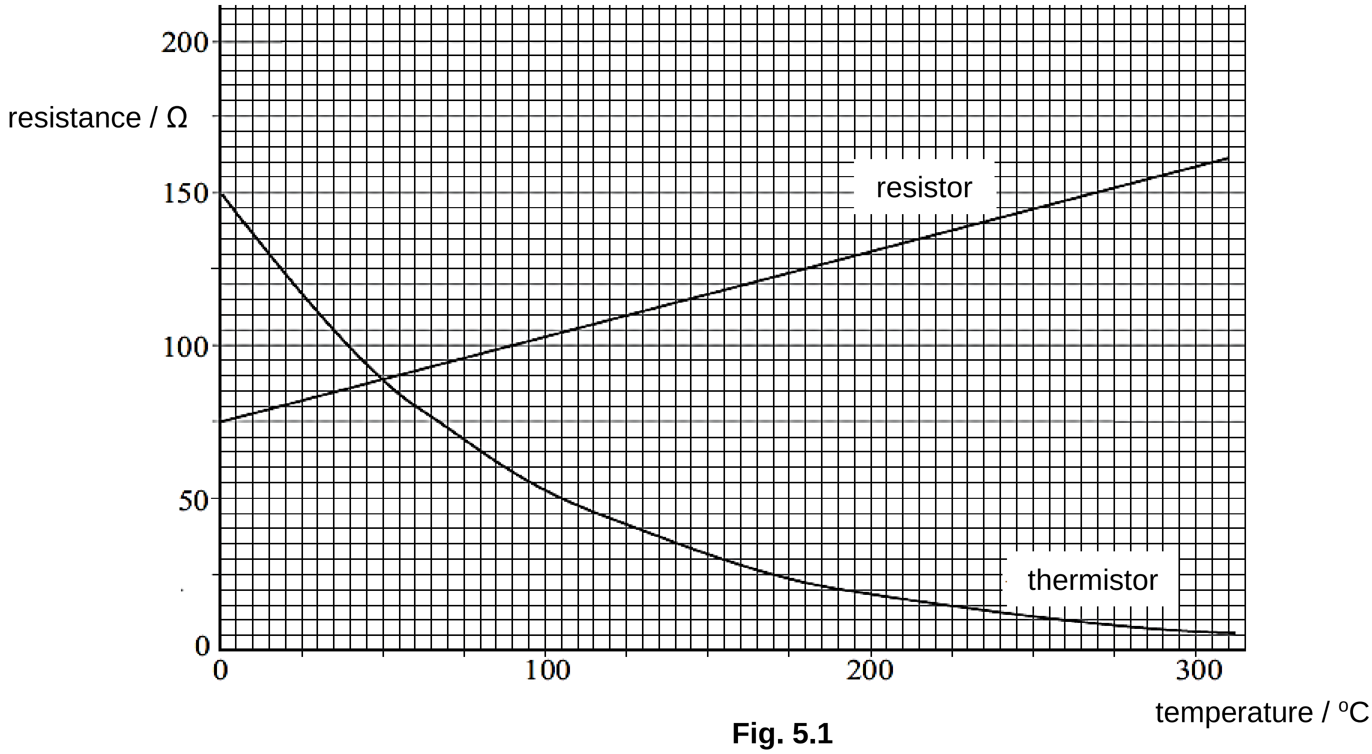

Fig. 5.1

(i) State the values of the resistance R_R and R_{Th} at a temperature of 105 °C.

R_R = ...Ω [1]

R_{Th}= ....Ω [1]

(ii) The resistor and thermistor are connected in series to a 12 V battery of negligible internal resistance, as shown in Fig. 5.2.

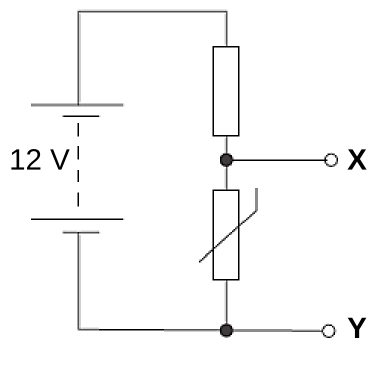

Fig. 5.2

Calculate the potential difference across **XY** at 105 °C.

potential difference across **XY** = ... V [2]

(iii) Assuming that the temperature of the resistor always equals the temperature of the thermistor, deduce the temperature, without any further calculations when the potential difference across the resistor is 6.0 V. Explain your answer.

……

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……

……[2]

(b) Fig. 5.3 shows a potentiometer, made from uniform resistance wire AB of length L and resistance R, connected in series with an e.m.f. source E of negligible internal resistance.

It is used to change the potential difference across an appliance of resistance S.

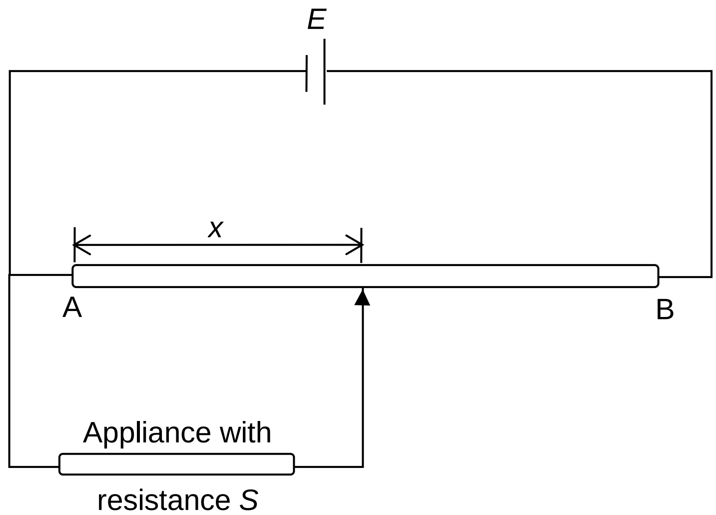

Fig. 5.3

(i) Derive an expression of the potential difference across the appliance as a function of the distance x of the sliding contact from the end A of the resistance wire in terms of E, x and L. Explain your working clearly.

expression of potential difference = ………………………… [2]

(ii) Hence or otherwise, calculate the current through the appliance when E = 5.0 V, x = 20.0 cm, L= 1.00 m and S = 10.0 Ω.

current through appliance = ……………………… A [1]

(iii) The appliance is removed and replaced with a cell of unknown e.m.f. ε and a galvanometer is connected in series with the cell, as shown in Fig. 5.4.

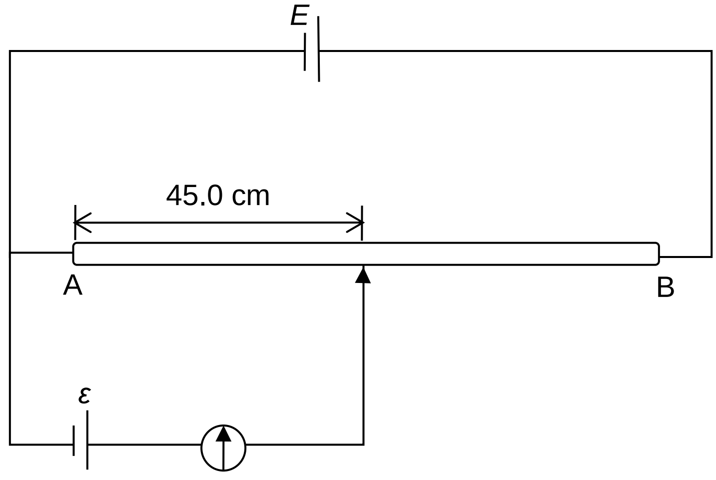

Fig. 5.4

The galvanometer shows null deflection when the sliding contact is at the 45.0 cm mark. Calculate ε, using the values of E and l given in **(b)(ii)**.

e.m.f. ε = ……………………… V [1]

[Total: 10]

6 **(a)** Define *magnetic field.*

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

(b) A positive ion with speed v is moving un-deviated, through a region of magnetic field of flux density B and electric field strength E, in a velocity selector, as shown in Fig. 6.1. The magnetic field is acting into the page.

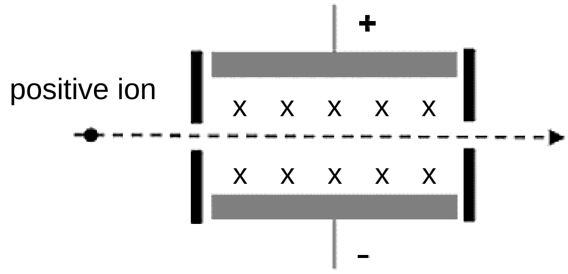

Fig. 6.1

(i) Explain how the combination of magnetic and electric fields allows the positive ion of only one speed v to pass through un-deviated.

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

(ii) A mass spectrometer is able to separate charged particles of different masses. Ions of different masses emerge from the velocity selector and enters a region of uniform magnetic flux density *B*', as shown in Fig. 6.2.

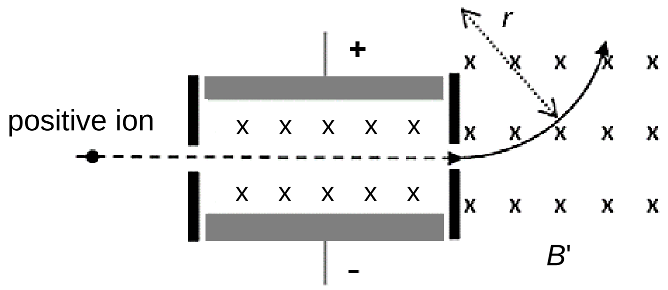

Fig. 6.2

In one experiment, carbon ions of atomic mass 12.0 u are found to be mixed with ions of an unknown element of the same charge. The carbon ions transverse a path of radius 22.4 cm and the ions of an unknown element transverse a path of radius 26.2 cm.

1. Explain why the ions will move in a circular path of radius r, after emerging from the velocity selector.

………

……… [1]

2. Determine the mass of the ions of an unknown element, in terms of u.

mass of unknown element = ………………………… u [2]

[Total: 7]

7 **Photomultiplier tubes**

Photomultiplier tubes (PMTs) are extremely sensitive detectors of light in the ultraviolet, visible, and near-infrared ranges of the electromagnetic spectrum. These detectors multiply the current produced by incident light by as much as 100 million times, in multiple dynode stages, enabling individual photons to be detected when the incident amount of light is low. Fig. 7.1 shows a schematic diagram of a PMT.

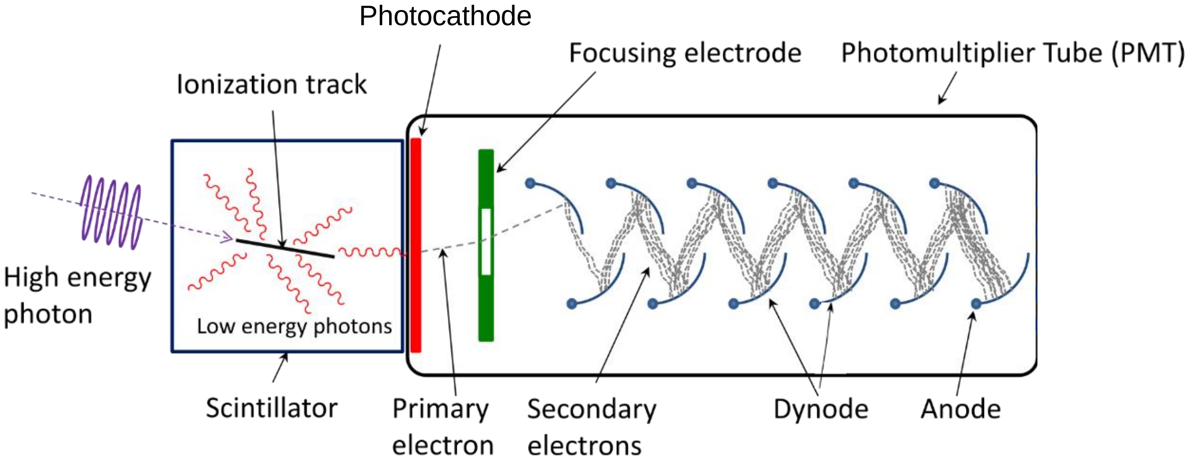

Fig. 7.1

<u>Principle of operation of a PMT</u>

Photomultipliers are typically constructed with an evacuated glass housing (using an extremely tight and durable glass-to-metal seal like other vacuum tubes), containing a photocathode, several dynodes, and an anode.

Incident photons strike the photocathode material, which is usually a thin vapour–deposited conducting layer on the inside of the entry window of the device. Electrons are ejected from the surface as a consequence of the photoelectric effect. These electrons are directed by the focusing electrode toward the electron multiplier, where electrons are multiplied by the process of secondary emission.

The PMT consists of a number of electrodes called *dynodes*. Each dynode is held at a more positive potential, by approximately 100 volt, than the preceding one.

A primary electron leaves the photocathode with the energy of the incoming photon, of about 3 eV for "blue" photons, minus the work function of the photocathode. A small group of primary electrons is created by the arrival of a group of initial photons. The primary electrons move toward the first dynode because they are accelerated by the electric field.

They each arrive with approximately 100 eV kinetic energy imparted by the potential difference. Upon striking the first dynode, more low energy electrons are emitted, and these electrons are in turn accelerated toward the second dynode.

The geometry of the dynode chain is such that a cascade occurs with an exponentially-increasing number of electrons being produced at each stage. This last stage is called the anode. This large number of electrons reaching the anode results in a sharp current pulse that is easily detectable, signaling the arrival of the photon(s) at the photocathode approximately 50 nanoseconds earlier.

The detected current depends on two factors: the number of electrons ejected from the photocathode (which in turn depends on the number of incoming photons and on their energy), and the Quantum Efficiency η of the photomultiplier. The Quantum Efficiency is defined as the number of electrons collected at the anode per unit time relative to the number of incident photons per unit time on the photocathode expressed as a percentage.

Fig. 7.2 shows the graph of photocathode responsivity R versus wavelength of incident light λ and some of Quantum Efficiency (QE) lines of a metal used as photocathode in the PMT. The intersections of the graph and the QE lines show the Quantum Efficiencies at various wavelengths.

For example, when the graph and the QE lines intersect at M as shown in Fig. 7.2, it means that the number of electrons collected at the anode per unit time is 10% of the total number of incident photons per unit time when a light of 510 nm is incident on the photocathode.

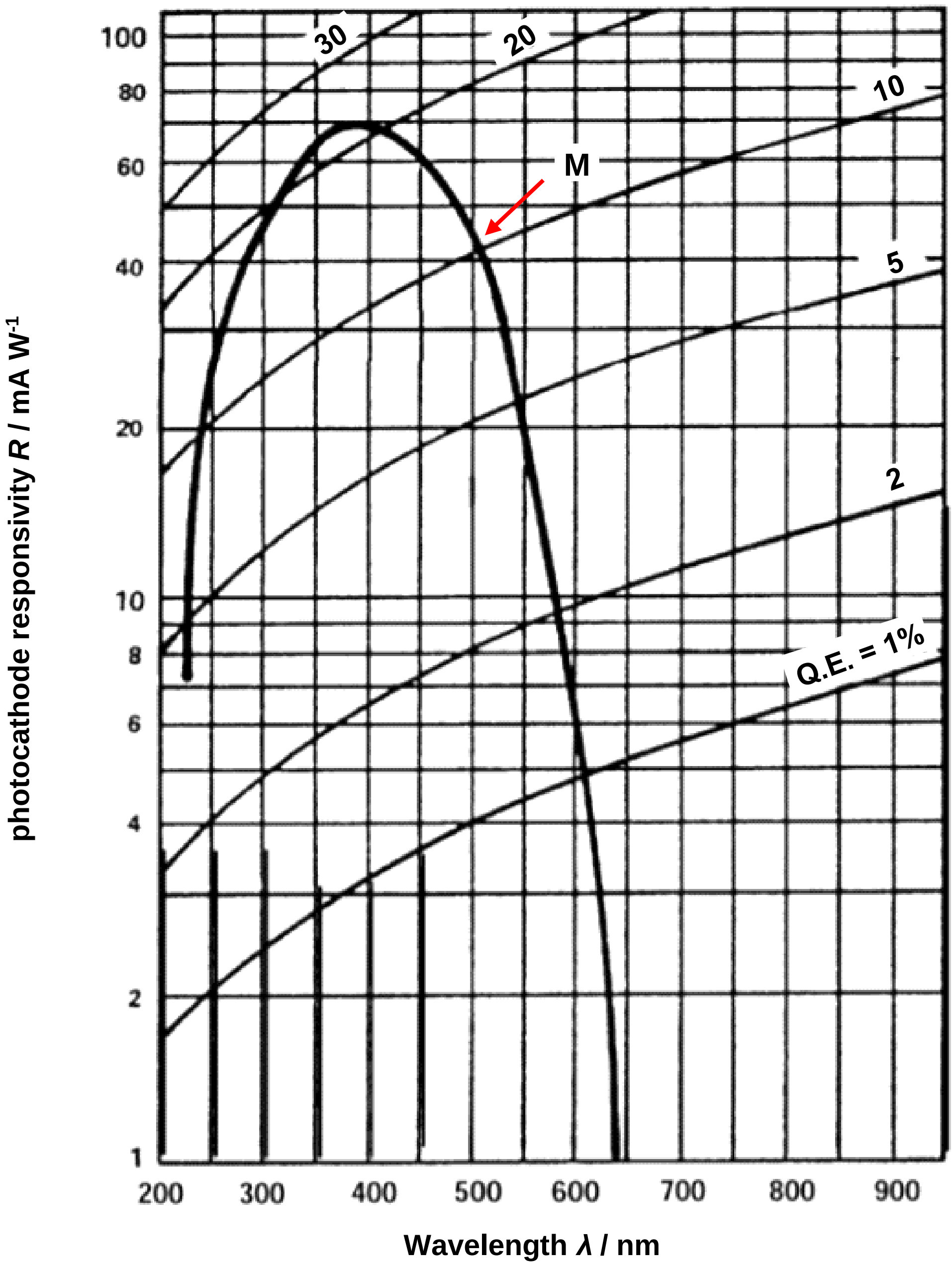

Fig 7.2

(a) **(i)** Explain what is meant by the term photoelectric effect.

……………………………………………………………………………………………………

……………………………………………………………………………………………………

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

(ii) State the wavelength that allows the photocathode to achieve its optimum responsivity.

wavelength = ………………………… nm [1]

(iii) With reference to Fig. 7.2, state the threshold wavelength and explain how it was determined.

……………………………………………………………………………………………………

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

(iv) The photocathode has a threshold frequency of 4.76×10^{14} Hz.

If a photomultiplier detects radiation of 450 nm, calculate the maximum speed of the photoelectron emitted from the photocathode.

maximum speed = ... m s^{-1} [3]

(v) Explain clearly why the photocathode used in a photomultiplier should preferably be one with a low work function.

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

(b) Light of wavelength 610 nm is now incident on the PMT.

(i) Given that the detected current from the PMT is 7.8×10^{-4} A, calculate the number of electrons per unit time reaching the anode.

number of electrons per unit time = ... s^{-1} [2]

(ii) Hence, using Fig. 7.2, calculate the number of incident photons per unit time on the photocathode.

number of incident photons per unit time = ... s^{-1} [1]

(iii) From Fig. 7.2, the photocathode responsivity of the PMT can be estimated to be 4.8 mA W^{-1}. Use your understanding of current and power, suggest the meaning of 4.8 mA W^{-1}

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……

……[1]

(c) **(i)** The relationship between Responsivity R and Quantum Efficiency η is stated as

$$\eta = \frac{Rhc}{e\lambda}$$

where λ is the wavelength of the incident light, h is the Planck constant and e is the elementary charge.

Using Fig. 7.2, show that for the photocathode used in the PMT, this relationship is true when η is 5 %.

[2]

(ii) Using the equation given in **(c)(i)**, complete Fig. 7.3.

η / %	λ / nm	R / mA W^{-1}
3	300	7.2
3	400	
3	500	12
3	600	
3	700	17

Fig. 7.3

[2]

(iii) Hence, plot the line η = 3 % on Fig. 7.2. [2]

(d) **(i)** Photomultipliers are usually shielded by a layer of soft iron at cathode potential. The external shield must also be electrically insulated.

Suggest why photomultipliers are electrically insulated.

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

(ii) Suggest a possible application of photomultiplier that can be used in the industry.

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[Total: 20]

[Turn over

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