H2 PHYSICS

Exam papers with worked solutions
(Selected from Top JC)

SET E
PAPER 3

Compiled by

THE PHYSICS CAFE

READ THESE INSTRUCTIONS FIRST

Write your name, class, 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 workings.
Do not use staples, paper clips, highlighters, glue or correction fluid.

Section A

Answer **all** questions.

Section B

Answer **any 2** questions.

You are advised to spend about one hour on each section.

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.

DATA AND FORMULAE

Data

speed of light in free space,	c	$= 3.00 \times 10^{8}$ m s^{-1}
permeability of free space,	μ_o	$= 4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space,	ε_o	$= 8.85 \times 10^{-12}$ F m^{-1}
		$\approx (1/(36\pi)) \times 10^{-9}$ F m^{-1}
elementary charge,	e	$= 1.60 \times 10^{-19}$ C
the Planck constant,	h	$= 6.63 \times 10^{-34}$ J s
unified atomic mass constant,	u	$= 1.66 \times 10^{-27}$ kg
rest mass of electron,	m_e	$= 9.11 \times 10^{-31}$ kg
rest mass of proton,	m_p	$= 1.67 \times 10^{-27}$ kg
molar gas constant,	R	$= 8.31$ J K^{-1} mol^{-1}
the Avogadro constant,	N_A	$= 6.02 \times 10^{23}$ mol^{-1}
the Boltzmann constant,	k	$= 1.38 \times 10^{-23}$ J K^{-1}
gravitational constant,	G	$= 6.67 \times 10^{-11}$ 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	$= p\Delta V$
Average kinetic energy of a molecule of an ideal gas	U	$= \frac{3}{2}kT$
hydrostatic pressure,	p	$= \rho gh$
gravitational potential,	Φ	$= -\frac{GM}{r}$
displacement of particle in s.h.m.	x	$= x_o \sin \omega t$
velocity of particle in s.h.m.	v	$= v_o \cos \omega t$
		$= \pm\omega\sqrt{(x_o^{\,2} - x^2)}$
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	$= x_o \sin \omega t$
transmission coefficient	T	$= \exp(-2kd)$
		where $k = \sqrt{\frac{8\pi^2 m(U-E)}{h^2}}$
radioactive decay,	x	$= x_o \exp(-\lambda t)$

decay constant, $\lambda = \dfrac{0.693}{t_{½}}$

Section A
Answer **all** the questions.

For Examiners' use

1 **(a)** Fig. 1.1 shows a rocket traveling in space.

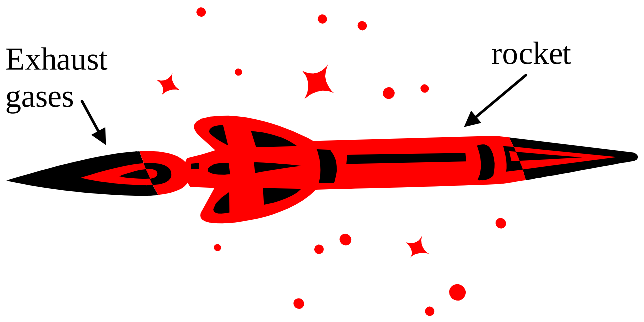

Fig. 1.1

Use your knowledge of Newton's laws to explain the origin of the force on the rocket as it expels exhaust gases at high velocity.

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(b) A bullet of mass 1.40×10^{-2} kg is fired horizontally from a gun with a velocity of 210 m s^{-1}. It hits and gets embedded within a stationary wooden block.

The block of wood has a mass of 1.50 kg and lies on a horizontal frictionless surface. After the impact, the wooden block (together with the embedded bullet) moves with a constant velocity.

(i) Calculate the momentum of the bullet just before it enters the wooden block.

momentum = …………………….. N s [1]

For Examiners' use

(ii) Calculate the velocity, v, of the wooden block after being hit by the bullet.

velocity v = …………………… m s^{-1} [2]

(iii) Explain whether or not kinetic energy is conserved in the impact.

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(iv) Fig. 1.2 shows the variation with time of the initial momentum of the wooden block before being hit by the bullet. The duration of impact is found to be 1.0 s.

1. Complete the graph for the wooden block after the impact
2. Draw in the same figure the variation with time of the momentum of the bullet before and after the impact.

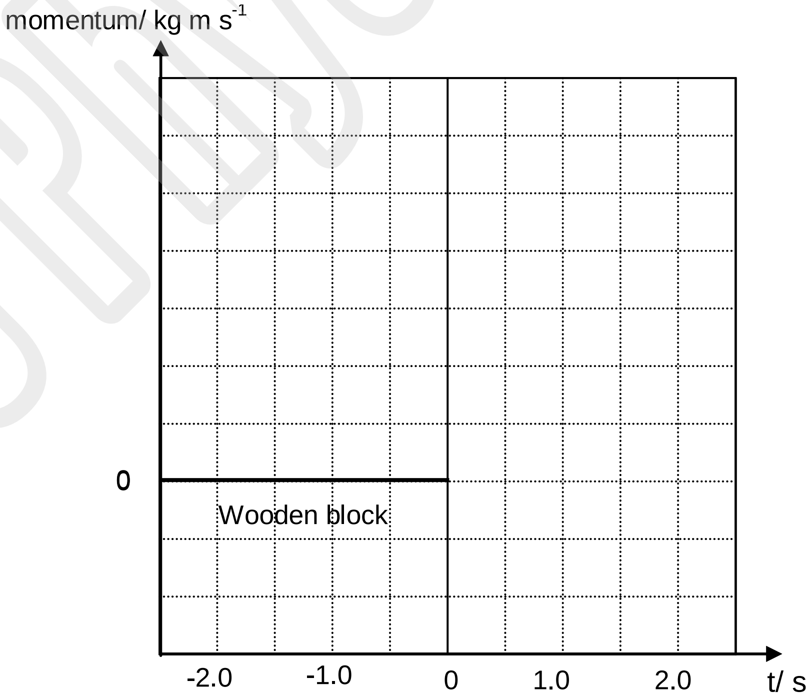

Fig. 1.2

[2]

For Examiners' use

2. An aircraft, of mass 2200 kg, takes off from an aircraft carrier with a speed of 10 m s^{-1} and reaches a speed of 85 m s^{-1} in 20 s at a height of 320 m above the aircraft carrier. During its flight up at an angle of 25° as shown in Fig. 2.1, it may be assumed that the aircraft experiences a constant drag force of 4.8 kN.

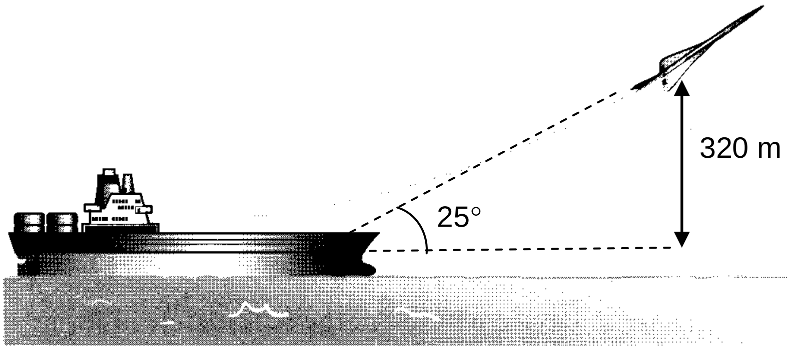

Fig. 2.1

(a) Calculate:

(i) the gain of potential energy of the aircraft in this 20 s,

gain in potential energy = ………………… J [1]

(ii) its gain of kinetic energy,

gain in kinetic energy = ………………… J [2]

(iii) the work done against the drag force.

For Examiners' use

work done = ………… J [2]

(b) **(i)** Estimate the power output of the aircraft's engines that is converted to useful energy in this time.

power output = ……………….. W [2]

(ii) The aircraft's fuel has an energy value of 50 MJ kg^{-1}. Given that 30% of the energy obtained from the fuel is used to increase the kinetic and gravitational potential energies of the aircraft, estimate the mass of fuel burnt in the 20 s taken to reach a height of 320 m.

mass of fuel burned = ………………….. kg [2]

For Examiners' use

3 A well-insulated vessel contains 0.20 kg of ice at –10 °C. The graph in Fig. 3.1 shows how the temperature of the ice would change with time if it were heated at a steady rate of 30 W and the contents were in thermal equilibrium at every stage.

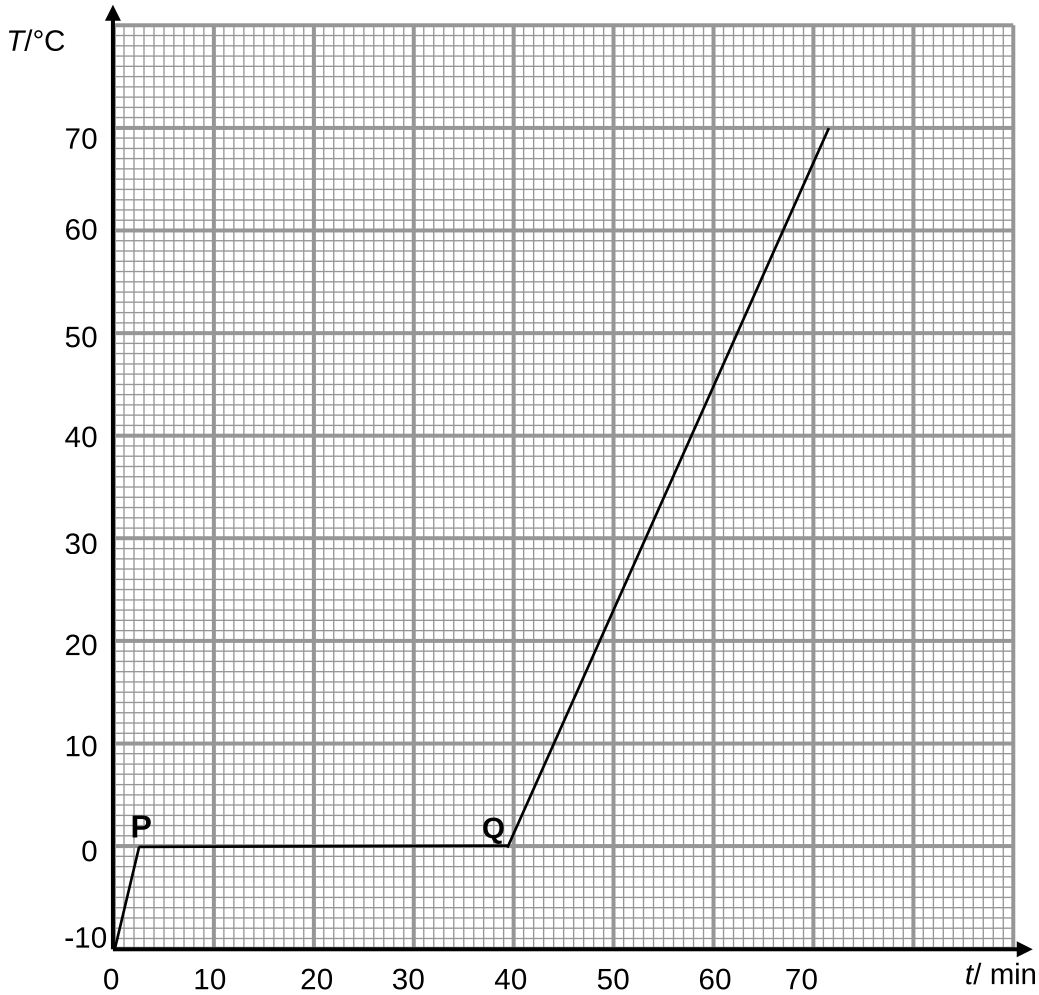

Fig. 3.1

(a) Explain using the kinetic model for matter why the change between points P and Q takes place without a change in temperature.

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For Examiners' use

(b) Use Fig. 3.1 to determine the specific latent heat of fusion of water.

Specific latent heat of fusion of water = ……………… J kg^{-1} [3]

(c) A student tries to plot this graph experimentally. He places crushed ice at –10 °C in a well-insulated beaker containing a small electric heater. What additional equipment would he need and how should he use them to obtain the data for his graph?

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(d) Suggest one precaution he should take to obtain a more accurate graph.

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(e) Gallium is a metal with a melting point of 29 °C. Its specific heat capacity, in both the solid and liquid phases, and its specific latent heat of fusion, are all smaller than those of water. Add to the graph in Fig. 3.1 a second line showing the results you would expect if 0.20 kg of gallium, initially at –10 °C, was heated at the same rate of 30 W. Label this graph **A**. [3]

For Examiners' use

4 (a) Fig. 4.1 shows a thermistor T connected in series with a fixed resistor of 18 kΩ and a source with negligible internal resistance which provides a constant e.m.f. of 12 V. A digital voltmeter of very high resistance is connected across the resistor. The thermistor is made of pure semiconductor.

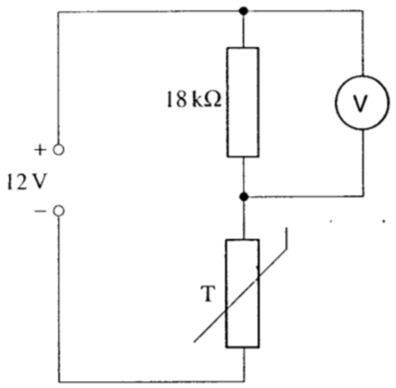

Fig. 4.1

At room temperature, the resistance of the thermistor is 12 kΩ. When it is placed in a hot liquid, its resistance falls to 2.0 kΩ.

(i) Explain, in terms of **band theory**, why the resistance of the thermistor falls when it is placed in a hot liquid.

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For Examiners' use

(ii) Calculate the reading of the voltmeter when the thermistor is in the hot liquid.

voltmeter reading = ……………… V [1]

(iii) The student replaces the digital voltmeter with an analogue voltmeter of resistance 10 kΩ. Determine the new reading shown on the voltmeter.

voltmeter reading = ……………… V [2]

For Examiners' use

(b) Fig. 4.2 below shows a circuit in which two 5.0 kΩ resistors R_1 and R_2 are connected in series with each other and a 5.0 V battery of negligible internal resistance. A diode is connected in parallel with each resistor as shown. When the diode is in forward bias mode, it has a conducting voltage of 0.70 V. In the reverse bias mode, the diode has infinite resistance.

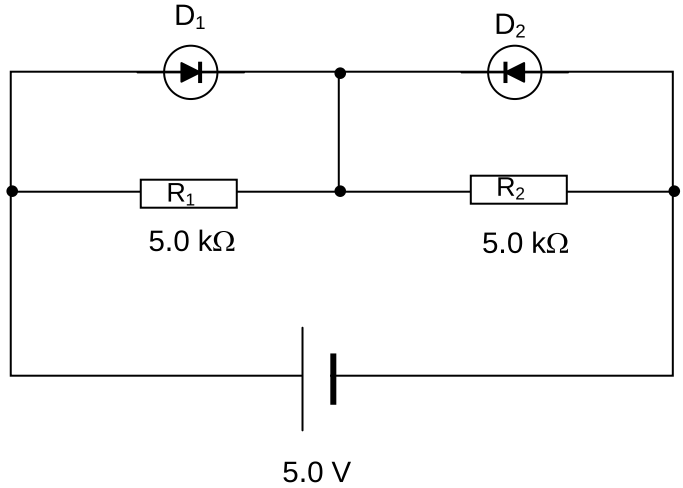

Fig. 4.2

Calculate

(i) the potential difference across resistor R_2

potential difference = ……………… V [2]

(ii) the total current supplied by the battery.

total current = ……………… A [2]

For Examiners' use

Section B

Answer **any two** questions.

5. This question involves the three different types of fields in Physics, namely electric, gravitational and magnetic.

(a) An electron of mass m_e carrying a charge of $-e$ is placed and released at point A in a region of uniform electric, gravitational and magnetic fields pointing to the right as shown in Fig. 5.1. The electric field strength is E, the gravitational field strength is g and the magnetic flux density is B.

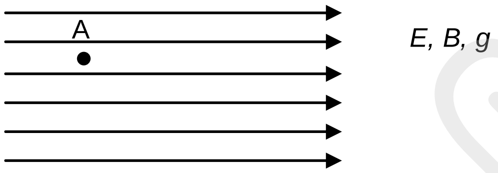

Fig. 5.1

State the magnitudes and directions of the forces acting on the electron due to the following fields in terms of the above variables:

(i) the electric field,

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(ii) the gravitational field and

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(iii) the magnetic field

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…………………………………………………………………………………… [5]

For Examiners' use

(b) The electron is then moved to point B and kept stationary there. Fig. 5.2 and Fig. 5.3 show the electrical potentials and gravitational potentials of the 2 points in the uniform fields.

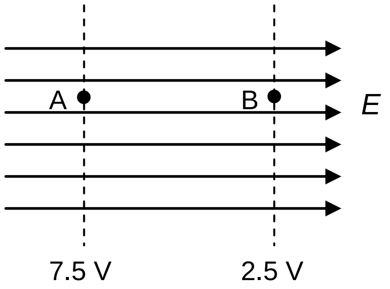

Fig. 5.2

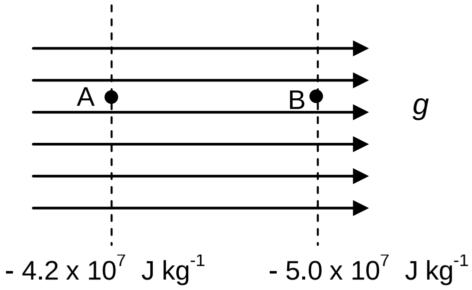

Fig. 5.3

(i) Define electrical potential at a point.

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(ii) The electrical potential at point A is positive but the gravitational potential at the same point is negative. Explain using the definition of potentials why this is so.

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For Examiners' use

(iii) Calculate the work done on the electron **against the electric field** in moving it from A to B.

work done on electron = ………………….. J [2]

(iv) Calculate the work done on the electron **against the gravitational field** in moving it from A to B.

work done on electron = ………………….. J [2]

(v) Given that the distance between A and B is 5.0 cm, calculate the magnitude of the electric field strength *E*.

magnitude of electric field strength *E* = ……………… N C^{-1} [2]

For Examiners' use

(c) Earth can be considered as a point mass of 6.0×10^{24} kg and radius 6.4×10^{6} m. A satellite is orbiting Earth at a height of 7.0×10^{6} m above Earth's surface.

(i) Determine the orbital speed of the satellite.

orbital speed of satellite = ………………… m s^{-1} [3]

(ii) A stone is to be projected from the satellite in a direction opposite to the instantaneous velocity of the satellite as shown in Fig. 5.4 such that it can totally escape from Earth's gravitational field. Determine the minimum speed of projection of the stone.

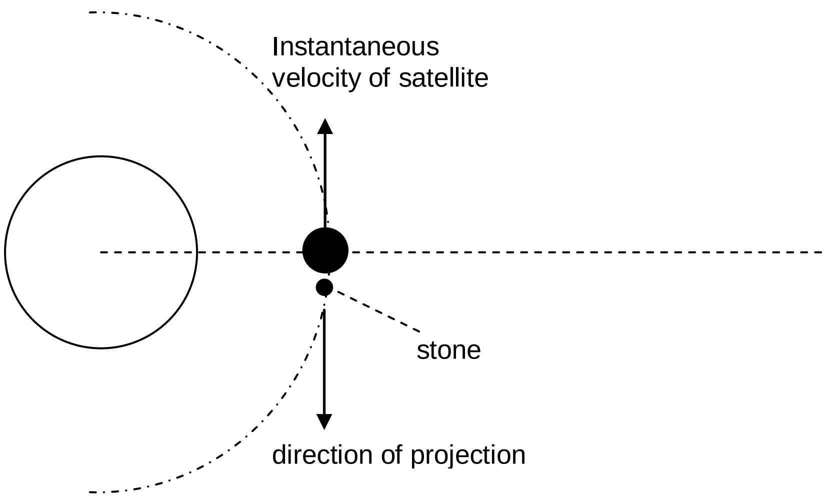

Fig. 5.4

minimum speed of projection = ……………….. m s^{-1} [2]

For Examiners' use

6. A tuning fork is shown in Fig. 6.1 below. It is made of a handle and two tines. It can be made to vibrate by knocking one of the tines sideways against a hard object.

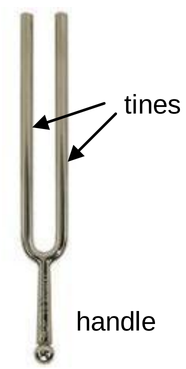

Fig. 6.1

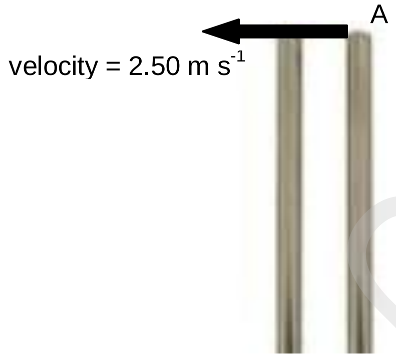

Fig. 6.2

(a) At time t = 0, the tuning fork is knocked against a hard object such that the tip of tine A is given an initial velocity of 2.50 m s^{-1} towards the left as shown in Fig. 6.2. Subsequently it vibrates about its equilibrium position with a frequency of 128 Hz. The subsequent motion of the tip of tine A can be considered to be simple harmonic motion.

(i) Explain what is meant by simple harmonic motion.

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(ii) Taking rightwards as positive, the variation of the displacement x of the tip of tine A and the time t can be expressed in the form:

$$x = B \sin(\omega t)$$

where B is an unknown value and ω the angular frequency of the oscillation. Determine the value of B in meters such that the above expression correctly describes the subsequent displacement of tine A after it was knocked.

For Examiners' use

value of *B* = …………… m [3]

(iii) Again taking rightward as positive, determine the displacement of tine A 1/8 of a cycle after it was knocked.

displacement of tine = …………… m [2]

(iv) What is the shortest time after the tip of tine A was knocked for its acceleration to be a maximum?

shortest time = …………. s [2]

(b) Tine A's vibrations subsequently causes the neighboring air molecules to vibrate such that a longitudinal wave of the same frequency is formed. Fig. 6.3 below shows the positions of the air molecules around the tuning fork at a particular instant.

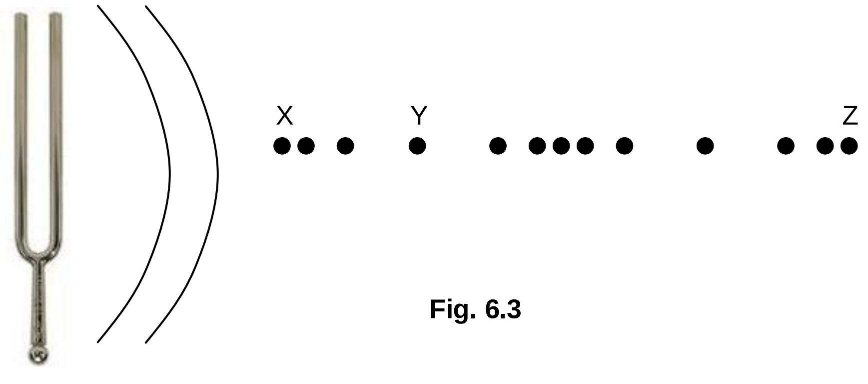

Fig. 6.3

(i) By considering the movement of air molecules, state and explain the pressure experienced by the air molecule at Y.

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For Examiners' use

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(ii) Given that the distance between X and Z is 5.2 m, calculate the speed of the longitudinal wave between X and Z.

speed of wave = …………….. m s^{-1} [2]

(iii) Determine the phase difference between X and Y.

phase difference = …………………. rad [1]

(c) The longitudinal waves created by tine A above can be assumed to have a power of 0.72 W and is equally generated in all directions. A microphone whose circular cross-section has radius 2.0 cm is placed 5.0 m away from the tine as shown in Fig. 6.4 (not to scale).

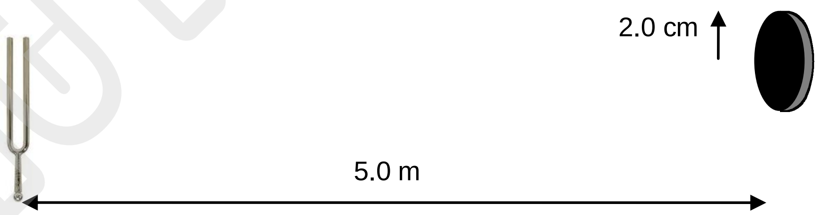

Fig. 6.4

(i) Determine the power received by the microphone

For Examiners' use

power received = …………………. W [3]

(ii) The microphone is replaced by a bigger one whose radius is twice of that of the previous one. At what distance away from the tine must the bigger microphone be placed so that it still picks up the same power?

distance away from tine = …………………… m [3]

7 (a) In 1905 Einstein developed a theory of the photoelectric effect based on the concept of "photons". One of the predictions of the theory was that the maximum kinetic energy of the photoelectrons has a linear relationship with the frequency of the light incident on the metal surface.

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

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

(ii) Show that the above prediction by Einstein is consistent with the principle of conservation of energy.

For Examiners' use

[3]

(b) Fig. 7.1 shows a circuit used for photoelectric emission experiments.

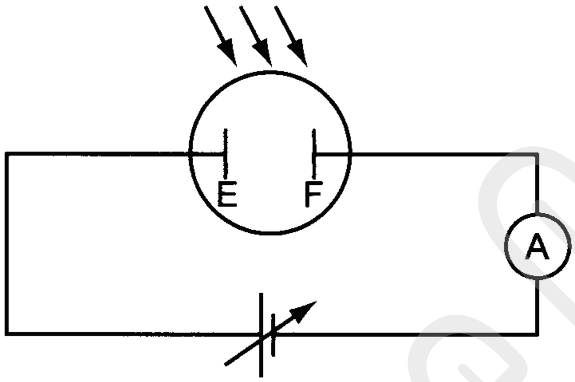

Fig. 7.1

The two electrodes E and F are made of **different metals**. The work function of electrode E is ϕ_E, and the work function of electrode F is ϕ_F.

Current-voltage (*I*-*V*) characteristics are obtained when both electrodes are illuminated with monochromatic light.

When the wavelength of the light is λ_1, the *I*-*V* characteristic is as shown in Fig. 7.2

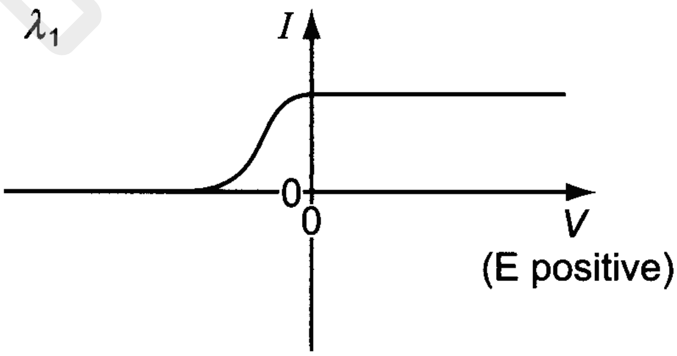

Fig. 7.2

(i) In another experiment, another light source of higher intensity is used. The variation of the photocurrent with potential applied was found to be different. Sketch the new graph on Fig. 7.2 and label it **A**. [2]

For Examiners' use

(ii) When the setup in Fig. 7.1 is illuminated with light of wavelength λ_2 instead, the *I*-*V* characteristic is as shown in Fig. 7.3.

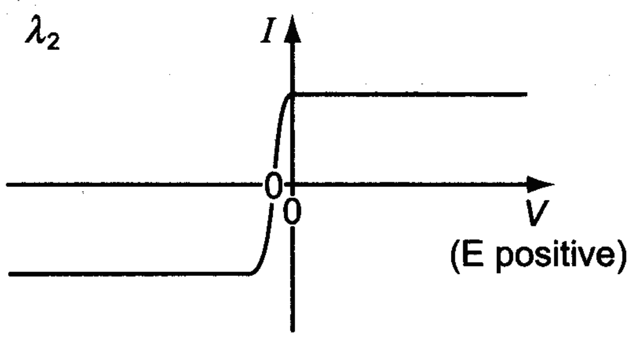

Fig. 7.3

1. State and explain which wavelength, λ_1 or λ_2, is larger.

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2. State and explain which work function, ϕ_E or ϕ_F, is larger.

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(c) In 1961, Jonsson carried out experiments that provided further evidence that electrons were diffracted by very narrow slits. This is illustrated in Fig. 7.4.

For Examiners' use

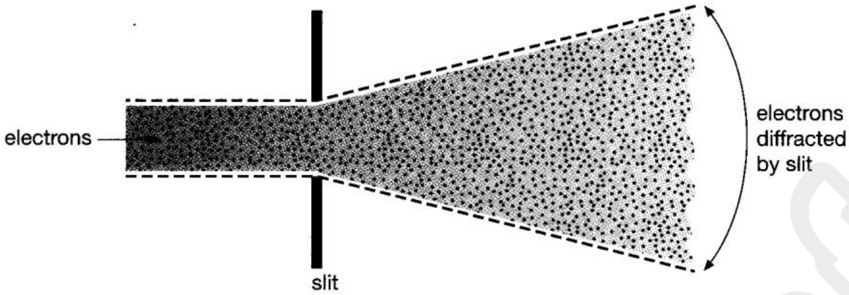

Fig. 7.4

(i) State what may be interpreted about the nature of electrons from such diffraction experiments.

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……………………………………………………………………………………… [1]

(ii) In a small television tube, electrons are accelerated from rest by a potential difference of 2000 V. For an electron, calculate the de Broglie wavelength λ.

de Broglie wavelength λ = ……………. m [3]

(iii) Explain why a person of mass 65 kg running at 9.0 m s^{-1} through an open door will not exhibit diffraction effects.

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(d) In 1981, with the invention of the scanning tunneling microscope (STM), scientists are able to "see' the surfaces literally atom by atom. Fig. 7.5 shows how the scanning tunneling microscope works. A conducting probe with a very sharp tip, just a few atoms wide, is brought to within a few tenths of a nanometer of a surface.

For Examiners' use

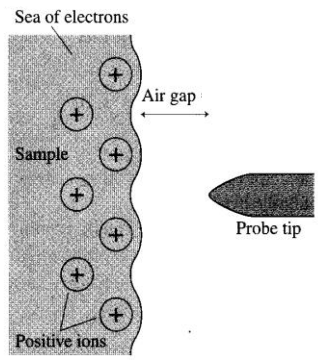

Fig. 7.5

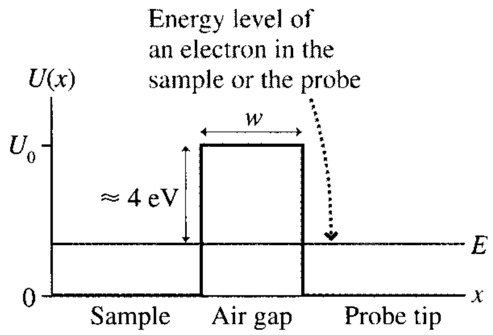

Fig. 7.6

Determine the probability that an electron will tunnel through a 0.45 nm gap from a metal to the STM probe if the work function is 4.0 eV as shown in Fig. 7.6.

probability = ……………… [3]