H2 PHYSICS

Exam papers with worked solutions
(Selected from Top JC)

SET E
PAPER 3
ANSWER

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 two** 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.

For Examiner's Use	
1	/ 10
2	/ 9
3	/ 11
4	/ 10
5	/ 20
6	/ 20
7	/ 20
Total	/ 80

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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	$= v_o \cos \omega t$ $= \pm\omega\sqrt{\left(x_o^2 - x^2\right)}$
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, $\lambda = \dfrac{0.693}{t_{½}}$

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Section A
Answer **all** the questions.

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

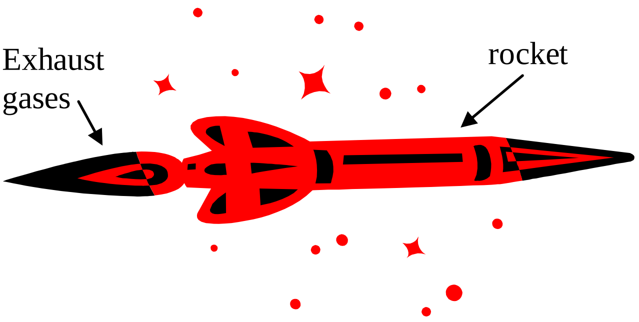

Fig. 1.1

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. [4]

The exhaust gases have momentum.
A rate of change of momentum takes place for the exhaust gases.
According to Newton's second law, there is a force exerted on the exhaust gases by the rocket.
According to Newton's third law, the force acting on the exhaust gases by the rocket is equal and opposite to the force on the rocket by the exhaust gas.
Hence there is a force acting of the rocket in the forward direction.

(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. [1]

$p = mv$
$p = 1.40 \times 10^{-2} \times 210 = 2.94$ kg m s^{-1}

(ii) Calculate the velocity, *v*, of the wooden block after being hit by the bullet. [2]

Total mass after impact = M
M = 1.50 + 0.014 = 1.514 kg
By conservation of linear momentum,
2.94 = 1.514v
v = 1.94 m s^{-1}

(iii) Explain whether or not kinetic energy is conserved in the impact. [1]

Kinetic energy of the bullet is not conserved.
Some of the kinetic energy of the bullet is converted into heat, acoustic energy, etc. [B1]
The impact is an inelastic collision.

(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. [2]
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.

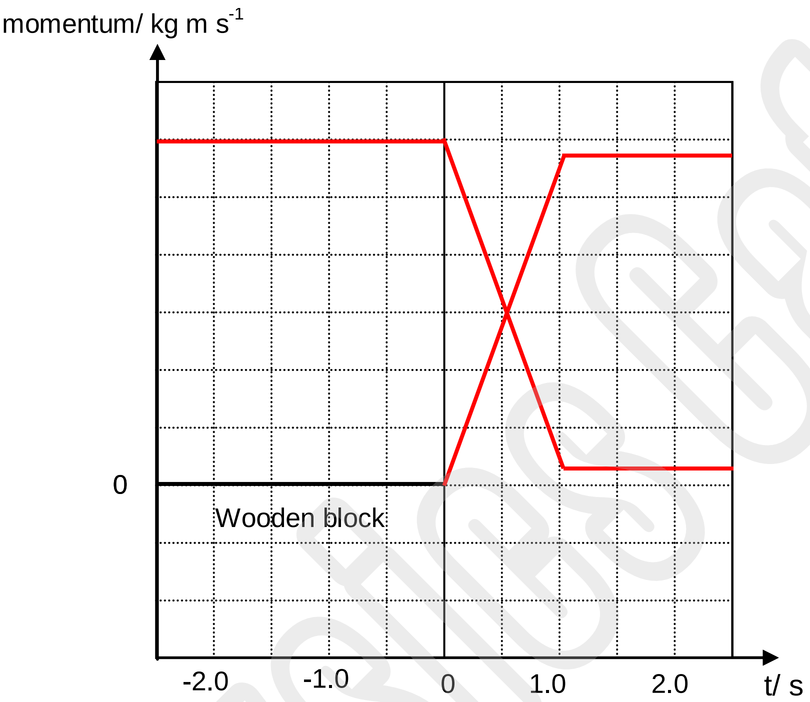

Fig. 1.2

2. 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.

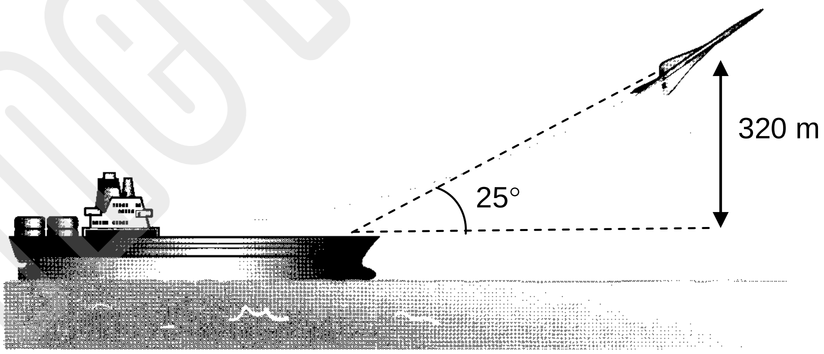

Fig. 2.1

(a) Calculate:

(i) the gain of potential energy of the aircraft in this 20 s, [1]

Gain in potential energy = mgh = 6.91×10^{6} J

(ii) its gain of kinetic energy [2]

Gain in kinetic energy = ½ mv^2 – ½ mu^2 = 7.84×10^6 J

(iii) the work done against the drag force [2]

Distance covered by aircraft = 320/ sin25° = 757 m

Work done = fs = 3.63×10^6 J

(b) (i) Estimate the power output of the aircraft's engines that is converted to useful energy in this time. [2]

Power output = work done to increase KE and GPE/ time = 7.38×10^5 W

(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 burned in the 20 s taken to reach a height of 320 m. [2]

Efficiency = power output/ power input = 0.30

Power input by fuel = 7.38×10^5 /0.3 = 2.458×10^6

Mass of fuel burned = $2.458 \times 10^6/50 \times 10^6$ = 0.0492 kg

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.

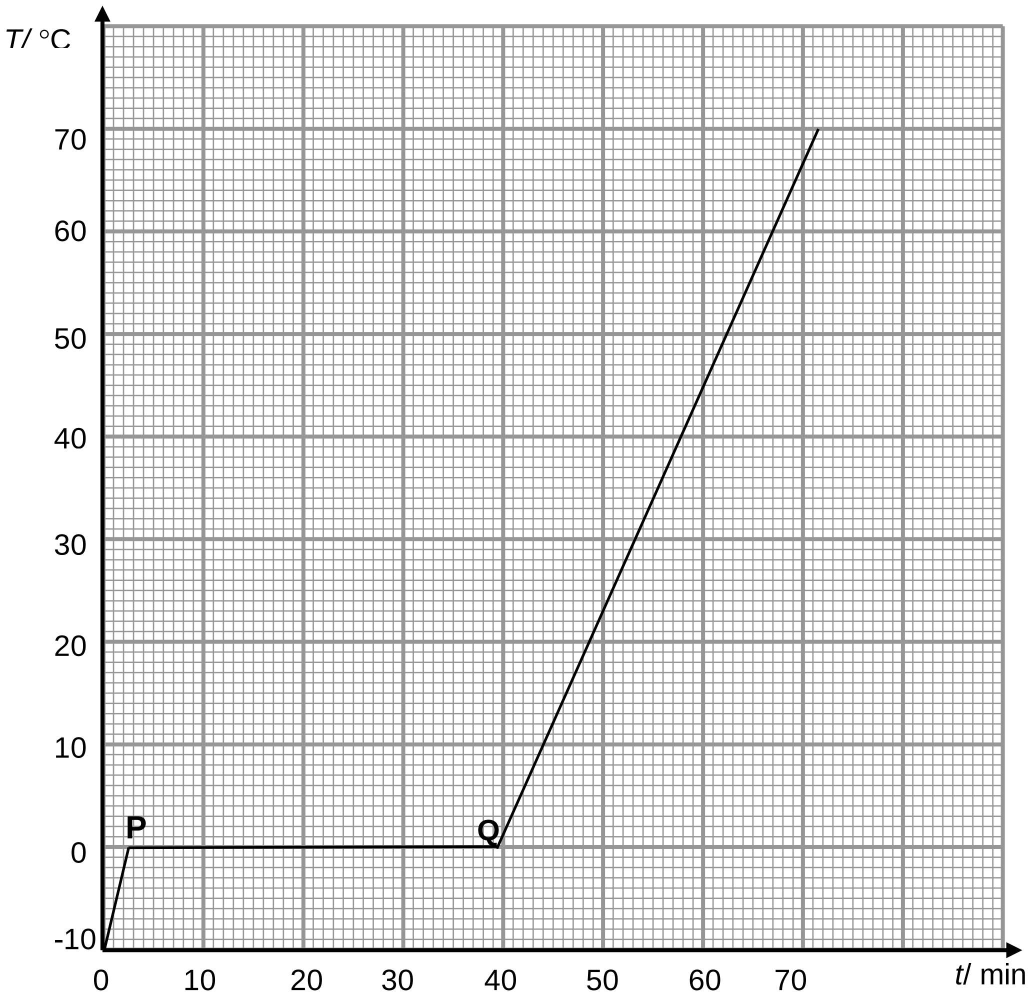

Fig. 3.1

(a) Explain using the kinetic model for matter why the change between points [2]

P and Q takes place without a change in temperature.
Between P and Q the ice is melting:
The heat supplied to the ice causes regular arrangement of the molecules breaks down/ arrangement becomes disordered and the molecules become further apart, increasing the potential energy. [B1]
The average kinetic energy remains constant and thus temperature remains unchanged. [B1]

(b) Use Fig. 3.1 to determine the specific latent heat of fusion of water. [3]
Time taken to melt = 39.5 min – 2.5 min = 37 min = 2220 s
Energy absorbed = power × time = 30 x 2220 = 66600 J
Specific latent heat of fusion L = Q/m =66600 /0.20 = 3.33×10^5 J kg^{-1}

(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? [2]
Would need a thermometer and a stopwatch/ a temperature sensor and a datalogger [B1]
Record temperature at regular time intervals [B1]

(d) Suggest one precaution he should take to obtain a more accurate graph. [1]
Eg. Stir to ensure even heating
Measure temperature well away from heater
Read thermometer at eye-level to avoid parallax error.

(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]
Line added to graph:
With a horizontal section at 29 °C (melting point)
Both gradients steeper than for water (smaller specific heat capacity so it warms up quicker)
Shorter horizontal section (smaller specific latent heat so less energy required to melt

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.

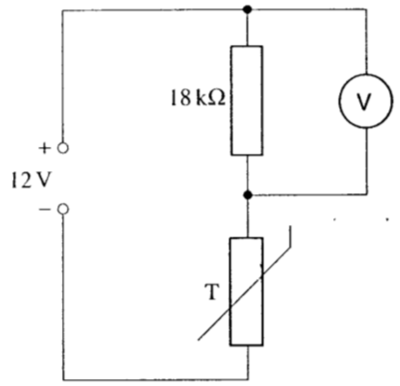

Fig. 4.1

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.

For a pure semi conductor, the gap between the conduction band and the valence band is small (~ 1 eV). [B1]
When the thermistor is placed in a hot liquid, the thermal energy gained from the hot liquid is sufficient to cause the electron to "jump" across the small band gap to become free electrons in the conduction band. At the same, holes are being formed in the valence bands. [B1]
Both the free electrons in the conduction band and holes in the valence band can now conduct electricity Thus, there is a large increase in the number of mobile charge carriers which decreases the resistance of the thermistor. [B1]

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

In the hot liquid, the resistance of thermistor = 2.0 kΩ
V = 18/(18+2.0) × 12V
Reading of voltmeter = 10.8 V [A1]

(iii) The student replaces the digital voltmeter with an analogue voltmeter of resistance 10 kΩ. Determine the new reading shown on the voltmeter.
Effective resistance of voltmeter and 18 kΩ resistor = 6.43 kΩ [C1]
Pd across effective resistance = 6.43/8.43 × 12 = 9.15 V
Reading on voltmeter = pd across effective resistance = 9.15 V [A1]

(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.

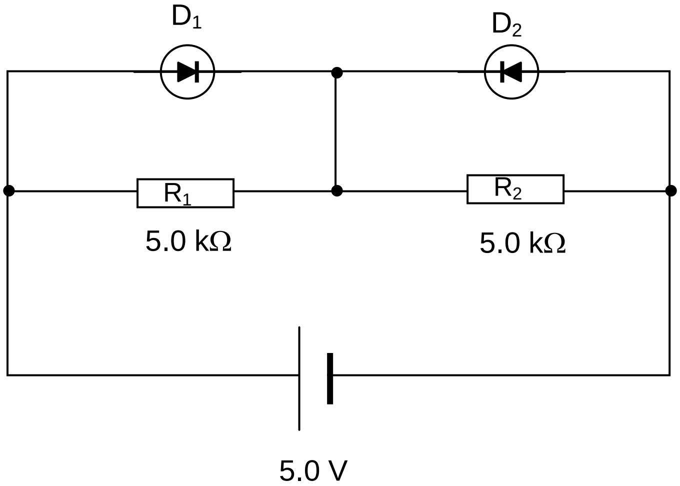

Fig. 4.2

Calculate

(i) the potential difference across resistor R_2

Diode D1 is conducting and hence p.d across R1 is 0.70 V,
p.d. across R2 = 5.0 – 0.70 = 4.30 V

(ii) the total current supplied by the battery.

Current through R2 = 4.3/5000 = 8.6×10^{-4} A.
Current supplied by battery = current through R2 = 8.6×10^{-4} A.

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.

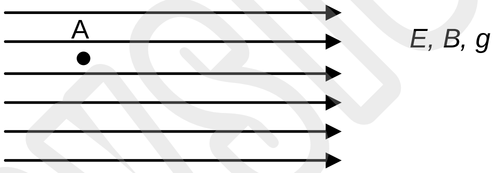

Fig. 5.1

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,

magnitude = Ee (B1)
direction = left (B1)

(ii) the gravitational field and

magnitude = $m_e g$ (B1)
direction = right (B1)

(iii) the magnetic field

magnitude = 0 (B1) [5]
(direction not required, deduct 1M if candidate states direction)

(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.

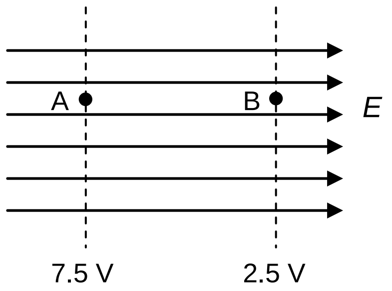

Fig. 5.2

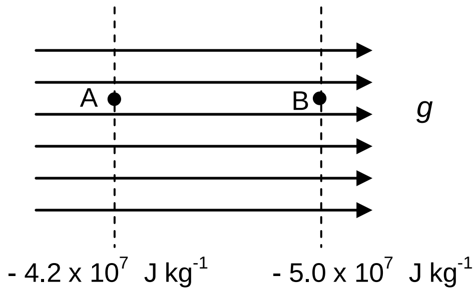

Fig. 5.3

(i) Define electrical potential at a point. [2]

Electrical potential at a point is defined as the work done per unit charge by external force in bringing a small unit positive charge from infinity to that point. (B2)

(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. [2]

Gravitational field is always attractive hence negative work is always done in bringing a unit mass from infinity to that point. (B1)

Alternatively:

Gravitational force is always attractive; to bring a unit mass from infinity to the point, the external force is opposite in direction to both the gravitational force and the displacement from infinity to that point, hence work done per unit mass by the external force is negative.

Electric field, on the other hand, can be attractive or repulsive, thus the work done by external force to bring a small positive test charge from infinity to that point can be positive. (B1)

Alternatively:

Electric force between the external test charge and the electric field can repulsive or attractive when the positive test charge is brought from infinity to that point in the field. The direction of the external force bringing in the test charge and the direction of displacement of the charge from infinity to the point can be opposite or in the same direction to each other, hence the work done can be positive or negative.

(iii) Calculate the work done on the electron **against the electric field** in moving it from A to B. [2]

WD = $q\Delta V$ (C1)

$= - 1.6 \times 10^{-19} \times (2.5 - 7.5)$

$= 8.0 \times 10^{-19}$ J (A1)

(iv) Calculate the work done on the electron **against the gravitational field** in moving it from A to B. [2]

WD = $m\Delta\varphi$ (C1)

$= 9.11 \times 10^{-31} \times [(-5.0) - (-4.2)] \times 10^{7}$

$= -7.29 \times 10^{-24}$ J (A1)

(v) Given that the distance between A and B is 5.0 cm, calculate the magnitude of the electric field strength *E*. [2]

$E = \Delta V/d$ (C1)

$= (7.5 - 2.5) / 0.050$

$= 100$ N C^{-1} (A1)

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(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. [3]

$F_G = F_C$ (C1)
$GMm/r^2 = mv^2/r$
$r = 6.4 \times 10^6 + 7.0 \times 10^6 = 1.34 \times 10^7$ m (C1)

$v = \sqrt{(GM/r)}$
$= \sqrt{(6.67 \times 10^{-11} \times 6.0 \times 10^{24} / 1.34 \times 10^7)}$
$= 5460$ m s^{-1} (A1)

(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. [2]

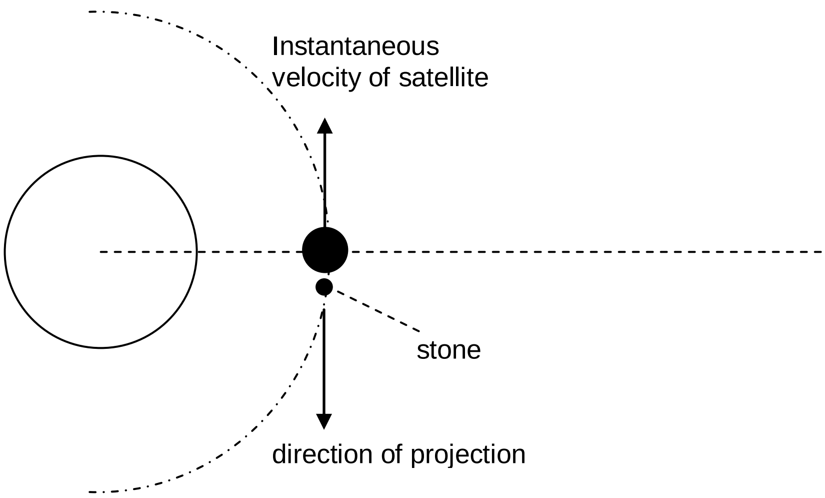

Fig. 5.4

By Principle of Conservation of Energy from point of projection to point of infinity:
Loss in KE = Gain in GPE
$\frac{1}{2} mv^2 - 0 = 0 - (-GMm/r)$
$v = \sqrt{(2GM/r)} = = \sqrt{(2 \times 6.67 \times 10^{-11} \times 6.0 \times 10^{24} / 1.34 \times 10^7)}$
$= 7730$ m s^{-1} (C1)
Since satellite was moving in the opposite direction with a orbital speed of 5460 m s^{-1},
Speed of projection = 5460 + 7730 = 13200 m s^{-1} (A1)

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.

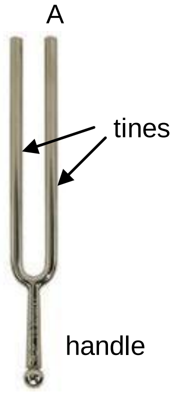

Fig. 6.1

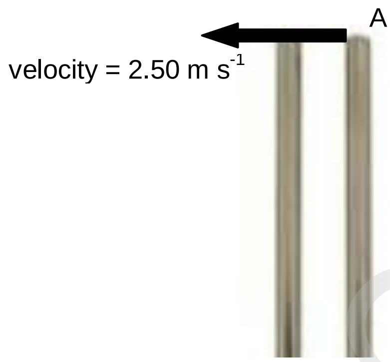

Fig. 6.2

(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. [2]

It is the motion of a particle such that the acceleration of the particle is directly proportional to its displacement (B1)

and the acceleration is always directed towards the equilibrium position. (B1)

(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: [3]

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

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

At equilibrium position, velocity is a maximum

Hence, $x_0\ \omega = 2.5$ (C1)

Since f = 128 Hz, $\omega = 2\pi f$ = 804.6 rad s^{-1}

x_0 = 2.5 / 804.6 = 3.11 mm or 0.00311 m (C1)

Since initial velocity is negative, B = -3.11 mm or - 0.00311 m (A1)

(iii) Again taking rightward as positive, determine the displacement of tine A 1/8 of a cycle after it was knocked. [2]

x = - 0.0031 sin ($2\pi/T$ x $T/8$) (C1)

= - 0.00219 m (A1)

Or

time elapsed, $t = T/8 = (2\pi/\omega) / 8$ = 0.000976 s (C1)

x = -0.0031 sin (ωt) = - 0.00219 m (A1)

(iv) What is the shortest time after the tip of tine A was knocked for its acceleration to be a maximum? [2]

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The position at which the tip is first at its maximum acceleration is when it is at its leftmost or ¼ cycle after being knocked. (C1)
Time = T/4 = $(2\pi/\omega)$ / 4 = 0.00195 s (A1)

(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.

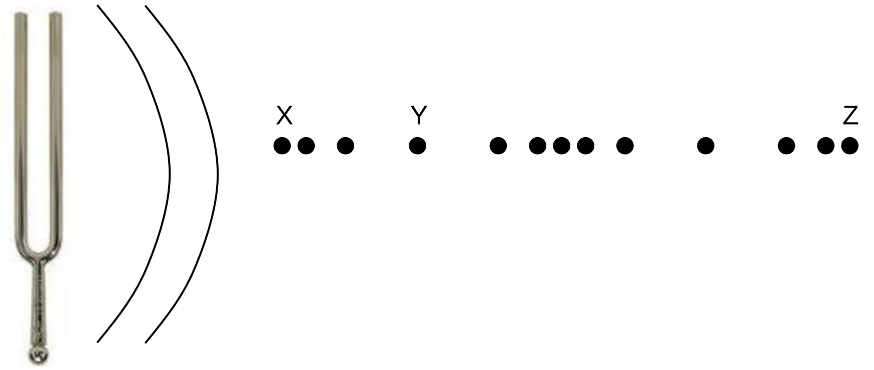

Fig. 6.3

(i) By considering the movement of air molecules, state and explain the pressure experienced by the air molecule at Y. [2]

Particle Y experiences lowest/minimum pressure (M1)
Since its neighboring particles move away from it simultaneously. (A1)

(ii) Given that the distance between X and Z is 5.2 m, calculate the speed of the longitudinal wave between X and Z. [2]

2 full cycles are found between X and Z
This means that the wavelength λ = 5.2 / 2 = 2.6 m (M1)
Since $v = f\lambda = 128 \times 2.6 = 333$ m s^{-1} (A1)

(iii) Determine the phase difference between X and Y. [1]

Between a rarefaction and compression, half a wave is found.
Hence, phase difference = π (A1)

(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).

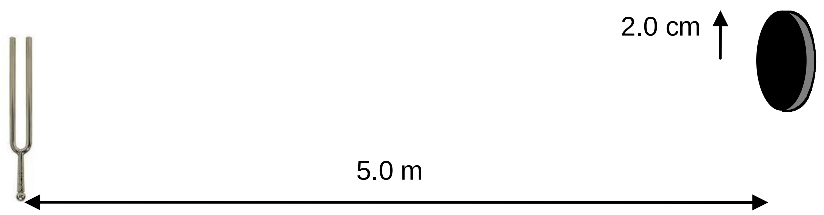

Fig. 6.4

(i) Determine the power received by the microphone [3]

Intensity of wave at position of microphone = $P / 4\pi x^2$ (C1)
= $0.72/[4\pi(5.0)^2]$
= 2.29×10^{-3} W m^{-2}
Power picked up by microphone = $I \times A$ = $(2.29 \times 10^{-3}) \times [\pi(0.02)^2]$ (C1)
= 2.88×10^{-6} W. (A1)

(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? [3]

Surface area of bigger microphone = 2^2 = 4 times of original microphone. (C1)
In order to pick up the same power, microphone must be shifted to a new location where the intensity of the wave is 1/4 times of the original value. (C1)
Hence, (A1)
$I/4 = P/(4\pi d^2)$ where d is distance to new position of bigger microphone
Thus, d = $\sqrt{4}$ x = $\sqrt{4} \times 5.0$ = 10.0 m

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". [2]

A photon is a **quantum** of electromagnetic radiation energy. [B1] Its energy is given by hf where h is the Planck constant and f is the frequency of the radiation. [B1]

(ii) Show that the above prediction by Einstein is consistent with the principle of conservation of energy. [3]

From Einstein's prediction,

$KE_{max} = af + b$

It was found experimentally that $KE_{max} = hf - \phi$.
where the work function energy ϕ of the metal and h the planck constant are constants,

Rearranging, $hf = KE_{max} + \phi$.
This means that the energy carried by the photon hf and absorbed by an electron equals to the work function energy ϕ of the electron and the maximum kinetic energy KE_{max} of the electron,

Since no energy is lost or destroyed but converted from one form to another, this implies that Einstein's prediction is consistent with the principle of conservation of energy

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

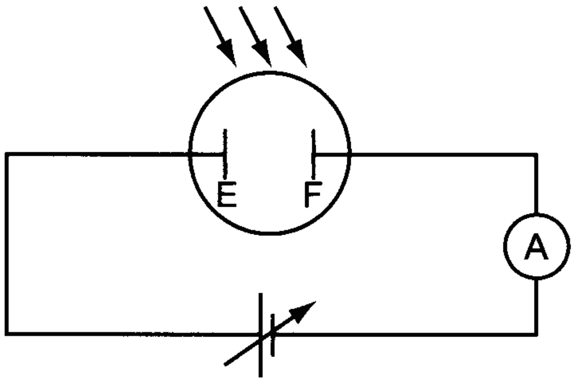

Fig. 7.1

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

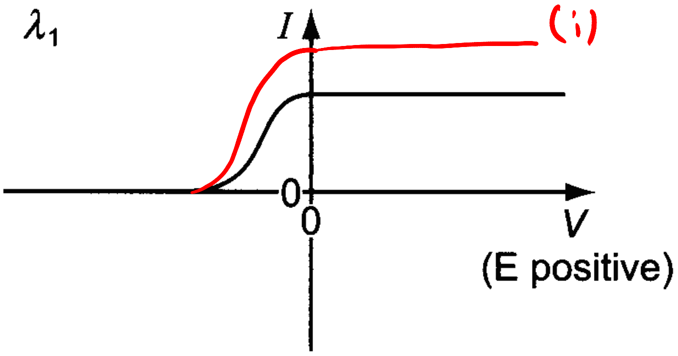

Fig. 7.2

(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]

(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.

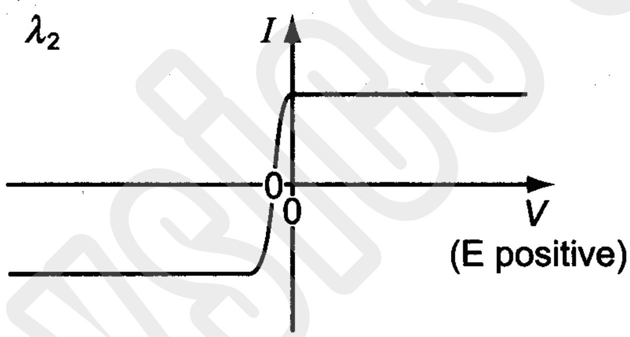

Fig. 7.3

(i) State and explain which wavelength, λ_1 or λ_2, is larger.

λ1 is larger. B1
λ2 can cause emission of electrons from both the metals E and F. B1

(ii) State and explain which work function, ϕ_E or ϕ_F, is larger.

ϕE is larger B1
as electrons can only be emitted from the metal E surface when light of higher frequency is shone on the metals. B1

(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.

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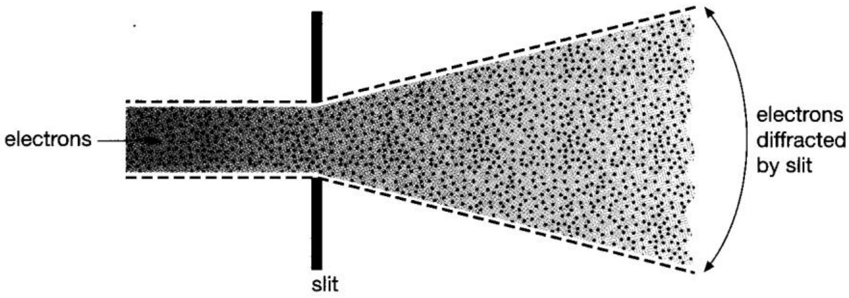


Fig. 7.4

(i) State what may be interpreted about the nature of electrons from such diffraction experiments. [1]

Moving electrons exhibit wave properties. [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.

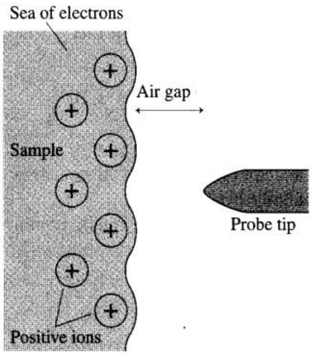
Kinetic Energy gained by electrons = eV = 3.2×10^{-16} J
Velocity = 2.65×10^{7} m s^{-1}
Momentum of electron = mv = 2.4×10^{-23} kg m s^{-1}
λ = h/p = 2.8×10^{-11} m

(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. [2]

The wavelength of the person is too small (compared with the width of the door). $\lambda \sim 10^{-36}$ m [B1]
For diffraction effects to be significant, the wavelength must be comparable to the size of the 'gap'. [B1]

Additional information: For a person to show diffraction effects, the gap size ought to be about 10^{-36} m, which is an impossibility. Electrons may be diffracted by matter because their de Broglie wavelength can be comparable to the separation of the atoms.

(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. [3]



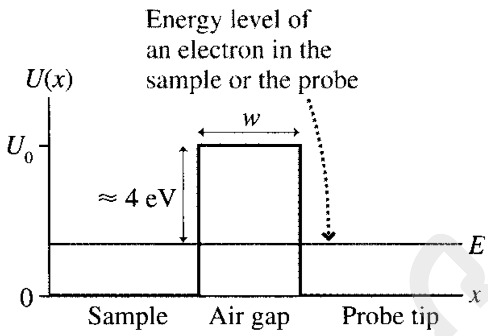


Fig. 7.5 Fig. 7.6

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.

U – E = 4.0 eV = 6.4×10^{-19} J [C1]

K = $\sqrt{\frac{8\pi^2 m(U-E)}{h^2}}$ = 1.023×10^{10} m^{-1} [C1]

Probability = transmission coefficient = e^{-2kd} = 1.0×10^{-4} [A1]

End of Paper

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