Class	Index Number	Name
24S		

ST. ANDREW'S JUNIOR COLLEGE
JC 2 2025
Preliminary Examination

PHYSICS, Higher 2 **9749/02**

Paper 2 Structured Questions **3rd September 2025**
2 hours

Candidates answer on the Question Paper.
No additional materials are required.

READ THESE INSTRUCTIONS FIRST

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

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

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	/ 12
2	/ 8
3	/ 7
4	/ 10
5	/ 10
6	/ 13
7	/ 20
Total	/ 80

This document consists of 23 printed pages including this page.

Data

speed of light in free space,	$c = 3.00 \times 10^{8}$ m s^{-1}
permeability of free space,	$\mu_o = 4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space,	$\varepsilon_o = 8.85 \times 10^{-12}$ F m^{-1}
	$= (1/(36\pi)) \times 10^{-9}$ 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,	$s = u t + \frac{1}{2} a t^2$
	$v^2 = u^2 + 2 a s$
work done on/by a gas,	$W = p \Delta V$
hydrostatic pressure,	$p = \rho g h$
gravitational potential,	$\phi = -\frac{Gm}{r}$
temperature,	$T/\text{K} = T/{}^{\circ}\text{C} + 273.15$
pressure of an ideal gas,	$p = \frac{1}{3}\frac{Nm}{V}\langle c^2\rangle$
mean translational kinetic energy of an ideal gas 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.,	$v = v_0 \cos \omega t$
	$v = \pm \omega \sqrt{x_0^2 - x^2}$
electric current	$I = Anvq$
resistors in series,	$R = R_1 + R_2 + ...$
resistors in parallel,	$1/R = 1/R_1 + 1/R_2 + ...$
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,	$B = \frac{\mu_0 I}{2\pi d}$
magnetic flux density due to a flat circular coil,	$B = \frac{\mu_0 N I}{2r}$
magnetic flux density due to a long solenoid,	$B = \mu_0 n I$
radioactive decay,	$x = x_o \exp(-\lambda t)$
decay constant,	$\lambda = \frac{\ln 2}{t_{1/2}}$

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

1 A toy car with a rocket engine moves along a horizontal track, as shown in Fig. 1.1.

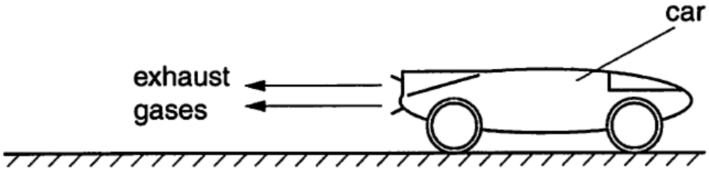


Fig. 1.1

The rocket engine produces a constant forward force of 4.6 N. The car loses mass continuously as exhaust gases are produced by the rocket.

(a) Use momentum considerations to explain why the rocket produces a forward force on the car.

....

....

....

....

....

.... [3]

(b) The variation with time t of the speed v of the car is shown in Fig. 1.2.

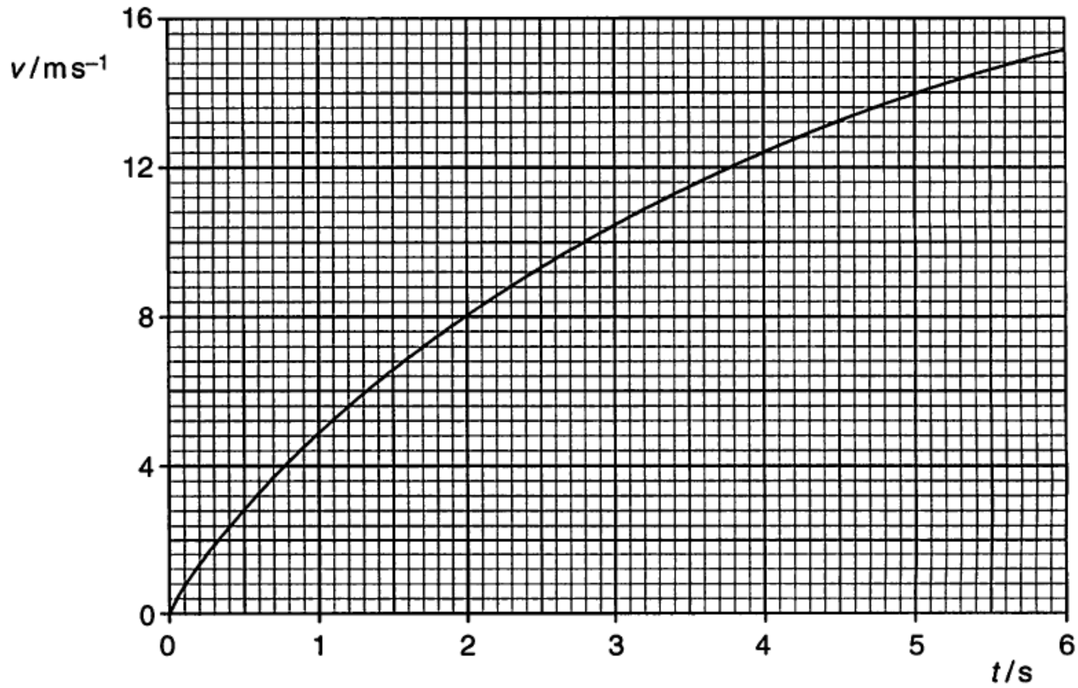


Fig. 1.2

At time t = 2.0 s, the mass of the car is 440 g.

(i) For the time t = 2.0 s,

1. use Fig. 1.2 to determine the acceleration of the car,

acceleration = …………………… m s^{-2} [2]

2. use your answer in **(i) part 1** to determine the magnitude of the resistive force acting on the car.

force = …………………… N [2]

(ii) Explain how it can be deduced that the resistive forces acting on the car increase with increase of speed.

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

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

(c) The toy car is now re-fuelled and then rotated so that it is pointing upwards.
It is suggested that the rocket engine produces sufficient force to propel the car vertically.
By considering the acceleration of the car at time t = 0 in Fig. 1.2, comment on this suggestion.

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

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

2 **(a)** State the principle of moments.

....

....

.... [1]

(b) A rigid uniform beam rests on a pivot at its centre, as shown in Fig. 2.1.

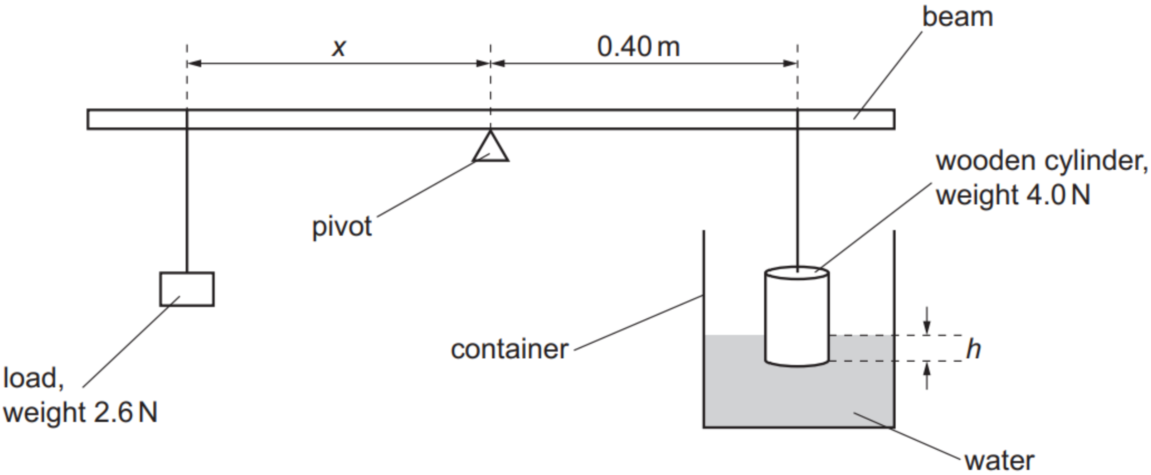


Fig. 2.1 (not to scale)

A load of weight 2.6 N is suspended from the beam at distance *x* from the pivot.

A wooden cylinder of weight 4.0 N is suspended from the beam at a distance of 0.40 m from the pivot on the opposite side of the pivot to the load. The cylinder rests in a container of water. The lower part of the cylinder is immersed in the water to depth *h*.

Initially, *h* is equal to 0.10 m and *x* is equal to 0.40 m. The system is in equilibrium.

(i) Use the principle of moments to show that the upthrust *U* exerted by the water on the cylinder is 1.4 N.

[2]

(ii) The density of the water is 1.0×10^3 kg m^{-3}.

Calculate the area *A* of the circular cross-section of the cylinder.

A = ………………………….. m^2 [2]

(c) More water is gradually added to the container in **(b)**, so that depth *h* in Fig. 2.1 gradually increases. The length *x* is continuously adjusted so that the system remains in equilibrium.

On Fig. 2.2, sketch the variation of *x* with *h*. Use the space below for any working.

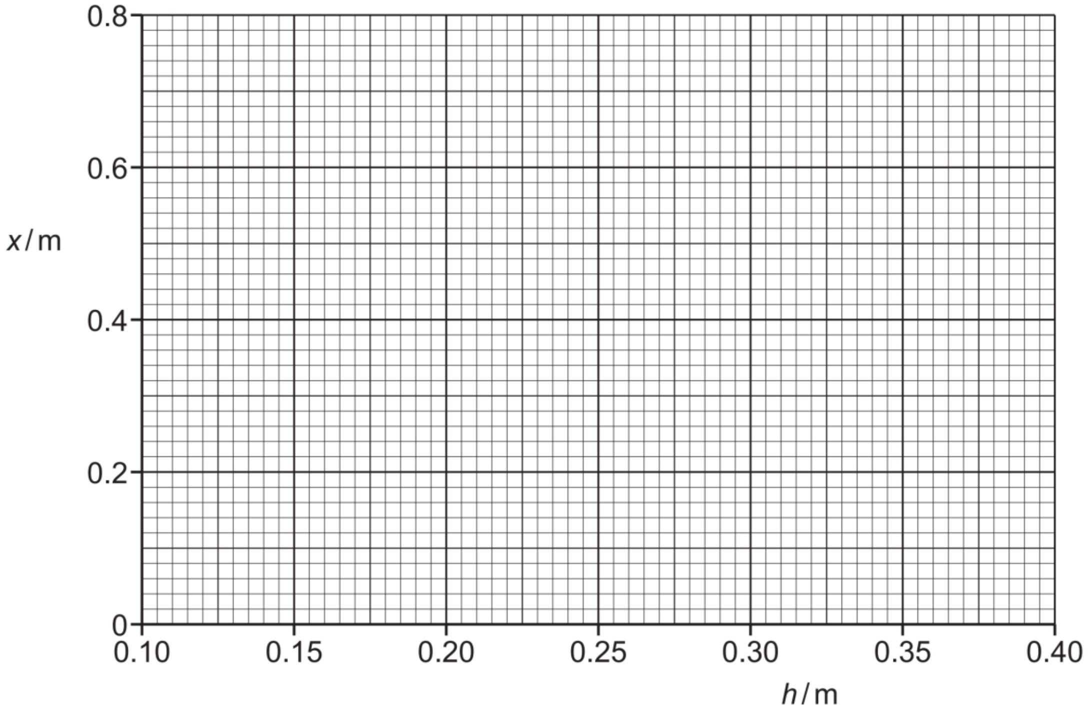


Fig. 2.2

[3]

3 **(a)** A planet may be assumed to be a uniform sphere. It has gravitational potential Φ at distance r from the centre of the planet. The variation with $1/r$ of Φ is shown in Fig. 3.1.

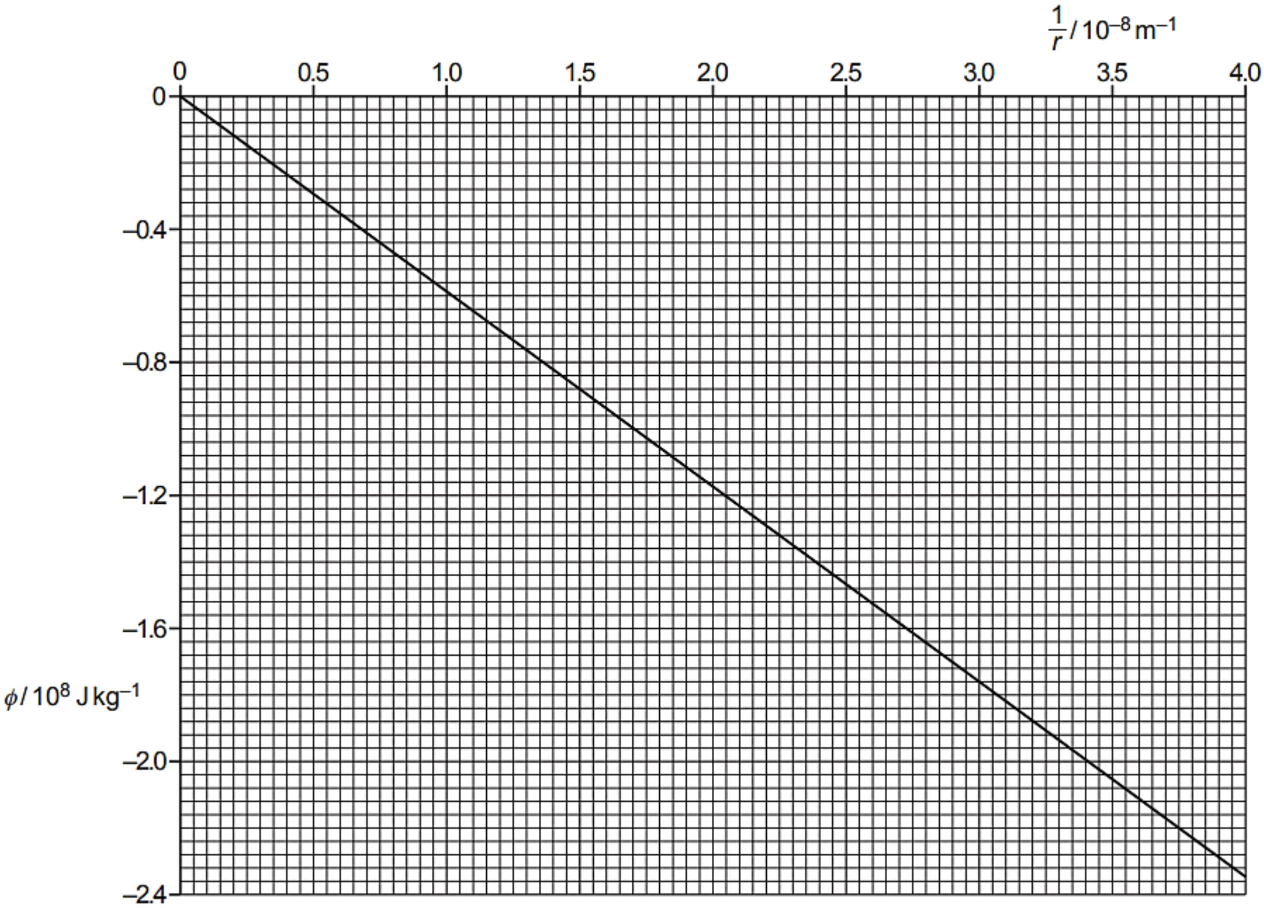


Fig. 3.1

(i) Show that the mass of the planet is 8.8×10^{25} kg.

[2]

(ii) The period of rotation of the planet is 0.72 Earth days.

A satellite in orbit around the planet remains above the same point on the surface of the planet. The speed of the satellite is 8400 m s^{-1}. The mass of the satellite is 1200 kg.

Determine the additional energy required to move the satellite from its orbit to infinity.

energy required = ... J [3]

(b) To move the satellite to a new, stable circular orbit closer to the planet, a short rocket thrust is required to begin the manoeuvre.

Explain the direction of this initial thrust.

....

....

....

....

.... [2]

4 Fig. 4.1 shows a mass-spring system placed on a frictionless slope.

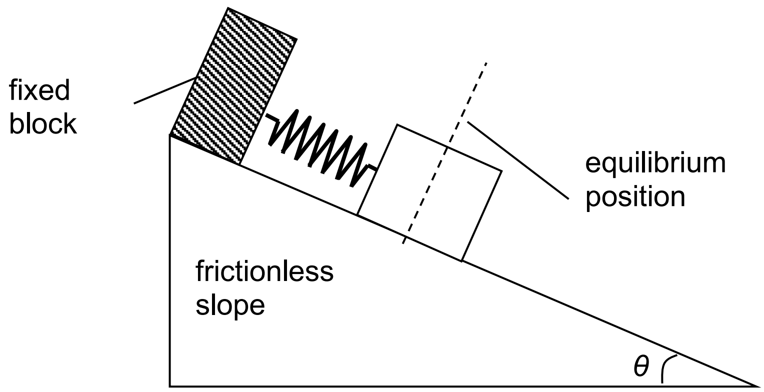


Fig. 4.1

The slope has an angle of θ from the horizontal. When a block of mass m is hung, the spring stretches by an extension of e and the mass remains in equilibrium.

The spring is further extended by x downwards, along the slope, and released for the mass-spring system to oscillate. The spring constant is k.

(a) Show that the acceleration a of the block at the lowest point is given by $a = -\frac{k}{m}x$.

[3]

(b) Explain how the expression in **(a)** shows the mass-spring system is oscillating in simple harmonic motion.

....

....

.... [2]

(c) The amplitude of oscillation of the mass-spring system is 3.0 cm.

Calculate the position of the mass from equilibrium when the speed of the mass is 25% of the maximum speed.

position = …………………… cm [2]

(d) A student removes the fixed block and attaches a variable frequency oscillator to the mass-spring system, as shown in Fig. 4.2.

Fig. 4.3 shows the variation of the amplitude of mass with the frequency of the oscillator.

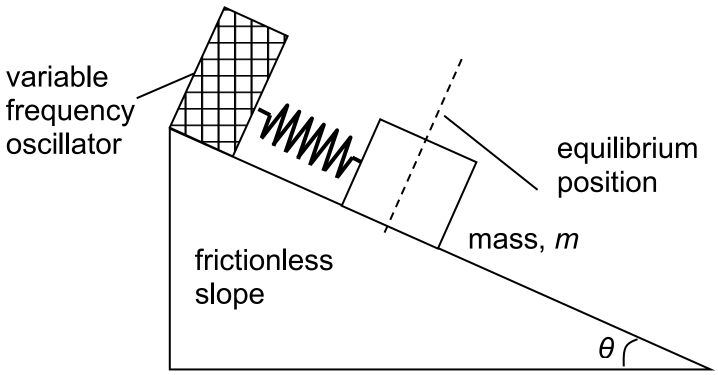


Fig. 4.2

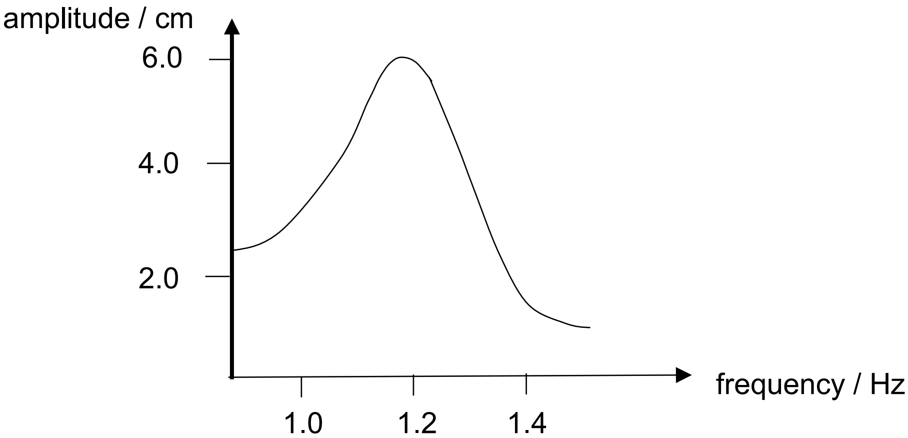


Fig. 4.3

(i) Explain the phenomenon illustrated in Fig. 4.3.

………………………………………………………………………………………………

………………………………………………………………………………………………

………………………………………………………………………………………………

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

(ii) Calculate the magnitude of maximum acceleration of the mass.

acceleration = …………………… m s^{-2} [1]

5 **(a)** State Ohm's law.

....

....

.... [1]

(b) A battery of electromotive force (e.m.f.) 6.2 V and negligible internal resistance is connected in a circuit to a uniform resistance wire, a voltmeter, a fixed resistor and a switch, as shown in Fig. 5.1.

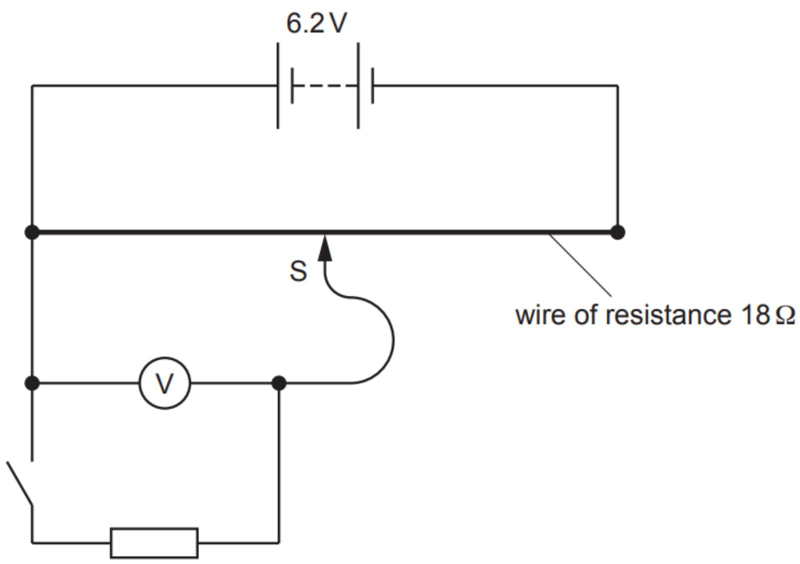


Fig. 5.1

The resistance wire has resistance 18 Ω, length 0.94 m and cross-sectional area $7.2 \times 10^{-8}\ m^2$. The slider S is positioned half-way along the length of the wire.

(i) Calculate the resistivity ρ of the material of the resistance wire.

ρ = ... Ω m [1]

(ii) The switch is now closed.

State whether there is an increase, decrease or no change to:

- the current in the battery

………………………………………………………………………………………..

- the voltmeter reading.

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

(iii) The switch remains closed. The slider S is moved along the resistance wire so that the voltmeter reading is 3.1 V.

On Fig. 5.1, draw a cross (×) on the resistance wire to show a possible new position of the slider. [1]

(c) The circuit in **(b)** is altered by changing the battery for one of a different e.m.f.
The switch is open.

A student records the following data for the resistance wire:

current in the wire	0.93 A
mean drift speed of charge carriers	1.3×10^{-3} m s^{-1}
number density of charge carriers	9.0×10^{28} m^{-3}.

(i) Determine the charge q of a charge carrier in the wire suggested by this data.

q = ………………………….. C [1]

(ii) With reference to the value of q, explain why the data recorded by the student cannot be correct.

………………………………………………………………………………………...

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

(d) A cell of electromotive force (e.m.f.) 1.8 V and internal resistance *r* is connected in parallel with a resistor of resistance 6.0 Ω and a filament lamp, as shown in Fig. 5.2.

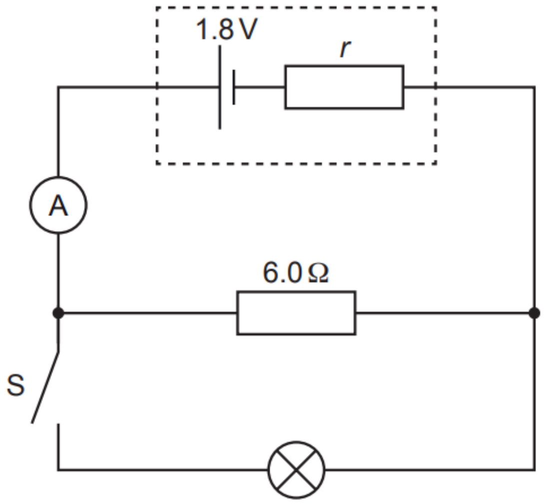


Fig. 5.2

Initially, the switch S is open.

At time t_1 switch S in Fig. 5.2 is closed. Fig. 5.3 shows the variation with time *t* of the ammeter reading I.

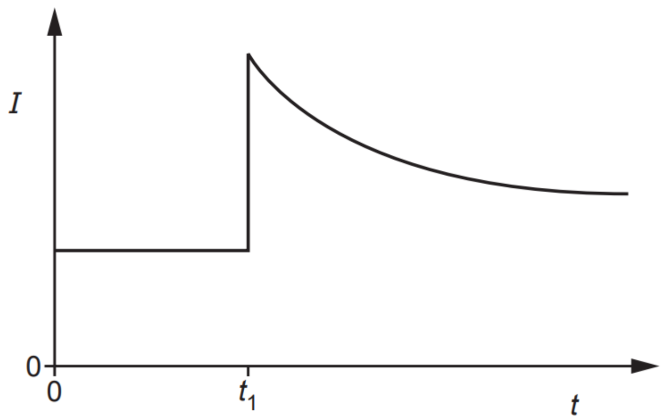


Fig. 5.3

By considering the effect of the lamp on the total resistance of the circuit, explain the variation of the ammeter reading shown in Fig. 5.3.

....

....

....

....

....

.... [3]

6 **(a)** In the fluorescent tube shown in Fig 6.1, electrons are accelerated from the filament and collide with a mercury atom, which is at its ground state.

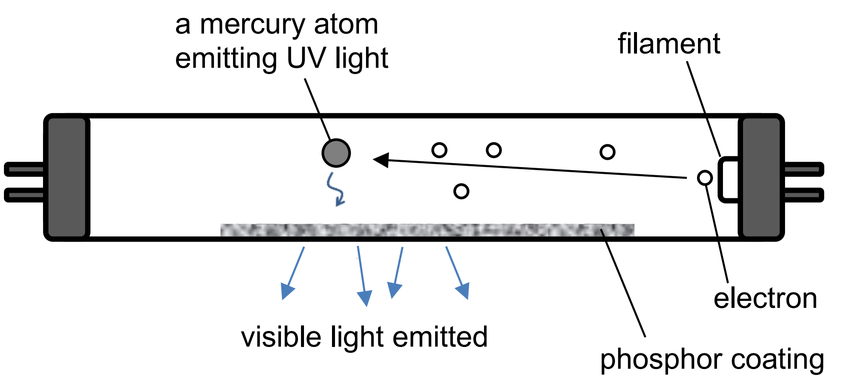


Fig. 6.1

Some of the energy levels of a mercury atom are represented in Fig. 6.2.

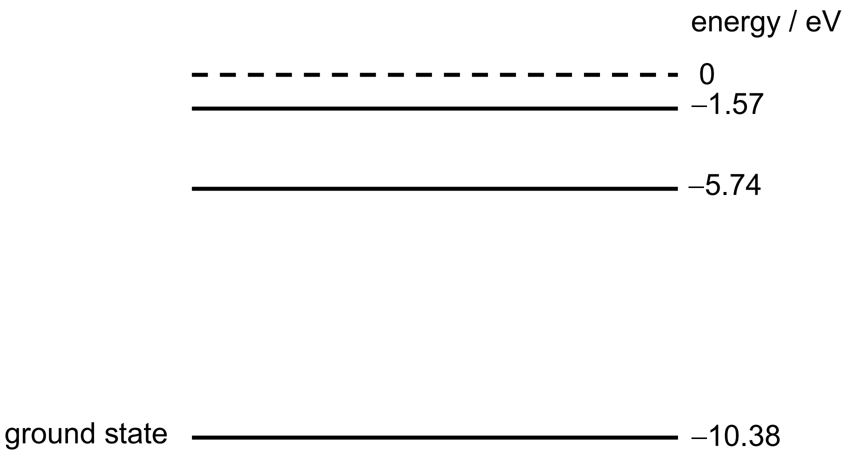


Fig. 6.2 (not to scale)

(i) In one particular interaction, an electron with kinetic energy 10.0 eV collides with a mercury atom at its ground state.

Determine the longest wavelength of UV radiation that can be emitted due to this interaction.

wavelength = ... m [2]

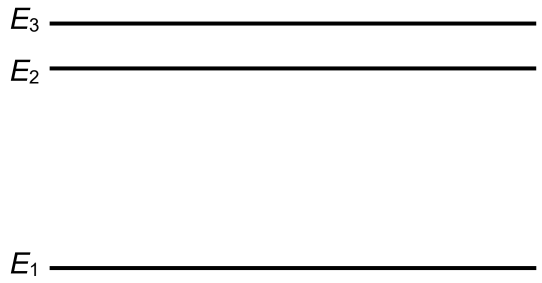
(ii) The UV photons emitted by the mercury atoms strike the phosphor coating on the inside of the fluorescent tube. The phosphor absorbs the UV photons and emits visible light by fluorescence.

Fig. 6.3 shows three energy levels E_1, E_2 and E_3 of an atom in the phosphor that are involved in the absorption of UV and emission of infrared and visible light.

On Fig. 6.3, draw arrows to indicate the following transitions:

(1) absorption of a UV photon
(2) emission of a red light photon
(3) emission of an infrared photon

Label the transitions clearly.



[1]

Fig. 6.3

(iii) Explain why the light emitted by the phosphor is of a longer wavelength than the UV light absorbed.

…………………………………………………………………………………………………

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

(b) In an experiment to demonstrate the wave-particle duality of matter, UV light of wavelength 310 nm is incident on a polished sodium metal plate in a vacuum. The work function of sodium is 2.28 eV.

(i) Explain the energy transformation that occurs during photoelectric emission.

…………………………………………………………………………………………………

…………………………………………………………………………………………………

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

(ii) Calculate the maximum kinetic energy of the photoelectrons emitted from the sodium plate.

maximum kinetic energy = ……………………… J [2]

(c) The emitted photoelectrons are directed as a beam towards a thin, polycrystalline graphite film. The electrons pass through the film and strike a fluorescent screen, producing a diffraction pattern as shown in Fig. 6.4 due to the wave-like properties of electron.

Assume that this diffraction pattern is formed only by the electrons possessing the maximum kinetic energy calculated in **(b)(ii)**.

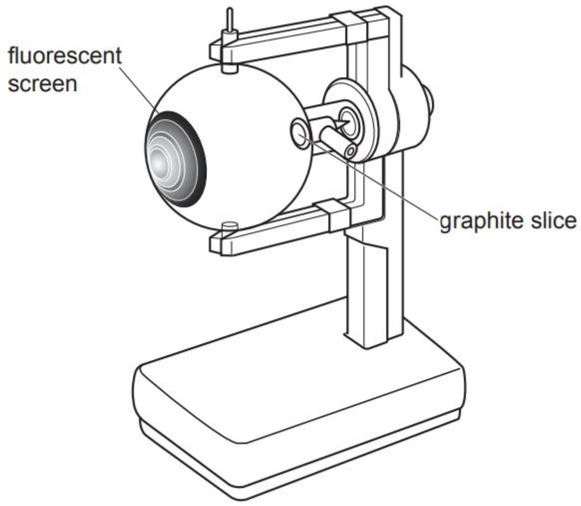


Fig. 6.4

(i) Determine the de Broglie wavelength of an electron with this maximum kinetic energy.

de Broglie wavelength = ………………………….. m [2]

(ii) Hence, explain why an observable diffraction pattern is formed.

……………………………………………………………………………………………

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

(iii) In reality, photoelectrons are emitted with a range of kinetic energies, from the maximum value calculated in **(b)(ii)** down to zero.

Explain how this range of energies affects the appearance of the diffraction pattern compared to the ideal one discussed in **(c)**.

……………………………………………………………………………………………

……………………………………………………………………………………………

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

7 Read the passage and answer the questions that follow.

In 1909, Robert Millikan and Harvey Fletcher developed an experiment to determine the fundamental charge of the electron. This was achieved by measuring the charge of oil drops in a known electric field. If each electron has the same charge, then the measured charge on the oil drops must be multiples of the same fundamental constant. Millikan received the Nobel Prize in Physics in 1923 for his precise measurement of this elementary electric charge and for his work on the photoelectric effect.

Fig. 7.1 shows the important features of the apparatus used by Millikan to measure the electron charge by observations on charged oil droplets.

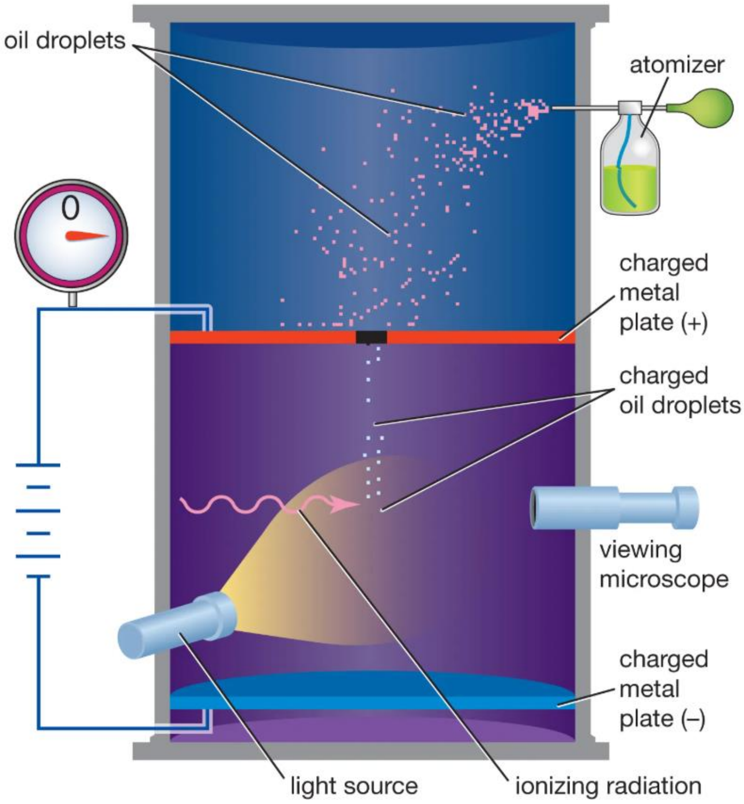


Fig. 7.1

In the apparatus, the viewing microscope is focused on the illuminated space under the hole through which oil droplets can enter. The atomizer introduces a mist of oil droplets through the hole in the top plate that is ionized by X-rays, making them negatively charged. When electric field is applied across the charged metal plates, the potential difference, V, between the plates can be adjusted until a particular oil droplet is suspended. The value V that suspends that specific oil droplet can then be measured.

By repeating the experiment multiple times with differently sized oil droplets and recording the potential difference used, the charge of each oil droplet can be determined as small integer multiples of a certain base value of electronic charge. It is proposed that this base value is the elementary electric charge e.

In this experiment, the mass of the oil droplet is not measured directly using a scale. Instead, it is calculated after the electric field is removed, causing the oil droplets to fall. They quickly reach a terminal velocity which may be measured using a microscope and stopwatch. The weight of an oil droplet is found by timing its fall at terminal speed over a standard distance, when the potential difference across the plates is zero.

Fig. 7.2 shows the relationship between the weight *W* of oil droplets and the time *T* taken by the oil droplets to fall 1.00 mm in air.

Fig. 7.2

The results shown in Fig. 7.3 were obtained with a Millikan apparatus.

For each oil droplet, the experimenter measured *V* across the plates at which the droplet was observed to be stationary. The distance between the plates was 4.42 mm.

The experimenter also measured the time *T* for the droplet to fall 1.00 mm in air at terminal speed after switching off the potential difference across the plates.

V / V	T / s	W / 10^{-14} N	Q / 10^{-19} C
770	11.2	2.9	1.66
230	10.0	3.4	6.53
1030	9.4	3.7	1.59
470	7.6		
820	6.9	5.9	3.18
395	6.2	7.0	7.83

Fig. 7.3

At terminal velocity, the gravitational force is balanced by the drag force, F_D, which is given by the following equation,

$$F_D = 6\pi \eta r v$$

where η is the coefficient of viscosity of the fluid and r, the radius of the oil droplet.

The coefficient of viscosity of air at room temperature is 1.8×10^{-5} kg m^{-1} s^{-1}.

(a) **(i)** Besides the elementary charge, state another fundamental constant that Millikan's oil drop experiment helped in determining its value.

.... [1]

(ii) Explain why the space housing the oil droplets between the metal plates should not be a vacuum.

....

.... [1]

(b) **(i)** Compute the missing values in Fig. 7.3.

W = ... x 10^{-14} N

Q = ... x 10^{-19} C [3]

(ii) When determining the value of Q in **(b)(i)**, explain why it is reasonable to neglect the upthrust of the oil droplet.

....

.... [1]

(iii) Using Fig. 7.3, determine, to four significant figures, the value of the elementary charge *e* from this experiment.

e = ………………….. x 10^{-19} C [2]

(c) **(i)** Measuring the terminal velocity of the droplet using the microscope and stopwatch can be difficult.

Suggest an instrument that can be used to make this measurement more easily.

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

(ii) Suggest why the oil droplets reach terminal velocity so quickly.

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

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

(iii) Calculate the radius of the oil droplet for the last row in Fig. 7.3.

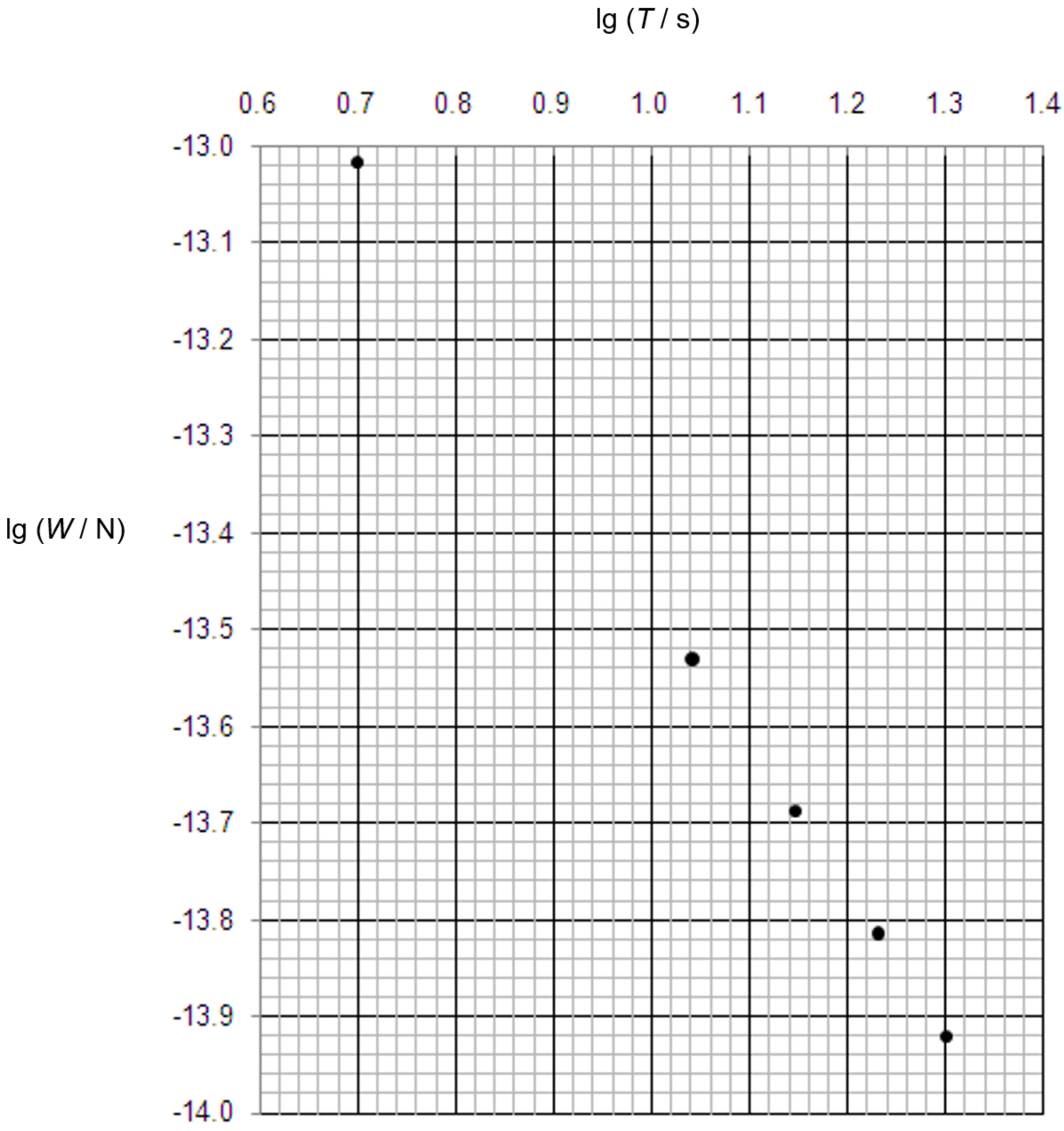
radius = ……………………… m [3]

(d) It is thought that, when the potential difference between the plates is zero, the weight W of an oil droplet varies with time, T, of its fall (at terminal speed over a standard distance) according to the equation

$$W = aT^{b} \qquad \text{----------} \qquad (1)$$

where a and b are constants.

Some data from Fig. 7.2 are used to plot the graph of Fig. 7.4



Fig, 7.4

(i) Use Fig. 7.2 to determine lg (W / N) for T = 8.0 s.

lg (W / N) = ... [1]

(ii) On. Fig. 7.4,

1. plot the point corresponding to T = 8.0 s, [1]

2. draw the line of best fit for the points. [1]

(iii) Use the line drawn in **(d)(ii)** to determine the constant b in equation (1).

b = ... [2]

(iv) Deduce, from your value of b in **(d)(iii)**, how the weight W of oil drop would depend on its terminal speed v.

[2]

End of paper

Solution for 2025 SAJC Prelim Paper 2

1 **(a)** By Principle of Conservation of Momentum, total momentum of toy car and exhaust gas remains constant since no net external force acts on the system. [1]

(Since momentum is a vector quantity), exhaust gas gains backward momentum, hence toy car gains forward momentum. [1]

Rate of change of momentum of car is the force rocket produces on car. [1]

(b) **(i)** **1.** Any indication of calculating gradient of tangent at 2.0s [1]
a = 2.8 m s^{-2} (accept: range 2.6 to 3.1 m s^{-2}) [1]

2. Net force = ma
Forward force – resistive force = (0.440)(2.8)
4.6 – resistive force = (0.440)(2.8) [1]
resistive force = 3.368 = 3.4 N [1]

(ii) As v increases, gradient of v-t graph, which is the acceleration, decreases. [M1]
(Mass of car is also decreasing.)
Since forward force is constant (at 4.6 N), resistive force must be increasing (so that net force is decreasing). [A1]

(c) From Fig. 1.2, acceleration due to rocket engine is approximately 8.89 m s^{-2}. This is less than gravitational acceleration of 9.81 m s^{-2}. [M1]

This means that the rocket engine is unable to propel the car vertically at t = 0. [A1]

However, as the force by rocket engine is constant (at 4.6 N) and car is losing mass (continuously as exhaust gases are produced), eventually acceleration due to rocket force > 9.81 m s^{-2} (or force > weight) and the car will be lifted off. [B1]

2 **(a)** For a system in rotational equilibrium, sum of clockwise moments about any point equals sum of anticlockwise moments about the same point [1]

(b) **(i)** Taking moment about the pivot, [1]

$2.6 \times 0.4 = (4.0 - U) \times 0.4$ [1]

U = (4.0 − 2.6)

= 1.4 N

(ii) $U = \rho g V$ and $A = V / h$ [1]

or

$p = h\rho g$ and $A = U / p$

or

$A = U / h\rho g$

$A = 1.4 / (0.10 \times 1.0 \times 10^3 \times 9.81)$

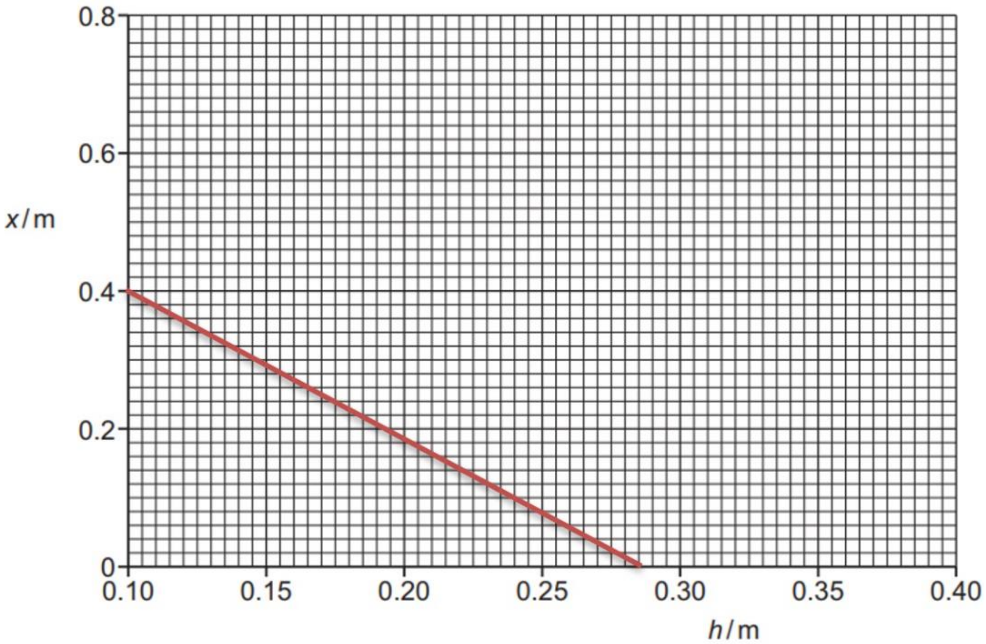
$= 1.43 \times 10^{-3}$ m^2

$= 1.4 \times 10^{-3}$ m^2 [1]

(c) line starting at (0.10, 0.40) [1]

straight line with negative gradient [1]

line ending at (0.28 to 0.29, 0) [1]



3 **(a)** **(i)** M = - gradient / G [1]
Proper substitution of values to find gradient = 5.9×10^{15} [1]

(ii) $GMm/r^2 = mr\omega^2$
$r^3 = (6.67 \times 10^{-11})(8.8 \times 10^{25})(0.72 \times 24 \times 60 \times 60)^2 / (4\pi^2)$
$r = 8.32 \times 10^7$ m [1]

To move satellite to infinity, GPE + KE + ΔE = 0
ΔE = - GPE – KE
= $-(-GMm/r) - \frac{1}{2} mv^2$ [1]
= $(6.67 \times 10^{-11})(8.8 \times 10^{25})(1200)/(8.32 \times 10^7) - \frac{1}{2} (1200)(8400^2)$
= 4.23×10^{10} J [1]

(b) At lower orbit (smaller *r*), total energy decreases / becomes more negative because $E_T = -GMm/(2r)$. [1]

Thrust must be directed opposite to the satellite's velocity, because the thrust must do negative work on the satellite to cause the required decrease in its total energy. [1]

4 **(a)** Taking downslope as positive, $mg \sin \theta - T = ma$ [1]

At equilibrium position: $mg \sin \theta - T = 0$
$mg \sin \theta - ke = 0$
$mg \sin \theta = ke$ [1]

At further extension x: $mg \sin \theta - k(e+x) = ma$
$mg \sin \theta - ke - kx = ma$
$ke - ke - kx = ma$ [1]
$a = -\frac{k}{m}x$

(b) <u>k and m are constants</u>, therefore a is proportional to x. [1]
<u>Negative sign</u> shows that a is always opposite to x [1]

(c) $v = \pm\, \omega\sqrt{x_0^2 - x^2}$

when $v = 0.25\, v_0$, $0.25v_0 = \omega\sqrt{x_0^2 - x^2}$
$0.25(x_0\omega) = \omega\sqrt{x_0^2 - x^2}$ [1]
$0.25(3.0) = \sqrt{3.0^2 - x^2}$
$x^2 = 8.25$
$x = 2.87 = 2.9$ cm [1]

(d) **(i)** The <u>driving frequency of the oscillator is equal to the natural frequency</u> of the mass-spring system, resulting in <u>resonance</u>. [1]

(maximum energy is transferred to the system) and the mass-spring system oscillates with <u>maximum amplitude</u>, [1]

(ii) $a_0 = x_0\omega^2 = (0.060)(2\pi \times 1.2)^2 = 3.41 = 3.4$ m s^{-2} [1]

5 **(a)** current (through a conductor is directly) proportional to potential difference (across the conductor) or vice versa
(provided that) temperature (of conductor remains) constant [1]

(b) **(i)** $R = \rho L / A$
$\rho = (18 \times 7.2 \times 10^{-8}) / 0.94 = 1.4 \times 10^{-6}\ \Omega$ m [1]

(ii) current in the battery: increase [1]
voltmeter reading: decrease [1]

(iii) cross marked on the resistance wire to right of the arrowhead of S, but not touching the right-hand end of the resistance wire [1]

(c) **(i)** $I = Anvq$
$q = 0.93 / [(7.2 \times 10^{-8}) \times (9.0 \times 10^{28}) \times (1.3 \times 10^{-3})]$
$q = 1.1 \times 10^{-19}$ C [1]

(ii) charge / q (value) is below 1.6×10^{-19} (C) [1]
or
charge cannot be below 1.6×10^{-19} (C)
or
(the charge carriers / q) should have a charge of 1.6×10^{-19} (C)

(d) Before t_1 / when current constant, the (total) resistance is constant

At t_1 / when current increases, the (total) resistance decreases (due to decrease of external resistance)

After t_1, temperature (of lamp) increases so the resistance of the lamp increases (so total resistance increases so the current in the ammeter decreases)
[3]

6 **(a)** **(i)** 10.0 eV electron has sufficient energy to excite mercury atom from ground state to energy level of –1.57 eV (because –1.57 – (–10.38) = 8.81 eV).

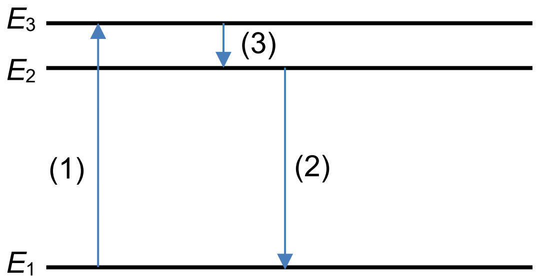
As atom de-excites from –1.57 to –5.74 eV, a photon is emitted. [1]

$$\frac{hc}{\lambda} = [-1.57 - (-5.74)] \times (1.6 \times 10^{-19})$$

$$\lambda = \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{6.672 \times 10^{-19}}$$

$$\lambda = 2.98 \times 10^{-7}\,\text{m}$$ [1]

(ii)



(iii) The phosphor atom absorbs a single high-energy UV photon, but it de-excites in multiple, smaller steps (or 2 steps). (Hence the emitted photons have less energy and longer wavelengths.) [1]

(b) **(i)** An incident photon transfers its entire energy (, given by E = hf,) to a single electron (on the metal surface). (note: emphasis is one-to-one, cannot accept photons) [1]

Part of this energy is used by the electron to overcome the work function of the metal. The remaining energy is converted into the (maximum) kinetic energy of the emitted photoelectron. [1]

(ii) Photon energy: E = hc / λ = $(6.63 \times 10^{-34})(3.00 \times 10^{8}) / (310 \times 10^{-9}) = 6.42 \times 10^{-19}$ J
Work function: Φ = $2.28 \times 1.60 \times 10^{-19} = 3.65 \times 10^{-19}$ J [1 for E or Φ]
KE_{max} = E − Φ = $(6.42 \times 10^{-19}) - (3.65 \times 10^{-19}) = 2.77 \times 10^{-19}$ J [1]

(c) **(i)** KE = $p^2/2m$
p = sqrt $[2(9.11 \times 10^{-31})(2.77 \times 10^{-19})] = 7.10 \times 10^{-25}$ kg m s^{-1} [1]

de Broglie wavelength: λ = h/p = $6.63 \times 10^{-34} / (7.10 \times 10^{-25}) = 9.34 \times 10^{-10}$ m. [1]

(ii) A pattern is formed because the electron's wavelength is of the same order of magnitude as the atomic spacing of about 10^{-10} m. [1]

(iii) Electrons with lower kinetic energy have longer wavelengths and are diffracted more (or range of wavelengths and range of angles of diffraction) [1]

This overlapping of many patterns causes the observed pattern to be smeared or blurred (sharp inner ring due to electrons with max KE). [1]

7 **(a)** **(i)** Planck's constant. [1]

(ii) For the oil droplets to acquire negative charges, electrons need to be removed from air molecules to attach to them. [1]

OR

Air is needed for the oil droplets to experience viscous force to acquire a terminal velocity (for the determination of the droplet's mass). [1]

(b) **(i)** Reading from the graph, $W = 5.1 \times 10^{-14}$ N [1]

$\frac{QV}{d} = W \quad \Rightarrow \quad Q = \frac{Wd}{V}$ [1]

$= \frac{(5.1 \times 10^{-14})(0.00442)}{470}$

$= 4.80 \times 10^{-19}$ C [1]

(ii) The density of air is very small (or 1/800) when compared to that of oil. [1]

(iii) $\frac{(1.66 + 6.53 + 1.59 + 4.80 + 3.18 + 7.83) \times 10^{-19}}{1 + 4 + 1 + 3 + 2 + 5}$ [1]

$= 1.599 \times 10^{-19}$ C (to 4 sig. fig.) [1]

(c) **(i)** Stroboscope / light gates / video camera [1]

(ii) The very small weight (mass) is quickly balanced out by the (effects of) air resistance. [1]

(iii) At terminal velocity, $F_D = W$

$6\pi \eta r v = 7.0 \times 10^{-14}$ [1]

Terminal velocity, $v = \frac{0.00100}{T} = \frac{0.00100}{6.2} = 0.0001613$ m s^{-1} [1]

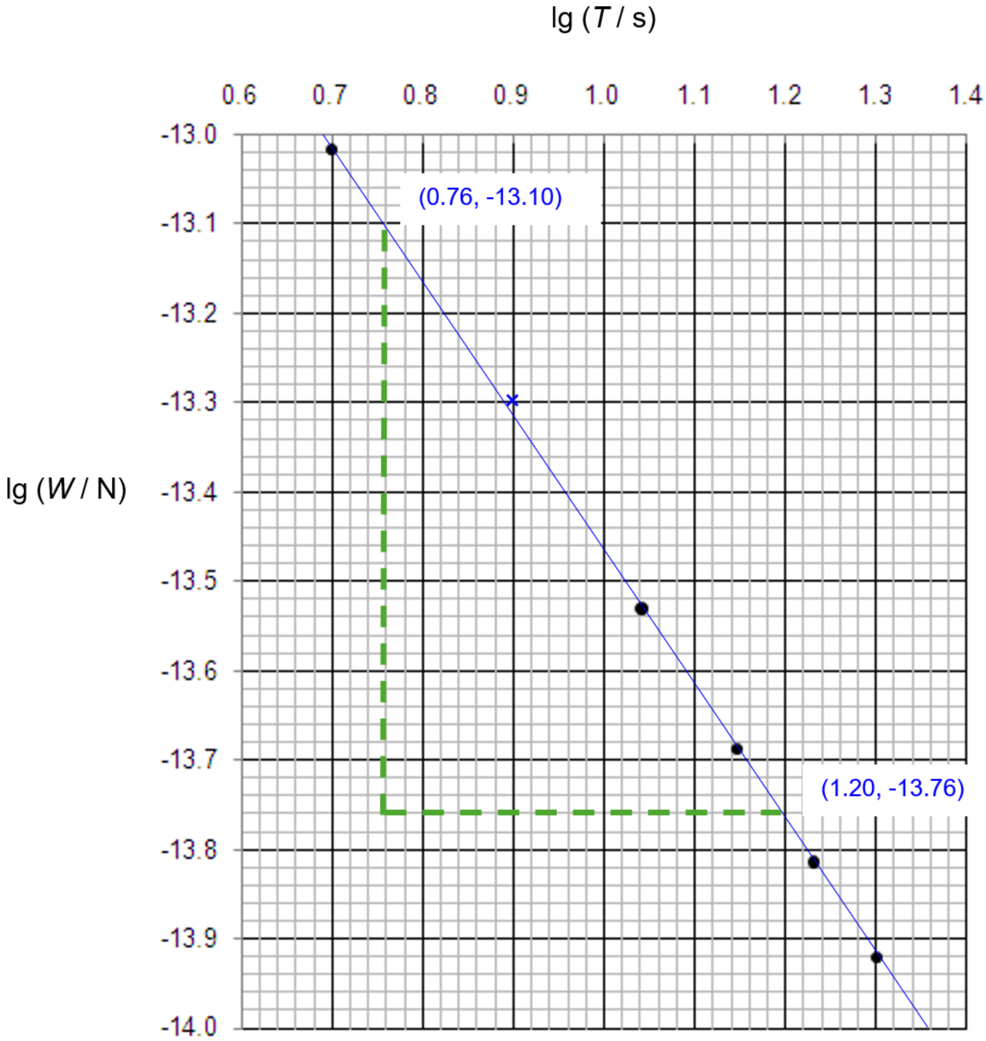
$r = \frac{7.0 \times 10^{-14}}{6\pi (1.8 \times 10^{-5})(0.0001613)}$

$= 1.28 \times 10^{-6}$ m [1]

(d) **(i)** When $T = 8.0$ s, $W = 4.7 \times 10^{-14}$ N.

lg (W / N) = -13.33 [1]

(ii) Correct plot [1]
Accurate line of best fit [1]



(iii) Gradient = b $= \dfrac{-13.10 - (-13.76)}{0.76 - 1.20}$ [1]

$= -1.50$ (range: -1.4 to -1.6) [1]

(iv) $W = aT^{-1.5} = a(\frac{1}{T})^{1.5}$

$v = \frac{d}{T}$, (where *d* is the 1.00 mm fall by the droplet.) [1]

Since <u>*a* and *d* are constants</u>,
$W \propto v^{1.5}$ [1]