HWA CHONG INSTITUTION
JC2 Preliminary Examination
Higher 2

CANDIDATE NAME		**CT GROUP**	23S
CENTRE NUMBER		**INDEX NUMBER**	

PHYSICS **9749/02**

Paper 2 Structured Questions **10 September 2024**

2 hours

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your Centre Number, index number and name in the spaces at the top of this page.
Write in dark blue or black pen on both sides of the paper.
You may use a soft 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.

The number of marks is given in brackets [ ] at the end of each question or part question.
You are reminded of the need for good English and clear presentation in your answers.

For Examiner's Use		
Paper 2		
1		**6**
2		**11**
3		**5**
4		**8**
5		**9**
6		**10**
7		**9**
8		**22**
Deductions		
Total		**80**

Data	
speed of light in free space,	$c = 3.00 \times 10^{8}$ m s^{-1}
permeability of free space,	$\mu_0 = 4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space,	$\varepsilon_0 = 8.85 \times 10^{-12}$ 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	$W = p\,\Delta V$
hydrostatic pressure	$p = \rho g h$
gravitational potential	$\phi = -\frac{Gm}{r}$
temperature	T/K = T/ °C + 273.15
pressure of an ideal gas	$P = \frac{1}{3}\frac{Nm}{V}\langle c^2 \rangle$
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.	$v = v_o \cos \omega t$ $= \pm\omega\sqrt{(x_o^2 - x^2)}$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \ldots$
resistors in parallel	$1/R = 1/R_1 + 1/R_2 + \ldots$
electric potential	$V = \frac{Q}{4\pi\varepsilon_0 r}$
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	$x = x_o \exp(-\lambda t)$
decay constant	$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$

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1 Fig. 1.1 shows an incident photon of momentum 7.30×10^{-22} kg m s^{-1} colliding with a stationary electron.

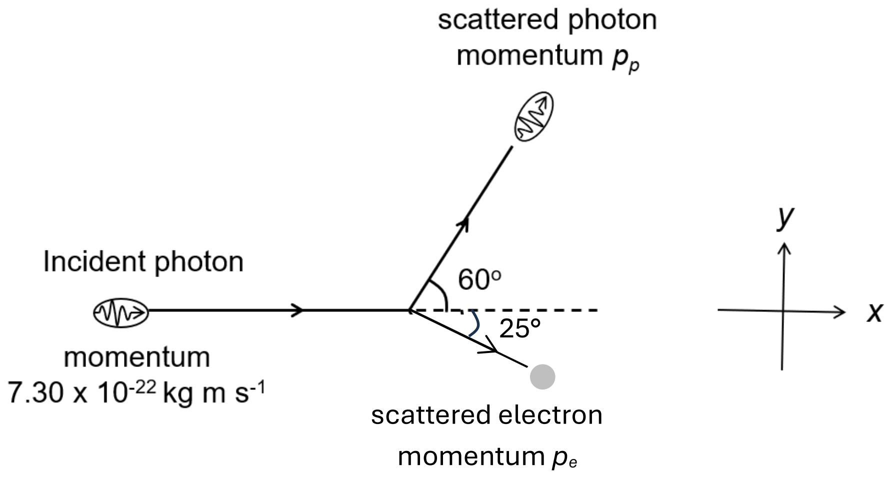

Fig. 1.1

After the collision, the photon is scattered off through an angle of 60° and has a momentum p_p. The electron gets scattered off at an angle of 52° with a momentum p_e. Their scattering angles are measured with respect to the path of the incident photon.

(a) Explain why linear momentum is conserved in this collision for the system of photon and electron.

....

.... [1]

(b) Consider the photon and electron as a system.

(i) State the total momentum of the system along the

1. *x*-direction,

momentum in *x*-direction = ... kg m s^{-1} [1]

2. *y*-direction.

momentum in *y*-direction = ... kg m s^{-1} [1]

(ii) Applying the principle of conservation of momentum in both directions, determine the momentum p_e of the electron after the collision.

momentum p_e of the electron = ...kg m s^{-1} [3]

[Total: 6]

2 **(a)** State Newton's law of gravitation.

....

....

....[2]

(b) Fig. 2.1 shows a hypothetical stable three-body system. The system comprises of three identical masses A, B and C orbiting about a common centre of rotation O.

The radius of orbit is 7.60×10^8 m.

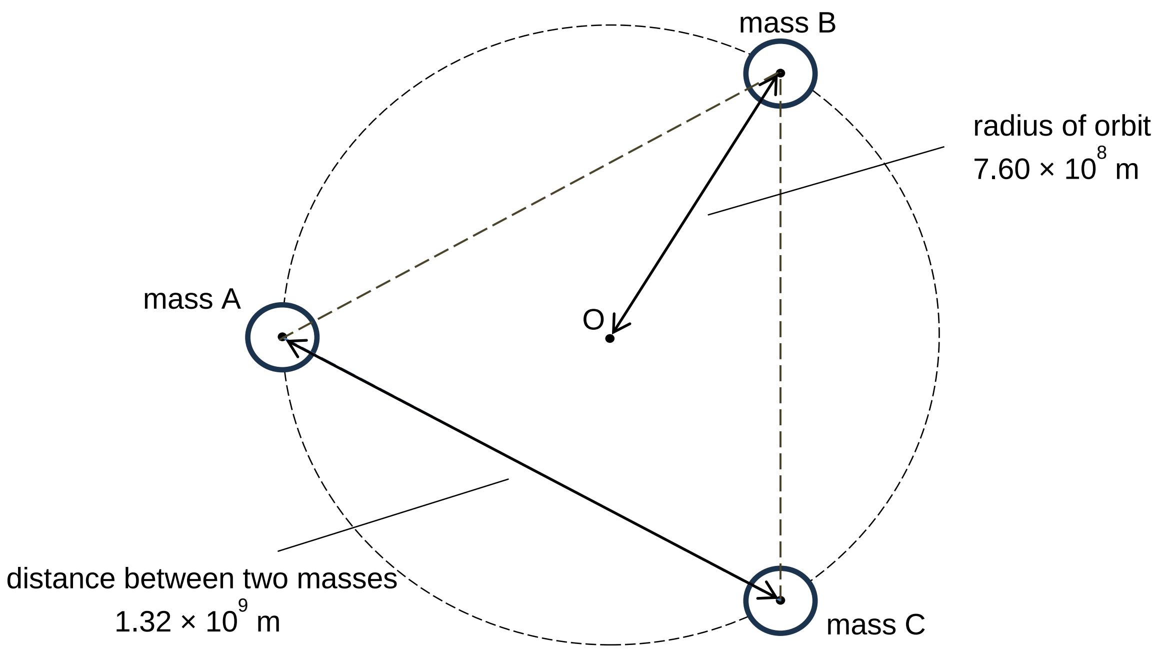

Fig 2.1

The masses are equally distributed along the circular path of orbit, such that the distance between any two masses is always the same.

The distance between the centres of any two masses is 1.32×10^9 m. Each mass is 6.20×10^{24} kg.

(i) Show that the resultant force on mass A is 2.55×10^{21} N.

[2]

(ii) Hence, calculate the period of orbit of the three masses about O. Explain your working.

period = ... s [3]

(iii) Explain why gravitational potential near this system of three masses is always negative.

....

....

....

.... [2]

(iv) Calculate the gravitational potential energy of this system of three masses.

gravitational potential energy = ... J [2]

[Total: 11]

3 **(a)** Describe what is meant by a *polarised* wave.

....

....

....

....[2]

(b) A narrow beam of light is incident on three ideal polarising filters A, B and C as illustrated in Fig. 3.1.

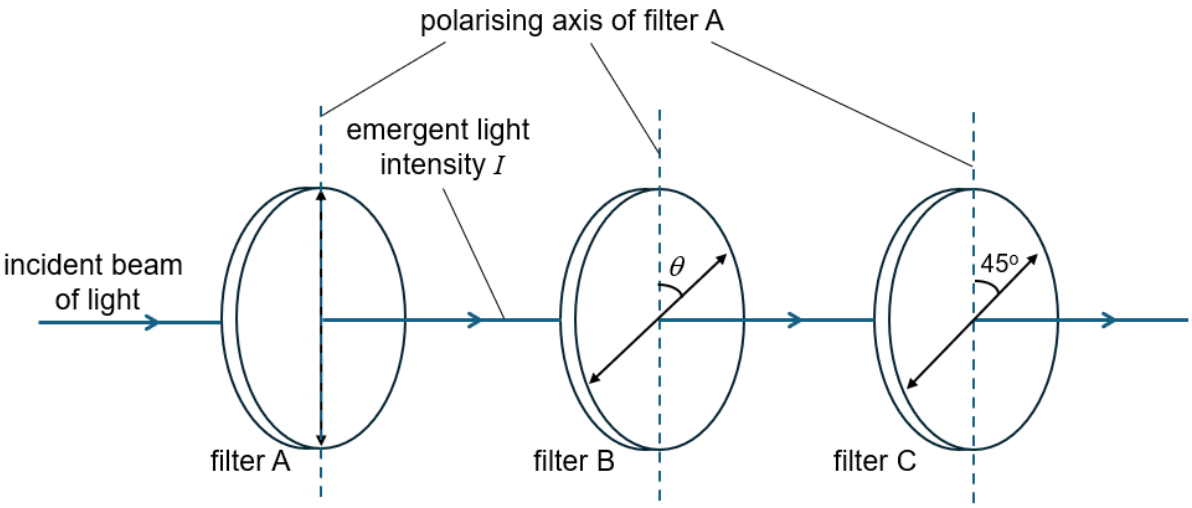

Fig. 3.1

The emergent beam after passing through filter A has an intensity of I.

Filter C is fixed in position such that its polarising axis is at an angle of 45° from the polarising axis of filter A.

Filter B is allowed to rotate. θ is the angle between the polarising axes of filter A and B.

(i) Polarising filter B is rotated from θ = 0° to θ = 180°.

Besides θ = 90°, there is another angle θ where the intensity of light emergent from filter C is zero. State the value of this angle.

θ = ... ° [1]

(ii) Filter B is adjusted such that $\theta = 60°$.

Determine the intensity of light, in terms of I, that emerges from filter C.

intensity = ... I [2]

[Total: 5]

4 An electron is travelling at right angles to a uniform magnetic field of flux density 1.2 mT, as illustrated in Fig. 4.1.

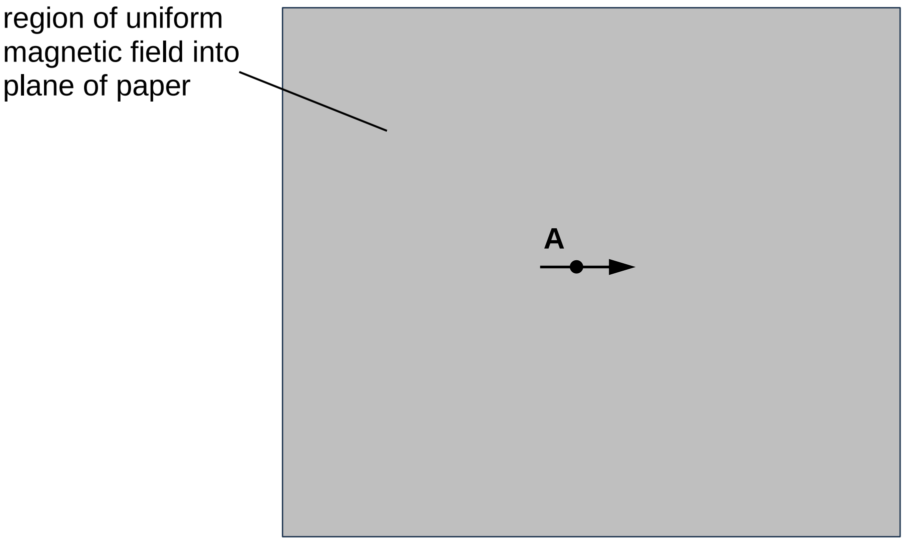

Fig. 4.1

The magnetic field is directed into the plane of the paper.

When the electron is at A, its velocity is 2.8×10^{7} m s^{-1} in the direction shown. This is normal to the magnetic field.

(a) **(i)** On Fig. 4.1, sketch the path of the electron, assuming that it does not leave the region of the magnetic field. [1]

(ii) Show that the radius of the path of the electron is 13 cm.

[2]

(b) **(i)** A uniform electric field is applied in the same region so that the electron now moves undeflected through the magnetic field.

1. Draw on Fig. 4.1 the direction of the electric field. Label your arrow **E**.

2. Determine the magnitude of the electric field strength.

magnitude of electric field strength = ... N C^{-1} [3]

(ii) If however, the direction of the uniform electric field is in the same direction as the magnetic field, describe the shape of the resultant path of the electron.

You may draw a sketch to illustrate the path if you wish.

....

.... [2]

[Total: 8]

5 Fig. 5.1 shows an a.c. power supply connected to three resistors.

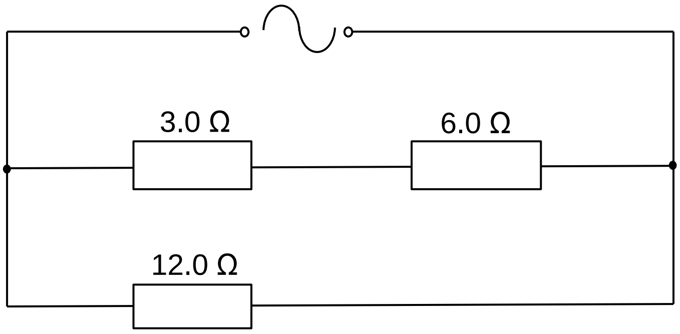

Fig. 5.1

The variation with time t of the voltage V of the power supply is given by the expression:

$$V = 15 \sin 628t$$

(a) Determine, for the power supply,

(i) the period T of the a.c. voltage,

T = ... s [1]

(ii) the root-mean-square (r.m.s.) voltage V_{rms},

V_{rms} = ... V [1]

(iii) the peak current I_0 from the power supply,

I_0 = ... A [2]

(iv) the mean power <*P*> dissipated in the resistor of resistance 6.0 Ω.

<*P*> = ... W [2]

(b) Use your answers in **(a)** to sketch, on the axes of Fig 5.2, the variation with time *t* of the power *P* transferred in the 6.0 Ω resistor, for two complete periods of the alternating potential difference. Label your axes and indicate relevant values.

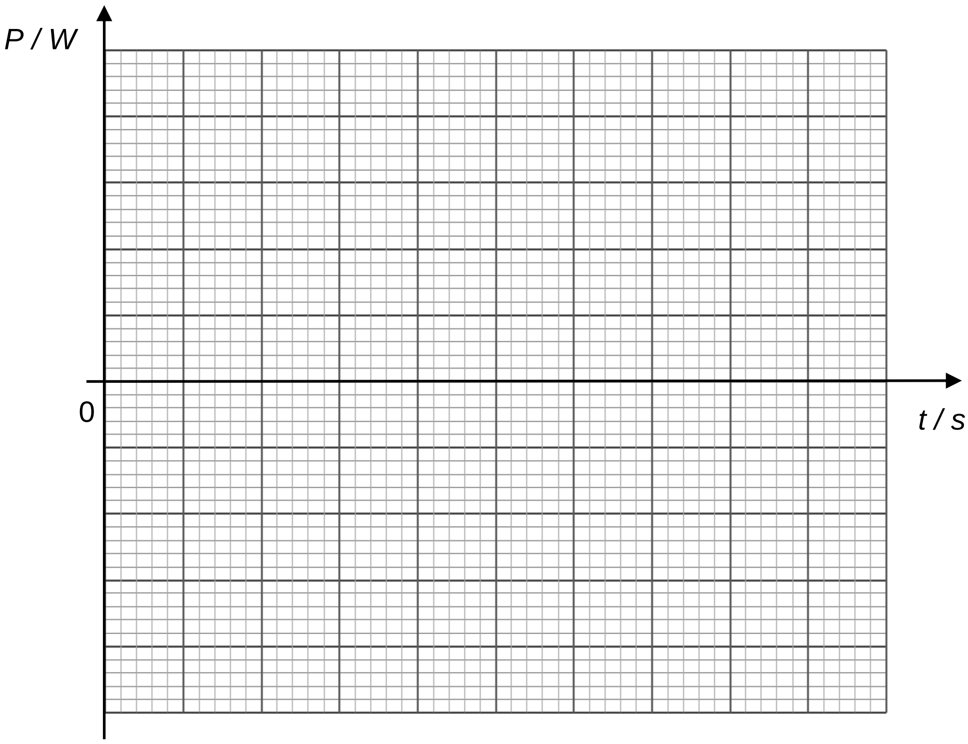

Fig. 5.2

[3]

[Total: 9]

6 Fig 6.1 shows the set-up of the Davisson and Germer experiment which was originally designed to measure the energy of electrons scattered from a nickel metal target.

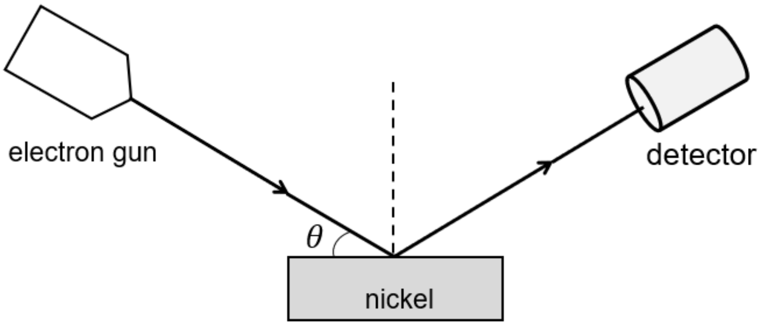

Fig. 6.1

Electrons are accelerated from rest through a potential difference of 100 V in the electron gun.

The accelerated beam of electrons, which emerge from the electron gun, is then directed at an angle θ with respect to the surface of the nickel target.

Electrons that are scattered from the nickel are collected by a detector which measures the rate I at which the charges are collected.

(a) Consider a single electron that is being accelerated inside the electron gun.

(i) Calculate the final speed attained by the electron before emerging from the gun.

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

(ii) Deduce the corresponding de Broglie wavelength of the electron.

de Broglie wavelength = ... m [2]

(b) The nickel metal has a regular crystalline geometry. Two horizontal atomic planes in the nickel metal, separated by distance *d*, are shown in Fig 6.2.

The electrons in the electron beam from the electron gun can take different paths to the nickel and then to the detector. Two possible paths, path 1 and path 2, are illustrated. Both paths make the same angle θ with respect to the planes.

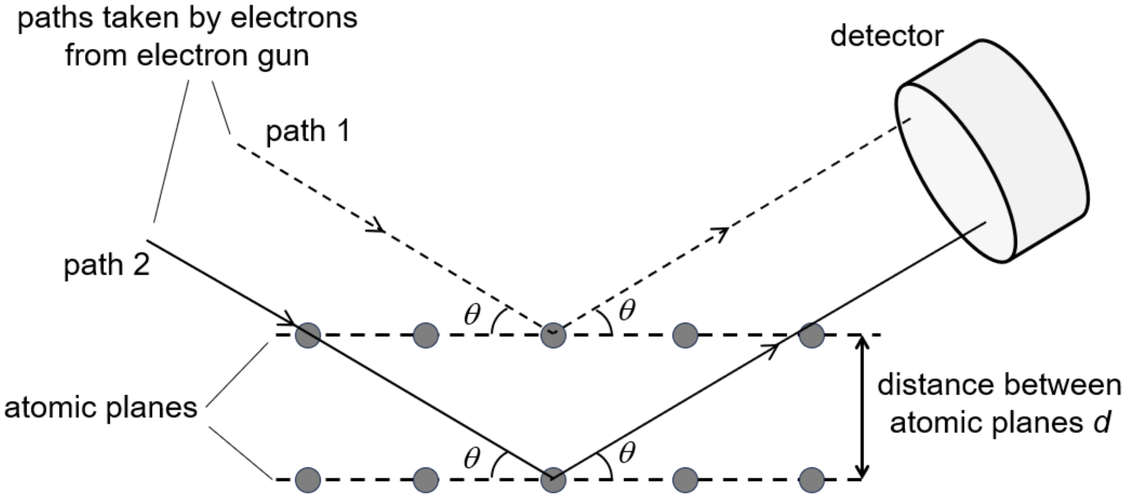

Fig. 6.2 (not to scale)

(i) Determine an expression, in terms of *d* and θ, for the path difference between the electrons of path 1 and path 2.

path difference = ... [1]

(ii) In a particular experiment, the angle θ that the electron beam makes with the atomic planes is kept constant while the accelerating voltage V of the electron gun is slowly increased.

Fig 6.3 shows the graph of the rate I at which the charges are detected against the square root of the accelerating voltage $\sqrt{V}$ for the experiment. The rate of charges detected fluctuates between a series of maximum and minimum values of I as V is increased.

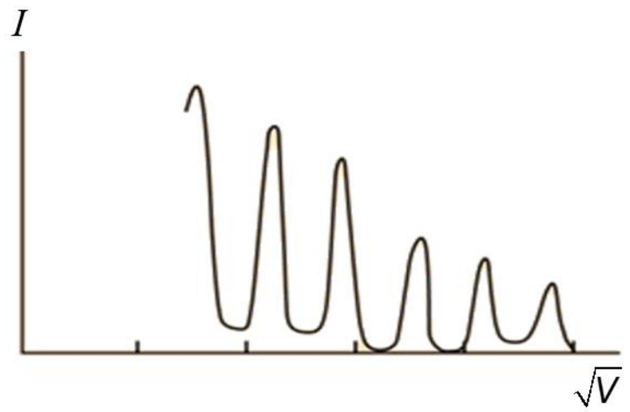

Fig 6.3

1. Describe and explain how the de Broglie wavelength of the electrons emerging from the electron gun changes as the accelerating voltage is increased.

....

....

....

....[2]

2. Hence, explain why the graph in Fig. 6.3 shows maximum values of I being detected at only certain accelerating voltages.

....

....

....

....

....

....[3]

[Total: 10]

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7 Potassium-42 is a radioactive isotope of potassium that is artificially produced in the laboratories for use in medical research studies involving potassium metabolism.

The nuclide Potassium-42 ($^{42}_{19}K$) undergoes radioactive decay to become Calcium-42 ($^{42}_{20}Ca$), a stable nuclide. A radioactive sample contains N_0 atoms of Potassium-42 at time $t = 0$. Fig. 7.1 shows the variation with time t of the number N of atoms of Potassium-42.

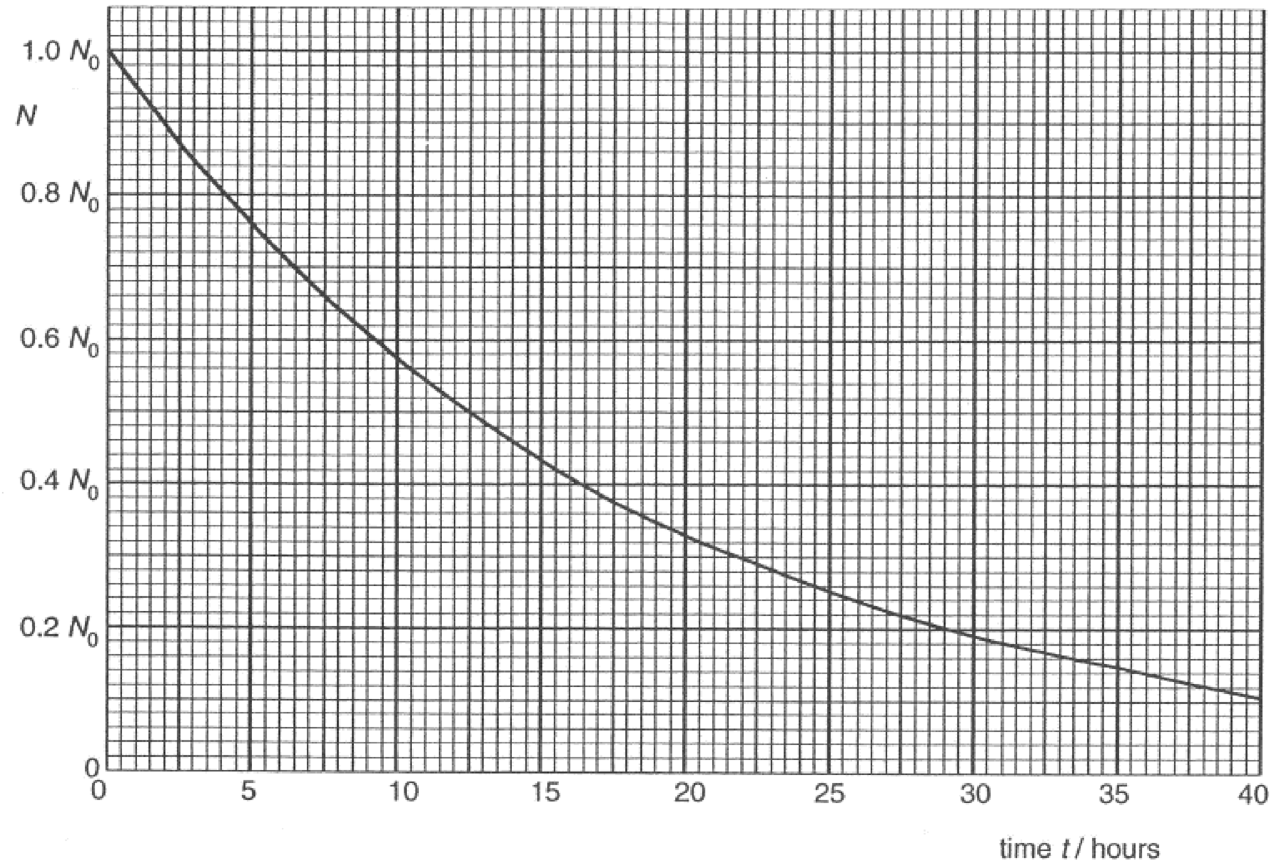

Fig. 7.1

(a) Define *half-life* of a radioactive sample.

....[1]

(b) Explain what is meant by the *activity* of a radioactive sample.

....[1]

(c) **(i)** Use Fig. 7.1 to determine the probability per unit time that Potassium-42 decays.

probability per unit time = ... s^{-1} [3]

(ii) Determine, in terms of N_0, the activity of Potassium-42 at t = 27.5 hours.

activity = ... N_0 Bq [2]

(d) Fig. 7.2 shows the variation of the logarithm of the activity A with time t for the decay of Potassium-42.

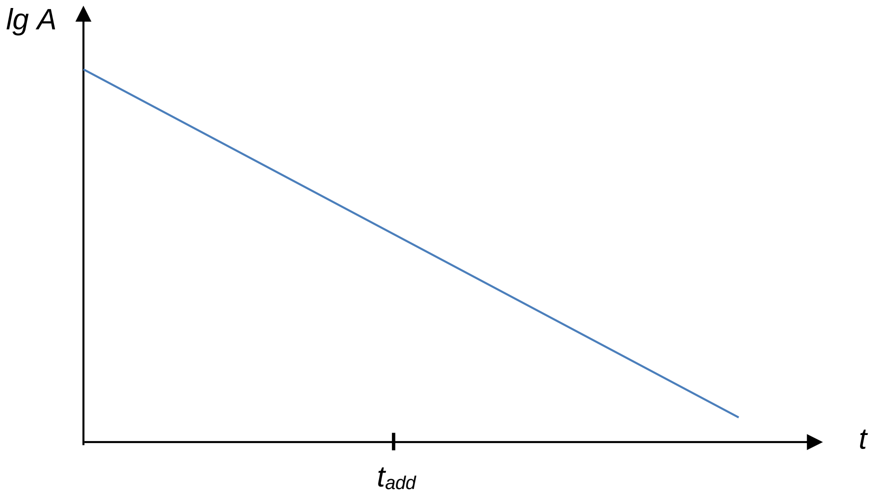

Fig. 7.2

(i) If more Potassium-42 is added to the sample at time t_{add}, sketch on Fig. 7.2 the new variation of the logarithm of A with time t. Label this graph **P**.

(ii) If instead of more Potassium-42, another nuclide of a *very much shorter* half-life were added, sketch also on Fig. 7.2 the new variation of the logarithm of A with time t. Label this graph **Q**. [2]

[Total: 9]

8 Read the passage below and answer the questions that follow.

In the world of competitive cycling, every detail can make a significant difference in a rider's performance. Athletes compete with one another, trying to be a bit better by improving both their bodies and their equipment. Factors such as strategy, equipment efficiency, and physical conditioning all play crucial roles in determining the outcome of races.

Many different types of bicycles exist, with each possessing its own unique strengths. To gain an edge over the competition, bicycle designers are constantly experimenting with different bicycle designs and shapes.

Fig. 8.1 shows the propulsive power *P* required, for 5 different types of bicycles to travel on **flat ground** at different speeds *v.*

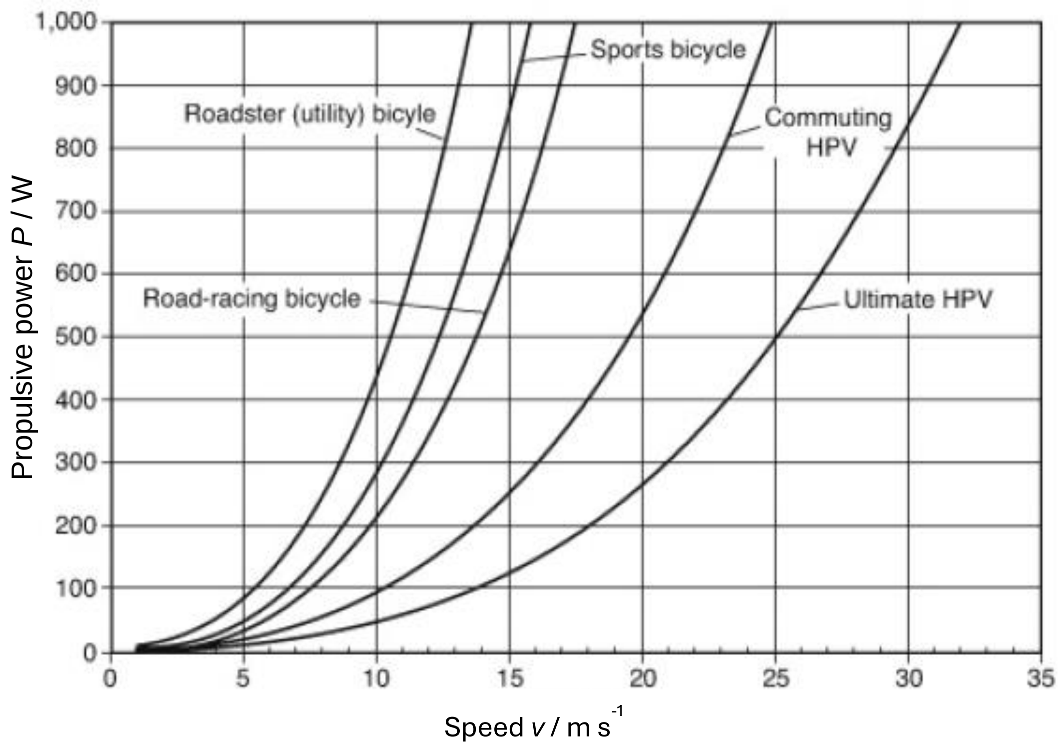

Fig. 8.1

More effort is required to ride fast against the wind or going uphill. A cyclist riding up a slope at a high speed experiences two main forces opposing his motion – slope resistance F_{slope} and air resistance F_{air} .

Slope resistance F_{slope} is related to the steepness of the road. Specifically, F_{slope} refers to the component of the rider (and bicycle)'s weight that acts parallel to the slope. The steepness of a road is commonly referred to as the slope, and is usually expressed as a percentage. Slope is calculated as a fraction ("*rise* over *run*") in which *rise* is the vertical distance and *run* is the horizontal distance. A notable example of a challenging slope is found in the Dirty Dozen bicycle race in Pittsburgh, Pennsylvania. The Canton Avenue hill section of the race is notorious for being one of the steepest in the world, boasting a distance of just 6.4 m, but with a slope of 37%!

Meanwhile, a rider moving at a greater speed experiences greater air resistance F_{air}. For a solo rider, it is suggested that F_{air} is related to the speed v by the equation

$$F_{air} = \frac{1}{2}\rho C_D A v^2$$

where ρ is the air density and the product $C_D A$ is the effective drag area.

For rider safety, the governing body, Union Cycliste Internationale, mandates the use of brakes on bicycles in their events. Brakes can be placed on the front and/or rear wheels of the bicycle, and their effectiveness is limited by the friction F between the wheel and the road.

Theory suggests that F is related to the normal contact force acting at that point N by the equation

$$F = \mu N$$

where μ is the coefficient of friction.

Consequently, both the frictional force acting on the front and rear wheels have different braking efficacy and serve different purposes in assisting the rider to brake effectively.

(a) For a competitive cyclist using an Ultimate HPV bicycle, travelling at constant speed of 25 m s^{-1} on flat ground,

(i) state the propulsive power required.

power = ... W [1]

(ii) Hence, determine the propulsive force provided by the rider.

propulsive force = ... N [2]

(iii) Calculate the effective drag area, $C_D A$ of the cyclist. You may assume that the air density is 1.0 x 10^{-3} g cm^{-3}.

effective drag area, $C_D A$ = ... m^2 [3]

(b) The competitive cyclist in **(a)** takes part in the Dirty Dozen race using the Ultimate HPV bicycle. The combined mass of the cyclist and his bike is 85 kg.

(i) Calculate the slope resistance F_{slope} that the cyclist experiences as he rides up the Canton Avenue hill section.

F_{slope} = ... N [3]

(ii) The cyclist rides up the Canton Ave hill section at a constant speed.

Determine

1. the work done against gravity for this section of the race.

work done = ... J [2]

2. the new propulsive power required by this cyclist if he wishes to maintain a constant speed of 25 m s^{-1} as he climbs the hill.

new propulsive power = ... W [3]

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(c) Fig. 8.3 shows some of the forces acting on the system of cyclist and bicycle as it *brakes*.

The combined weight of the cyclist and his bicycle is W. N_1 and N_2 are the normal contact forces acting on the front and rear wheels, respectively. Consequently, the frictional forces acting on the front and rear wheels are μN_1 and μN_2, respectively.

The centre of mass of the system is located 114 cm above the ground. The rear wheel of the bicycle is located at a horizontal distance of 43 cm from the centre of mass, and the horizontal distance between the centres of both wheels is 107 cm.

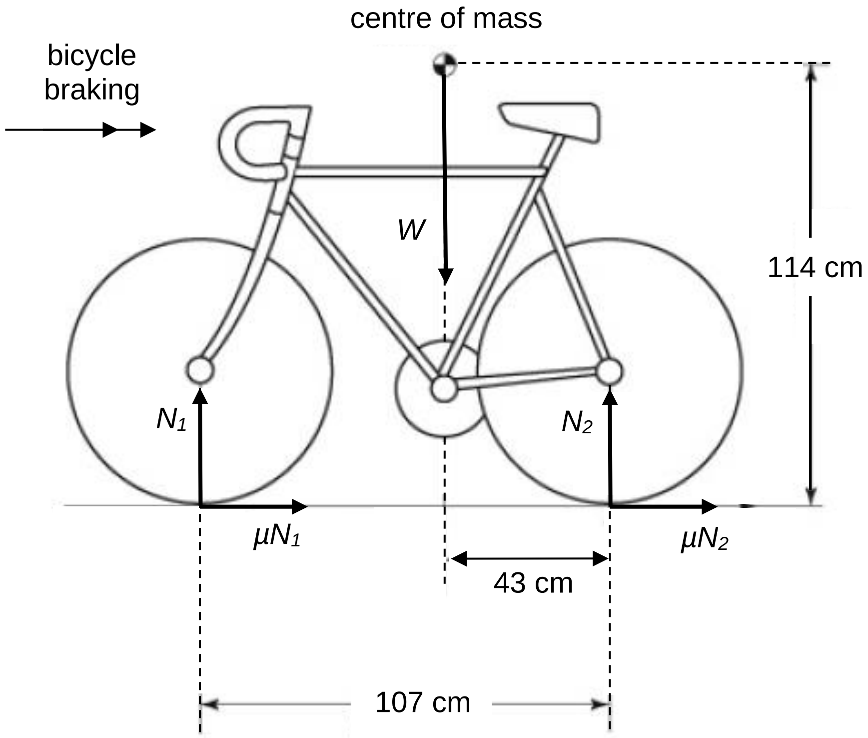

Fig. 8.3

The coefficient of friction μ between the ground and the wheels of the bicycle is 0.37.

(i) Using Newton' second law of motion, determine the magnitude of the cyclist's deceleration.

deceleration = ... m s^{-2} [3]

(ii) Taking moments about the centre of mass, show that

$$N_1 = 0.80\,W.$$

[2]

(iii) Determine the ratio of the deceleration contributed by the front wheel to that contributed by the back wheel.

ratio = ... [1]

(iv) When a cyclist brakes too quickly, his centre of mass will tend to move forward due to inertia.

By considering the torques due to individual forces about the centre of mass, explain why a cyclist will tend to flip forward.

....

....

.... [2]

[Total: 22]

END OF PAPER

Copyright Acknowledgements: Bicycling Science, third edition (David Gordon Wilson, 2004)