OCR
Oxford Cambridge and RSA

Thursday 16 June 2022 – Morning

A Level Physics A

H556/03 Unified physics

A Level Physics Online . com

Time allowed: 1 hour 30 minutes

You must have:
- the Data, Formulae and Relationships Booklet

You can use:
- a scientific or graphical calculator
- a ruler (cm/mm)

Please write clearly in black ink. **Do not write in the barcodes.**

Centre number 8 9 6 2 6 Candidate number 4 3 3 8

First name(s) Lewis

Last name Matheson

INSTRUCTIONS

- Use black ink. You can use an HB pencil, but only for graphs and diagrams.
- Write your answer to each question in the space provided. If you need extra space use the lined pages at the end of this booklet. The question numbers must be clearly shown.
- Answer **all** the questions.
- Where appropriate, your answers should be supported with working. Marks might be given for a correct method, even if your answer is wrong.

INFORMATION

- The total mark for this paper is **70**.
- The marks for each question are shown in brackets **[ ]**.
- Quality of extended response will be assessed in questions marked with an asterisk (*).
- This document has **20** pages.

ADVICE

- Read each question carefully before you start your answer.

Answer **all** the questions.

1 The table shows some data on the planet Venus.

Mass / kg	4.87×10^{24}
Radius / km	6050
Density of atmosphere at surface / kg m^{-3}	65
Period of rotation about its axis / hours	5830

(a) Calculate the magnitude of the gravitational field strength *g* at the surface of Venus.

Give your answer to **3** significant figures.

$$g = \frac{GM}{r^2} = \frac{6.67\times10^{-11} \times 4.87\times10^{24}}{(6050\times10^3)^2} = 8.8745$$

g = ...8.87...... N kg^{-1} **[3]**

(b) Two identical space probes, **A** and **B**, land on a flat surface on Venus.

Probe **A** lands at the north pole. Probe **B** lands on the equator.

Each probe has mass 760 kg and volume 1.7 m^3.

(i) Calculate the centripetal acceleration *a* of probe **B** at the equator due to the rotation of Venus about its axis.

$$a = \omega^2 r \qquad \omega = \frac{2\pi}{T}$$

$$a = \frac{4\pi^2 r}{T^2} = \frac{4\pi^2 \times 6050\times10^3}{(5830\times60\times60)^2}$$

$$= 5.422\times10^{-7}$$

a = ...5.42×10^{-7}...... m s^{-2} **[3]**

(ii) The atmosphere exerts the same upthrust on each probe.

Using your answer to **(a)**, calculate the upthrust acting on each probe.

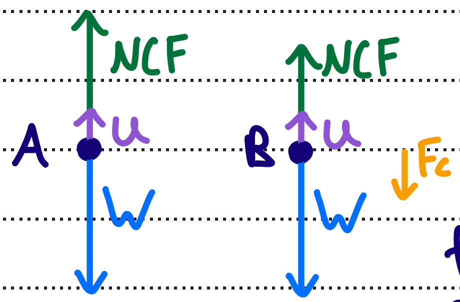
$\rho = \frac{m}{V}$ $m = \rho V = 65 \times 1.7 = 110.5$ kg ✓

Upthrust = weight of fluid displaced = mg ✓

$= 110.5 \times 8.8745 = 980.63$

upthrust = ... 9.8×10^2 ✓ .... N **[3]**

(iii) Explain which probe will experience the greater normal contact force from the surface of Venus.



No centripetal forces required at A ∴ no resultant force. ✓

A resultant force acts towards the centre of Venus at B to provide the centripetal force ✓, therefore the normal contact force is smaller. ✓

[3]

A: NCF = W − U

B: NCF = W − U − F_c

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2 A student investigates the oscillations of a uniform rod of length *L* which is pivoted at the top, as shown in **Fig. 2.1**.

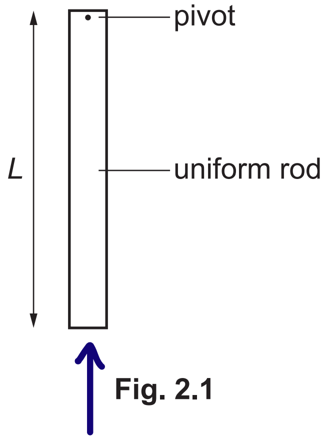


Fig. 2.1

(a) Describe how to determine accurately the period *T* of oscillations of this rod.

Use a stopwatch ✓ to time 10 oscillations and divide by 10 to determine the period. ✓ Time from the equilibrium position with a fiducial marker.

[2]

(b) The relationship between the frequency f of the oscillations of the rod and its length L is

$$f = \frac{1}{2\pi}\sqrt{\frac{3g}{2L}},$$

where g is the acceleration of free fall.

The student varies the length L of the rod and determines the period T for each length.

The student plots a graph of T^2 against L, shown in **Fig. 2.2**. A line of best fit has already been drawn.

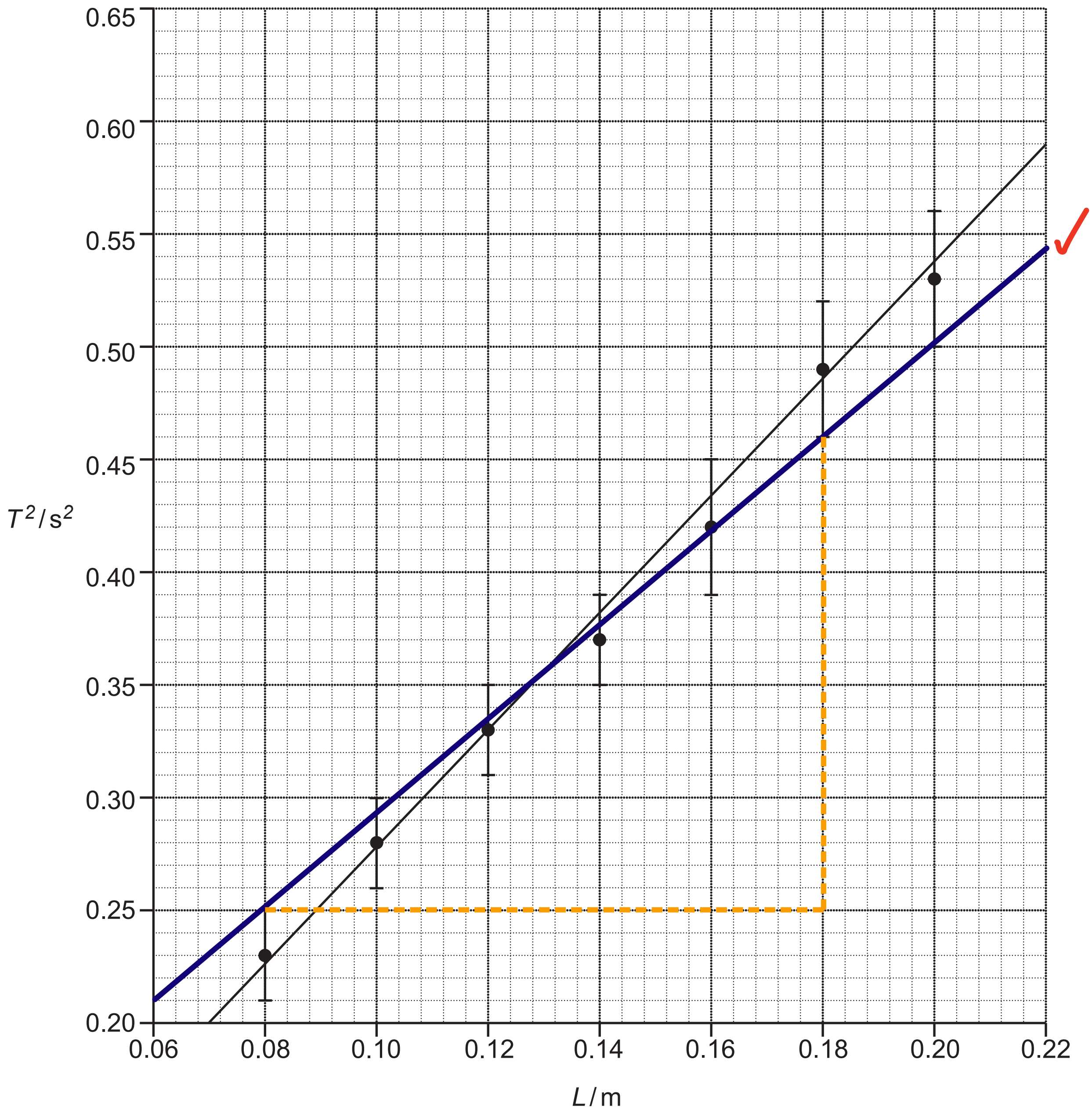


Fig. 2.2

(i) Show that the gradient of the graph is given by the equation

gradient = $\frac{8\pi^2}{3g}$

$f = \frac{1}{2\pi}\sqrt{\frac{3g}{2L}}$ $\quad f^2 = \frac{1}{4\pi^2}\cdot\frac{3g}{2L} = \frac{3g}{8\pi^2 L}$

$f = \frac{1}{T}$ $\quad f^2 = \frac{1}{T^2}$ $\quad \frac{1}{T^2} = \frac{3g}{8\pi^2 L}$ ✓ $\quad T^2 = \frac{8\pi^2}{3g} L$ ✓

$y = m\,x + c$

[2]

(ii) The gradient of the line of best fit on **Fig. 2.2** is 2.64 $s^2 m^{-1}$.

Use this value to determine g.

gradient $= \frac{8\pi^2}{3g}$ $\quad g = \frac{8\pi^2}{3 \times \text{gradient}}$ ✓ $= \frac{8\pi^2}{3 \times 2.64} = 9.969$

g = 9.97 ✓ $m s^{-2}$ **[2]**

(iii) Draw a line of worst fit on **Fig. 2.2**. **[1]**

(iv) Use your line of worst fit to calculate the percentage uncertainty in g.

$\text{gradient}_{worst} = \frac{0.46 - 0.25}{0.18 - 0.08} = 2.1\ s^2 m^{-1}$ ✓

% uncertainty $= \frac{m_{best} - m_{worst}}{m_{best}} \times 100 = \frac{2.64 - 2.1}{2.64}$ ✓ $\times 100$

percentage uncertainty = 20 ✓ % **[3]**

(v) Use the true value of g (9.81 $m s^{-2}$) to evaluate the accuracy of the student's value of g from this experiment. Include a calculation in your answer.

Percentage difference $= \frac{9.969 - 9.81}{9.81} \times 100 = 1.62\%$ ✓

Percentage difference in their final value is less than the percentage uncertainty in their data, therefore the result is accurate. ✓ **[2]**

3 **(a)** In beta-plus decay, a proton decays into three other particles.

Write a nuclear equation for this process.

$$p \rightarrow n + \beta^{+} + \nu_e$$

[2]

(b)* A student, supervised by their teacher, carries out an experiment with three unlabelled radioactive sources.

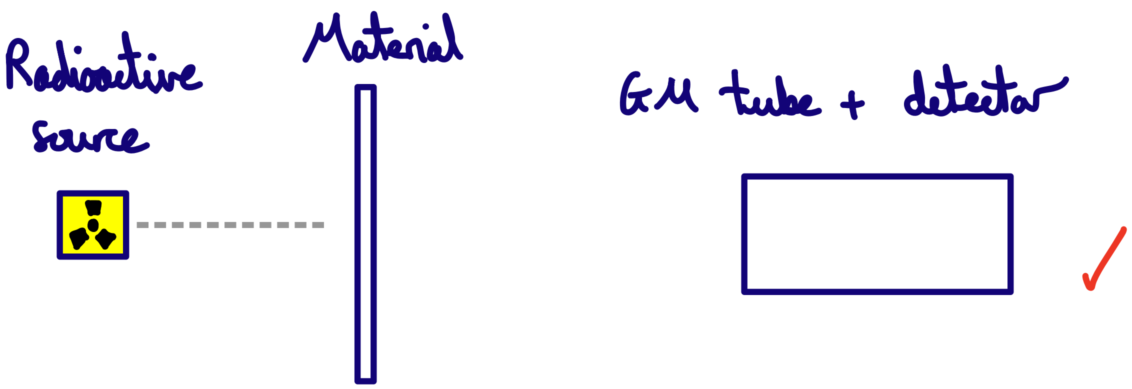
The student is told that each source emits only one type of radiation. One emits gamma rays, one emits beta-minus particles and one emits beta-plus particles.

The student has the following equipment:

- a selection of materials with different thicknesses
- a strong magnet
- a radiation counter (GM tube and counter).

Explain how the student can use this equipment to determine safely which radiation each source emits.

You may use the space below to draw a diagram. **[6]**



Measure the background radiation for several minutes. Subtract this count rate from subsequent readings.

Using tongs to handle the source, clamp the radioactive source pointing away from you. Record the count rate over a fixed period of time for each source.

Record the count-rate for different distances between the source and detector.

Add a thick aluminium sheet between the source and the detector and record the count-rate.

Finally, send the radiation between the N and S poles of a magnet to detect how it is deflected. ✓✓✓

Additional answer space if required

The gamma source will have the longest range in air, beta + will have the shortest due to annihilation with electrons.

Gamma will penetrate aluminium but both beta do not. The gamma is also undeflected by a magnetic field, but β^- deflected the other way to β^+. Fleming's LHR could be used to determine the charge on the particles. ✓✓

4 Astronomers can detect microwave background radiation coming from space in every direction.

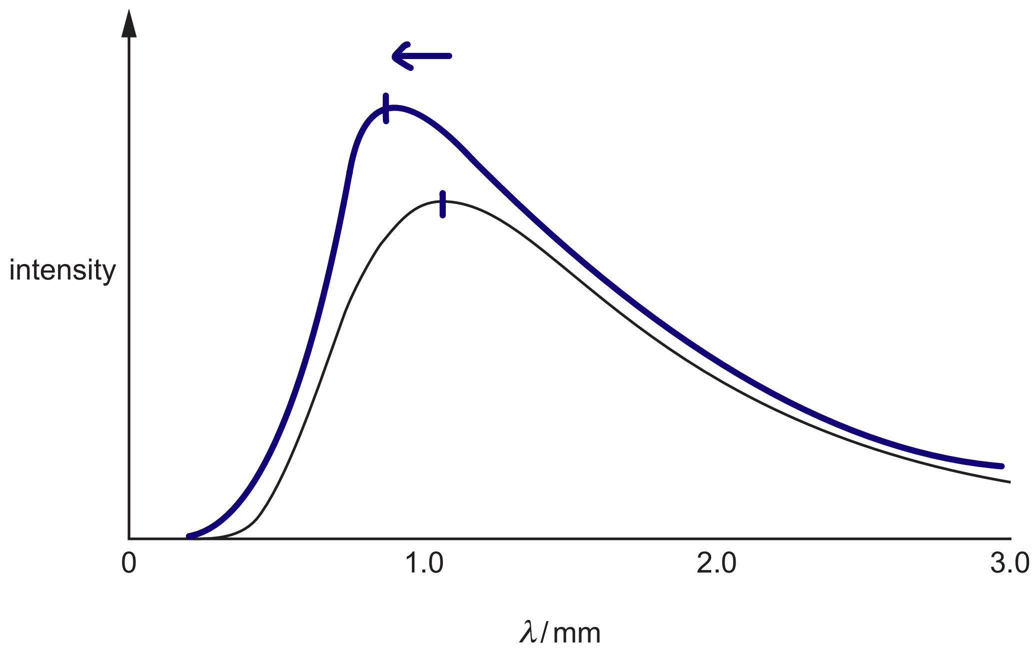
The temperature of this microwave radiation is 2.7 K and its **total** intensity is about 3×10^{-6} W m^{-2}.

(a) Describe the origin of the microwave background radiation.

During the Big Bang the Universe was hot ∴ gamma radiation emitted ✓ As the Universe expanded the wavelength stretched to microwave wavelengths. ✓ **[2]**

(b) The figure below shows how the intensity of the microwave background radiation varies with its wavelength λ.

The **peak** intensity is at a wavelength of 1.1 mm.



This spectrum of microwave background radiation changes with temperature according to Wien's displacement law.

(i) Suggest and explain how the spectrum might have looked in the distant past. You may draw on the figure to support your answer.

$\lambda_{max} T$ = constant ∴ $\lambda_{max} \propto 1/T$ ✓
As it was hotter in the past the peak wavelength would be at a lower value so further to the left. ✓ **[2]**

(ii) Calculate the energy of a photon which has a wavelength of 1.1 mm.

$E = \frac{hc}{\lambda} = \frac{6.63\times10^{-34} \times 3.00\times10^{8}}{1.1\times10^{-3}} = 1.808\times10^{-22}$ ✓

energy = 1.8×10^{-22} ✓ J **[2]**

(iii) Estimate the number of photons of microwave background radiation incident per second on the back of your hand.

Assume that all emitted photons have the energy calculated in **(ii)**, and that the back of your hand has a surface area of 150 cm^2.

$I = \frac{P}{A}$ $\quad P = IA = 3\times10^{-6} \times 150\times10^{-4} = 4.5\times10^{-8}$ W ✓

$n = \frac{\text{energy } s^{-1}}{\text{energy per photon}} = \frac{4.5\times10^{-8}}{1.808\times10^{-22}} = 2.48861\times10^{14}$

number of photons per second = 2.5×10^{14} ✓ s^{-1} **[2]**

(iv) A scientist suggests that the microwave background radiation could be used as an energy source.

The scientist proposes using large tanks of water to absorb the microwave radiation.

Estimate the maximum rise in temperature that could be produced per second for a large cylindrical tank of depth 5.0 m. Assume that all microwave radiation incident on the top of the tank is absorbed.

density of water = 1000 kg m^{-3}
specific heat capacity of water = 4200 J kg^{-1} K^{-1}

$E = Pt = IAt$ $\quad A = \frac{V}{h}$ $\quad E = \frac{IVt}{h}$

$E = mc\Delta\theta = \frac{IVt}{h}$ $\quad \frac{\Delta\theta}{t} = \frac{I}{hc}\frac{V}{m}$ ✓ $\quad \rho = \frac{m}{V}$ $\quad \frac{V}{m} = \frac{1}{\rho}$

maximum rise in temperature per second = 1.4×10^{-13} ✓ °C s^{-1} **[3]**

$\frac{\Delta\theta}{t} = \frac{I}{hc\rho} = \frac{3\times10^{-6}}{5.0\times4200\times1000}$ ✓ $= 1.42857\times10^{-13}$

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5 A student experiments with microwaves emitted from a transmitter. The frequency f of the microwaves from the transmitter can be adjusted.

(a) The microwaves are produced by an alternating current in the transmitter.

In one experiment, f is 11 GHz. In a wire in the transmitter, the magnitude of the **maximum** alternating current is 20 mA. The wire has cross-sectional area $1.4 \times 10^{-8}\,m^2$ and is made of a metal with free electron number density $8.0 \times 10^{28}\,m^{-3}$.

(i) Show that the maximum drift velocity of each free electron in the wire is about $0.1\,mm\,s^{-1}$.

$I = nAev$ ✓ $v = \frac{I}{nAe} = \frac{20\times10^{-3}}{8.0\times10^{28}\times1.4\times10^{-8}\times1.60\times10^{-19}}$ ✓

$v = 1.116\times10^{-4}\,ms^{-1} = 0.1116\times10^{-3}\,ms^{-1} = 0.116\,mms^{-1}$ ✓ ≈ 0.1

[3]

(ii) The student models the average motion of the free electrons in the wire as simple harmonic motion.

Use your answer to **(i)** to calculate the amplitude A of this motion.

$V_{max} = \omega A = 2\pi f A$ ✓

$A = \frac{V_{max}}{2\pi f} = \frac{1.116\times10^{-4}}{2\pi\times11\times10^{9}}$ ✓ $= 1.6148\times10^{-15}$

A = 1.6×10^{-15} ✓ m **[3]**

(iii) Without further calculation, explain how the maximum acceleration of a free electron varies as the frequency f is adjusted, provided that the maximum alternating current remains constant.

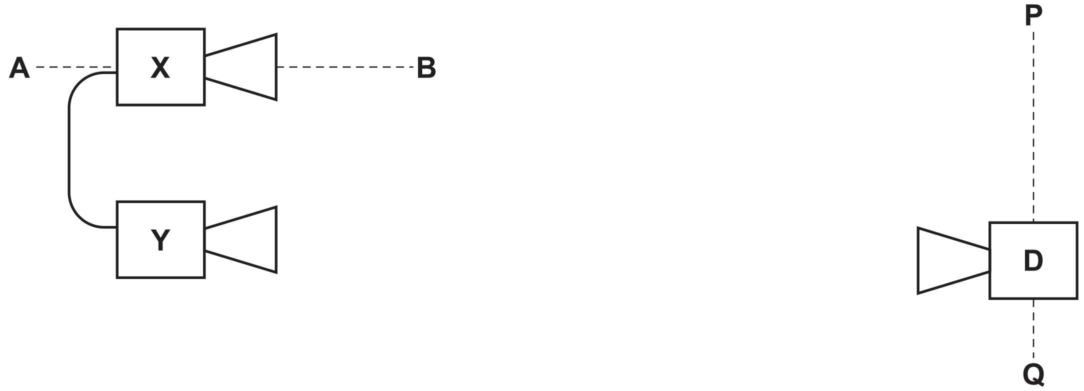
$a_{max} = \omega^2 A$ $\quad V_{max} = \omega A$

$a_{max} = \omega\omega A = \omega V_{max} = 2\pi f V_{max}$ ✓

[2]

$a_{max} \propto f$ ✓ as V_{max} is constant

(b) The student connects two microwave transmitters **X** and **Y**, and places them in front of a microwave detector **D**, as shown in the diagram below.



The transmitters **X** and **Y** produce **coherent** vertically polarised microwaves with the same frequency *f*.

The detector **D** is sensitive to vertically polarised microwaves only.

When the detector **D** is moved along the line **PQ**, a pattern of maximum and minimum intensity is observed. Adjacent maxima are separated by a distance *x*.

(i)* Explain:

- why this pattern of intensity occurs
- the expected relationship between the frequency *f* and the distance *x*
- how to verify this relationship experimentally. **[6]**

Interference occurs. When the path difference is equal to a whole number of wavelengths then it is exactly in phase ∴ constructive interference occurs leading to maximum intensity. When the path difference equal to an odd number of half wavelengths there is destructive interference and minimum intensity. ✓✓

$\lambda = ax/D$ and $c = f\lambda$ $\lambda = c/f$

$\frac{ax}{D} = \frac{c}{f}$ $x = \frac{cD}{af}$ $\therefore x \propto \frac{1}{f}$

and xf = constant ✓✓

Use a ruler along line QP to measure x.
Connect an oscilloscope to transmitter to measure f.

Additional answer space if required

Keeping a and D constant, vary f and measure x. The calculated value of fx should be constant. ✓✓

(ii) Transmitter **X** is rotated about the line **AB** and the experiment is repeated at different orientations until it has been rotated by 180°.

Describe and explain the observed patterns of maximum and minimum intensity.

At 90° the pattern disappears. ✓
At 180°, the intensity is the same as at 0° but max/min positions are reversed. ✓
Only when waves are in the same plane do they interfere to the maximum value. ✓

[3]

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6 **(a)** Define the **time constant** of a circuit containing a capacitor of capacitance C and a resistor of resistance R.

Time taken for the current to fall to 1/e of its initial value. ✓ **[1]**

(b) The capacitor circuit shown in **Fig. 6.1** can be used to smooth oscillating electrical signals.

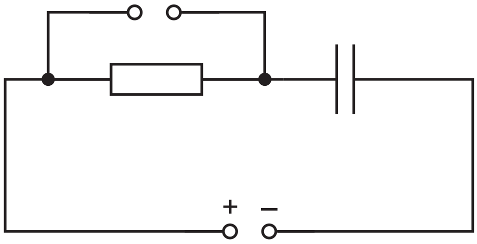

Fig. 6.1

(i) **Fig. 6.2** shows the input signal of potential difference (p.d.) V against time t.

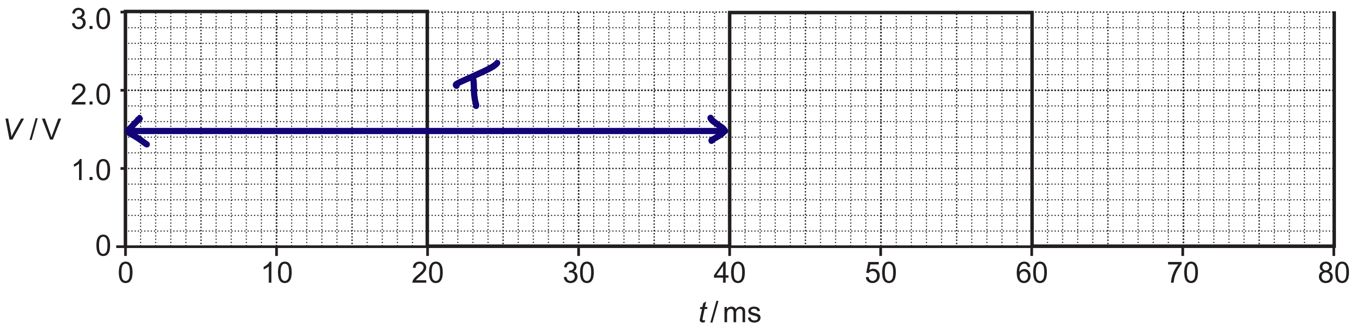

Fig. 6.2

Calculate the frequency f of this input signal.

$$f = \frac{1}{T} = \frac{1}{40 \times 10^{-3}} = 25$$ ✓

f = 25 ✓ Hz **[2]**

(ii) **Fig. 6.3** shows the variation of the charge Q on the positive plate of the capacitor with time t.

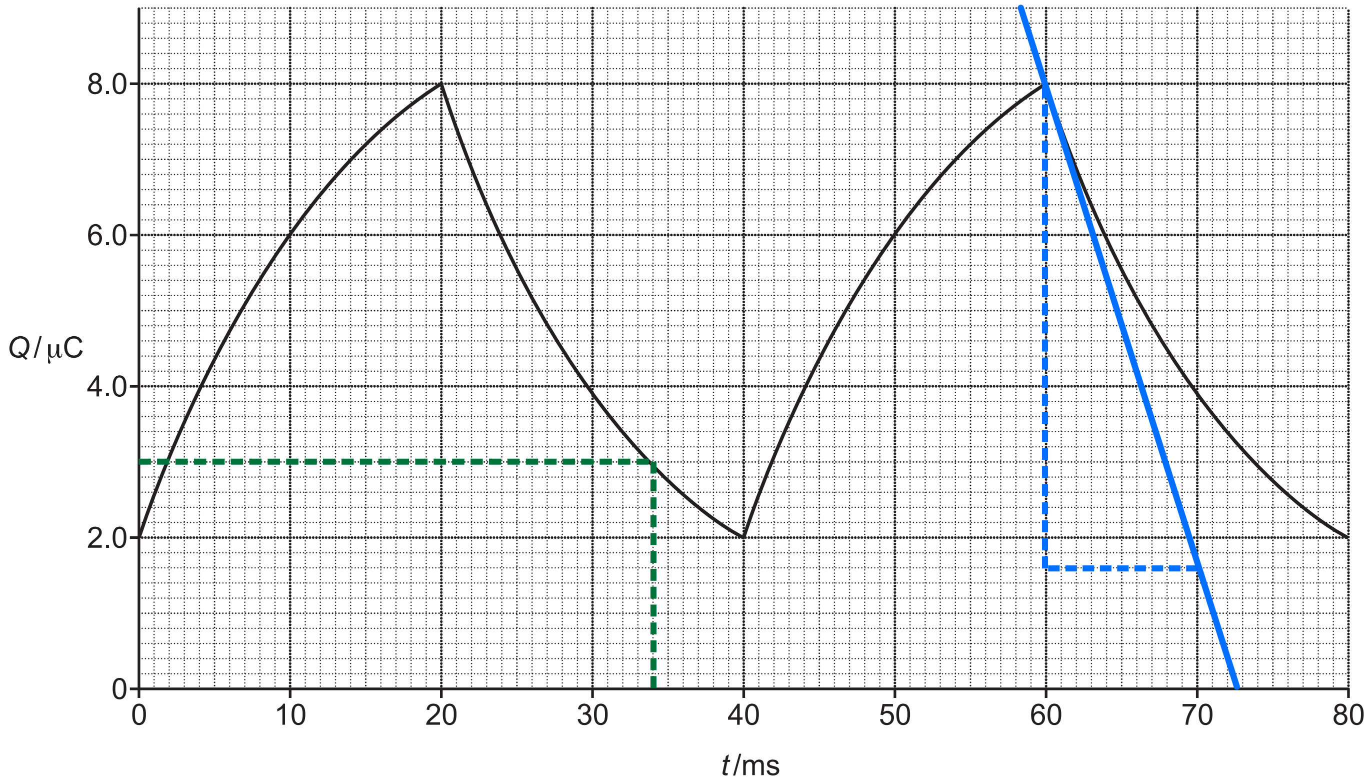

Fig. 6.3

Use a discharging section of the graph in **Fig. 6.3** to determine the time constant of the circuit. Give your answer in ms.

$Q = \frac{8.0}{e} = 2.94$ ✓ ∴ $t = 34$ ms but $\Delta t = 14$ ms

time constant = 14 ✓ ms **[2]**

(iii) By drawing a suitable tangent to the graph in **Fig. 6.3**, calculate the maximum current in the resistor.

$I = \frac{\Delta Q}{\Delta t} = \text{gradient}$ ∴ $I_{max} = |\text{steepest gradient}|$

$= \frac{(1.6 - 8.0) \times 10^{-6}}{(70 - 60) \times 10^{-3}}$ ✓ $= -6.4 \times 10^{-4}$

maximum current = 6.4×10^{-4} ✓ A **[2]**

(iv) **On Fig. 6.4** below, sketch the variation of the current I in the resistor with time t. Include an appropriate label and scale on the vertical axis.

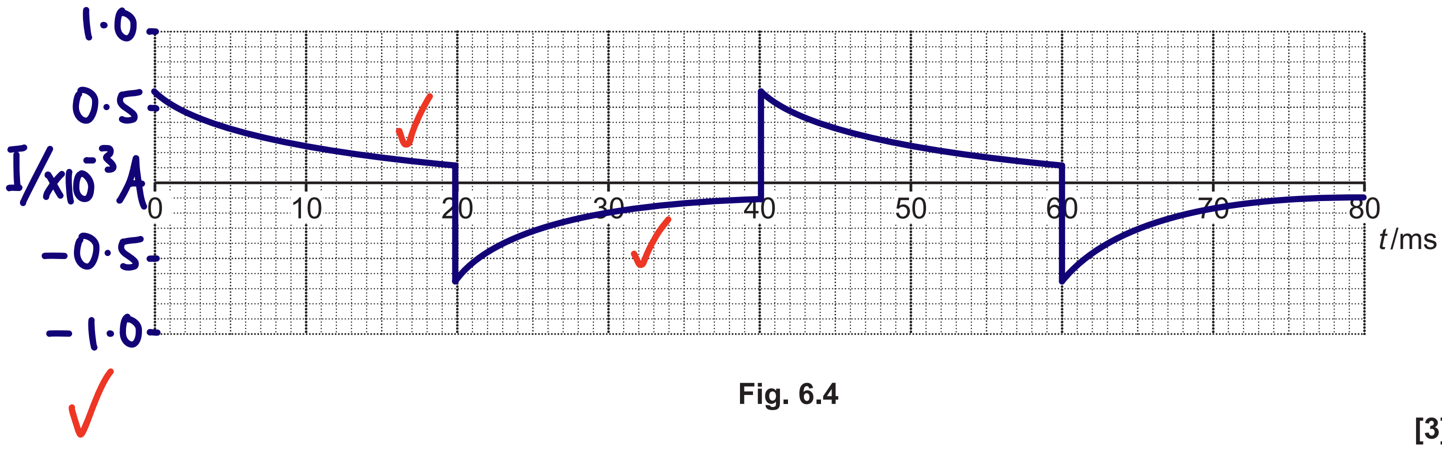

Fig. 6.4

[3]

END OF QUESTION PAPER

ADDITIONAL ANSWER SPACE

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