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MODEL
ANSWERS
(SSLD)

Winchester College

5th year Easter Revision Papers 2010

Paper 2: Part A Written Paper

Time allowed: 2 hours

Total marks: 100

Write your name, candidate number and centre number at the top of this page, and on all separate pages you hand in.

Answer ALL questions.

It is recommended that you spend 1 hour 30 mins on section A. This section is worth 75 marks. Answer on the question paper.

It is recommended that you spend 30 minutes on section B, not including reading time. This section is worth 25 marks. Answer on separate paper.

You may need the following data in the solution of numerical problems. All values are approximate.

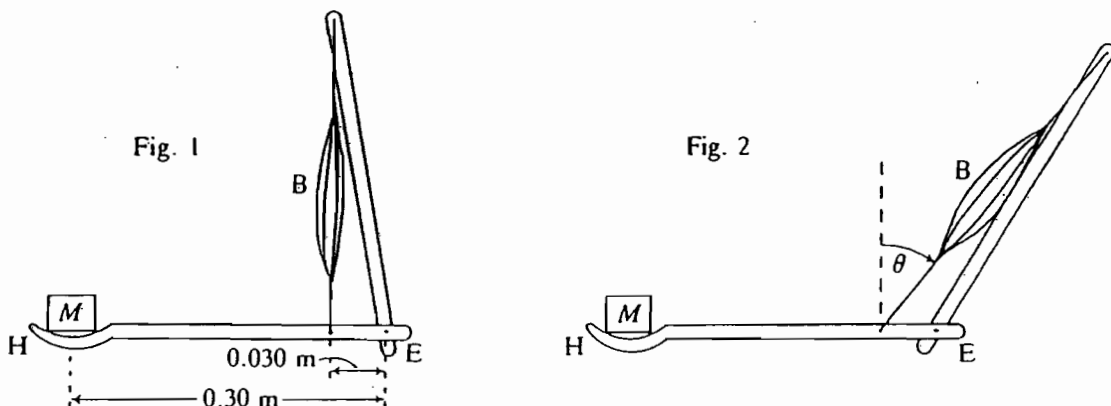
Universal gravitational constant (G)	$6.7 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
Earth's gravitational field strength at its surface (g)	9.8 N kg^{-1}
Boltzmann constant (k)	$1.4 \times 10^{-23} \text{ J K}^{-1}$
Avogadro constant (L)	$6.0 \times 10^{23} \text{ mol}^{-1}$
Planck constant (h)	$6.6 \times 10^{-34} \text{ J s}$
Charge on an electron (e)	$1.6 \times 10^{-19} \text{ C}$
Mass of an electron (m_e)	$9.1 \times 10^{-31} \text{ kg}$
Mass of a proton or neutron (m_p, m_n)	$1.7 \times 10^{-27} \text{ kg}$
Speed of light in vacuo (c)	$3.0 \times 10^8 \text{ m s}^{-1}$
Molar Gas Constant (R)	$8.3 \text{ J K}^{-1} \text{ mol}^{-1}$
Permittivity constant (ϵ_0)	$8.85 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$
$\frac{1}{4\pi\epsilon_0}$	$\approx 9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$
Permeability constant (μ_0)	$4\pi \times 10^{-7} \text{ H m}^{-1}$
1 year $\approx 3 \times 10^7 \text{ s}$	
1 day $\approx 8 \times 10^4 \text{ s}$	
	1 eV $\approx 1.6 \times 10^{-19} \text{ J}$

SECTION A (7.5 marks)

2

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1 The diagram, Fig. 1, shows a model of a human arm in which E represents the elbow, and H the hand. The biceps muscle B is acting vertically with a mass M held in the hand, and the forearm horizontal.



(a) Neglecting the mass of the forearm and hand, calculate the force provided by the muscle B, in Fig. 1, to keep the hand at rest when $M = 5.0$ kg.

Clockwise moment = anticlockwise moment.

$$\therefore (Mg \times 0.30\text{m}) = F \times 0.030\text{m}$$

$$\Rightarrow F = Mg \times \frac{0.30\text{m}}{0.030\text{m}} = 5.0\text{kg} \times 9.8\text{Nkg}^{-1} \times 10$$

$$= \underline{\underline{490\text{N}}} \quad [3]$$

(b) Estimate what additional force must be provided by the muscle if the mass of the forearm and hand is approximately 2.0 kg.

State clearly any assumption made, and make a reasoned comment on the accuracy of your answer.

Assume the mass per unit length of the arm is constant, so that its centre of mass is halfway along, 0.15 m from the elbow.

From the diagram, this looks reasonable, except that the hand looks a little thinner, so the true centre of mass may be closer to the elbow.

Our assumption would lead to $(2.0\text{kg} \times 9.8\text{Nkg}^{-1} \times 0.15\text{m}) = F_{\text{extra}} \times 0.030\text{m}$

$$\Rightarrow F_{\text{extra}} = \frac{2.0\text{kg} \times 9.8\text{Nkg}^{-1} \times 0.15\text{m}}{0.030\text{m}} = 98\text{N} \quad [3]$$

The error we discussed might mean the true value is lower though.

(c) Describe the way in which the force provided by the muscle B must change when the model arm moves increasing the angle θ as shown in Fig. 2. Justify your answer.

The force must increase. To keep the arm in equilibrium, the anticlockwise moment must stay the same. But the anticlockwise moment will be given by the expression: $0.30\text{m} \times \text{vertical component of force}$.

Since θ is increasing, and the vertical component is $F \cos \theta$,

F must increase to keep $F \cos \theta$ constant. [2]

2 In an experiment to measure the absorption of gamma-rays a G.M. tube is placed at a fixed distance from a source as shown in Fig. 3.

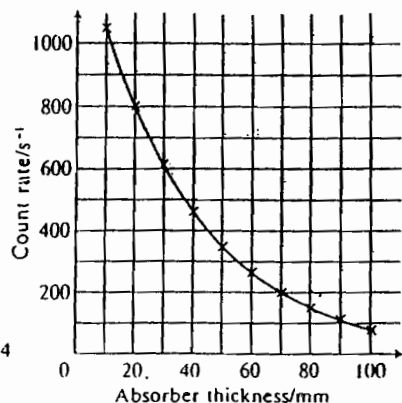
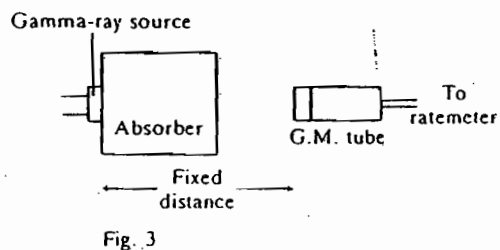


Fig. 4 shows how the number of gamma-rays detected per second varies with absorber thickness. (Here and elsewhere in this question the background count is assumed to be negligible.)

(a) Use the graph to show that the relationship between the count-rate and the absorber thickness is exponential.

From $t = 20\text{ mm}$ to $t = 45\text{ mm}$ the count rate falls from 800 s^{-1} to 400 s^{-1} .

From $t = 45\text{ mm}$ to $t = 70\text{ mm}$ the count rate falls from 400 s^{-1} to 200 s^{-1} .

A fixed increase in thickness leads to a fixed factor reduction in count rate - characteristic of exponential relationship. The half-thickness is 25 mm . [2]

(b) With the absorber removed the count rate is 50 counts per second when the G.M. tube is 1000 mm from the source.

The distance between the G.M. tube and the source is then reduced to 250 mm.

(i) Calculate the new count-rate.

Count rate $\propto \frac{1}{r^2}$. So a 4-fold reduction in r should lead to a 16 times increase in count rate.

New count rate is $50 \times 16 = 800\text{ counts/s}$. [2]

(ii) What would the count-rate become if 25 mm of absorber were now inserted between the source and the G.M. tube?

This is one half-thickness. It should halve the rate to 400 counts per second.

[2]

(c) Using the graph deduce the distance from source to G.M. tube in the original experiment shown in Fig. 3.

With 25 mm of absorber in the way, the graph indicates about 700 counts per second. This is $\frac{7}{4}$ times the rate in part (i).

This suggests a distance $\sqrt{\frac{4}{7}}$ times as far from the source.

$$= \sqrt{\frac{4}{7}} \times 250\text{ mm} = \underline{190\text{ mm}} \text{ to 2 s.f.}$$

[3]

3

4

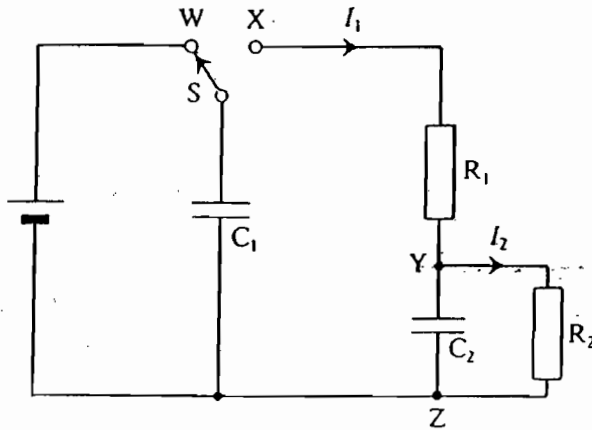
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Fig. 5

In the above circuit, Fig. 5, the resistors R_1 and R_2 are of equal resistance, R , and the capacitor C_2 is initially uncharged.

The graphs below, Figs. 6 and 7, show how the currents I_1 and I_2 vary with time from the instant the switch S is moved from W to X .

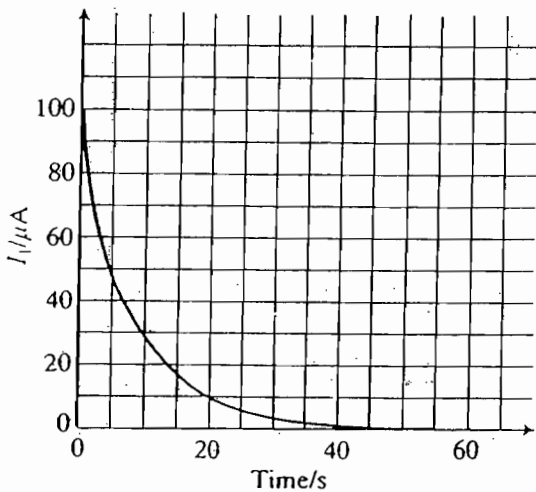


Fig. 6

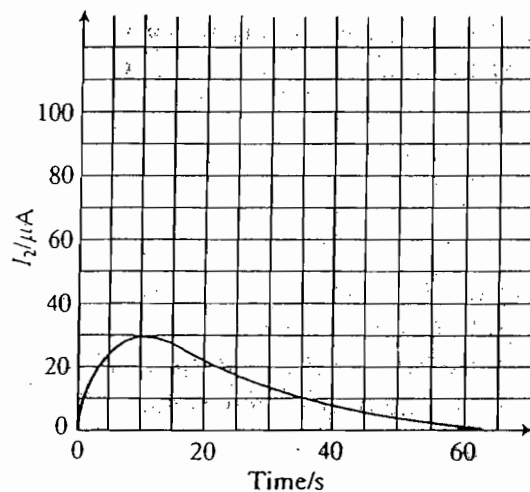


Fig. 7

(a) Although they have different shapes, the areas underneath the two graphs are the same. Say why this must be so.

Since current is rate of change of charge, the area under the current-time graph must represent total charge in charge.

All the charge passing from X to Y must eventually flow through R_2 as well.

The area under graph 1 represents the total charge flowing off C_1 . The area under graph 2 represents the total charge flowing through R_2 . So these two areas must be equal.

[2]

(b) Explain why I_2 rises during the first few seconds.

C_2 is charging at first. The p.d. between Y and Z rises from zero at $t=0$ as this happens. I_2 will equal $\frac{\text{p.d. across } C_2}{R_2}$, so since R_2 is constant, it must rise too.

[3]

(c) At time $t = 10$ s, $I_1 = I_2$.

Hence show that the ratio $\frac{\text{p.d. across } C_1}{\text{p.d. across } C_2} = 2$ at this instant.

$$\begin{aligned} \text{p.d. across } R_1 + \text{p.d. across } R_2 &= \text{p.d. across } C_1 \\ \text{p.d. across } R_2 &= \text{p.d. across } C_2. \end{aligned}$$

But $V = IR$, and I and R are the same for both resistors.

$$\text{So p.d. across } R_1 = \text{p.d. across } R_2.$$

Thus the p.d. across C_1 must be twice that across C_2 .

[3]

4 Fig. 8 shows a standing wave pattern of a steel guitar string stretched between two supports, called the nut and the bridge, on a guitar.

The fundamental standing wave pattern shown produces a note of frequency 280 Hz.

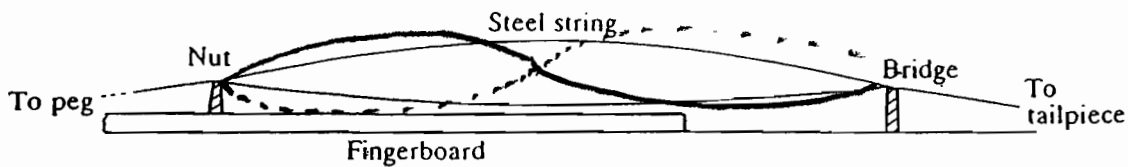


Fig. 8

(a) By placing a finger lightly at certain places on the string it is possible to produce further standing wave patterns with other specific frequencies.

(i) Sketch on Fig. 8 one of these standing wave patterns, and

(ii) state its frequency..... 560 Hz

[2]

(b) The speed, c , of a transverse wave along a stretched string is given by $c = \sqrt{\frac{T}{\mu}}$, where T is the tension and μ the mass per unit length of the string.

Show that the fundamental frequency f is given by $f = \frac{1}{2l} \sqrt{\frac{T}{\mu}}$, where l is the vibrating length of the string between nut and bridge.

For the fundamental, $\lambda = 2l$.

$$\text{Since } c = f\lambda, \quad f = \frac{c}{\lambda} = \frac{1}{2l} \sqrt{\frac{T}{\mu}}.$$

[3]

(c) Assuming that both l and μ remained constant, calculate the frequency of the new fundamental mode of vibration if the tension were halved.

Since $f \propto \sqrt{T}$, it would decrease by factor $\sqrt{2}$.

The new frequency would be $\sqrt{2} \times 280 \text{ Hz} = \underline{\underline{396 \text{ Hz}}}$.

[2]

(d) In practice μ , the mass per unit length, changes because the string contracts when the tension is reduced.

Consider a situation in which the tension is halved.

(i) If the strain reduction produced were 0.4% what would be the percentage change in μ ? State both the size and sign of the change.

$\mu = \frac{\text{mass}}{\text{length}}$. A strain reduction of 0.4% will reduce the length by approximately 0.4%.

This should increase μ by approximately 0.4%.

[3]

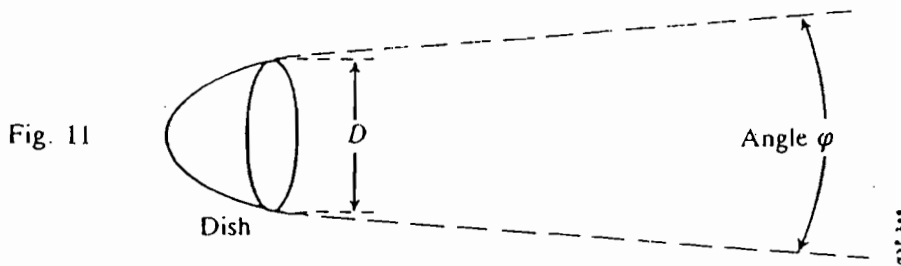
(ii) Write down the percentage error this would cause in your answer to (c). State, giving your reasoning, whether the actual frequency would be higher or lower than that you calculated.

Since $f \propto \sqrt{\frac{T}{\mu}}$, this would cause a % error of about 0.2%. Since the true μ is larger than we assumed in c, the true f should be smaller than we calculated.

[3]

Turn over for Question 5.

6 As part of a communication system a source of radio waves is placed at the principal focal point of a dish of aperture D . The majority of the energy is emitted within an angle ϕ into a cone-shaped beam, as shown in Fig. 11.



(a) Say why a parallel-sided beam of radiation cannot be produced whatever the shape of the dish.

Since D is not infinite, diffraction will occur, because the radiation has wave properties.

[2]

(b) Angle ϕ , measured in radians, is about $2 \times \frac{1.2\lambda}{D}$, where λ is the mean wavelength of the radio waves.

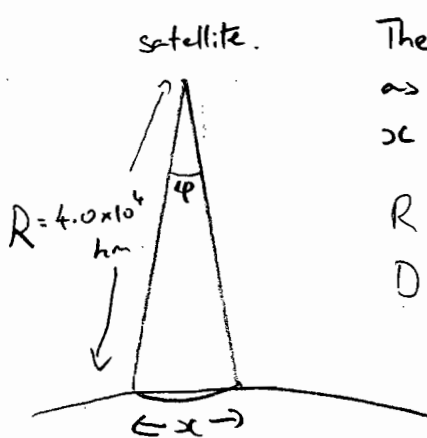
What is the effect on ϕ of doubling the carrier frequency of the signal?

Doubling f will halve λ and thus halve ϕ .
(since $c = f\lambda$ and c is constant).

[2]

(c) Such a source is placed on a satellite in orbit 4.0×10^4 km above the surface of the Earth. The dish is of diameter 10 m and the source emits at a frequency of 1.5 GHz. The beam is aimed vertically downwards.

Show that the energy emitted within the angle ϕ is being directed towards an area of about 3×10^{12} m² on the surface of the Earth.



The beam will fall on a circular area of diameter x as shown in the diagram.

$$x \approx R\phi = R \times \left(2 \times \frac{1.2\lambda}{D} \right)$$

$$R = 4.0 \times 10^7 \text{ m}$$

$$D = 10 \text{ m}$$

$$\lambda = \frac{c}{f} = \frac{3.0 \times 10^8 \text{ m s}^{-1}}{1.5 \times 10^9 \text{ Hz}} = 0.20 \text{ m}$$

$$\Rightarrow x = 4.0 \times 10^7 \text{ m} \times 2 \times \frac{1.2 \times 0.20 \text{ m}}{10 \text{ m}} = 1.9 \times 10^6 \text{ m}$$

$$\text{Area} = \pi r^2 = \pi \left(\frac{1}{2}x \right)^2 = \underline{\underline{2.8 \times 10^{12} \text{ m}^2}}$$

[3]

9

(d) However, due to the effect of the atmosphere, only 25% of the transmitted energy reaches this area. Calculate the minimum area required for a receiver on the Earth's surface requiring an input signal of at least 10^{-10} W, if the output power of the source is 200 W. State any assumptions you make.

Received power (P_r) = received intensity (I_r) \times receiver area (A_r).

$$I_r = 0.25 \times \frac{\text{output power } (P_T)}{\text{total area } A_T}$$

$$\text{Thus } P_r = 0.25 \times \frac{P_T}{A_T} \times A_r$$

$$\Rightarrow A_r = \frac{P_r A_T}{0.25 P_T}$$

This assumes the power is evenly spread over the area A_T - we are ignoring the intensity variations in the wave diffraction pattern.

$$= \frac{10^{-10} \text{ W}}{200 \text{ W}} \times \frac{1}{0.25} \times (2.8 \times 10^{12} \text{ m}^2)$$

[4]

$$= \underline{\underline{5.6 \text{ m}^2}}$$

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1 A beam of electrons produced by an electron gun is displaced a vertical distance, s , on passing through the electric field between two parallel charged plates of length, l , in a vacuum, as shown in Fig. 1.

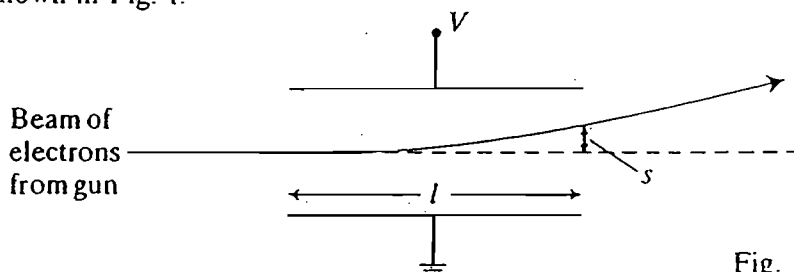


Fig. 1

(a) The potential difference, V , between the deflecting plates is doubled. State giving your reasoning, precisely what effect, if any, this has on

(i) the force on an electron between the plates,

This would double the potential gradient $\frac{V}{d}$,
thus doubling the electrical field
and hence doubling the force.

(ii) the time an electron takes to travel the distance l ,

This force is vertical and thus should not affect the electron's horizontal motion.

The time taken to travel l should not change.

(iii) the vertical displacement s .

The vertical displacement s should be given by $\frac{1}{2}at^2$,
where a is the acceleration caused by the electrical forces.

Doubling a should double s .

[5]

(b) The beam of electrons is replaced by a beam of positive ions in order that the charge-to-mass ratio of these may be determined. It is found that the deflection, s , is now very small.

Suggest two changes to the experimental set-up either of which would increase the deflection.

(i) Bring the plates closer together.

(ii) Increase l , giving more time to deflect the ions.

For one of these calculate the change required to increase the deflection by a factor of ten.

If l is increased by a factor x , the time taken will also increase by a factor x . This will increase the deflection by a factor x^2 , since $s = \frac{1}{2}at^2$.

So $s \propto l^2$. To get a deflection 10 times as great,
we could increase l by a factor $\sqrt{10}$.

[3]

2 Use these data to answer this question which is about the energy available from nuclear reactions.

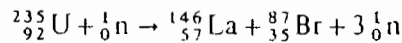
	Atomic mass/u
${}^1_0\text{n}$	1.01
${}^{235}_{92}\text{U}$	235.04
${}^{146}_{57}\text{La}$	145.90
${}^{87}_{35}\text{Br}$	86.92

Speed of light in vacuo $c \approx 3.0 \times 10^8 \text{ m s}^{-1}$

Atomic mass unit $u \approx 1.66 \times 10^{-27} \text{ kg}$

1 year $\approx 3 \times 10^7 \text{ s}$

(a) During the nuclear fission of ${}^{235}_{92}\text{U}$ by slow neutrons the following nuclear reaction occurs.



(i) Calculate the mass change, in atomic mass units, that occurs at the fission of a single uranium atom.

<p>Original mass:</p> $\begin{array}{r} 235.04u \\ + 1.01u \\ \hline 236.05u \end{array}$	<p>Final mass:</p> $\begin{array}{r} 145.90u \\ + 86.92u \\ + 3.03u \\ \hline 235.85u \end{array}$	<p>Change:</p> $\begin{array}{r} 236.05u \\ - 235.85u \\ \hline 0.20u \end{array}$
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(ii) Show that the energy corresponding to this mass change is about $3.0 \times 10^{-11} \text{ J}$.

$$\begin{aligned} \Delta E = \Delta m c^2 &= (0.20 \times 1.66 \times 10^{-27} \text{ kg}) \times (3 \times 10^8 \text{ m s}^{-1})^2 \\ &= 2.988 \times 10^{-11} \text{ J} \end{aligned}$$

(iii) Suggest in what form, from the atomic viewpoint, most of this energy would probably 'appear'.

Kinetic energy of the fission fragments.

[4]

(b) Assuming that this is the only reaction to occur, calculate the energy change resulting from the fission of 1.0 kg of ${}^{235}_{92}\text{U}$.

$$\frac{1.0 \text{ kg}}{235.04 \times (1.66 \times 10^{-27} \text{ kg})} \times 2.988 \times 10^{-11} \text{ J} = \underline{\underline{7.7 \times 10^{16} \text{ J}}}$$

[2]

(c) Assume that the overall efficiency of a nuclear power station giving an output of 100 MW is 25%. Calculate the time, in years, for which 1000 kg of ${}^{235}_{92}\text{U}$ can fuel such a station.

Efficiency of 25% indicates ~~power production of 400~~
power input (rate at which uranium is releasing energy)
of 400 MW.

$$\begin{aligned} \text{Yearly energy} &= 400 \times 10^6 \text{ W} \times 3.16 \times 10^7 \text{ seconds} \\ &= \underline{\underline{1.26 \times 10^{16} \text{ J}}} \end{aligned}$$

[2]

1000 kg of uranium can release $7.7 \times 10^{16} \text{ J}$. So answer $\frac{7.7 \times 10^{16} \text{ J}}{1.26 \times 10^{16} \text{ J}} = \underline{\underline{6 \text{ years}}}$

6 In the circuit diagram (Fig. 5), AB is a strip of conducting paper with resistance per unit length of $5.0 \Omega \text{ mm}^{-1}$.

The paper strip is 2000 mm long and 30 mm wide.

The battery and connecting wires have negligible resistance.

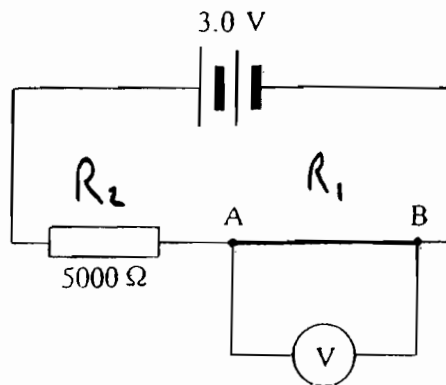


Fig. 5

(a) Calculate

(i) the resistance of the paper strip,

$$\text{Resistance} = 2000 \text{ mm} \times 5.0 \Omega \text{ mm}^{-1} = 10 \text{ k}\Omega.$$

(ii) the voltmeter reading.

$$V = V_{\text{in}} \frac{R_1}{R_1 + R_2} = 3 \text{ V} \times \frac{10 \text{ k}\Omega}{15 \text{ k}\Omega} = 2 \text{ V}.$$

[3]

(b) AB is now replaced by a strip of the same material, length and thickness but with a width that increases uniformly from 10 mm at A to 30 mm at B.

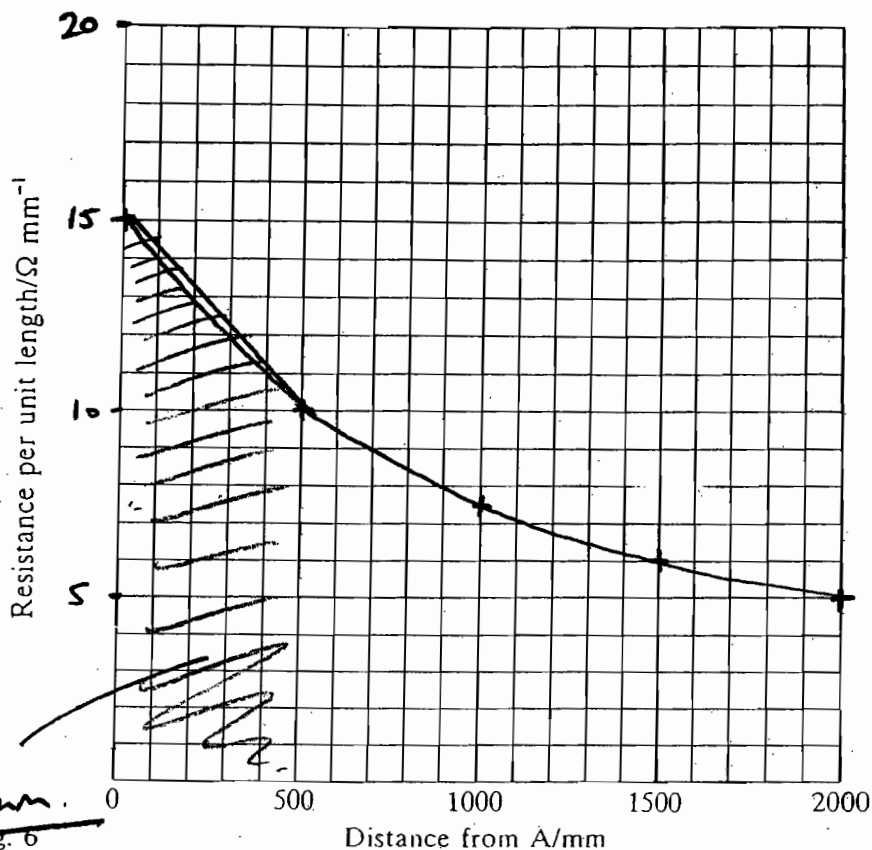
(i) Complete the table below by calculating the width and resistance per unit length at each of the intermediate points listed.

Distance from A/mm	Width/mm	Resistance per unit length/ $\Omega \text{ mm}^{-1}$
0	10	15.0
500	15	10.0
1000	20	7.5
1500	25	6.0
2000	30	5.0

13

(ii) Use the axes provided below (Fig. 6) to draw a graph showing how the *resistance per unit length* of this strip varies between A and B.

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[3]

(c) Use your graph to estimate the total resistance of the strip. Show clearly how you obtain your result.

The total resistance will be the area under the graph.

We could approximate it as a series of trapeziums.

$$\begin{aligned} & (500 \text{ mm} \times 12.5 \Omega \text{ mm}^{-1}) + (500 \text{ mm} \times 8.75 \Omega \text{ mm}^{-1}) \\ & + (500 \text{ mm} \times 6.75 \Omega \text{ mm}^{-1}) + (500 \text{ mm} \times 5.5 \Omega \text{ mm}^{-1}) \end{aligned}$$

$$= \underline{\underline{16750 \Omega}} \quad \text{Though this will be a slight overestimate}$$

[2]

SECTION B (25 marks)

14

Read the following passage carefully and then answer all the questions printed after it.

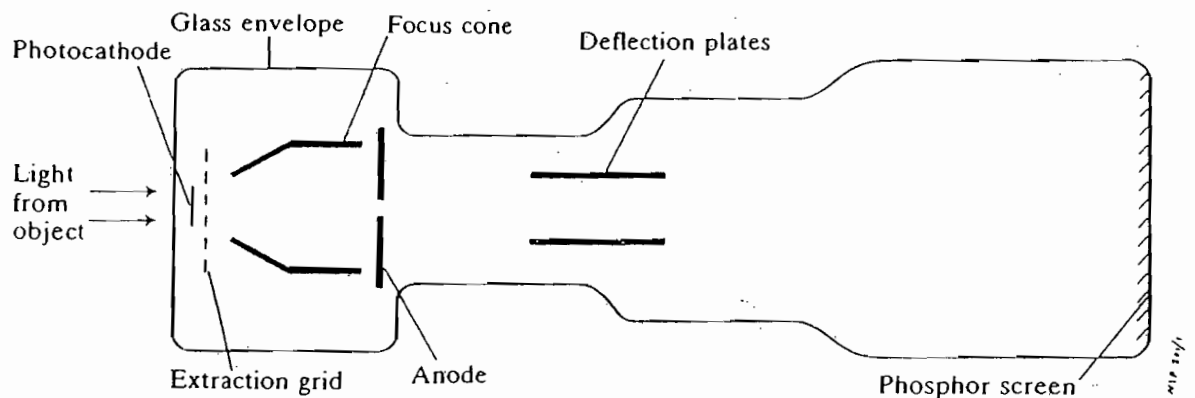
Adapted from T. A. Hall, 'Taking Pictures a Hundred Million Times a Second',
National Electronics Review (1984)

Introduction

Dramatic sequences of pictures of fast moving objects, such as insects in flight, have been taken with standard cameras working very quickly at rates of up to 1000 frames per second. In this type of camera the film is held still whilst each image is formed and then the film is moved rapidly on to the next position. In between frames a shutter blocks off the image to prevent blurring. At high rates this puts enormous stress on the film and there is a tendency for the film to tear. Higher framing rates of up to about 250 000 frames per second can be achieved by an alternative 'fixed-film' design in which the film is kept still and a sequence of images is moved across it. The movement of the optical image is achieved by a mirror which is made to rotate at a very high speed. Synchronisation of the camera to the event is a serious problem and the method is only suitable for brightly illuminated or self-luminous objects. To achieve even faster framing rates it has been necessary to develop framing cameras based on an image converter tube, which uses electronics to produce the sequenced images.

The Image Converter Tube

In an image converter tube, the mechanical movement of the mirror has been abandoned in favour of using an electric field to move an electron image.



Plan of Image Converter Tube (not to scale)

Initially an optical image is focused, using a lens, on to a photocathode which is inside the vacuum envelope of the tube. The photocathode is semitransparent and near to it is a grid of fine wires called the extraction grid. Photoelectric emission takes place from the photocathode, and the grid directs emitted electrons towards the anode. The photo-electrons are accelerated towards the anode by a potential difference of about 20 kV between anode and cathode. By adjusting the potential of the focus cone, a well focused inverted image of the original optical image is formed on the screen. Because of the high energy gained by the photoelectrons, each electron is able to produce many light photons in the phosphor screen, so that the final image is many times brighter than the initial optical image.

In the region between the anode and the screen the electrons maintain a constant speed, which 25 for an anode p.d. of 20 kV is approximately one-quarter the speed of light. In this region the electrons can be deflected from their path by applying fairly modest potential differences to a set of deflection plates. Typically the distance between a pair of plates is such that a potential difference of 1000 volts is sufficient to cause the electron image to move from one side of the screen to the other. A sequence of several images can be produced by applying a 'staircase' voltage waveform to the deflection plates, 30 thus deflecting the electron beam to different parts of the screen. The potential difference is constant for a time whilst an image is formed on the screen, before rapidly changing to another constant value to enable another image to be formed further across the screen. A photograph can be taken of the sequence of images on the screen, thus giving a permanent record.

Making the Camera even Faster

35

In developing the image converter tube to produce a hundred million frames a second, several problems exist. One major problem is that of transit time, this being the time each electron spends between the deflection plates.

If the p.d. between the plates is suddenly changed, those electrons leaving the plates will be unaffected, whereas those just entering the region between the plates will be affected for the whole of 40 their passage. Hence the position of the image on the screen cannot change instantaneously. To get a recognisable image it has been found that the time between the start of each consecutive image must be at least three times the transit time. Hence transit time is a limiting factor in the maximum framing rate.

1 In the passage it is reported that standard cameras can be made to take many pictures per second, but *at high rates this puts enormous stress on the film* (lines 5 and 6).

(a) What is meant by *stress*?

(b) Explain how such large stresses on the film arise.

[3]

2 An attempt is to be made to take photographs of a bullet 20 mm long as it passes through a thin target at approximately 800 m s^{-1} .

The bullet is to be photographed as it moves across the field of view, using a 'fixed-film' type of framing camera (lines 6-11), with the intention of obtaining a sequence of images.

(a) (i) Calculate how long it will take the bullet to pass through the target.

(ii) What is the maximum number of frames you might expect in the sequence?

(b) (i) Identify two practical difficulties in taking such photographs with the 'fixed-film' type of camera.

(ii) Suggest how one of the problems might be solved.

[5]

3 The following statements are made in the passage about electrons accelerated by a p.d. of 20 kV:

(i) their speed is approximately one-quarter the speed of light (line 26).

(ii) each electron produces many light photons in the screen (lines 22-3).

(a) Justify statement (i).

(b) Estimate the number of photons produced by each electron (statement (ii)). Assume $\lambda = 5 \times 10^{-7} \text{ m}$. Indicate clearly any other assumptions you make.

[6]

16

4 It is stated in the passage that a p.d. of 1000 volts is sufficient to move the photo-electrons from one side of the screen to the other in an image converter tube (lines 28-9).

Draw a graph, with labelled axes, of the voltage signal against time which could be applied to the deflection plates, to build up a sequence of 5 images at a rate of 200 000 images per second.

Label with the letter **A** all sections of the graph where the electron image is being formed, and with the letter **B** all sections where the position of the electron image is being moved. [3]

5 One possible method of reducing 'transit time' would be to increase the p.d. used to accelerate the photo-electrons.

Suggest and explain two possible effects this could have on the images on the screen, assuming the same deflection p.d. is used. [4]

6 (a) Identify two factors which have enabled the 'electronic method' of recording a sequence of images to be considered an improvement on previous methods.

(b) Suggest one situation in which a high framing rate camera can yield information of use to a physicist or engineer. Say why you think the information obtained would be useful. [4]

1a) Stress is force per unit area.

b) The film has to be still while the image is formed, but then it has to move on quickly in order to get ~~the~~ into position for the next frame. The faster the frame rate, the less time there is for this to happen. The film's velocity must thus change in a very short time. This means a very high acceleration ($a = \frac{\Delta v}{\Delta t}$) and thus a larger force on the film ($F = ma$). This force, acting on the fairly small cross-sectional area of the film, produces high stress ($\text{stress} = \frac{\text{force}}{\text{area}}$).

$$\text{2a) time} = \frac{\text{distance}}{\text{speed}} = \frac{20 \text{ mm}}{800 \text{ ms}^{-1}} = \frac{2 \times 10^{-2} \text{ m}}{8 \times 10^2 \text{ ms}^{-1}} = 0.25 \times 10^{-4} \text{ s} = \underline{\underline{25 \mu\text{s}}}$$

ii) At a frame rate of 250 000 frames per second, you might get a ~~at~~ maximum of $(25 \times 10^{-6} \text{ s}) \times (25 \times 10^5 \text{ frames/s}) = \underline{\underline{62.5 \text{ frames}}}$.

b) i) It will be difficult to take the photo at exactly the moment when the bullet passes through the target ("synchronization of the camera to the event is a serious problem").

Also each frame of the photo only receives a small amount of light from the bullet, as the exposure time is so short.

ii) The second of these problems might be helped by illuminating the apparatus with very bright light.

3a) The electrons are accelerated by a p.d. of 20kV.

Their energy is given by $e \times V$ where e is the charge on an electron - this is the electrical potential energy lost

This energy becomes the kinetic energy of the electrons, which is approximately given by $\frac{1}{2}mv^2$ (approximate because we are neglecting special relativity).

$$\text{So we can say: } \frac{1}{2}mv^2 = eV$$

$$\Rightarrow v^2 = \frac{eV}{\frac{1}{2}m}$$

$$m = 9.1 \times 10^{-31} \text{ kg}$$

$$e = 1.6 \times 10^{-19} \text{ C}$$

$$V = 2.0 \times 10^4 \text{ V}$$

$$\Rightarrow v = \sqrt{\frac{2eV}{m}} = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \text{ C} \times 2.0 \times 10^4 \text{ V}}{9.1 \times 10^{-31} \text{ kg}}}$$

$$= \sqrt{\frac{2 \times 1.6 \times 2.0}{9.1}} \times 10^8 \text{ m s}^{-1}$$

$$= 0.70 \times 10^8 \text{ m s}^{-1}$$

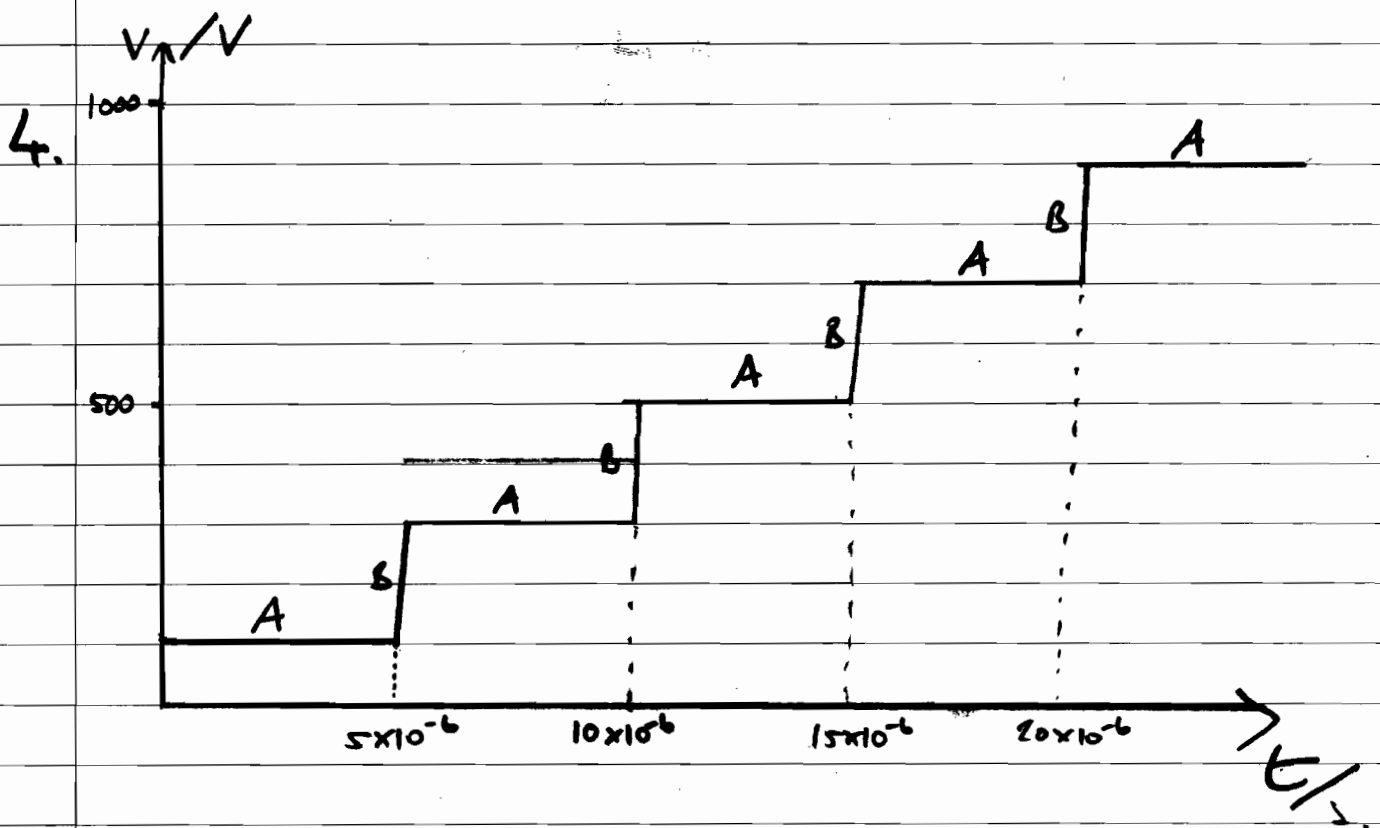
which is about 23% of the speed of light.

b) The energy of a single photon is given by $hf = hc/\lambda$.

Assuming that all the electron's energy goes into light, and that all the light produced has the same wavelength of 500nm, we can say:

$$n = \frac{eV}{hf} = \frac{eV\lambda}{hc} = \frac{1.6 \times 10^{-19} \text{ C} \times 2.0 \times 10^4 \text{ V} \times 5 \times 10^{-7} \text{ m}}{6.63 \times 10^{-34} \text{ J s} \times 3 \times 10^8 \text{ m s}^{-1}}$$

$$= 0.8 \times 10^4 \text{ (about 8000)}$$



5. Increasing the accelerating p.d. would tend to make the images ~~smaller~~ brighter, since each electron would acquire more kinetic energy.

The images would also be closer together. Since their horizontal velocity is greater, the transit time is reduced (as per the design) and so the deflection caused by the plates will be much less.

6a) The number of frames per second that can be obtained is much higher than with optical methods. This allows events happening over smaller time intervals to be analysed.

The image is also brighter than one obtained with an optical system, so that it is not necessary to illuminate the object so brightly.

The device is probably less prone to break than a system with film, since there is no need to move a strip of film along.

b) One rapid process that might be analysed with a high-speed camera is fracture. The point at which a material fails under stress and the way in which cracks develop would be important things to know when designing objects that are placed under high stress.