OCR
RECOGNISING ACHIEVEMENT

OXFORD CAMBRIDGE AND RSA EXAMINATIONS

Advanced GCE

PHYSICS A — 2825/02

Health Physics

Thursday **22 JUNE 2006** Afternoon 1 hour 30 minutes

Candidates answer on the question paper.
Additional materials:
Electronic calculator

Candidate Name	Centre Number	Candidate Number

TIME 1 hour 30 minutes

INSTRUCTIONS TO CANDIDATES

- Write your name in the space above.
- Write your Centre number and Candidate number in the boxes above.
- Answer **all** the questions.
- Write your answers in the spaces provided on the question paper.
- Read each question carefully and make sure you know what you have to do before starting your answer.

INFORMATION FOR CANDIDATES

- The number of marks is given in brackets [ ] at the end of each question or part question.
- The total number of marks for this paper is 90.
- You may use an electronic calculator.
- You are advised to show all the steps in any calculations.
- The first eight questions concern Health Physics. The last question concerns general physics.

FOR EXAMINER'S USE		
Qu.	**Max**	**Mark**
1	7	
2	7	
3	11	
4	11	
5	8	
6	6	
7	12	
8	8	
9	20	
TOTAL	90	

This question paper consists of 19 printed pages and 1 blank page.

SP (SLM/CGW) T11359/4

Data

speed of light in free space,	$c = 3.00 \times 10^{8}\ \mathrm{m\,s^{-1}}$
permeability of free space,	$\mu_0 = 4\pi \times 10^{-7}\ \mathrm{H\,m^{-1}}$
permittivity of free space,	$\epsilon_0 = 8.85 \times 10^{-12}\ \mathrm{F\,m^{-1}}$
elementary charge,	$e = 1.60 \times 10^{-19}\ \mathrm{C}$
the Planck constant,	$h = 6.63 \times 10^{-34}\ \mathrm{J\,s}$
unified atomic mass constant,	$u = 1.66 \times 10^{-27}\ \mathrm{kg}$
rest mass of electron,	$m_e = 9.11 \times 10^{-31}\ \mathrm{kg}$
rest mass of proton,	$m_p = 1.67 \times 10^{-27}\ \mathrm{kg}$
molar gas constant,	$R = 8.31\ \mathrm{J\,K^{-1}\,mol^{-1}}$
the Avogadro constant,	$N_A = 6.02 \times 10^{23}\ \mathrm{mol^{-1}}$
gravitational constant,	$G = 6.67 \times 10^{-11}\ \mathrm{N\,m^{2}\,kg^{-2}}$
acceleration of free fall,	$g = 9.81\ \mathrm{m\,s^{-2}}$

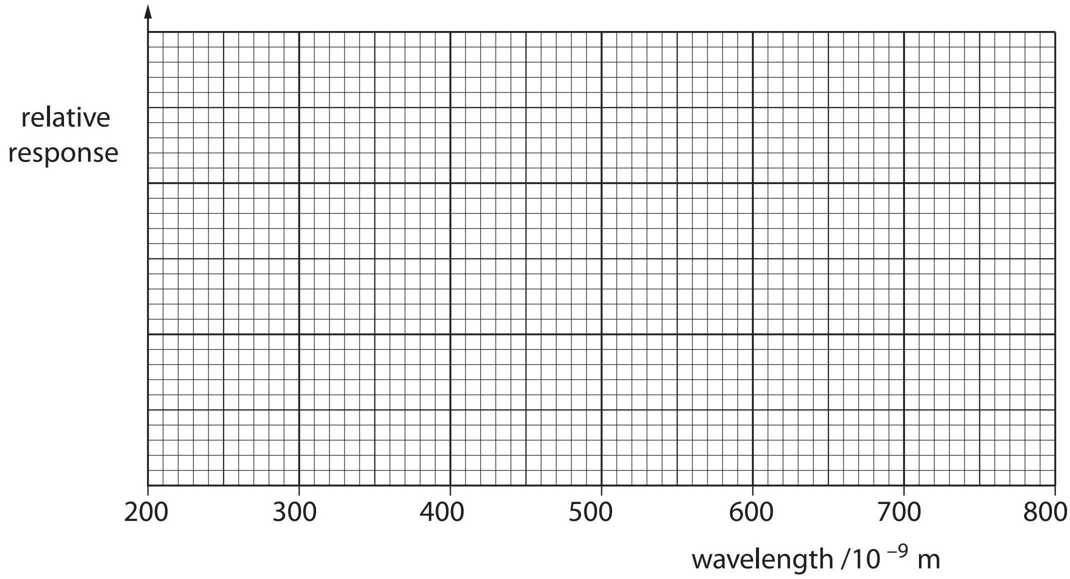
Formulae

uniformly accelerated motion,	$s = ut + \frac{1}{2}at^2$
	$v^2 = u^2 + 2as$
refractive index,	$n = \frac{1}{\sin C}$
capacitors in series,	$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots$
capacitors in parallel,	$C = C_1 + C_2 + \ldots$
capacitor discharge,	$x = x_0 e^{-t/CR}$
pressure of an ideal gas,	$p = \frac{1}{3}\frac{Nm}{V}<c^2>$
radioactive decay,	$x = x_0 e^{-\lambda t}$
	$t_{\frac{1}{2}} = \frac{0.693}{\lambda}$
critical density of matter in the Universe,	$\rho_0 = \frac{3H_0^2}{8\pi G}$
relativity factor,	$= \sqrt{(1 - \frac{v^2}{c^2})}$
current,	$I = nAve$
nuclear radius,	$r = r_0 A^{1/3}$
sound intensity level,	$= 10 \lg \left(\frac{I}{I_0}\right)$

Answer all the questions.

1 The retina contains light-sensitive receptor cells called rods and cones. These cells respond differently to both light intensity and wavelength.

(a) On Fig. 1.1, sketch the relative responses of each of the three types of cone with wavelength. Use the letters R (red), G (green) and B (blue) to label the appropriate graph.



[3]

Fig. 1.1

(b) Fig. 1.2 shows the path of rays of light from an object. These rays are refracted by the eye and form an image on the retina at the yellow spot. Peripheral vision (vision around the object on which the eye is focused) occurs when images are formed on the rest of the retina.

A diagram has been removed due to third party copyright restrictions

Details: A diagram of a human eye showing rays of light from an object entering the eye

Fig. 1.2

(i) Explain photopic vision in terms of the action of the relevant light-sensitive receptor cells.

....

....

.... [2]

(ii) Describe how the sight of a person changes when light intensity falls and suggest the type of receptor cell used for peripheral vision.

....

....[2]

[Total: 7]

2 The range of accommodation for an eye is 2.50 D. The power of this eye when viewing an object at its near point of 40.0 cm is 61.3 D. Assume that all of the refraction in the eye occurs at the front surface of the cornea.

(a) **(i)** Calculate to three significant figures, the power of this eye when viewing an object at infinity.

power = ... D [2]

(ii) Calculate the distance of the image from the cornea, when viewing an object at infinity.

distance = ...m [2]

(b) Calculate the power of the corrective lens needed to allow this person to focus comfortably on an object at the near point of 25.0 cm.

power = ... D [3]

[Total: 7]

3 Equal changes in intensity are not perceived by the ear as equal changes in loudness.

(a) **(i)** Show that the change in intensity level for a sound as its intensity increases from $3.0 \times 10^{-7}\,\mathrm{W\,m^{-2}}$ to $6.0 \times 10^{-7}\,\mathrm{W\,m^{-2}}$ is about 3 dB.

[3]

(ii) Describe how the sensitivity of the ear to loudness varies across the range of audible frequencies.

....

....

....

....[2]

(b) The intensity level in an examination hall during an examination is 35.0 dB. Calculate the factor by which the sound intensity increases at the end of the examination if the intensity level as pupils leave the hall is 75.0 dB.

factor = ... [4]

(c) Sound of intensity $3.16 \times 10^{-5}\,\mathrm{W\,m^{-2}}$ is incident on an eardrum of area $60.0\,\mathrm{mm^2}$. Calculate the power incident on the eardrum.

power = ... W [2]

[Total: 11]

4 (a) Resonance occurs in the auditory canal at a frequency of about 2000 Hz. For this question, consider the auditory canal to act as a tube that is closed at one end. See Fig. 4.1. The speed of sound in air is 330 m s^{-1}.

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Details: A diagram of the inside of an ear, showing the ear flap, the ear drum, the auditory canal, nodes and anti-nodes

Fig. 4.1

(i) Calculate the wavelength of sound that causes resonance in the auditory canal at a frequency of 2000 Hz.

wavelength = ... m [3]

(ii) Use your answer to (i) to calculate an estimate of the length of the auditory canal.

length = ... m [1]

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(b) Describe how the structure of the ear allows sound energy incident on the ear drum to be transferred to the fluid in the inner ear. Your response should make reference to the design features of the middle ear that amplify the pressure at the oval window.

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....[7]

[Total: 11]

5 Fig. 5.1 shows a cross-section of a radiographic detector which uses film and intensifying screens. Describe how an image of an internal body structure may be produced using X-ray film. Within your answer you should include details of the use and advantages of an intensifying screen.

A diagram has been removed due to third party copyright restrictions

Details: A diagram showing a cross-section of a radiographic detector which uses film and intensifying screens

Fig. 5.1

....[8]

[Total: 8]

For Examiner's Use

6 This question is about the effects of ionising radiation.

(a) Define the term *exposure*.

....

....[1]

(b) Exposure is related to absorbed dose by a factor f. The value of this factor for an X-ray photograph of a broken bone is $80\,\mathrm{J\,C^{-1}}$. The exposure received during this X-ray is $2.5 \times 10^{-5}\,\mathrm{C\,kg^{-1}}$.

(i) Calculate the absorbed dose. Give a unit for your answer.

absorbed dose = ... unit .... [2]

(ii) The quality factor Q for the X-rays used above is 1.2.

1 Explain what is meant by *quality factor*.

....

....[1]

2 Calculate the dose equivalent for the absorbed dose calculated in **(i)**. State the SI unit for your answer.

dose equivalent = ... unit .... [2]

[Total: 6]

For Examiner's Use

7 (a) Explain how ultrasound is produced using a piezoelectric crystal such as quartz.

....

....

....[2]

(b) Quartz is a compound of silicon and oxygen. Each silicon atom is attached to four oxygen atoms. See Fig. 7.1 below. Each oxygen atom carries a negative charge. The silicon atom carries a positive charge.

Two diagrams have been removed due to third party copyright restrictions

Details: A diagram of a silicon atom attached to four oxygen atoms and a diagram showing a silicon ion and an oxygen ion in an electric field

Fig. 7.1 Fig. 7.2

(i) On Fig. 7.2, draw possible positions for the negatively-charged oxygen ions when an electric field is applied in the direction shown. The central silicon ion and one oxygen ion have been drawn in for you. [1]

(ii) Use your answer to (i) to explain why a single crystal of quartz is piezoelectric.

....

.... [1]

(c) Acoustic impedance Z is the product of the density ρ of a medium and the speed of ultrasound v.

The fraction f of ultrasound reflected at a boundary between two media of acoustic impedances Z_1 and Z_2 is given by the equation

$$f = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$$

medium	density ρ / kg m^{-3}	ultrasound velocity v / m s^{-1}
air	1.299	330
skin	1075	1590
coupling medium	1090	1540
bone	1750	4080

Fig. 7.3

(i) Use the data in Fig. 7.3 to find the fraction *f* of ultrasound reflected at an air-skin boundary.

f = ...[2]

(ii) Hence explain the need for a coupling medium in ultrasound imaging.

....

....

....

....[2]

Question 7 is continued on the next page.

[Turn over

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(d) Fig. 7.4 is a CRO display showing the reflected ultrasound signal from the front edge **F** and the rear edge **R** of a bone. The time-base setting is $1.0 \times 10^{-5}\,s\,cm^{-1}$.

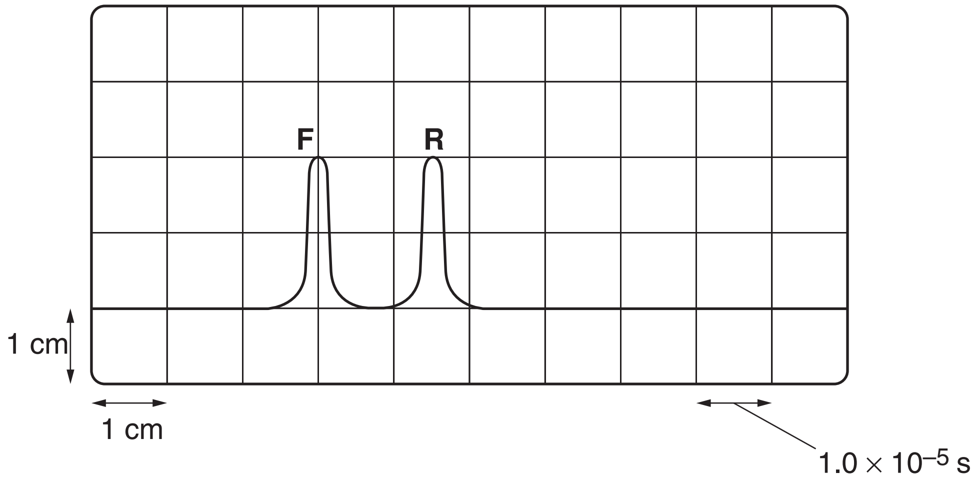

Fig. 7.4

Using appropriate data from Fig. 7.3 and Fig. 7.4, calculate the thickness of the bone.

thickness = ... cm [4]

[Total: 12]

8 **(a)** **(i)** Describe the effect on living matter of exposure to ionising radiation.

....

....

....

....

....[3]

(ii) State **three** factors that determine the extent of the effect described in **(i)**.

....

....

....

....

....[3]

(b) Fig. 8.1 gives some facts concerning the effects of ionising radiation on living tissue.

	stochastic effect	non-stochastic effect
cells unable to reproduce		
cancer caused		
the severity increases with dose		
a threshold dose is required below which there is no effect on living tissue		

Fig. 8.1

Put a tick in the appropriate column on Fig. 8.1 to show whether the facts indicate a stochastic or a non-stochastic effect. [2]

[Total: 8]

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9 Most man-made objects launched into space are satellites placed in a particular orbit around the Earth to function as TV transmitters, telephone relays or weather stations. Some spacecraft, however, have been launched to travel into much deeper space to explore the outer planets of our solar system. All spacecraft whether satellites or deep space probes, must communicate with Earth by transmitting a radio signal. The circuits producing the signal require battery power and batteries require recharging from an energy source.

Most satellites in orbit around the Earth derive their power from a panel of solar cells which convert sunlight into electrical energy. One such telecommunications satellite transmits a continuous 360 W signal powered from its battery for 24 hours per day. The battery is recharged from a solar panel which has an efficiency of 16% while in direct sunlight of light intensity $1.5\,\mathrm{kW\,m^{-2}}$.

(a) Suggest what happens to the 84% of light energy which reaches the solar panel but is not converted to electrical energy.

....

....[1]

(b) **(i)** Calculate the minimum surface area of solar panel required to produce the 360 W for the transmitter.

surface area = ... m^2 [2]

(ii) Give **two** reasons why the surface area would have to be much greater than your answer above.

1. ....

....

2. ....

....[2]

For a spacecraft launched into the outer regions of the solar system, it is not practical to have its battery recharged by solar panels. Such spacecraft use a Radioisotope Thermoelectric Generator (RTG). This generator has no moving parts and contains two different metals joined to form a closed electric circuit. When the two junctions between these metals are kept at different temperatures, an electric current is produced. One junction is cooled by space while the other is heated by the decay from a radioactive isotope. RTGs are very reliable sources of power.

Nowadays, RTGs use plutonium-238 which is an alpha emitter with a half-life of 88 years. Each alpha particle is emitted with a kinetic energy of 5.0 MeV.

(c) State **one** reason why solar panels are not practical in deep space.

....

....[1]

(d) Suppose such a spacecraft transmits for 120 minutes each day from a 12 V circuit which draws a current of 5.0 A while transmitting back to Earth. During the rest of the day, the transmitting circuit is shut down. The battery charging, however, carries on continuously.

(i) Show that the energy required per day for transmission is about 0.4 MJ.

[2]

(ii) The overall efficiency in the RTG battery charging system is 25%. Show that the steady power output required from the RTG is about 20 W.

[2]

(iii) Calculate the minimum activity of the source (i.e. the number of 5 MeV alpha particles emitted per second) required to generate this power.

activity = ... Bq [2]

(e) **(i)** Show that the decay constant λ of Pu-238 is 2.5×10^{-10} s^{-1}.

[2]

(ii) Calculate the number N of nuclei of Pu-238 required to generate the activity calculated in **(d)(iii)**.

N = ... [2]

(iii) Calculate the mass of Pu-238 corresponding to this number of nuclei.

mass = ... kg [2]

(f) Plutonium is one of the most dangerous chemical poisons known, as well as being a radioactive hazard. It has been estimated that 1 kg of this substance, suitably distributed, would be enough to kill everyone on Earth. Comment on the risks involved in using plutonium as a fuel for spacecraft.

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....[2]

[Total: 20]

END OF QUESTION PAPER

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