RECOGNISING ACHIEVEMENT

ADVANCED GCE UNIT **2825/02**

PHYSICS A

Health Physics

THURSDAY 21 JUNE 2007 Afternoon

Time: 1 hour 30 minutes

Additional materials: Electronic calculator.

CUP/T24042

Candidate Name

Centre Number

Candidate Number

INSTRUCTIONS TO CANDIDATES

- Write your name, Centre Number and Candidate Number in the boxes above.
- Answer **all** the questions.
- Use blue or black ink. Pencil may be used for graphs and diagrams only.
- Read each question carefully and make sure you know what you have to do before starting your answer.
- Do **not** write in the bar code.
- Do **not** write outside the box bordering each page.
- WRITE YOUR ANSWER TO EACH QUESTION IN THE SPACE PROVIDED. ANSWERS WRITTEN ELSEWHERE WILL NOT BE MARKED.

INFORMATION FOR CANDIDATES

- The number of marks for each question 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 six questions concern Health Physics. The last question concerns general physics.

FOR EXAMINER'S USE		
Qu.	**Max.**	**Mark**
1	**9**	
2	**10**	
3	**11**	
4	**15**	
5	**12**	
6	**13**	
7	**20**	
TOTAL	**90**	

This document consists of **19** printed pages and **1** blank page.

SPA (MML 13180 3/06) T24042/8 **[Turn over**

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

Answer **all** the questions.

1 Fig. 1.1 shows a simple model to demonstrate the forces exerted by back muscles for a person bending over at an angle of 30° to the horizontal.

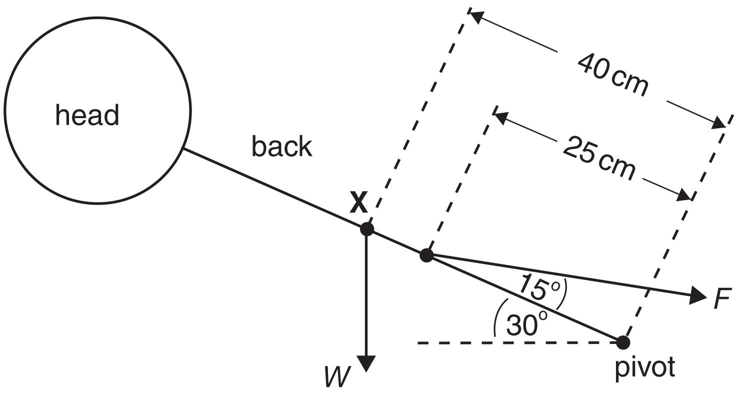

Fig. 1.1

The back muscles may be considered to act as a single force *F* through a point on the back situated 25 cm from the pivot and making a **constant** angle of 15° with the back. The weight *W* of the upper body acts through a point **X**, situated a distance of 40 cm from the pivot.

(a) Calculate for an upper body weight *W* of 450 N, the size of the force *F* needed by the back muscles to keep the back at an angle of

(i) 30° to the horizontal

F = ... N [4]

(ii) 70° to the horizontal.

F = ... N [1]

(b) Explain including reference to your answers to **(a)**, the body position which should be adopted when lifting heavy loads from the ground.

....

....

....

....

....

....

.... [4]

[Total: 9]

2 Full-body CT scans produce detailed 3-D information about a patient and can identify cancers at an early stage in their development.

(a) Describe how a CT scan image is produced, referring to the physics principles involved.

....

....

....

....

....

....

....

....

....

.... [7]

(b) State and explain **two** reasons why full-body CT scans are not offered for regular checking of healthy patients.

....

....

....

.... [3]

[Total: 10]

BLANK PAGE

PLEASE DO NOT WRITE ON THIS PAGE

3 Fig. 3.1 shows how the minimum detectable intensity varies with frequency for a 55 year-old man over his audible range of frequencies.

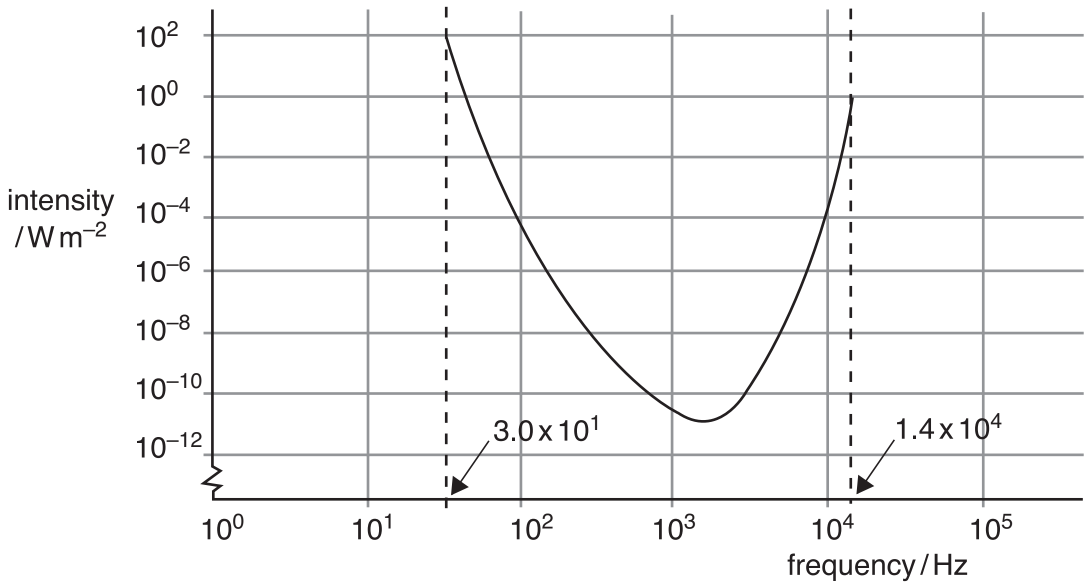

Fig. 3.1

(a) Describe how the hearing of this man compares with that of a person with normal hearing capabilities.

....

....

....

....

....

.... [3]

(b) **(i)** Calculate the intensity of a sound of intensity level 65 dB.

intensity = ... W m^{-2} [3]

(ii) Describe using information from the graph what the man hears when

1 he listens to a conversation at 65 dB

....

....

....

.... [2]

2 he listens to music at an average intensity of 10^{-8} W m^{-2}.

The bass notes are in the frequency range 20–40 Hz, the singing is in the range 0.080 kHz–2.0 kHz and the percussion includes frequencies up to 12 kHz.

....

....

....

.... [3]

[Total: 11]

4 An eye, when relaxed, focuses on an object at infinity. Accommodation occurs in order for the eye to focus on an object at its near point of 25 cm.

(a) Describe how the eye adjusts to perform accommodation. Begin your answer by making reference to the eye when focusing on an object at infinity.

....

....

....

....

.... [2]

(b) Calculate the maximum change in power for this eye.

Give a unit for your answer.

change in power = ... unit .... [3]

(c) A patient suffers from clouding of the lens. This clouding prevents light from reaching the retina and causes blindness. A medical student suggests that removing the lens would restore vision to some extent.

The patient has the eye lens removed.

Using your knowledge of the refracting system of the eye, describe and explain the quality of sight of the patient, when viewing an object which is first far away and then close to the eye.

....

....

....

....

....

.... [4]

(d) In order for a light sensitive cell in the retina to be stimulated, a minimum of 10 photons per second must reach the cell. 3 cells need to be stimulated to trigger a single nerve fibre. 85% of the photons incident on the eye reach the retina.

At low light intensity, 5000 nerve fibres must be triggered each second in order to just form a recognisable image.

(i) Calculate the minimum number of photons incident each second on the **cornea** needed to just form an image.

number = ... [3]

(ii) If the average wavelength of the incident light is 4.0×10^{-7} m, calculate the minimum power of light needed to just form an image.

power = ... W [3]

[Total: 15]

5 **(a)** Describe the principles of the production of a short pulse of ultrasound using a piezoelectric transducer.

....

....

....

....

....

....

....

.... [5]

(b) Fig. 5.1 shows a trace on a cathode-ray oscilloscope (CRO) of an ultrasound reflection from the front edge and rear edge of a foetal head.

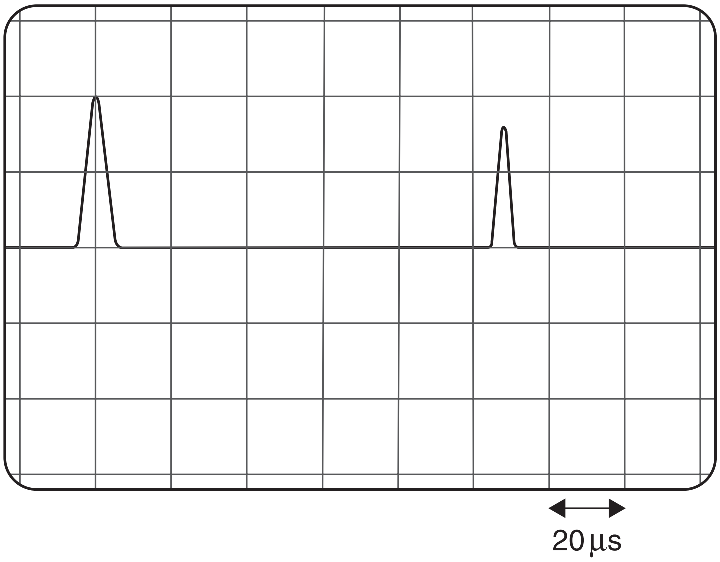

Fig. 5.1

The CRO timebase is set to $20\,\mu s\,cm^{-1}$. The speed of ultrasound in the foetal head is $1.5 \times 10^3\,m\,s^{-1}$.

(i) Calculate the size of the foetal head.

size = ... cm [4]

(ii) State and explain what would be seen on the CRO screen if gel had **not** been applied between the ultrasound transducer and the skin of the mother.

....

....

....

....

....

.... [3]

[Total: 12]

6 **(a)** Discuss why exposure to ionising radiation is employed in the treatment of malignant cells.

....

....

.... [2]

(b) When radiation penetrates air, ionisation occurs. The total amount of positive charge created in 1 kilogram of air is called the *exposure*.

An X-ray beam of photon energy 200 keV causes an exposure of $25\,\mu C\,kg^{-1}$ in one hour. The energy required to produce an ion-pair in air is 34 eV.

Calculate

(i) the number of ion-pairs created in a kilogram of air in the hour

number = ... [1]

(ii) the absorbed dose for the $25\,\mu C\,kg^{-1}$ exposure. Give the SI unit for your answer.

absorbed dose = ... unit .... [3]

(c) The effects on bone and muscle of radiation from the X-ray beam in **(b)** are compared with radiation from a 30 keV X-ray beam over the same time interval. This is done using a factor *f* that is defined by the equation

absorbed dose in a substance = $f \times$ exposure.

The results of the comparison are given in the table.

substance	*f* for 200 keV X-rays / $J\,C^{-1}$	*f* for 30 keV X-rays / $J\,C^{-1}$
bone	38	150
muscle	37	38

(i) Using the exposure in **(b)(ii)** calculate the absorbed dose in bone for the 200 keV X-ray.

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

(ii) Explain why radiation of photon energy 30 keV is used to target certain malignant cells. Suggest the type of therapy that might make use of these low energy X-rays.

....

....

....

.... [3]

(iii) Calculate the *quality factor* if the dose equivalent for the absorbed dose in bone, using the 200 keV source of X-rays as in **(c)(i)**, is 1.71 mSv.

quality factor = ... [2]

[Total: 13]

7 The suspension system for road vehicles can be modelled using springs and masses. The natural frequency of oscillation *f* for a mass *m* supported by a spring is given by

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

where *k* is the spring constant.

(a) (i) A spring is found to compress by 40 mm when loaded with a mass of 5000 kg. Show that the spring constant *k* is $1.2 \times 10^6\,\mathrm{N\,m^{-1}}$.

[2]

(ii) A 5000 kg mass is supported by four such springs as shown in Fig. 7.1.

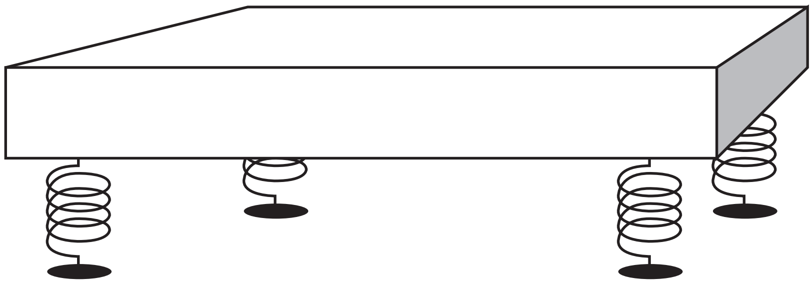

Fig. 7.1

Calculate the natural frequency of oscillation of the mass.

natural frequency = ... Hz [2]

(b) The suspension systems of large lorries require springs made from rods which may be several centimetres thick. Steel rod of this diameter would snap if bent into shape at room temperature. To prevent this the rod is 'hot-coiled': it is heated from 20 °C to 1000 °C before being wound into a spring.

The method of heating is electrical, using a supply of 50 V, which passes a current of 12 000 A through the steel rod. Large contacts at each end of the rod are necessary and these are water-cooled (see Fig. 7.2).

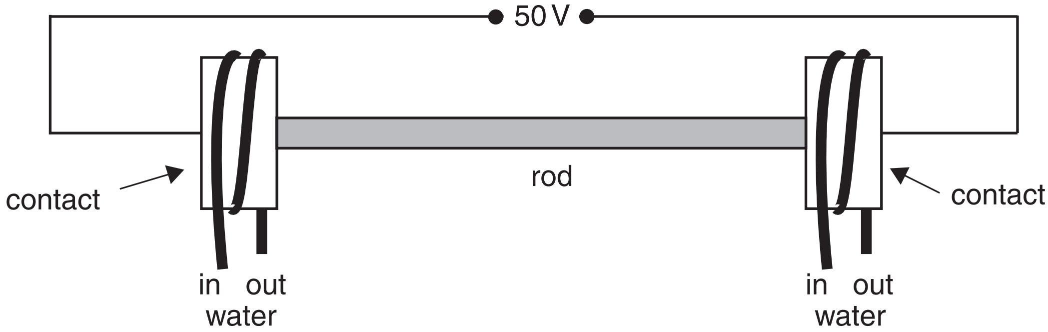

Fig. 7.2

(i) Calculate the resistance of the rod, assuming that the voltage across it is 50 V.

resistance = ... Ω [1]

(ii) Show that the electrical power generated in the rod is 600 kW.

[1]

The mass of the rod is 15 kg.

The specific heat capacity of steel is $420\,\mathrm{J\,kg^{-1}\,K^{-1}}$.

(iii) Calculate the energy required to heat the rod from 20 °C to 1000 °C.

energy = ... J [2]

(iv) Calculate the minimum time required to heat the rod to 1000 °C.

minimum time = ... s [2]

(c) In practice the time taken to reach 1000 °C is greater than the value found in **(b)(iv)**. Consequently, the total energy supplied is found to vary according to the time taken for the heating process. The relationship between the energy supplied and time taken is shown in Fig. 7.3.

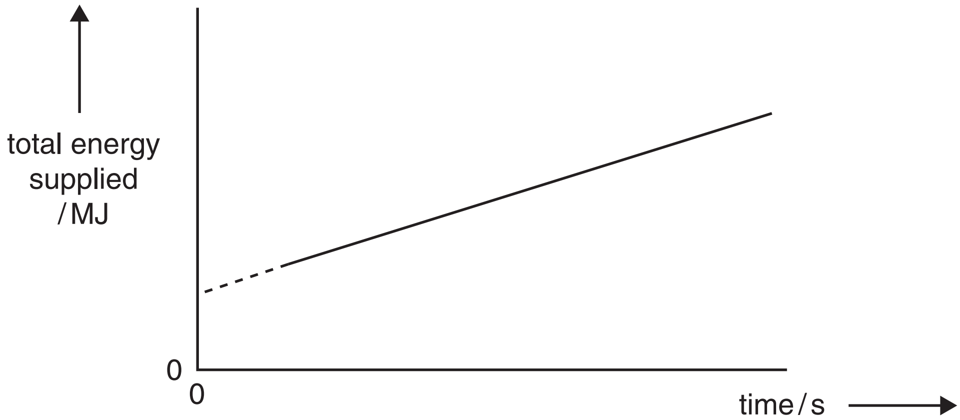

Fig. 7.3

Discuss **two** ways in which energy is lost from the rod during heating and explain the trend shown by the graph in Fig. 7.3.

....

....

....

....

....

.... [3]

(d) A spring is made from a steel rod of the same length but with **twice** the radius.

Suggest, **with reasons**, how the following will change.

(i) The resistance of the rod.

....

....

....

.... [2]

(ii) The time taken to heat the rod from 20 °C to 1000 °C, using the same voltage across the rod.

....

....

....

....

.... [3]

(iii) The natural frequency of the mass-spring system in **(a)**.

....

....

....

.... [2]

[Total: 20]

END OF QUESTION PAPER

PLEASE DO NOT WRITE ON THIS PAGE