Version 1.1

Surname				Other Names					
Centre Number					Candidate Number				
Candidate Signature									

General Certificate of Education
June 2003
Advanced Level Examination

PHYSICS (SPECIFICATION A) PHA6/W
Unit 6 Nuclear Instability: Medical Physics Option

Friday 20 June 2003   Afternoon Session

AQA

ASSESSMENT and
QUALIFICATIONS
ALLIANCE

In addition to this paper you will require:
- a calculator;
- a pencil and a ruler.

Time allowed: 1 hour 15 minutes

For Examiner's Use			
Number	Mark	Number	Mark
1			
2			
3			
4			
5			
Total (Column 1)			
Total (Column 2)			
TOTAL			
Examiner's Initials			

Instructions
- Use blue or black ink or ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions in the spaces provided. All working must be shown.
- Do all rough work in this book. Cross through any work you do not want marked.

Information
- The maximum mark for this paper is 40.
- Mark allocations are shown in brackets.
- The paper carries 10% of the total marks for Physics Advanced.
- A *Data Sheet* is provided on pages 3 and 4. You may wish to detach this perforated sheet at the start of the examination.
- You are expected to use a calculator where appropriate.
- In questions requiring description and explanation you will be assessed on your ability to use an appropriate form and style of writing, to organise relevant information clearly and coherently, and to use specialist vocabulary where appropriate. The degree of legibility of your handwriting and the level of accuracy of your spelling, punctuation and grammar will also be taken into account.

Data Sheet

- A perforated *Data Sheet* is provided as pages 3 and 4 of this question paper.

- This sheet may be useful for answering some of the questions in the examination.

- You may wish to detach this sheet before you begin work.

Fundamental constants and values

Quantity	Symbol	Value	Units
speed of light in vacuo	c	3.00×10^8	m s^{-1}
permeability of free space	μ_0	$4\pi \times 10^{-7}$	H m^{-1}
permittivity of free space	ε_0	8.85×10^{-12}	F m^{-1}
charge of electron	e	1.60×10^{-19}	C
the Planck constant	h	6.63×10^{-34}	J s
gravitational constant	G	6.67×10^{-11}	$\text{N m}^2 \text{ kg}^{-2}$
the Avogadro constant	N_A	6.02×10^{23}	mol^{-1}
molar gas constant	R	8.31	$\text{J K}^{-1} \text{ mol}^{-1}$
the Boltzmann constant	k	1.38×10^{-23}	J K^{-1}
the Stefan constant	σ	5.67×10^{-8}	$\text{W m}^{-2} \text{ K}^{-4}$
the Wien constant	α	2.90×10^{-3}	m K
electron rest mass (equivalent to $5.5 \times 10^{-4}\text{u}$)	m_e	9.11×10^{-31}	kg
electron charge/mass ratio	e/m_e	1.76×10^{11}	C kg^{-1}
proton rest mass (equivalent to 1.00728u)	m_p	1.67×10^{-27}	kg
proton charge/mass ratio	e/m_p	9.58×10^7	C kg^{-1}
neutron rest mass (equivalent to 1.00867u)	m_n	1.67×10^{-27}	kg
gravitational field strength	g	9.81	N kg^{-1}
acceleration due to gravity	g	9.81	m s^{-2}
atomic mass unit (1u is equivalent to 931.3 MeV)	u	1.661×10^{-27}	kg

Fundamental particles

Class	Name	Symbol	Rest energy /MeV
photon	photon	γ	0
lepton	neutrino	ν_e	0
		ν_μ	0
	electron	$e^\pm$	0.510999
	muon	$\mu^\pm$	105.659
mesons	pion	$\pi^\pm$	139.576
		π^0	134.972
	kaon	$K^\pm$	493.821
		K^0	497.762
baryons	proton	p	938.257
	neutron	n	939.551

Properties of quarks

Type	Charge	Baryon number	Strangeness
u	$+\frac{2}{3}$	$+\frac{1}{3}$	0
d	$-\frac{1}{3}$	$+\frac{1}{3}$	0
s	$-\frac{1}{3}$	$+\frac{1}{3}$	-1

Geometrical equations

$arc\ length = r\theta$

$circumference\ of\ circle = 2\pi r$

$area\ of\ circle = \pi r^2$

$area\ of\ cylinder = 2\pi rh$

$volume\ of\ cylinder = \pi r^2 h$

$area\ of\ sphere = 4\pi r^2$

$volume\ of\ sphere = \frac{4}{3}\pi r^3$

Mechanics and Applied Physics

$v = u + at$

$s = \left(\dfrac{u+v}{2}\right) t$

$s = ut + \dfrac{at^2}{2}$

$v^2 = u^2 + 2as$

$F = \dfrac{\Delta(mv)}{\Delta t}$

$P = Fv$

$efficiency = \dfrac{power\ output}{power\ input}$

$\omega = \dfrac{v}{r} = 2\pi f$

$a = \dfrac{v^2}{r} = r\omega^2$

$I = \sum mr^2$

$E_k = \frac{1}{2} I\omega^2$

$\omega_2 = \omega_1 + \alpha t$

$\theta = \omega_1 t + \frac{1}{2}\alpha t^2$

$\omega_2^2 = \omega_1^2 + 2\alpha\theta$

$\theta = \frac{1}{2}(\omega_1 + \omega_2)t$

$T = I\alpha$

$angular\ momentum = I\omega$

$W = T\theta$

$P = T\omega$

$angular\ impulse = change\ of$
$\quad angular\ momentum = Tt$

$\Delta Q = \Delta U + \Delta W$

$\Delta W = p\Delta V$

$pV^\gamma = constant$

$work\ done\ per\ cycle = area$
$\quad of\ loop$

$input\ power = calorific$
$\quad value \times fuel\ flow\ rate$

$indicated\ power\ as\ (area\ of\ p - V$
$\quad loop) \times (no.\ of\ cycles/s) \times$
$\quad (no.\ of\ cylinders)$

$friction\ power = indicated$
$\quad power - brake\ power$

$efficiency = \dfrac{W}{Q_{in}} = \dfrac{Q_{in} - Q_{out}}{Q_{in}}$

$maximum\ possible$

$\quad efficiency = \dfrac{T_H - T_C}{T_H}$

Fields, Waves, Quantum Phenomena

$g = \dfrac{F}{m}$

$g = -\dfrac{GM}{r^2}$

$g = -\dfrac{\Delta V}{\Delta x}$

$V = -\dfrac{GM}{r}$

$a = -(2\pi f)^2 x$

$v = \pm 2\pi f \sqrt{A^2 - x^2}$

$x = A \cos 2\pi ft$

$T = 2\pi\sqrt{\dfrac{m}{k}}$

$T = 2\pi\sqrt{\dfrac{L}{g}}$

$\lambda = \dfrac{\omega s}{D}$

$d \sin\theta = n\lambda$

$\theta \approx \dfrac{\lambda}{D}$

$_1 n_2 = \dfrac{\sin\theta_1}{\sin\theta_2} = \dfrac{c_1}{c_2}$

$_1 n_2 = \dfrac{n_2}{n_1}$

$\sin\theta_c = \dfrac{1}{n}$

$E = hf$

$hf = \phi + E_k$

$hf = E_1 - E_2$

$\lambda = \dfrac{h}{p} = \dfrac{h}{mv}$

$c = \dfrac{1}{\sqrt{\mu_0 \varepsilon_0}}$

Electricity

$\epsilon = \dfrac{E}{Q}$

$\epsilon = I(R + r)$

$\dfrac{1}{R_T} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3} + \cdots$

$R_T = R_1 + R_2 + R_3 + \cdots$

$P = I^2 R$

$E = \dfrac{F}{Q} = \dfrac{V}{d}$

$E = \dfrac{1}{4\pi\varepsilon_0}\dfrac{Q}{r^2}$

$E = \frac{1}{2} QV$

$F = BIl$

$F = BQv$

$Q = Q_0 e^{-t/RC}$

$\Phi = BA$

Turn over ▶

$$magnitude\ of\ induced\ e.m.f. = N \frac{\Delta\Phi}{\Delta t}$$

$$I_{rms} = \frac{I_0}{\sqrt{2}}$$

$$V_{rms} = \frac{V_0}{\sqrt{2}}$$

Mechanical and Thermal Properties

$$the\ Young\ modulus = \frac{tensile\ stress}{tensile\ strain} = \frac{F}{A}\frac{l}{e}$$

$$energy\ stored = \tfrac{1}{2} Fe$$

$$\Delta Q = mc\,\Delta\theta$$

$$\Delta Q = ml$$

$$pV = \tfrac{1}{3} Nm\overline{c^2}$$

$$\tfrac{1}{2} m\overline{c^2} = \tfrac{3}{2} kT = \frac{3RT}{2N_A}$$

Nuclear Physics and Turning Points in Physics

$$force = \frac{eV_p}{d}$$

$$force = Bev$$

$$radius\ of\ curvature = \frac{mv}{Be}$$

$$\frac{eV}{d} = mg$$

$$work\ done = eV$$

$$F = 6\pi\eta rv$$

$$I = k\frac{I_0}{x^2}$$

$$\frac{\Delta N}{\Delta t} = -\lambda N$$

$$\lambda = \frac{h}{\sqrt{2meV}}$$

$$N = N_0 e^{-\lambda t}$$

$$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$$

$$R = r_0 A^{\frac{1}{3}}$$

$$E = mc^2 = \frac{m_0 c^2}{\left(1 - \dfrac{v^2}{c^2}\right)^{\frac{1}{2}}}$$

$$l = l_0 \left(1 - \frac{v^2}{c^2}\right)^{\frac{1}{2}}$$

$$t = \frac{t_0}{\left(1 - \dfrac{v^2}{c^2}\right)^{\frac{1}{2}}}$$

Astrophysics and Medical Physics

Body	Mass/kg	Mean radius/m
Sun	2.00×10^{30}	7.00×10^{8}
Earth	6.00×10^{24}	6.40×10^{6}

1 astronomical unit = 1.50×10^{11} m

1 parsec = 206265 AU = 3.08×10^{16} m = 3.26 ly

1 light year = 9.45×10^{15} m

Hubble constant (H) = 65 kms^{-1} Mpc^{-1}

$$M = \frac{angle\ subtended\ by\ image\ at\ eye}{angle\ subtended\ by\ object\ at\ unaided\ eye}$$

$$M = \frac{f_o}{f_e}$$

$$m - M = 5 \log \frac{d}{10}$$

$$\lambda_{max} T = constant = 0.0029\ m\ K$$

$$v = Hd$$

$$P = \sigma A T^4$$

$$\frac{\Delta f}{f} = \frac{v}{c}$$

$$\frac{\Delta\lambda}{\lambda} = -\frac{v}{c}$$

$$R_s \approx \frac{2GM}{c^2}$$

Medical Physics

$$power = \frac{1}{f}$$

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} \quad and \quad m = \frac{v}{u}$$

$$intensity\ level = 10 \log \frac{I}{I_0}$$

$$I = I_0 e^{-\mu x}$$

$$\mu_m = \frac{\mu}{\rho}$$

Electronics

Resistors

Preferred values for resistors (E24)
Series: 1.0 1.1 1.2 1.3 1.5 1.6 1.8 2.0 2.2 2.4 2.7 3.0 3.3 3.6 3.9 4.3 4.7 5.1 5.6 6.2 6.8 7.5 8.2 9.1 ohms
and multiples that are ten times greater

$$Z = \frac{V_{rms}}{I_{rms}}$$

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots$$

$$C_T = C_1 + C_2 + C_3 + \cdots$$

$$X_C = \frac{1}{2\pi f C}$$

Alternating Currents

$$f = \frac{1}{T}$$

Operational amplifier

$$G = \frac{V_{out}}{V_{in}} \qquad voltage\ gain$$

$$G = -\frac{R_f}{R_1} \qquad inverting$$

$$G = 1 + \frac{R_f}{R_1} \qquad non\text{-}inverting$$

$$V_{out} = -R_f \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right) \qquad summing$$

SECTION A: NUCLEAR INSTABILITY

Answer **all** parts of this question.

1 **Figure 1** shows a grid of neutron number against proton number. A nucleus $_Z^A X$ is marked.

neutron number
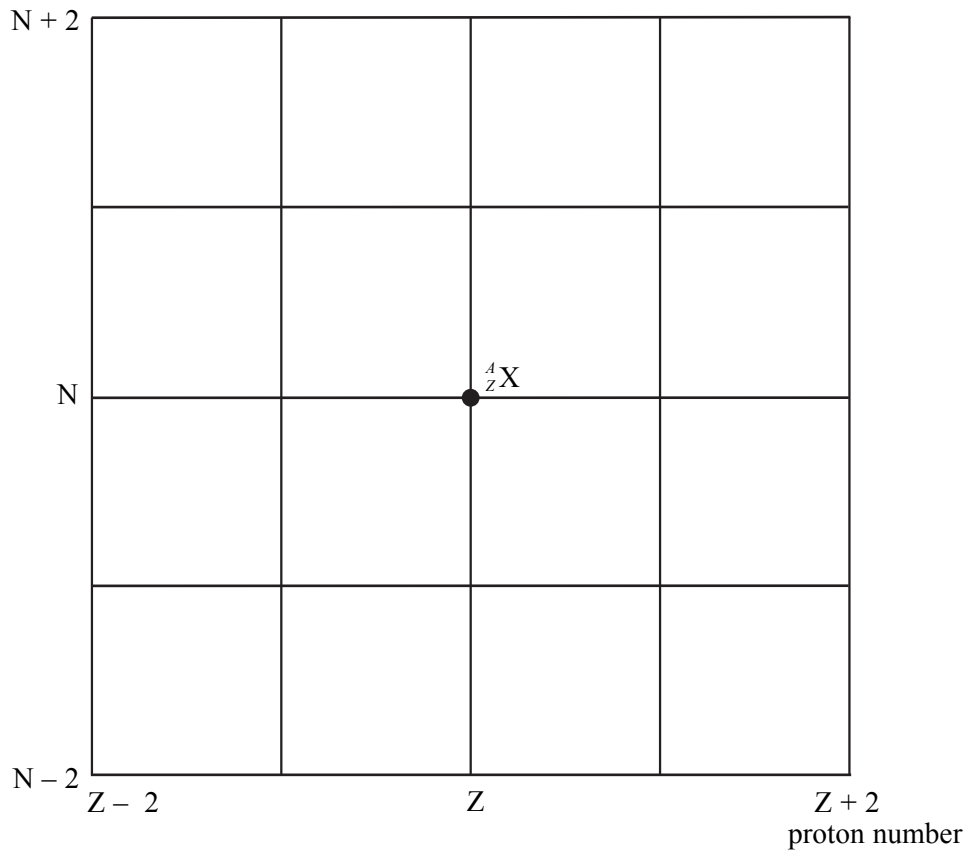
Figure 1

(a) Draw arrows on **Figure 1**, each starting on $_Z^A X$ and ending on a daughter nucleus after the following transitions:

(i) β⁻ emission   (label this arrow A)
neutron emission (label this arrow B)
electron capture   (label this arrow C).

(ii) Give the equation for electron capture by the nucleus $_Z^A X$.

....

(4 marks)

Turn over ▶

(b) When $^{27}_{12}\text{Mg}$ decays to $^{27}_{13}\text{Al}$ by β^- decay, the daughter nucleus is produced in one of two possible excited states. These two states are shown in **Figure 2** together with their corresponding energies.

$^{27}_{12}\text{Mg}$ $E/10^{-13}\,\text{J}$

4.18

1.63

1.33

$^{27}_{13}\text{Al}$ 0.00 (ground state)
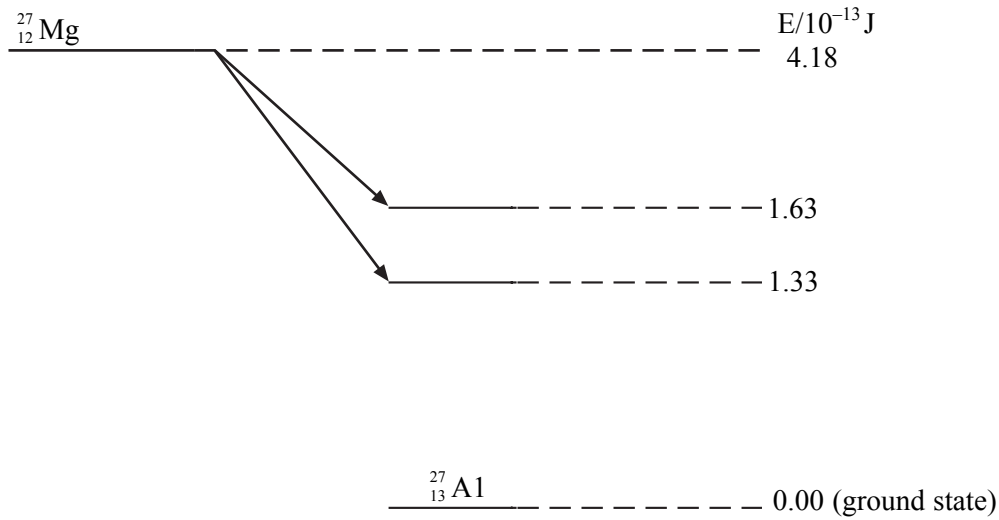
Figure 2

(i) Calculate the maximum possible kinetic energy, in J, which an emitted β^- particle can have.

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(ii) The excited aluminium nuclei emit γ photons. Calculate each of the three possible γ photon energies in J.

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(iii) Calculate the frequency of the most energetic γ photon emitted.

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(3 marks)

(c)   (i)   State and explain **two** precautions that should be taken when working with a sample of $^{27}_{12}$Mg in a school laboratory.

You may be awarded marks for the quality of written communication in your answer.

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(ii)   Discuss which of the two types of radiation, β⁻ or γ, emitted from a sample of $^{27}_{12}$Mg would be the more hazardous.

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....

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(3 marks)

$\overline{10}$

TURN OVER FOR THE NEXT QUESTION

Turn over ▶

SECTION B: MEDICAL PHYSICS

Answer **all** questions.

2 (a) The diagram represents a simplified version of a normal eye, with no sight defects, looking at a distant point object.

Complete the paths of the two rays.

eye lens

rays from
distant
point
object

optic
axis

fovea

cornea
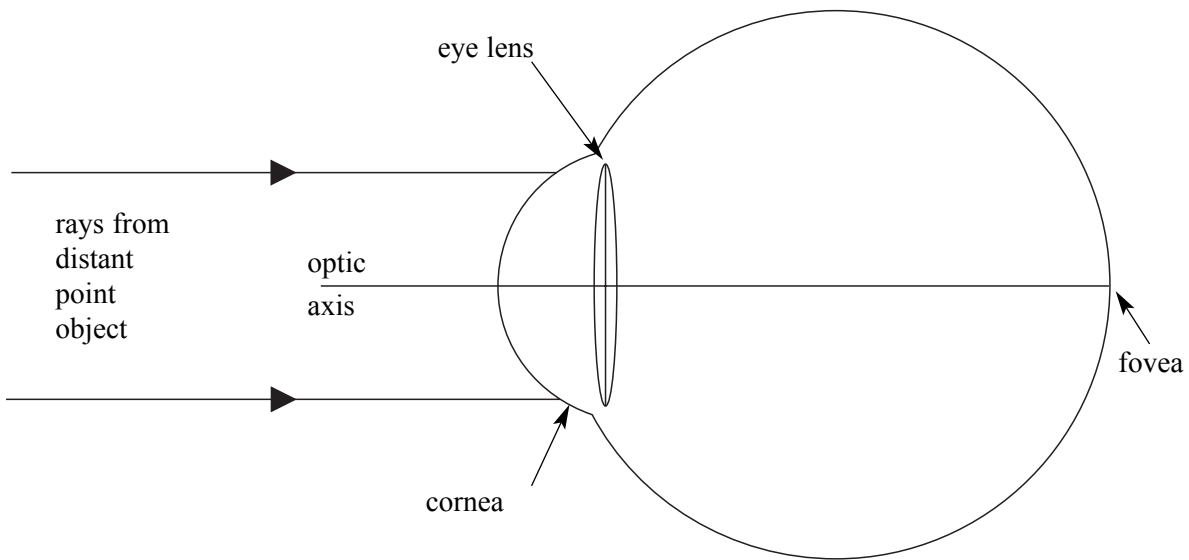
(2 marks)

(b) Describe the distribution of receptors over the retina.

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(2 marks)

(c) (i) State the purpose of the iris.

....

....

(ii) Describe how this purpose is achieved when the eye is exposed to bright light.

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(2 marks)

(d) (i) State what is meant by *accommodation*.

....

....

(ii) Describe how accommodation is achieved.

....

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....

....

(2 marks)

$\dfrac{}{8}$

TURN OVER FOR THE NEXT QUESTION

Turn over ▶

3 The graph shows the variation of membrane potential difference with time of a nerve fibre, known as an action potential.

(a) Complete the graph by adding suitable axes, units and scales. *(3 marks)*

(b) Describe the processes involved in the production of such an action potential when a nerve is stimulated.

You may be awarded marks for the quality of written communication in your answer.

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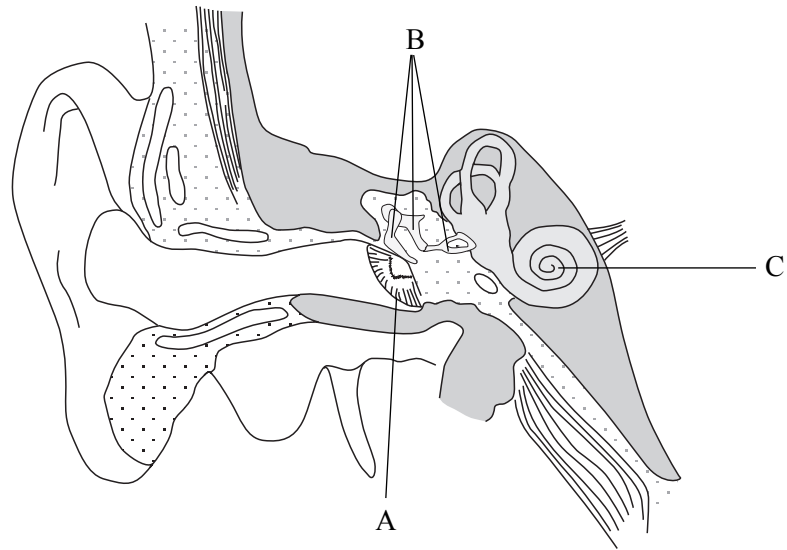
(3 marks)

4 The diagram shows a vertical section through a human ear.

(a) Name and state the functions of the parts labelled A, B and C in the diagram.

A name ....

function...

....

B name ....

function...

....

C name ....

function...

....

(6 marks)

(b) An ear has a threshold of hearing at a particular frequency at an intensity level of 42 dB. Calculate the intensity of sound incident on the ear.

$I_0 = 1.0 \times 10^{-12} \, \text{W m}^{-2}$

....

....

....

(2 marks)

8

Turn over ▶

5 Diagnostic X-rays are produced using a rotating anode X-ray tube.

(a) (i) State **two** methods which can be used to increase the intensity of the X-ray beam produced by the tube.

method 1 ....

method 2 ....

(ii) For each method of increasing intensity, state the effect on the maximum X-ray photon energy.

method 1 ....

method 2 ....

(3 marks)

(b) Before taking an X-ray photograph, the X-ray beam emerging from the tube is passed through an aluminium filter. State and explain the reason for filtering the X-rays.

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(3 marks)

QUALITY OF WRITTEN COMMUNICATION *(2 marks)*

END OF QUESTIONS