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MINISTRY OF EDUCATION, SINGAPORE
in collaboration with
CAMBRIDGE ASSESSMENT INTERNATIONAL EDUCATION
General Certificate of Education Advanced Level
Higher 2

CANDIDATE NAME

CENTRE NUMBER S

INDEX NUMBER

T4572683491

PHYSICS

9749/02

Paper 2 Structured Questions

October/November 2021

2 hours

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your Centre number, index number and name in the spaces at the top of this page.
Write in dark blue or black pen on both sides of the paper.
You may use an HB pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.
DO **NOT** WRITE ON ANY BARCODES.

The use of an approved scientific calculator is expected, where appropriate.
Answer **all** questions.

The number of marks is given in brackets [ ] at the end of each question or part question.

PIVOT The Centre of Physics

This document consists of **22** printed pages and **2** blank pages.

Singapore Examinations and Assessment Board

Cambridge Assessment International Education

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Data

speed of light in free space	$c = 3.00 \times 10^{8}\,\text{m s}^{-1}$
permeability of free space	$\mu_0 = 4\pi \times 10^{-7}\,\text{H m}^{-1}$
permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12}\,\text{F m}^{-1}$
	$(1/(36\pi)) \times 10^{-9}\,\text{F m}^{-1}$
elementary charge	$e = 1.60 \times 10^{-19}\,\text{C}$
the Planck constant	$h = 6.63 \times 10^{-34}\,\text{J s}$
unified atomic mass constant	$u = 1.66 \times 10^{-27}\,\text{kg}$
rest mass of electron	$m_e = 9.11 \times 10^{-31}\,\text{kg}$
rest mass of proton	$m_p = 1.67 \times 10^{-27}\,\text{kg}$
molar gas constant	$R = 8.31\,\text{J K}^{-1}\,\text{mol}^{-1}$
the Avogadro constant	$N_A = 6.02 \times 10^{23}\,\text{mol}^{-1}$
the Boltzmann constant	$k = 1.38 \times 10^{-23}\,\text{J K}^{-1}$
gravitational constant	$G = 6.67 \times 10^{-11}\,\text{N m}^2\,\text{kg}^{-2}$
acceleration of free fall	$g = 9.81\,\text{m s}^{-2}$

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Formulae

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$
work done on / by a gas	$W = p\Delta V$
hydrostatic pressure	$p = \rho gh$
gravitational potential	$\phi = -\frac{Gm}{r}$
temperature	$T/\text{K} = T/^\circ\text{C} + 273.15$
pressure of an ideal gas	$p = \frac{1}{3}\frac{Nm}{V} < c^2 >$
mean translational kinetic energy of an ideal gas molecule	$E = \frac{3}{2}kT$
displacement of particle in s.h.m.	$x = x_0 \sin \omega t$
velocity of particle in s.h.m.	$v = v_0 \cos \omega t$ $= \pm \omega \sqrt{x_0^2 - x^2}$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \ldots$
resistors in parallel	$1/R = 1/R_1 + 1/R_2 + \ldots$
electric potential	$V = \frac{Q}{4\pi\varepsilon_0 r}$
alternating current / voltage	$x = x_0 \sin \omega t$
magnetic flux density due to a long straight wire	$B = \frac{\mu_0 I}{2\pi d}$
magnetic flux density due to a flat circular coil	$B = \frac{\mu_0 NI}{2r}$
magnetic flux density due to a long solenoid	$B = \mu_0 nI$
radioactive decay	$x = x_0 \exp(-\lambda t)$
decay constant	$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$

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Answer **all** the questions in the spaces provided.

1 A block is held at rest on a straight, frictionless slope. The slope is at an angle to the horizontal bench, as shown in Fig. 1.1.

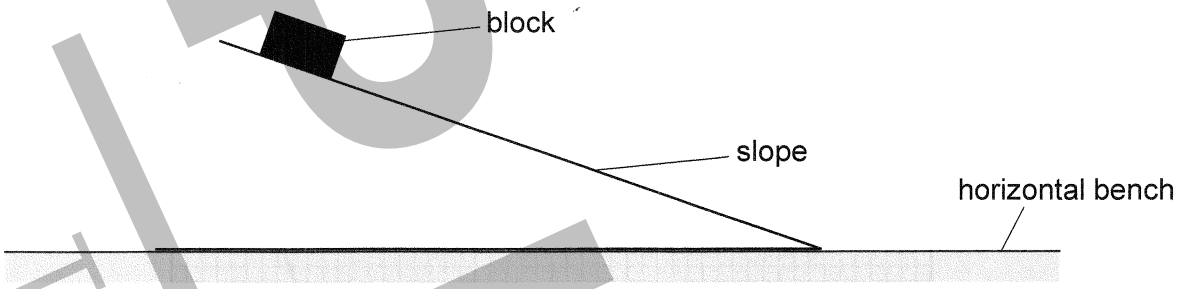


Fig. 1.1

The block is then released from rest at time $t = 0$.

(a) Describe the motion of the block down the slope.

The block slides down the slope with constant acceleration.

..... [1]

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(b) The variation with time t of the displacement s of the block is shown in Fig. 1.2.

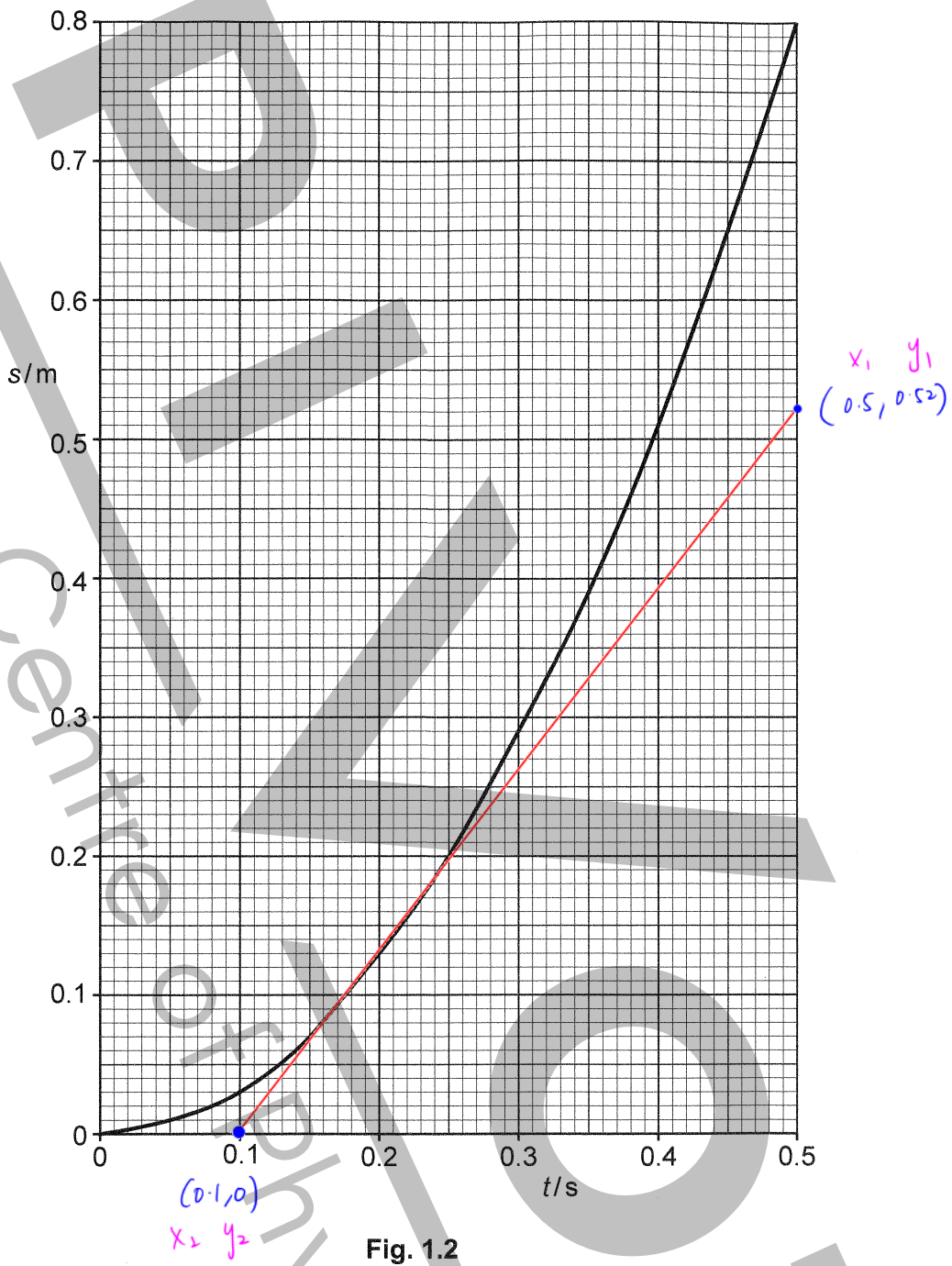


Fig. 1.2

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(i) On Fig. 1.2, draw a tangent to determine the speed of the block at time $t = 0.20\,s$.

$v = \frac{\Delta s}{\Delta t} = \frac{y_1 - y_2}{x_1 - x_2} = \frac{0.52 - 0}{0.5 - 0.1} = 1.30\,ms^{-1}$ (3sf) #

speed = 1.30 $m s^{-1}$ [2]

(ii) Use your answer in **(b)(i)** to determine the acceleration of the block at time $t = 0.20\,s$.

$v = u + at$

$\therefore a = \frac{v - u}{t} = \frac{1.30 - 0}{0.2} = 6.50\,ms^{-2}$ #

acceleration = 6.50 $m s^{-2}$ [2]

[Total: 5]

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2 A ball of mass 0.62 kg is dropped from rest. It hits a horizontal surface and rebounds. The variation with time t of the momentum p of the ball when not in contact with the ground is shown in Fig. 2.1.

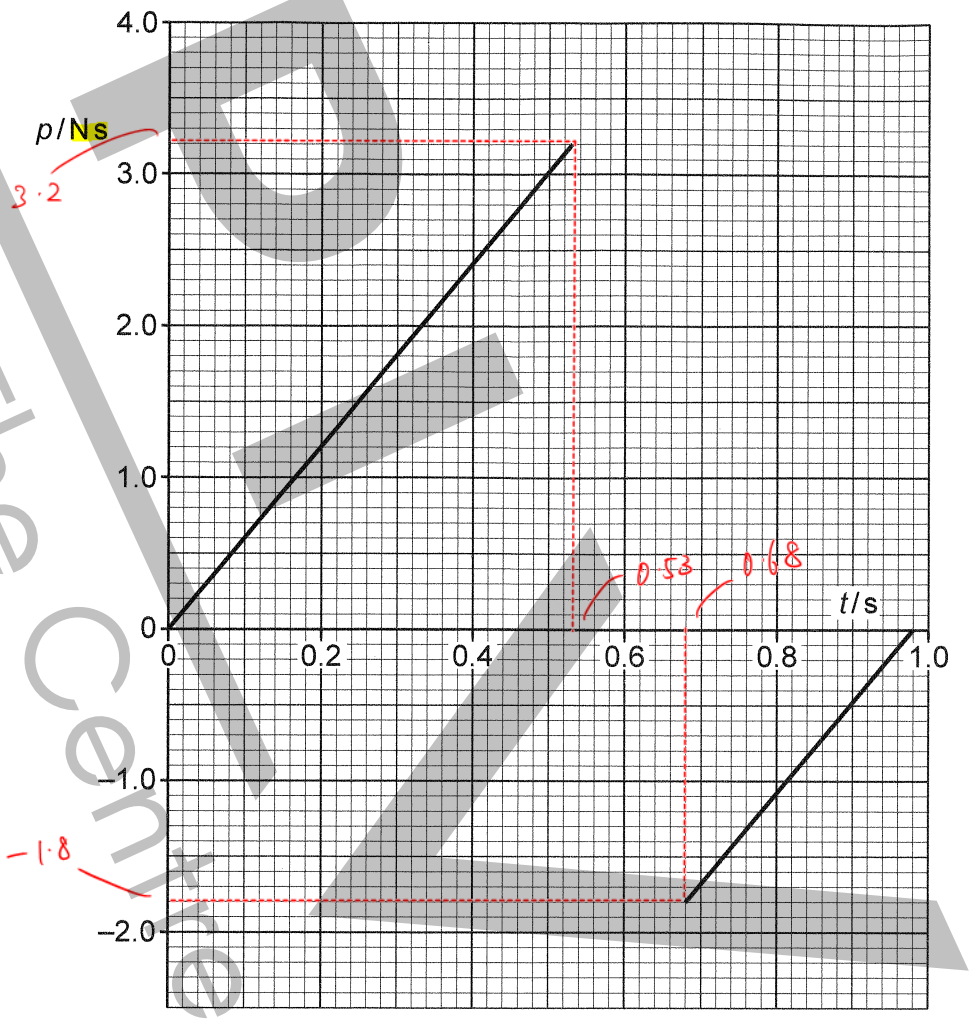


Fig. 2.1

(a) Calculate the kinetic energy E_k of the ball as it makes contact with the surface.

$E = \frac{p^2}{2m} = \frac{(3.2)^2}{2(0.62)} = 8.25806$

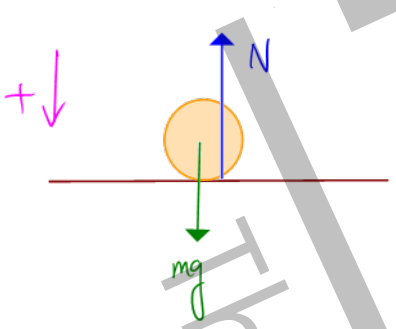
$= 8.26\,J$ (3sf) *

E_k = 8.26 J [3]

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(b) Determine the magnitude of the average force exerted by the ground on the ball when the ball is in contact with the surface. Show your working.

By N2L, $F_{net} = \frac{\Delta p}{\Delta t} = \frac{p_f - p_i}{\Delta t} = \frac{-1.8 - 3.2}{0.68 - 0.53} = -33.333\,N$



$\therefore F_{net} = mg - N$

$\therefore N = mg - F_{net}$

$= (0.62)(9.81) - (-33.33)$

$= 39.415$

$= 39.4\,N$ (3sf) *

force = 39.4 N [4]

(c) The ball loses the same percentage of its kinetic energy every time it rebounds.

Determine the number of times the ball rebounds before its total energy decreases to less than 5.0% of its initial energy. Show your working.

< 0.05

KE before hitting ground $= 8.25806\,J$

KE after hitting ground $= \frac{p^2}{2m} = \frac{(-1.8)^2}{2(0.62)} = 2.612\,J$

$\therefore$ % KE loss $= \frac{8.25806 - 2.612}{8.25806} \times 100\% = 68.359\%$

$\therefore$ % KE remaining after each bounce $= 100\% - 68.359\% = 31.6406\%$.

Hence $8.25806\left(\frac{31.6406}{100}\right)^n < (0.05)(8.25806)$

Take lg on both sides

$n \lg(0.316406) < \lg(0.05)$

$\therefore n > 2.603$, $n \in \mathbb{Z}^+$

$\therefore n = 3$ *

number = 3 [3]

[Total: 10]

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3 A sign PQ and its support stand are in equilibrium on a horizontal surface, as shown in Fig. 3.1.

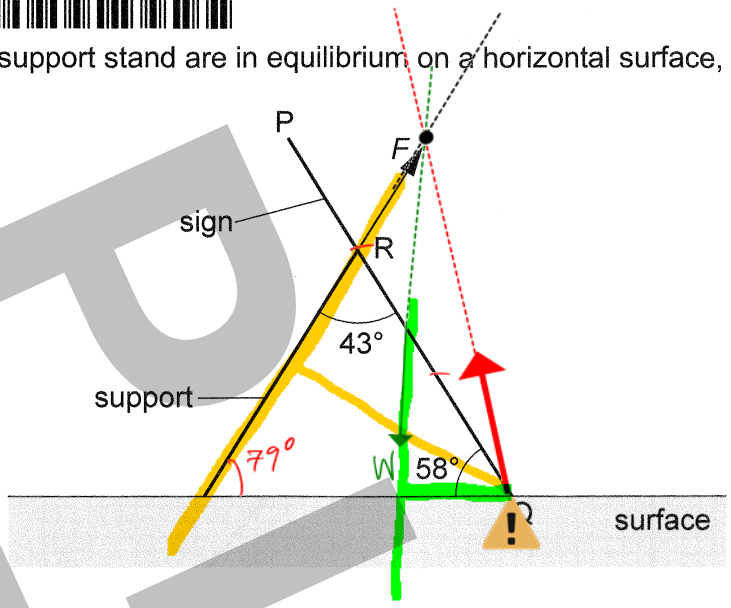


Fig. 3.1 (not to scale)

The sign is uniform and has a mass of 2.3 kg. The sign is at an angle of 58° to the surface.

The support joins to the sign at point R where PR = $\frac{PQ}{3}$. The support is at an angle of 43° to the sign and exerts a force *F* on the sign. Force *F* is parallel to the support.

(a) By taking moments about point Q, determine the force *F*.

Let L be the length of PQ.

TCW = TACW

$F\left(\frac{2}{3}L\sin 43\right) = W\left(\frac{1}{2}L\cos 58\right)$, $W = mg$

$\therefore F = \frac{(2.3)(9.81)\left(\frac{1}{2}\right)(\cos 58)\left(\frac{3}{2}\right)}{\sin 43} = 13.148 = 13.1\,N\ (3sf)$

$F =$ 13.1 N [3]

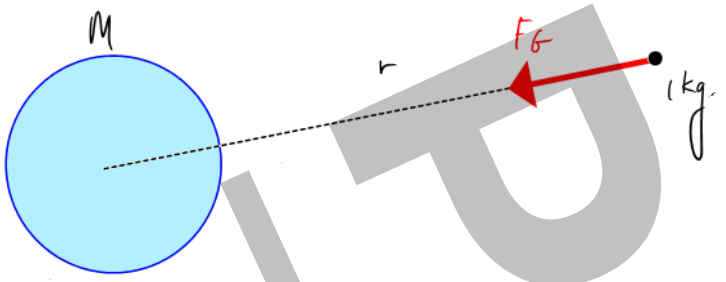
(b) Explain why the force acting on the sign at Q is not vertical.

For the sign to be in equilibrium, the net forces and the net torque about any point must be zero. These forces must form a closed loop polygon and must pass through a single point. For force F, its weight and the force acting on the sign at Q to pass through a single point, the force acting on the sign at Q cannot be vertical. [2]

[Total: 5]

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4 **(a)** Derive, from Newton's law of gravitation and the definition of gravitational field strength, an expression for the gravitational field strength g at a distance r from a point mass M.



By definition, g is defined as the gravitational force acting on unit mass at a point

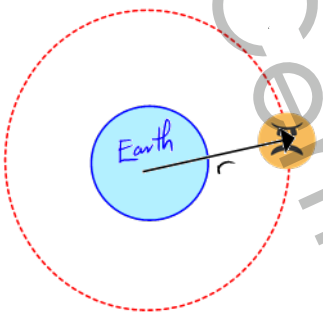
$\therefore g = \frac{GM(1)}{r^2} = \frac{GM}{r^2}$ # derived.

[1]

(b) A satellite is in a circular orbit about the Earth with a period of 110 minutes. 6600 s

For this satellite, the Earth may be considered to be a point mass of 6.0×10^{24} kg situated at its centre.

Determine the gravitational field strength g at the location of the satellite. Show your working.



$F_G = F_C$

$\frac{GMm}{r^2} = mr\left(\frac{2\pi}{T}\right)^2$

$\therefore r^3 = \frac{GMT^2}{4\pi^2}$

$\therefore r = \sqrt[3]{\frac{GMT^2}{4\pi^2}} = \sqrt[3]{\frac{(6.67\times10^{-11})(6\times10^{24})(6600)^2}{4\pi^2}} = 7.6149\times10^6$ m

$\therefore g = \frac{GM}{r^2} = \frac{(6.67\times10^{-11})(6\times10^{24})}{(7.6149\times10^6)^2} = 6.901 = 6.90$ N kg^{-1} #

g = 6.90 N kg^{-1} [4]

(c) Explain why, near the surface of the Earth, the gravitational field strength is equal to the acceleration of free fall.

An object of mass, m, is free falling when acted only by the gravitational attractive force, F_G. By Newton's 2nd law, $g_{freefall} = \frac{F_G}{m}$. By definition, gravitational field strength, $g = \frac{F_G}{m}$. Hence, the acceleration of free fall equals the gravitational field strength near the surface of the Earth.

[3]

[Total: 8]

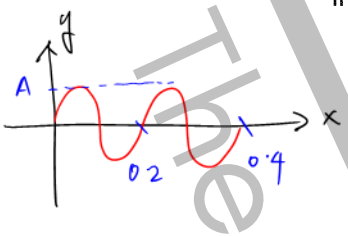
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5 **(a)** Two waves, each having the same amplitude and a frequency of 1700 Hz, travel in opposite directions at a speed of 340 m s^{-1}. A stationary wave of maximum intensity I_0 is formed as the result of the superposition of these two waves.

On Fig. 5.1, sketch a line to show the variation with distance x from a node of the intensity of the stationary wave for values of x from $x = 0$ to $x = 0.4$ m.

$v = f\lambda$

$\therefore \lambda = \frac{v}{f} = \frac{340}{1700} = 0.2$



$I \propto A^2$

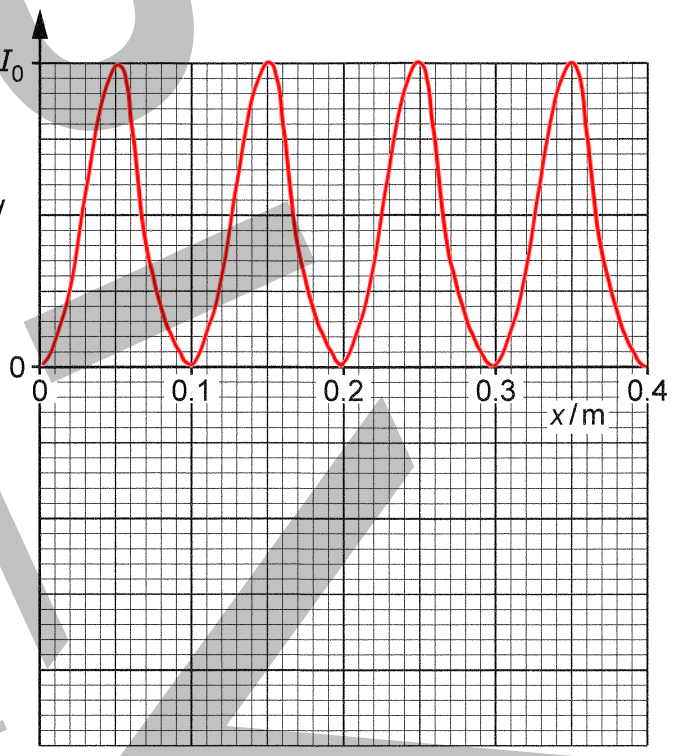


Fig. 5.1

[3]

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(b) A sound wave has a frequency of 250 Hz and passes a point X.

On Fig. 5.2, sketch a line to show the variation with time t of the change in air pressure due to the wave passing X. Your line should extend from $t = 0$ to $t = 8.0$ ms.

$T = \frac{1}{f} = \frac{1}{250} = 4\text{ms}$

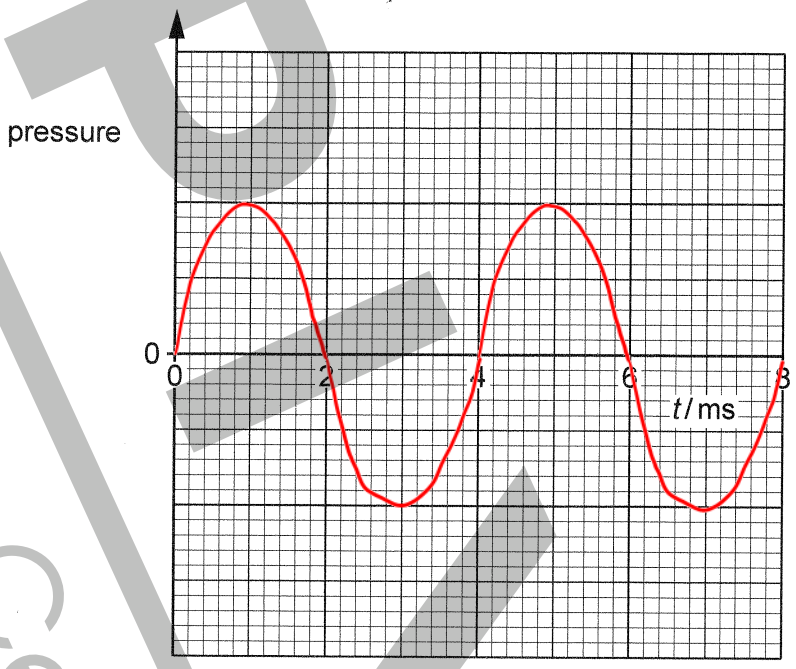


Fig. 5.2

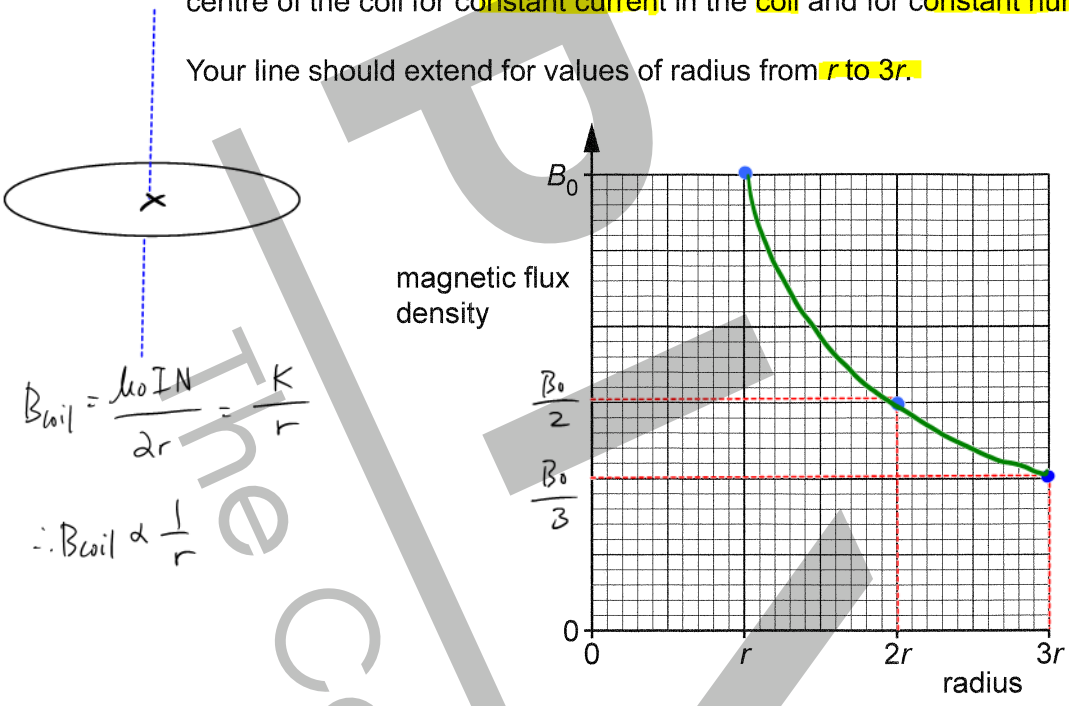
[2]

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(c) A constant current in a flat coil of radius r produces a magnetic field of flux density B_0 at its centre.

On Fig. 5.3, sketch a line to show the variation with radius r of the magnetic flux density at the centre of the coil for constant current in the coil and for constant number of turns.

Your line should extend for values of radius from r to $3r$.



$B_{coil} = \frac{\mu_0 I N}{2r} = \frac{K}{r}$

$\therefore B_{coil} \propto \frac{1}{r}$

Fig. 5.3

[3]

[Total: 8]

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6 (a) A lamp is connected in parallel to a resistor of resistance *R*. These are connected in series to a resistor of resistance 3.0 Ω and a power supply of electromotive force (e.m.f.) 6.0 V and of negligible internal resistance, as shown in Fig. 6.1.

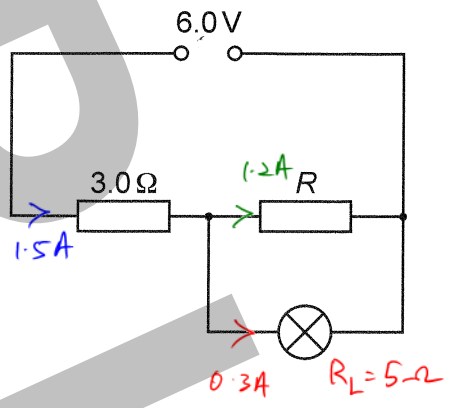


Fig. 6.1

The current in the lamp is 0.30 A and its resistance is 5.0 Ω.

(i) Determine the resistance *R*. Show your working.

$V_L = I_L R_L$
$= (0.3)(5)$
$= 1.5\,V$

∴ By pot. div. principle

$V_{3\Omega} = 6 - 1.5 = 4.5\,V$

Hence $I_{3\Omega} = \frac{V_{3\Omega}}{R_{3\Omega}} = \frac{4.5}{3} = 1.5\,A$

Hence by KCL, $I_R = 1.5 - 0.3 = 1.2\,A$

$\therefore V_R = I_R R_R$

Hence $R_R = \frac{V_R}{I_R} = \frac{V_L}{I_R} = \frac{1.5}{1.2} = 1.25\,\Omega$ (3sf) #

R = ... 1.25 ..... Ω [3]

(ii) The power supply transfers 120 J of energy to the circuit.

Determine the energy transferred in the lamp. Show your working.

$E_T = V_T I_T t = 120\,J$

$\therefore t = \frac{120}{V_T I_t} = \frac{120}{(6)(1.5)} = 13.3333\,s$ (time duration)

$\therefore E_L = V_L I_L t$
$= (1.5)(0.3)(13.3333)$
$= 6.00\,J$ (3sf)
#

energy = ... 6.00 ..... J [3]

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(iii) Explain why the current in the filament lamp is greatest when the current is first switched on.

When lamp is first switched on, its temperature is low and hence its resistance is low. Hence, by ohms law, current is largest when lamp is first switched on. As current passes through the lamp, the lattice ions vibrate vigorously, thereby increasing the impedance between the charge flow, hence decreasing current flow. [2]

(b) Two lengths of resistance wire, X and Y, made from different materials, are connected in series to a power supply, as shown in Fig. 6.2.

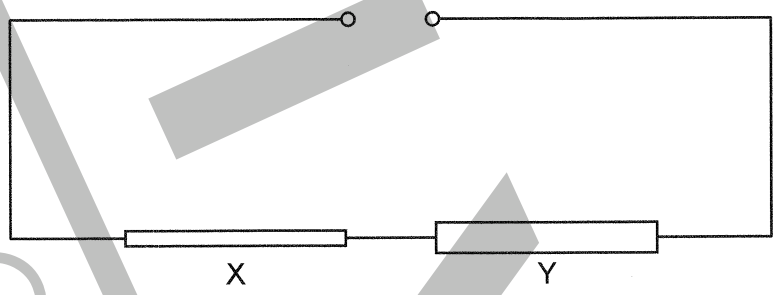


Fig. 6.2

Wire X has half the radius of wire Y. $\frac{r_x}{r_y} = \frac{1}{2}$

The drift velocity of the electrons in wire X is three times the drift velocity of the electrons in wire Y. $\frac{v_x}{v_y} = 3$

Determine the ratio

$$\frac{\text{number density of charge carriers in Y}}{\text{number density of charge carriers in X}} = \frac{n_y}{n_x}$$

Show your working.

From $I = nAvq$ & since I flow through X & Y is the same,

$$\therefore \frac{I_y}{I_x} = \frac{n_y A_y v_y q}{n_x A_x v_x q} = \frac{n_y \pi r_y^2 v_y q}{n_x \pi r_x^2 v_x q}$$

(1) (?) (2^2) ($\frac{1}{3}$)

$$\therefore \frac{n_y}{n_x} = \frac{3}{4} = 0.750 \text{ (3sf)}$$ *

ratio = 0.750 [3]

[Total: 11]

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7 In the original Rutherford alpha particle scattering experiment, alpha particles were fired at a thin gold ($^{197}_{79}Au$) foil. As a result of the experiment, the model of the atom was changed.

(a) State and explain the evidence from this experiment that changed the model of the atom in terms of its charge distribution and its mass distribution.

charge distribution When α-particles (positively charged Helium nucleus) were directed towards the thin gold foil, a small number of α-particles were deflected at a scattering angle of about 5° – 90°. Very few α particles (~1 in 8000) were deflected at a scattering angle of approximately 180°, suggesting a near head on collision with the gold nuclei. This means that the nucleus of the atom is small (~5% of atom), positively charged and located at approximately the centre of atom.

mass distribution Very few α-particles (~1 in 8000) were deflected at scattering angles of about 180°, suggesting a near head on collision with the gold nucleus. This means that the nucleus of the atom must be very small (~5% of atom), positive, containing almost entire mass of the atom (protons and neutrons), to even cause the α-particles to recoil almost backwards. [4]

(b) The alpha particles had an initial energy of 5.59 MeV when a long distance from a gold ($^{197}_{79}Au$) nucleus.

Calculate the minimum possible separation between an alpha particle and the gold nucleus.

By CoE, KE loss = EPE gain.

$5.59\,\text{MeV} = \frac{Qq}{4\pi\varepsilon_0 r}$

$\therefore r = \frac{1}{4\pi\varepsilon_0} \cdot \frac{Qq}{1} \cdot \frac{1}{5.59\,\text{MeV}} = \frac{(8.99\times10^{9})(79)(1.6\times10^{-19})(2)(1.6\times10^{-19})}{5.59\times10^{6}\times1.6\times10^{-19}} = 4.065\times10^{-14}\,\text{m}$

$= 4.07\times10^{-14}\,\text{m}$ (3sf) #

separation = 4.07×10^{-14} m [3]

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(c) Alpha particles may be produced from the radioactive decay of an isotope of radon ($^{222}_{86}Rn$) into an isotope of polonium (Po).

A stationary nucleus of radon emits an alpha particle.
The alpha particle has a binding energy per nucleon of 7.08 MeV.
The products of the radioactive decay have a total kinetic energy of 6.62 MeV.

The binding energy per nucleon of radon is 7.69 MeV.

Determine the binding energy per nucleon of polonium. Show your working.

$^{222}_{86}Rn \longrightarrow {}^{4}_{2}He + {}^{218}_{84}Po$

$E_{LHS} = (7.69)(222) = 1707.18\ MeV$

$E_{RHS} = (4)(7.08) + (218)(BE_{Po}) = 28.32 + 218\,BE_{Po}$

Since energy released, $E_{RHS} > E_{LHS}$ by 6.62 MeV

$\therefore\ 1707.18\ MeV + 6.62\ MeV = 28.32\ MeV + 218\,BE_{Po}$

Hence $BE_{Po} = 7.7315 = 7.73\ MeV/nucleon$ (3sf)

binding energy per nucleon = 7.73 ..... MeV [4]

[Total: 11]

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8 Read the passage below and answer the questions that follow.

X-rays have many uses today, including medical imaging, radiotherapy, X-ray diffraction and luggage scanning at airports.

In an evacuated X-ray tube, electrons are emitted from a heated filament (or cathode). They are then accelerated through a potential difference and strike a heavy-metal target (or anode), usually tungsten. The target is usually made to rotate at 3000 revolutions per minute. At any instant in time, the effective mass of the target in the electron beam is 12 g. The X-ray tube is illustrated in Fig. 8.1.

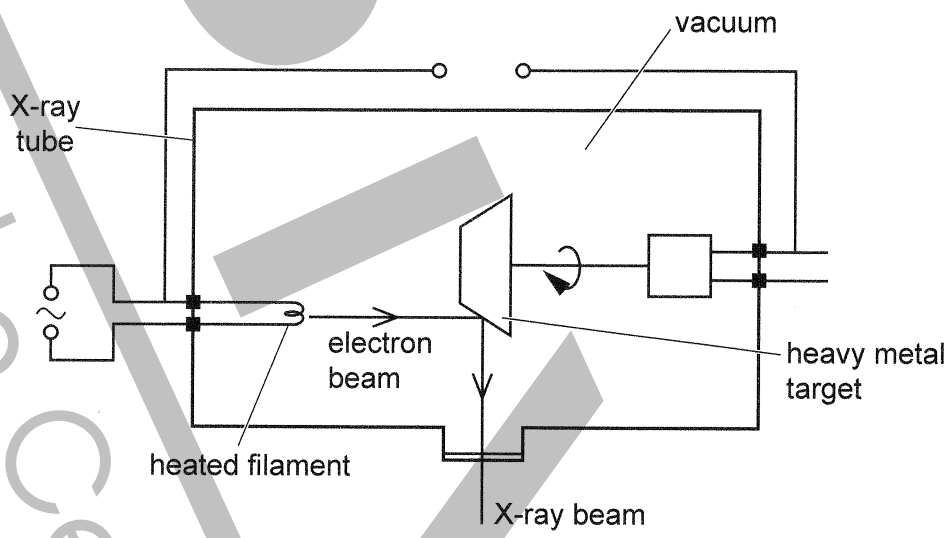


Fig. 8.1 (not to scale)

Typical data for producing an X-ray image are given in Table 8.1.

Table 8.1

accelerating voltage / kV	65
beam current / A	0.12
exposure time / s	1.1

V
I
t

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The deceleration of the electrons at the target results in the emission of X-ray photons. These X-ray photons cover a range of wavelengths as shown in a simplified form in Fig. 8.2.

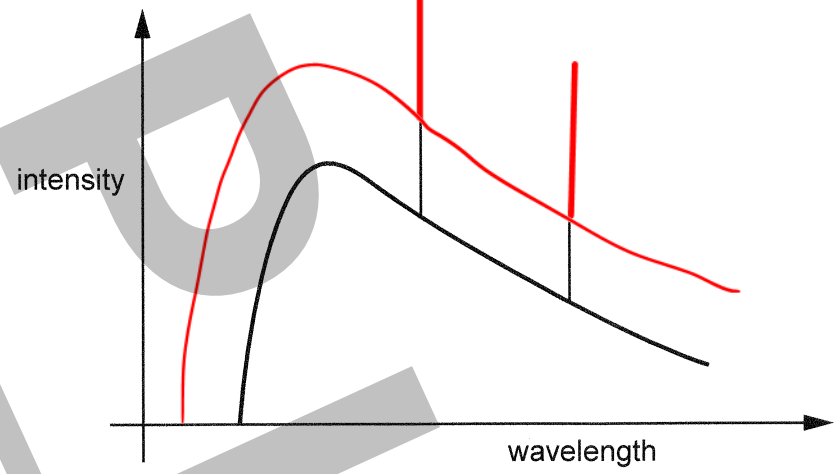


Fig. 8.2

The broad spectrum of photons is produced by the deceleration of the electrons by differing amounts. Only 1% of the electron beam energy becomes the energy of X-ray photons, with the remaining 99% dissipated as thermal energy.

As the X-ray beam passes through matter, its intensity is attenuated (reduced) by a number of processes. One of these is the Compton effect where the X-ray photon is scattered from an outer shell electron, giving energy to the electron in the process. The electron is ejected from the atom. Another process is the photoelectric effect, where the incident X-ray photon is completely absorbed, ejecting an inner, orbital electron. For low energy X-ray imaging, the photoelectric effect is the dominant process and the attenuation through matter is proportional to the atomic number cubed, Z^3. The average Z number of soft tissue is 7 and the average Z number of bone is 14. X-ray photons that usefully contribute to the X-ray image travel straight through the body.

$A \propto Z^3$ (atomic no.)

The transmitted X-ray photons are incident on a thin sheet of photographic film which is developed to reveal the image. In modern, digital X-ray machines, flat-panel detectors are used in order to detect the incoming X-ray photons. This process is much more sensitive than using photographic film.

The attenuation of the incident intensity of a parallel X-ray beam as it passes through matter results in its intensity decreasing exponentially. The transmitted intensity depends on the thickness x of the matter and the linear attenuation coefficient μ of the matter. This is similar to the exponential decrease with time in the activity of a radioactive element. A successful X-ray image has a good contrast if there are significant differences between the transmitted X-ray photon intensities in different regions of the image.

Where an X-ray image is to be produced of similar tissues, a contrast medium may be used. For example, a patient may be asked to drink a solution containing barium ($Z = 56$) in order to investigate their digestive system.

In X-ray imaging, a single exposure to X-rays is used to produce a two-dimensional image of an object. Computed tomography (CT) scanning uses X-ray beams in order to produce a three-dimensional image. In CT scanning, the X-ray source spirals down the object taking many X-ray images which are combined to produce a three-dimensional image.

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(a) Explain why the X-ray tube is evacuated.

It is to prevent the electrons from being scattered by air particles and not being able to reach the target metal. [1]

(b) On Fig. 8.2, draw the spectrum of X-ray photons produced when both the beam current and the accelerating potential difference are increased.

[3]

(c) **(i)** Calculate the thermal energy produced in the target as a result of producing a typical X-ray image.

Thermal Energy = 99% of Electron Energy $= (0.99)\,VIt$

$= (0.99)(65000)(0.12)(1.0)$

$= 8494.2$

$= 8490\ J\ (3sf)$

energy = 8490 J [2]

(ii) Assume that all the energy in **(c)(i)** is absorbed by the effective mass of a stationary tungsten target.

Estimate its temperature rise.

The specific heat capacity of tungsten is $130\,J\,kg^{-1}\,K^{-1}$.

$Q = mc\theta$

$\therefore \theta = \frac{Q}{mc} = \frac{8494.2}{(\frac{12}{1000})(130)} = 5445 = 5450\ °C\ (3sf)$ #

temperature rise = 5450 °C [2]

(iii) The melting point of tungsten is 3400 °C. Explain why the anode is rotated.

To ensure that the electron beam hits all parts of the target anode evenly, rather than at one specific portion. [1]

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(d) (i) The Compton effect involves the scattering of an incident X-ray photon.

Complete the diagram in Fig. 8.3 to show possible paths of the electron and scattered X-ray photon. Label your diagram.

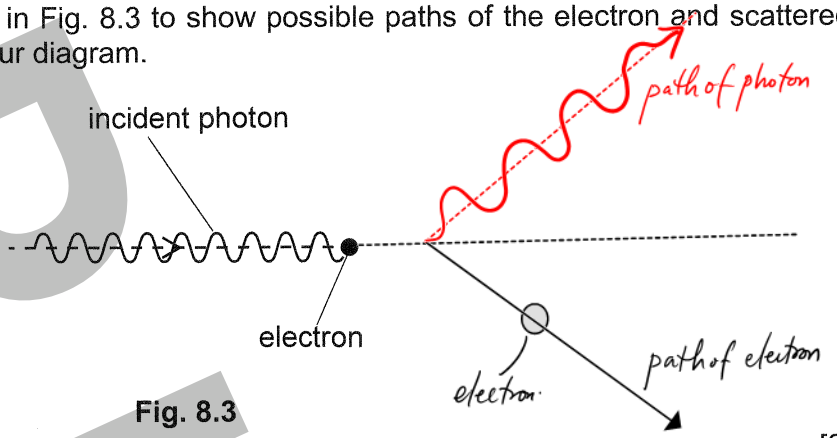


Fig. 8.3

[2]

(ii) State and explain the change, if any, of the wavelength of the X-ray photon due to scattering.

Wavelength increases. When the photon is incident on the electron, it loses some of its energy. Since energy is inversely proportional to wavelength, from Planck's law, the wavelength increases, resulting in a redshift. [1]

(iii) Suggest the effect on the X-ray image of photons produced by Compton scattering.

Due to Compton Scattering, the photons' intensity is reduced and they travel in random directions. Hence, the X-ray image have poor contrast [2]

(e) An X-ray beam is attenuated in matter due to the photoelectric effect.

Calculate the ratio

$$\frac{\text{attenuation of X-rays in bone}}{\text{attenuation of X-rays in soft tissue}}.$$

Attenuation $\propto Z^3$

$Z_{ST} = 7$, $Z_B = 14$

$\therefore$ Ratio $= \left(\frac{14}{7}\right)^3 = 2^3 = 8.00$ (3sf) #

ratio = 8.00 [1]

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(f) Derive an expression, in terms of the linear attenuation μ, for the thickness $x_{1/2}$ of matter needed to decrease the intensity of a parallel X-ray beam to half of its incident intensity. Show your working.

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

$\therefore \frac{I_0}{2} = I_0 e^{-\mu x_{1/2}}$

$\frac{1}{e^{\mu x_{1/2}}} = \frac{1}{2}$

So $e^{\mu x_{1/2}} = 2$

Take ln on both sides,

$\therefore \mu x_{1/2} = \ln 2$

and $x_{1/2} = \frac{\ln 2}{\mu}$ *

[2]

(g) Suggest an advantage to the patient of the use of more sensitive detectors.

It allows very small medical issues that would have not been detected, to be noticed. [1]

(h) Explain why a patient drinks a barium solution in order that a successful image of the digestive system may be produced.

Barium which has a Z value of 56, would produce a larger attenuation of incident X-rays (56^3). Hence, there would now be significant differences between the X-ray intensities in the different regions, thereby improving the contrast. [2]

(i) Suggest and explain a disadvantage to the patient who has a CT scan rather than a single two-dimensional X-ray.

In X-ray imaging, only a single exposure of X-rays is used to produce the 2D image. In CT scans, X-ray beams spirals down the object taking many X-ray images to produce the 3D image. The patient has more exposure to the X-rays in a CT scan. The X-rays, a form of ionizing radiation, can damage living cells and cause cancer. [2]

[Total: 22]

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