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

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.

[Turn over

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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.

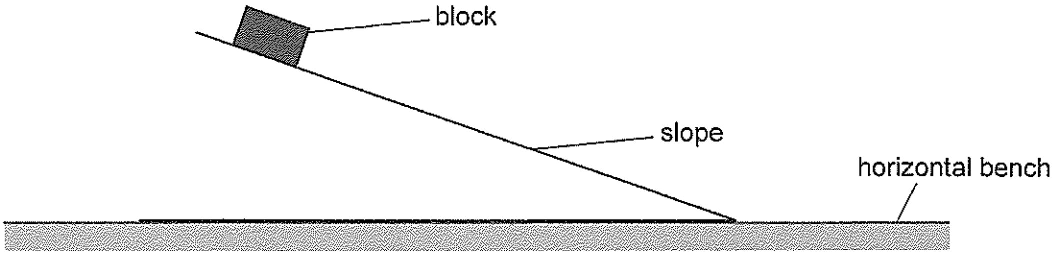

Fig. 1.1

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

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

constant acceleration OR ✓ [A1]

velocity/speed increases at constant rate. [1]

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

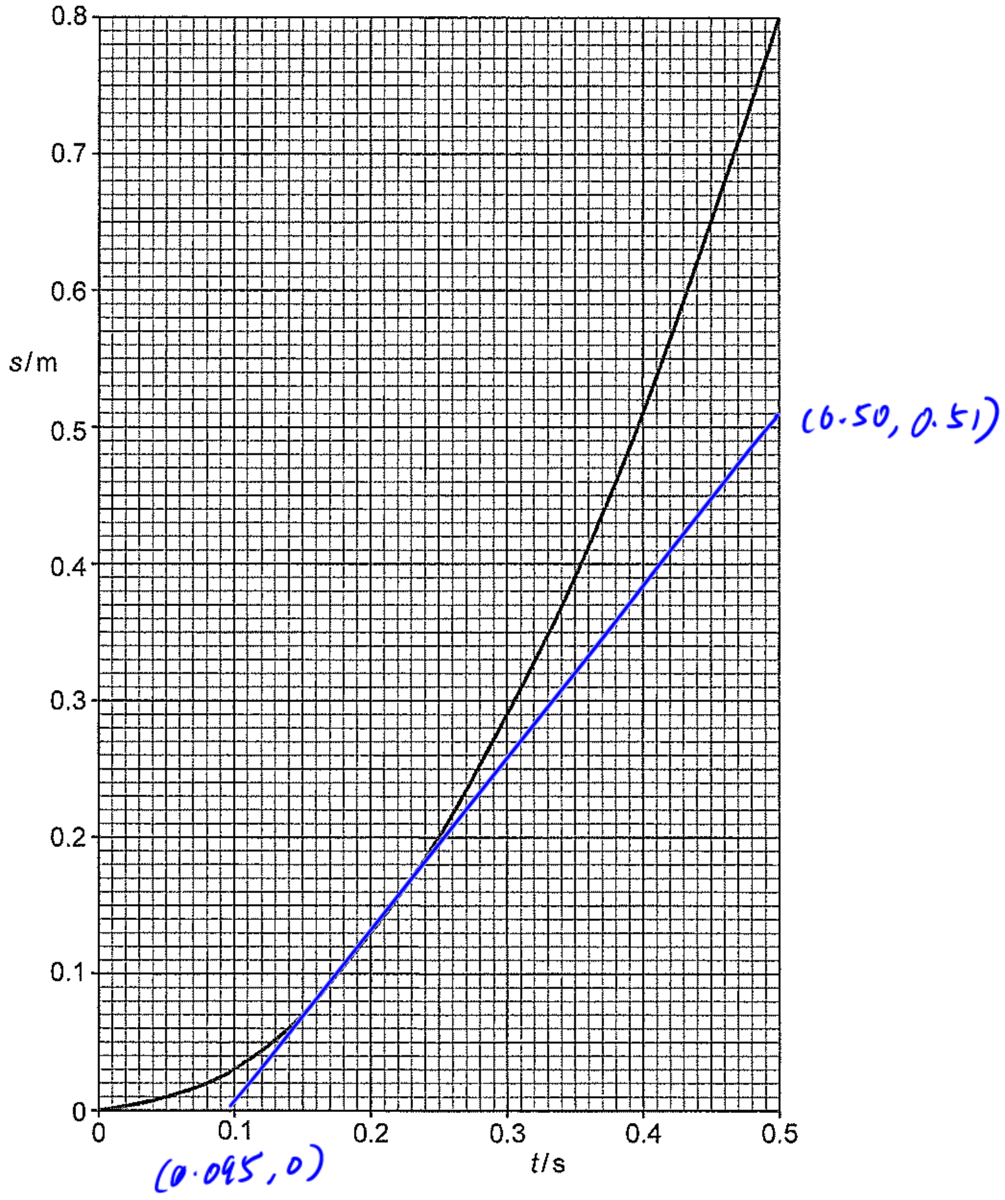

Fig. 1.2

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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.

Speed = $\frac{0.51 - 0}{0.500 - 0.095}$ ✓ [M1] = 1.26 m/s

speed = 1.26 OR 1.3 ✓ [A1] m s^{-1} [2]

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

a = $\frac{1.26 - 0}{0.20}$ ✓ [M1] = 6.3 m/s^2

acceleration = 6.3 OR 6.4 ✓ [A1] 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.

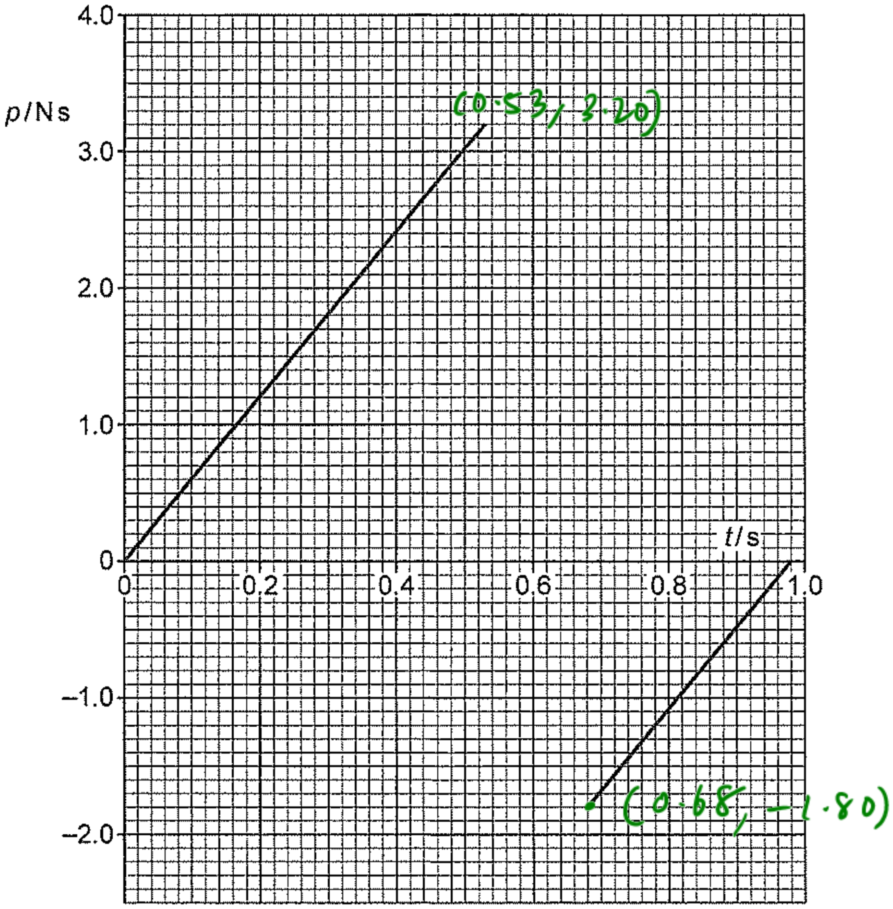

Fig. 2.1

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

$P_{max} = 3.2$ Ns ✓ [B1]

$E_k = \frac{p^2}{2m} = \frac{3.2^2}{2(0.62)} = 8.258$ J $= 8.3$ J ✓ [M1]

E_k = 8.3 OR 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.

$\Delta p = p_f - p_i = -1.8 - 3.2 = -5.0\ Ns$ ✓ [B1]

$\Delta t = 0.68 - 0.53 = 0.15\ s$

$F_{net} = \frac{\Delta p}{\Delta t} = \frac{-5.0}{0.15} = -33.3\ N$ ✓ [B1]

$-33.3 = mg - N = (0.62)(9.81) - N$ ✓ [M1]

$N = 39.4\ N$

force = 39 OR 39.4 N [4] ✓ [A1]

(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.

KE after rebound $= \frac{p^2}{2m} = \frac{1.8^2}{2(0.62)} = 2.6129\ Ns$

% loss in 1 rebound $= \frac{8.258 - 2.6129}{8.258} \times 100\% = 68.36\%$ ✓ [B1]

$\frac{5}{100} \times 8.258 = 8.258\,(1 - 0.6836)^n$ ✓ [M1] (% retained)

$n = 2.6$

number = 3 [3] ✓ [A1]

[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.

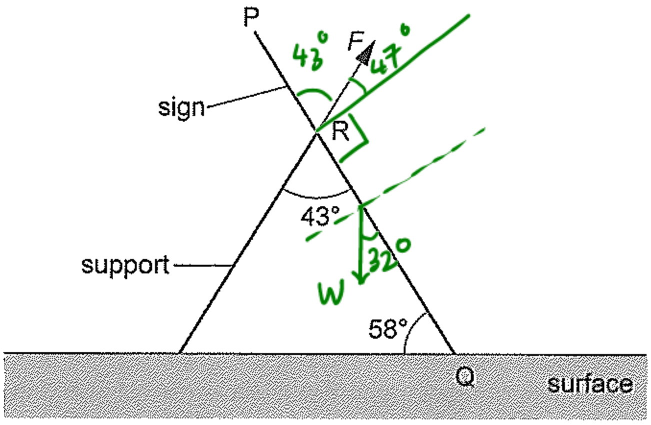

Fig. 3.1 (not to scale)

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*.

$RQ = \frac{2}{3}L$ ✓ [C1]

$F\cos 47° \times \frac{2}{3}L = (2.3)(9.81)\sin 32° \left(\frac{L}{2}\right)$ ✓ [M1]

$F = 13.15$ N

F = 13 OR 13.1 N [3] ✓ [A1]

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

Net / resultant force is zero. ✓ [B1]

Horizontal component of F must be balanced by horizontal component of Q. ✓ [B1] [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.

gravitational field strength g is gravitational force F per unit mass m.

$$g = \frac{F}{m} = \frac{\frac{GMm}{r^2}}{m} = \frac{GM}{r^2}$$

✓ [A1]

[1]

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

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.

Gravitational force provides centripetal force. ✓ [B1]

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

$$r^3 = \frac{GMT^2}{4\pi^2} = \frac{6.67 \times 10^{-11} \times 6.0 \times 10^{24} \times (110 \times 60)^2}{4\pi^2}$$

$$r = 7.615 \times 10^6 \text{ m.}$$ ✓ [C1]

$$g = \frac{GM}{r^2} = \frac{6.67 \times 10^{-11} \times 6.0 \times 10^{24}}{(7.615 \times 10^6)^2} = 6.9 \text{ N kg}^{-1}$$ ✓ [M1]

g = ...6.9 ✓...... N kg^{-1} [4] [A1]

(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 only acted by gravitational force F. ✓ [B1]

By Newton's 2nd law, free fall acceleration = F/m ✓ [B1]

By definition, gravitational field strength g = F/m ✓ [B1]

[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.

shape – ✓ [B1]

4 loops – ✓ [B1]

Correct frequency & amplitude – ✓ [B1]

$v = f\lambda$

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

$= 0.2$ s

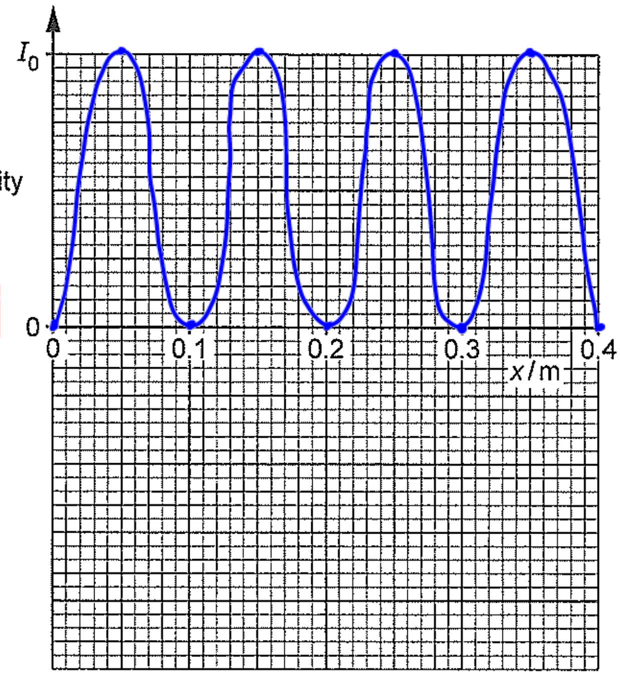

Fig. 5.1

[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.

$T = \frac{1}{250}$

$= 4$ ms

period = 4ms ✓ [B1]

sinusoidal ✓ [B1]

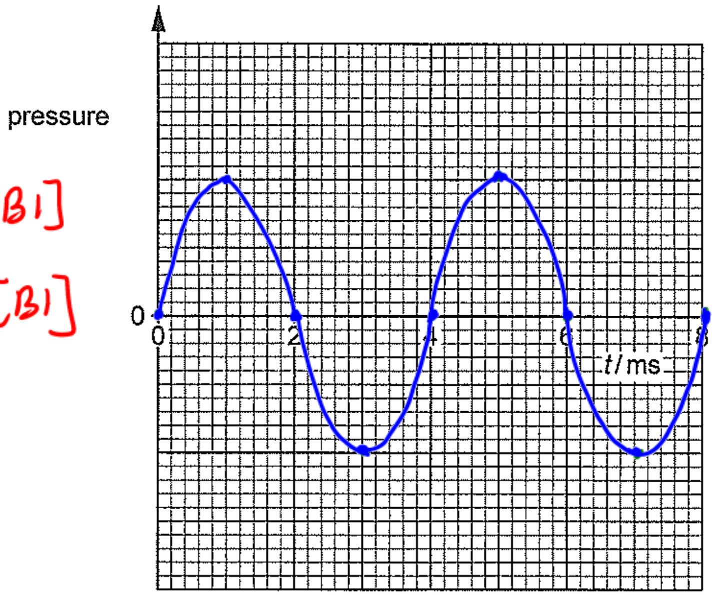

Fig. 5.2

[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 $3r$.

$B = \frac{\mu_0 N I}{2r} \propto \frac{1}{r}$

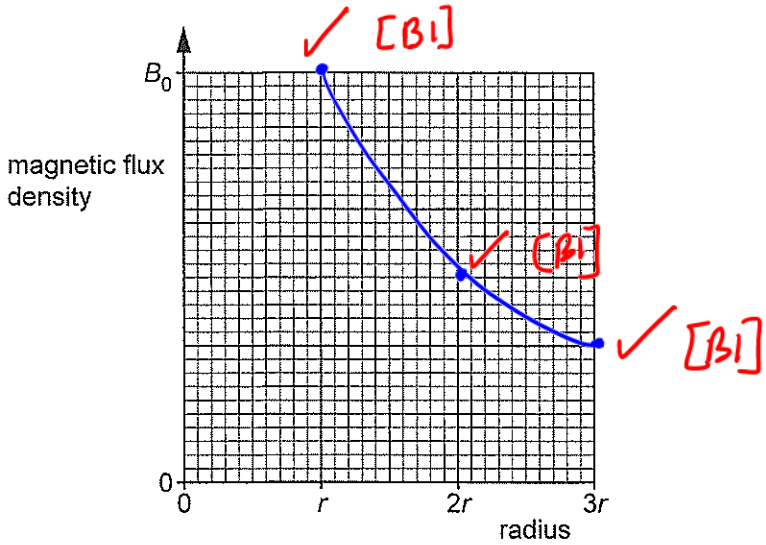

Fig. 5.3

[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.

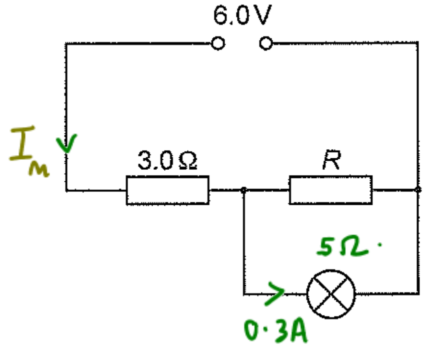

Fig. 6.1

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

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

$V_{lamp} = 0.3 \times 5 = 1.50$ V

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

$I_M = \frac{4.5}{3} = 1.5$ A ✓ [C1]

$I_R = 1.5 - 0.3 = 1.2$ A ✓ [M1]

$R = \frac{1.5}{1.2} = 1.25\ \Omega$

R = 1.25 OR 1.3 Ω [3] ✓ [A1]

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

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

$120 = EIt = (6)(1.5)t$

$t = 13.3$ s ✓ [B1]

$E_{lamp} = \frac{V^2}{R}t = \frac{1.5^2}{5}(13.3) = 5.985$ J ✓ [M1]

energy = 6.00 OR 6.0 J [3] ✓ [A1]

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

when temperature increases, resistance increases. ✓ [B1]
Initially, temperature of filament still low, so resistance still low. ✓ [B1]
Therefore, current is maximum. [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.

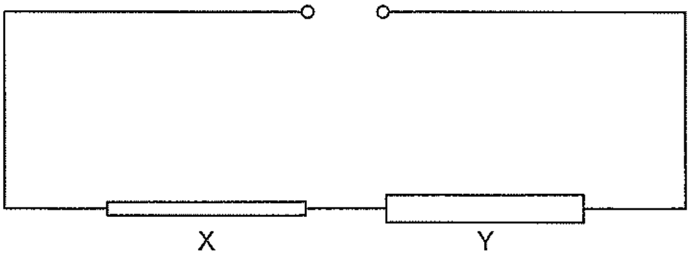

Fig. 6.2

$r_X = \frac{1}{2} r_Y$

$V_X = 3 V_Y$

$I = nAve$

$n = \frac{I}{Ave} \propto \frac{1}{Av}$

$n \propto \frac{1}{r^2 v}$

Wire X has half the radius of wire Y.

The drift velocity of the electrons in wire X is three times the drift velocity of the electrons in wire Y.

Determine the ratio

$$\frac{\text{number density of charge carriers in Y}}{\text{number density of charge carriers in X}}.$$

Show your working.

$$\frac{n_y}{n_x} = \frac{(Av)_x}{(Av)_y} = \frac{(r^2 v)_x}{(r^2 v)_y} = \left(\frac{1}{2}\right)^2 (3) = \frac{3}{4}$$

✓ [C1] ✓ [M1]

ratio = $3:4$ OR $\frac{3}{4}$ OR 0.75 ✓ [A1] [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 majority alpha particles went straight through shows that atom is mainly made of empty spaces. ✓ [B1]
Some deflected at more than 10°, imply nucleus is positively charged. ✓ [B1]

mass distribution
[M1] ✓ A very small portion deviated at large angles (more than 90°) or came straight back, indicates that mass of
[A1] ✓ nucleus is massive and highly concentrated in a small charged volume. [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.

$$\frac{Qq}{4\pi\varepsilon_0 r} = 5.59 \times 1.6 \times 10^{6} \times 10^{-19}$$ ✓ [C1]

$$\frac{(2e)(79e)}{4\pi(8.85\times10^{-12})r} = 5.59 \times 1.6 \times 10^{-13}$$ ✓ [M1]

$$r = 4.066 \times 10^{-14}$$

✓ [A1]

separation = 4.1×10^{-14} OR 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.

$^{222}_{86}Rn \rightarrow ^{218}_{84}Po + ^{4}_{2}\alpha$

BE of α = 4 × 7.08 = 28.32 MeV
BE of Rn = 222 × 7.69 = 1707.18 MeV } ✓ [C1]

$E_{released} = BE_p - BE_R$

$6.62 = (BE_{Po} + 28.32) - 1707.18$ ✓ [B1]

$BE_{Po} = 1685.48$ MeV

$\frac{BE_{Po}}{nucleon} = \frac{1685.48}{218} = 7.73$ ✓ [M1]

✓ [A1]

binding energy per nucleon = 7.73 MeV [4]

(2sf is not acceptable)

[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.

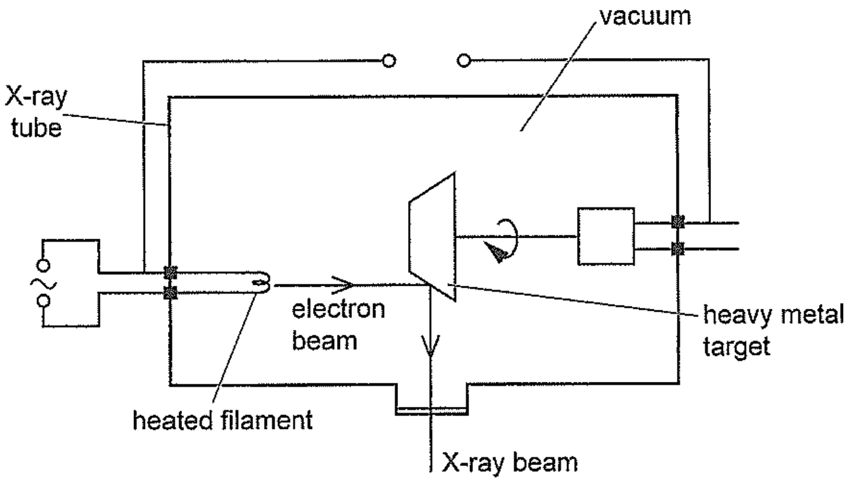

Fig. 8.1 (not to scale)

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

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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.

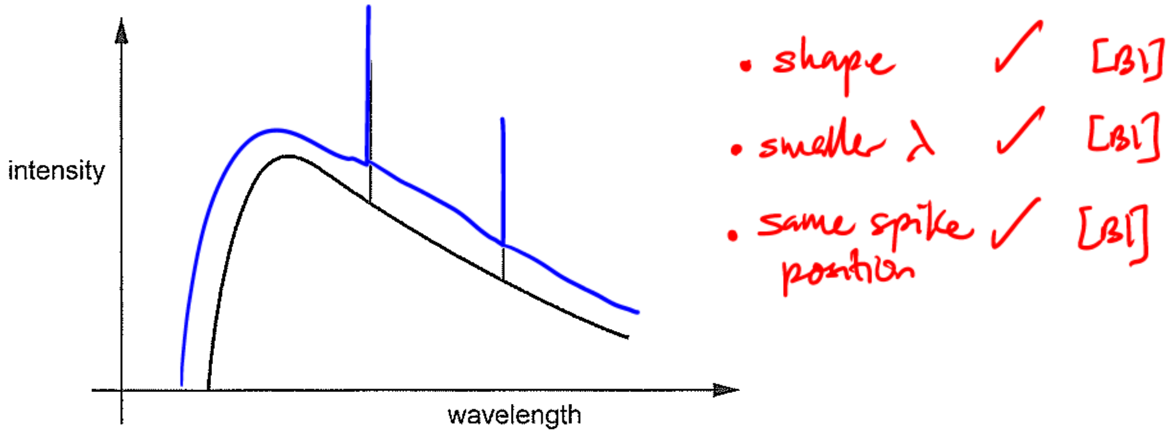

Fig. 8.2

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.

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.

prevent electrons from colliding with air molecules. ✓ [A1]

[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 $= (99\%)(q\Delta V) = 0.99(It)(V)$

$= 0.99 \times 0.12 \times 1.1 \times 65000$ ✓ [M1]

$= 8494.2\ J$

energy = 8500 OR 8490 J [2] ✓ [A1]

(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}.

$\Delta\theta = \frac{Q}{mc} = \frac{8494.2}{\frac{12}{1000} \times 130} = 5445\ ^{\circ}C$ ✓ [M1]

temperature rise = 5400 OR 5450 °C [2] ✓ [A1]

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

To prevent melting of tungsten (due to constant bombardment at specific area) ✓ [A1]

[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.

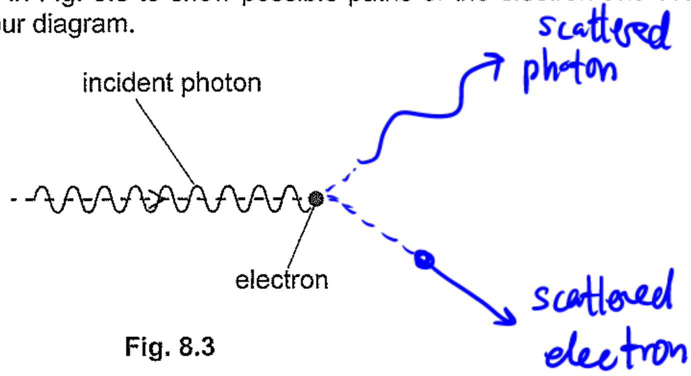

Fig. 8.3

✓ [B1] ✓ [B1] [2]

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

wavelength of photon increases as its energy decreases due to transference of energy to the electron. ✓ [A1] [1]

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

poorer contrast ✓ [B1]

lower intensity ✓ [B1]

[2]

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

Calculate the ratio

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

$Z_{tissue} = 7$, $Z_{bone} = 14$

$A \propto Z^3$

$\therefore \frac{Z_{bone}}{Z_{tissue}} = \frac{14^3}{7^3}$

ratio = 8.0 ✓ [A1] [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.

$$I = I_0 e^{-\mu x}$$ ✓ [M1]

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

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

$$x_{1/2} = \frac{\ln 2}{\mu}$$ ✓ [A1]

[2]

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

non-invasive medical treatment can be given to the patient at early stage. ✓ [B1]

[1]

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

Z for barium is greater than bone & tissue, so greater attenuation of photons occur, results ✓ [M1] in greater contrast while observing same tissues at different regions. ✓ [A1]

[2]

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

CT scan requires multiple exposure to X-ray scan. ✓ [B1]
X-ray is ionizing radiation & hazardous/cause cancer to develop easily. ✓ [B1]

[2]

[Total: 22]

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