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

Radiotherapy, also known as radiation therapy, harnesses the power of ionising radiation to destroy malignant cells and tumours. Radioactive isotopes can be chosen that emit the type and energy of radiation desired in the treatment.

Among various types of ionising particles, alpha radiation has received renewed interest in its unique properties. Alpha particles (α-particles), composed of two protons and two neutrons, are relatively massive and highly charged. This makes them highly ionising but with very short range in biological tissue — typically less than 0.1 mm. As such, α-particles emitting isotopes like radium-225 (${}^{224}_{88}Ra$) are increasingly being explored in targeted alpha therapy to deliver concentrated damage to malignant cells while sparing nearby healthy cells.

Radiation dosimetry is the quantitative description of the effect of radiation on living tissue. The *absorbed dose* of radiation is defined as the energy delivered to the tissue per unit mass. The SI unit of absorbed dose, the joule per kilogram, is known as the *gray* (Gy): $1\text{ Gy} = 1\text{ J kg}^{-1}$.

Absorbed dose by itself is not an adequate measure of biological effect because equal energies of different kinds of radiation cause different extents of biological effect. The variation is described by a numerical factor called the *quality factor* (QF) of each specific radiation. X-rays with 200 keV of energy are defined to have a QF of 1, and the effects of other radiation can be compared experimentally.

Fig. 7.1 shows the QF values for several radiations.

radiation	QF / Gy
X-rays	1
electrons	1.5
slow neutrons	4
protons	10
α-particles	20
heavy ions	20

Fig. 7.1

The biological effect is described by the product of the absorbed dose and the QF of the radiation; this quantity is called the *biologically equivalent dose*, or simply the equivalent dose. The SI unit of equivalent dose for humans is the sievert (Sv):

$$\text{equivalent dose (Sv)} = \text{QF} \times \text{absorbed dose (Gy)}$$

Fig. 7.2 shows a graph of the number of ion-pairs formed by an α-particle travelling through air. After 70 mm the α-particle captures two electrons to become a helium-4 atom and ionisation stops.

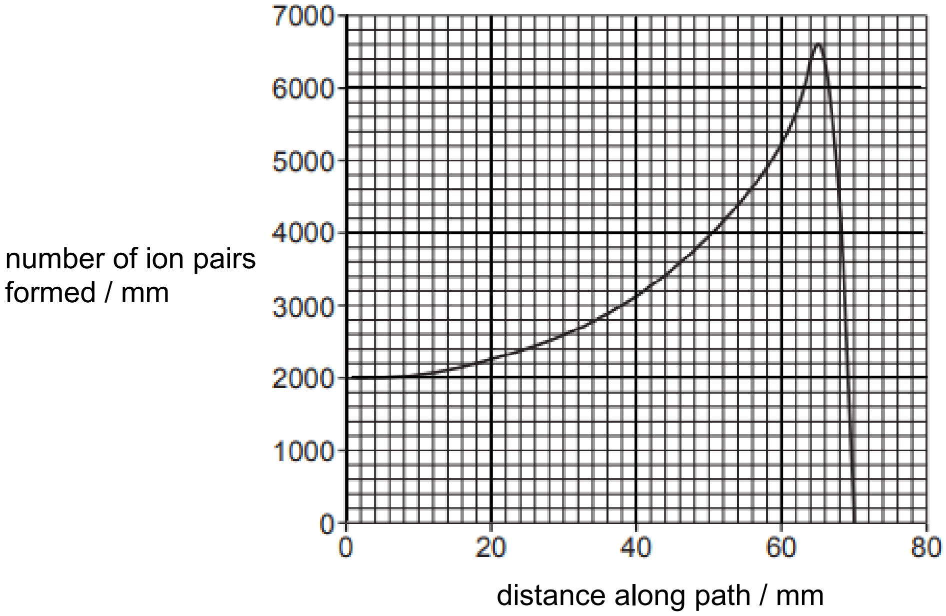

Fig. 7.2

(a) (i) State how Fig. 7.2 shows that an α-particle produces about 240 000 ion pairs along its track.

....

.... [1]

(ii) It takes 30 eV to produce an ion-pair.

Estimate the kinetic energy of the α-particle when it is ejected from a nucleus. Explain your reasoning.

Reasoning: ....

....

kinetic energy = ... MeV [2]

(iii) Explain why beta particles have a longer range in air than alpha particles of the same initial energy.

....

....

.... [1]

(b) A stationary nucleus of radium-224 nuclide decays by emission of an α-particle into a nucleus of radon (Rn).

(i) Complete the equation for the decay of radium-224 ($^{224}_{88}Ra$).

$$^{224}_{88}Ra \rightarrow {}^{\text{..........}}_{\text{..........}}Rn + {}^{\text{..........}}_{\text{..........}}\alpha$$

[1]

(ii) Use the principle of conservation of linear momentum, calculate the percentage of the total energy released in the decay that the α-particle carries away.

percentage = ... % [3]

(c) Radiotherapy involving α-particles is delivered to a group of cells of total mass 4.0 g for two hours.

Data for the therapy is given in Table 7.1.

Table 7.1

mass of radium nucleus	223.97191 u
mass of radon nucleus	219.96420 u
mass of α-particle	4.00150 u
activity of alpha source	18 kBq

(i) Use your answer in **(b)(ii)** and data in Table 7.1 to calculate the energy of an α-particle released when a nucleus of radium decays.

energy = ... J [3]

(ii) Show that the total number of decays during the therapy is 1.3×10^{8}. State an assumption you make in your calculation.

Assumption: ………………………………………………………………………………..……..

………………………………………………………………………………………………… [2]

(iii) For the radiotherapy using α-particles, calculate

1. the total energy absorbed by the tissue,

total energy = ... J [1]

2. the absorbed dose to the tissue,

absorbed dose = ... Gy [2]

3. the equivalent dose to the tissue,

equivalent dose = ... Sv [1]

(d) The thyroid gland naturally absorbs iodine to produce thyroid hormones. Therefore, radioactive iodine isotopes like iodine-123 ($^{123}_{53}\mathrm{I}$) and iodine-131 ($^{131}_{53}\mathrm{I}$) in small doses are used to image the thyroid gland and assess its function, and in large doses are used to treat thyroid disease.

Iodine-123 has a half-life of 13.2 hours and emits a 0.16 MeV γ-ray photon. Iodine-131 undergoes beta emission (β-emission) with a half-life of 8.04 days, emitting electrons with energies up to 0.61 MeV and γ-ray photons of energy 0.36 MeV.

A thyroid cancer treatment involves administration of 3.7 GBq of iodine-131.

(i) Calculate the number of iodine-131 nuclei administered in a typical thyroid cancer treatment.

number of iodine-131 nuclei = ... [2]

(ii) Suggest why iodine-123 is preferred for imaging over iodine-131.

....

....

.... [1]

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