inkPhysics

ANSWER BOOK

Radionuclide imaging and PET

Medical physics · Year 13

AQA 3.10.6 · CIE 24.3 · OCR A 6.5.2

12 questions · 32 marks

NAVY EDITION

SECTION A · Warm-up

A1 A radioactive nuclide chemically attached to a biologically active molecule, such as a glucose analogue, which the body takes to wherever that molecule is used. The radiation it emits from there is detected to map the tracer's location. [2]

A2 Gamma photons are penetrating enough to escape the body and be detected outside; alpha or beta radiation would be absorbed inside the patient, delivering dose but no image. The half-life must be long enough for the tracer to be prepared, administered and imaged, but short enough that the patient is not left radioactive for weeks. [3]

A3 X-ray and CT images show structure: what the anatomy looks like. A tracer image shows function: where the body is actually using the labelled molecule, so which tissue is active, inflamed or failing. [2]

SECTION B · Standard

B1 The lead collimator admits only gamma photons travelling nearly parallel to its channels, so each detected photon's origin lies along a known line; oblique photons are absorbed by the slats. The scintillator converts each admitted gamma into a flash of light whose position is recorded, building a map of the tracer's location one photon at a time. [3]

B2 24 hours is four half-lives, so $A/A_0 = (1/2)^4 = 0.0625 \approx 1/16$, about 6%. [3]

B3 The positron and electron annihilate: both particles vanish and their rest energy becomes two gamma photons travelling in opposite directions. Each photon carries 511 keV, the rest energy of one electron through $E = mc^2$. [3]

B4 $E = mc^2 = 9.11 \times 10^{-31} \times (3.00 \times 10^8)^2 = 8.20 \times 10^{-14}$ J. Dividing by 1.60×10^{-19} J eV^{-1} gives about 5.1×10^5 eV ≈ 511 keV. [3]

B5 The electron-positron pair is very nearly at rest when it annihilates, so its total momentum is close to zero. Momentum is conserved, so the two photons must carry equal and opposite momenta: they leave back to back. [2]

SECTION C · Stretch

C1 The patient lies inside a ring of gamma detectors. When two 511 keV photons arrive at opposite sides of the ring at effectively the same instant, they are taken to come from one annihilation, which must lie on the straight line joining the two detectors. Recording hundreds of thousands of such coincidence lines, the scanner finds where they intersect: the places where the tracer, and so the biological activity, is concentrated. [4]

C2 $E = 511$ keV $= 8.20 \times 10^{-14}$ J. $f = E/h = 8.20 \times 10^{-14}/6.63 \times 10^{-34} = 1.24 \times 10^{20}$ Hz. [2]

C3 One eighth is three half-lives, so $t = 3 \times 110 = 330$ minutes (5.5 hours). [2]

C4 The scanner emits nothing: it is purely a detector, listening for gamma photons leaving the body. The radiation dose comes from the injected tracer itself, whose positrons annihilate inside the patient. Choosing a short half-life and a small activity keeps that dose low while still giving enough coincidences for an image. [3]