OCR
Oxford Cambridge and RSA

A Level Physics B (Advancing Physics)

H557/02 Scientific literacy in physics

Advance Notice Article

Practice paper – Set 2
To be read on receipt

To prepare candidates for the Practice paper.

NOTES FOR GUIDANCE (CANDIDATES)

1. This Advance Notice contains an article which is needed in preparation for a question in the externally assessed examination H557/02 Scientific literacy in physics.

2. You will need to read the article carefully and also have covered the learning outcomes for A Level in Physics B (Advancing Physics). The examination paper will contain questions on the article. You will be expected to apply your knowledge and understanding of the work covered in A Level in Physics B (Advancing Physics) to answer this question. There are 20–25 marks available on the question paper for this question.

3. You can seek advice from your teacher about the content of the article and you can discuss it with others in your class. You may also investigate the topic yourself using any resources available to you.

4. You will not be able to bring your copy of the article, or other materials, into the examination. The examination paper will contain a fresh copy of the article as an insert.

5. You will not have time to read this article for the first time in the examination if you are to complete the examination paper within the specified time. However, you should refer to the article when answering the questions.

INSTRUCTION TO EXAMS OFFICER/INVIGILATOR

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Medical uses of gamma rays

Gamma rays are electromagnetic photons of energies usually more than about 100 keV. Medicine is one area where gamma rays have found uses. Radiotherapy was one of the earliest uses of gamma radiation, but uses in medical imaging have developed over the past decades as imaging techniques have improved and new sources of gamma radiation have become available.

Radiotherapy

Cancerous tissues are more susceptible to radiation damage than normal tissue so normal tissue will recover from a radiation dose that would destroy a tumour. Substantial doses, a few sieverts (Sv) in size, are needed, although the dose is administered over several sessions in order to allow the healthy tissue to recover. Such doses are many orders of magnitude greater than those experienced in everyday life. The gamma source usually chosen for radiotherapy is cobalt-60. This has a half-life of 5.3 years and emits two gamma rays of energies 1.17 and 1.33 MeV. To ensure the maximum dose reaches the tumour with minimum damage to healthy tissue, the radiation source can be rotated during treatment as shown in Fig. 1.

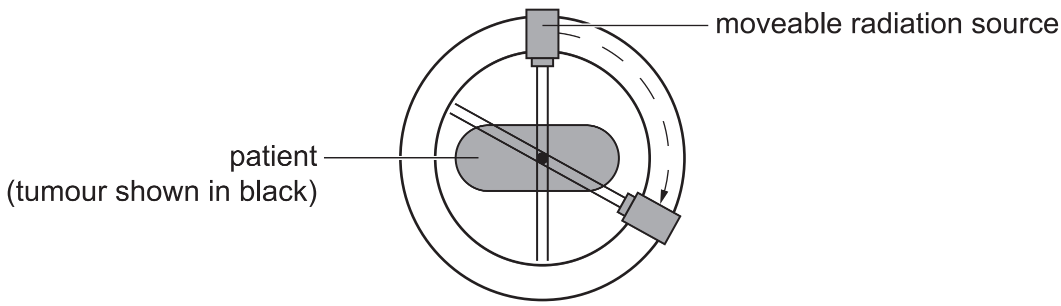

Fig. 1

Medical Imaging

Gamma scans are a useful method of investigating the functioning of organs. A chemical which is usually taken up by a particular organ is 'labelled' with a radioisotope. The radiochemical is injected into the body and the blood stream quickly carries it to the organ in question, where it is absorbed by healthy tissue. A gamma-detector near the body can detect which parts of the organ imaged are working properly, as these areas will be emitting gamma photons. Damaged areas of the organ will not absorb the radiochemical and so will not emit gamma photons.

An efficient detector of gamma photons needs a large mass of material containing nuclei of a large proton number. A crystal of sodium iodide doped with thallium fulfils this requirement. This crystal absorbs gamma photons and emits visible photons. The visible photons are detected by photomultiplier tubes mounted on the crystal. Using an array of photomultiplier tubes allows the radiographer to obtain an image of the region of interest.

Photons emitted from the sodium iodide crystal strike the light-sensitive photocathode which emits a single electron when it absorbs a visible photon. This electron is accelerated onto a multiplying electrode (a dynode), knocking off extra electrons as it collides. These electrons pass between a series of these electrodes, exponentially increasing the number of electrons. Eventually, a cascade of electrons reaches the anode as shown in Fig. 2.

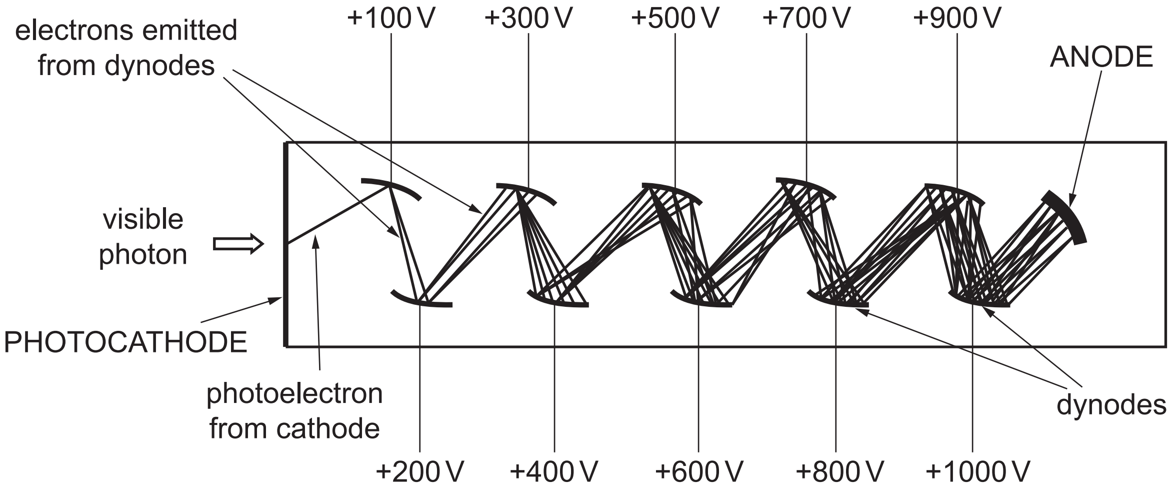

Fig. 2

Early gamma scans used nuclides such as iodine-131, which is absorbed by the thyroid gland in the neck. Unfortunately, iodine-131 emits beta particles as well as gamma photons during the decay

$$^{131}_{53}\mathrm{I} \longrightarrow {}^{131}_{54}\mathrm{Xe} + {}^{0}_{-1}\mathrm{e} + {}^{0}_{0}\bar{\nu}.$$

Technetium-99m is now commonly used as a gamma emitter in imaging. The technetium-99m nucleus is at a higher energy level than the ground state and decays down to the ground state, emitting a 140 keV photon as it does so.

PET scans

Positron emission tomography (PET) uses beta-plus decay as a source of positrons. Oxygen-15 is commonly used as the positron emitter. A proton in the oxygen-15 nucleus decays into a neutron, a positron and a neutrino:

$$^{15}_{8}\mathrm{O} \longrightarrow {}^{15}_{7}\mathrm{N} + {}^{0}_{+1}\mathrm{e} + {}^{0}_{0}\nu$$

Once emitted, the positron travels a very short distance before annihilating with an electron to produce a pair of gamma photons of characteristic energy. These photons travel in opposite directions and are detected by a pair of gamma cameras on opposite sides of the patient. Coincidence circuitry in the detector ensures that only simultaneous gamma photons travelling in opposite directions are counted. These photons are the product of positron-electron annihilation. This ability to discount noise, together with the rotation of the detectors around the patient, allows the source of positrons to be identified with an accuracy of ± 2 mm. With a resolution of 2 mm in each direction, the emissions from a brain of volume 600 cm^3 would be coded in a set of 75 000 pixels.

Generating and using short-lived positron emitters

Positron emitters are artificially produced by increasing the proton content of nuclei by 'firing' extra protons, alpha particles or hydrogen-2 nuclei into stable nuclei. Particle accelerators are used which give the accelerated particles energies in the range 3–18 MeV range.

Positron emitters used in medicine have short half-lives, which is both an advantage and a problem. For example, the half-life of fluorine-18, a positron emitter, is only 110 minutes and about half that is taken producing a radiochemical suitable for medical uses from the fluorine-18.

Protection of patients and medical staff

Although patients undergoing radiotherapy need high doses, these must be restricted to the regions of the body under treatment. Dense shields obstruct the passage of gamma photons to healthy tissue. Radiographers, the medical personnel involved in treating patients, must avoid exposure. The entire area of the treatment suite is screened off and shielded by thick, dense concrete walls. In places where it is necessary to absorb the radiation more effectively, such as the side of the gamma-source container, a denser material such as lead is used, because it has a smaller 'half-thickness'. The half-thickness of a material is that thickness which reduces the intensity of the beam to one-half of its initial value. If I_0 is the intensity of the gamma rays with no absorber present, the intensity will fall to I with an absorber of thickness x present where $I = I_0 e^{-\mu x}$. The absorption coefficient μ(m^{-1}) is a constant for particular materials and energies of gamma ray photons.

A simpler and cheaper method of limiting radiation dose is to make use of the inverse-square law: doubling the distance from source to the exposed individual will reduce the intensity by a factor of four.

END OF ADVANCE NOTICE ARTICLE