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**2019 Year 11 Physics**

**Task 5: Test 3 – Nuclear Physics - Answers**

( /58 Marks Total)

1. a) The radioisotope carbon-14 is formed by neutrons from primary cosmic rays striking nitrogen atoms in the upper atmosphere.

What is the identity of the particle labelled "X"?

147N + 10n --> 146C + X

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(1 mark)

b) The radioactive carbon-14 then decays back to nitrogen-14. What is the identity of the particle labelled "Y"?

146C --> 147N + Y

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(1 mark)

2. The radioisotope cobalt-60, used for the medical irradiation of malignant tumours, has a half-life of 5.3 years.

a) If the original activity of a cobalt-60 source was 800 MBq, what would be the activity after 15.9 years?

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(3 marks)

b) Estimate how long it would take for the original activity to decrease to

12.5 MBq.

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(3 marks)

3. The radiation dose given by radiation therapy varies according to the quality of the machine, and the care taken by the radiologist. It ranges from around 60.0 microgray to around 10.0 milligray for the treatment of the chest area.

a) Which is the preferable dose to receive?

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(1 mark)

b) Assuming that the chest area has a mass of about 20 kg, what is the energy, in joules, deposited in the chest during a 10.0 milligray radiation therapy exposure?

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(2 marks)

4. One method for measuring your exposure to radiation is to wear a badge containing photographic film. The film is covered by opaque plastic, and different areas of the film are covered by different thicknesses of metal.

a) What sorts of radiation will the film detect?

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(2 marks)

b) What sorts of ionising radiation will the film not detect? Why?

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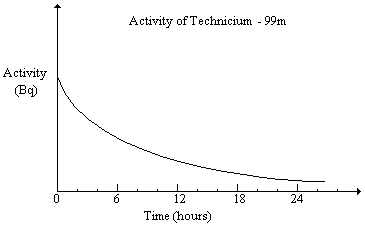
(2 marks)

c) What is the purpose of the different metal coverings?

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(2 marks)

5. Technetium-99m is a commonly used radioisotope. The graph below shows the activity of a technetium-99m sample over a 24 hour time period.



1. Using the graph, determine the half life of technetium-99m.

Show on the graph how you arrived at your answer.

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(2 marks)

b) Why, in some circumstances, do hospitals prefer to use radioisotopes with a short half-life for diagnostic purposes?

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(1 mark)

6. PET (positron emission tomography) scans can be used to pin-point and map epileptic sites in the brain. A suitable carrier or 'tracer' chemical is tagged with nitrogen-13 and injected into the blood of the epileptic person. The tracer tends to accumulate at sites in the brain which are, at that instant, most active. The detector 'maps' these sites. Nitrogen-13 is a positron emitter and it has a half-life of 9.97 minutes.

a) If the original tracer chemical has an activity of 4.00 kBq, calculate the time needed for the activity to drop to 1.00 kBq.

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(3 marks)

b) Find the atomic number and mass number of nitrogen-13's daughter nucleus.

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(1 mark)

c) The positrons emitted in the patient’s body combine with electrons to totally convert to energy as gamma rays.

0+1e + 0-1e --> 200γ

Determine the energy of the gamma ray photons produced.

Use the velocity of light (c) = 3.00 x 108 ms-1 and mass of an

electron (me) = 9.11 x 10-31 kg

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(2 marks)

7. A 100 MW nuclear reactor is operating at 60.0% of its maximum power output. The reactor uses fissile uranium-235 fuel, a water moderator and cadmium control rods.

a) What would be the effect on the power output if the control rods were slowly withdrawn from the reactor core? Explain

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(2 marks)

b) What would be the effect on the power output if the moderator was 'removed' from the core? Explain.

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(2 marks)

8. One of the many possible fission reactions for uranium-235 is given below.

10n + 23592U --> 14156Ba + 9236Kr + neutrons

a) How many neutrons are produced in the above reaction? Show working.

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(2 marks)

b) Would this reaction be capable of sustaining a chain reaction in U-235 if a moderator was present? Explain.

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(2 marks)

9. a) Define the term "binding energy' in a nuclear physics context.

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(4 marks)

9. b) Calculate, using the data listed below, the binding energy of hydrogen-2.

mass of 21H..........3.3435 x 10-27 kg

mass of a neutron....1.6750 x 10-27 kg

mass of a proton.....1.6726 x 10-27 kg

speed of light c.....3.00 x 108 ms-1

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(4 marks)

10. A 95 kg miner absorbs altogether 1.0 joule of energy from radiation present in a uranium mine over a one-year interval.

a) What is this dose in gray?

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(2 marks)

b) If this absorbed dose is due to beta radiation, what is the equivalent dose in sievert? Comment if this dose falls within the recommended guidelines for workers in the industry

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(3 marks)

c) If the dose is due to alpha radiation from inhalation of radon gas, what is the equivalent dose in sieverts? Comment if this dose falls within the recommended guidelines for workers in the industry.

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(3 marks)

**Comprehension: (10 marks)**

***Read the article then answer the questions that follow.***

New Scientist in April 1991.

**Long Wait Ends for Medical Cyclotron**

More than 20 years after it was first proposed, Australia’s first medical cyclotron was installed this month at the Royal Prince Alfred Hospital in Sydney.

The opening of the cyclotron ends many years of dispute as to where it should be sited. It took the Australian Nuclear Science and Technology Organisation (ANSTO) a long time to convince the government that the equipment should be located at a hospital and not with the research reactor at Lucas Heights in Sydney’s southern suburbs. Rex Boyd, director of the cyclotron project, says U.S. experience showed that doctors would not send seriously ill patients to a facility away from a major hospital.

By September, the National Medical Cyclotron will be cranking out radioisotopes for use in the hospital’s new positron emission tomography (PET) centre, which is expected to cater for about 1000 patients a year. PET scans help doctors to diagnose heart disease, cancer, and numerous brain disorders such as Alzheimer’s disease and epilepsy.

It will produce radioisotopes previously unavailable in Australia, the most important of which are carbon-11, nitrogen-13, oxygen-15 and fluorine-18. These isotopes are useful only for short periods of time before they break apart, which is why scientists and clinicians cannot simply import them form abroad.

(A radioisotope is a radioactive form of an element which differs in mass from the more stable form. Radioisotopes break up spontaneously emitting high energy particles. They can be used medically as tracers and for measuring concentrations of substances.)

According to Boyd, the A$22 million cyclotron - made in Belgium by Ion Beam Applications (IBA) can produce a wide variety of radioisotopes because it can accelerate either protons or deuterons. The radioisotopes are created when those particles strike a specially prepared target at high velocity. The isotopes then travel down two “beam lines” from the cyclotron to a laboratory where they are purified and turned into biologically active radio-pharmaceuticals.

It is hoped that the sale of longer-lived radioisotopes will cover the facility’s annual A$3 million operating cost. IBA is also supplying a much smaller machine to the Austin Hospital in Melbourne. The mini-accelerator, as it is called, will produce radioisotopes for PET applications alone.

Leigh Dayton, Sydney.

1. One of the radioisotopes which will be produced by the cyclotron is nitrogen -13. With reference to the article, explain what happens in the cyclotron to produce the nitrogen-13. (2 mark)

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2. a. What reason is given for Australia not importing supplies of fluorine-18 and oxygen-15 for example? Explain. (2 mark)

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1. An important medical tracer which is currently produced at Lucas Heights is technetium-99. Tc-99 has a half-life of 6.00 hours. If a 20.0 g sample of Tc-99 is produced at 6.00 am, what mass will still be active at 6.00 am the next day? (2 mark)

3. All the major diagnostic hospitals around Australia use Tc-99. Supplies are dispatched from Lucas Heights to all capital cities every 3 days or so. However, it is not Tc-99 which is sent but molybdenum-99 instead. Mo-99, which has a half-life of 72 hours, produces Tc-99. The Tc-99 is then withdrawn by the doctors as required.

a. (i) Complete the nuclear equation to show the missing particle. (1 mark)

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(ii) What type of radiation is this? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ (1 mark)

b. Explain the advantage of sending Mo-99 instead of Tc-99. (2 marks)

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RELEVANT EQUATIONS

Half-life:

if an = activity after n half lives

ai = initial activity

n = No. half lives.

n = No. half lives.

T = time period.

t­1/2 = half life.

Dose: absorbed dose = energy absorbed

mass of absorbing tissue

dose equivalent = absorbed dose x quality factor

Energy: E = mc2 if: E = energy produced.

m = mass defect.

c = speed of light.

RELEVANT DATA

TABLE OF NUCLEAR REST MASSES

PARTICLE SYMBOL REST MASS (kg)

electron/positron.. 0-1e/0+1e......... 9.11 x 10-31

proton/hydrogen..... 11p/11H.......... 1.6726 x 10-27

neutron............ .10n.............. 1.6750 x 10-27

deuterium........... 21H.............. 3.3435 x 10-27

tritium............ .31H........... 5.0074 x 10-27

helium-3............ 32He............. 5.0065 x 10-27

helium-4............ 42He............. 6.6447 x 10-27

lithium-7........... 73Li............. 1.16478 x 10-26

carbon-12.......... 126C.............. 1.99213 x 10-26

carbon-14.......... 146C.............. 2.32478 x 10-26

nitrogen-14........ 147N.............. 2.32466 x 10-26

TABLE OF QUALITY FACTORS

RADIATION TYPE APPROXIMATE QUALITY FACTOR

gamma rays................. 1

beta particles.............. 1

slow neutrons............... 3

fast neutrons................. 10

alpha particles............... 20

TABLE OF MAXIMUM ALLOWABLE DOSE

CLASSIFICATION MAXIMUM DOSE PER YEAR

Nuclear industry worker.............. 20 mSv

General public........................ 5 mSv

***1 mark***