Physics Year 11 ATAR

Test 2: Nuclear Physics

SIDE Teachers name: ________________________

Student authentication statement

I hereby certify that I completed this test according to the instructions below.

Name: ___________________ Signature: ____________________ Date: ________

Supervisor authentication statement

I verify that this test was completed according to the instructions below.

Name: ___________________ Signature: ____________________ Date: ________

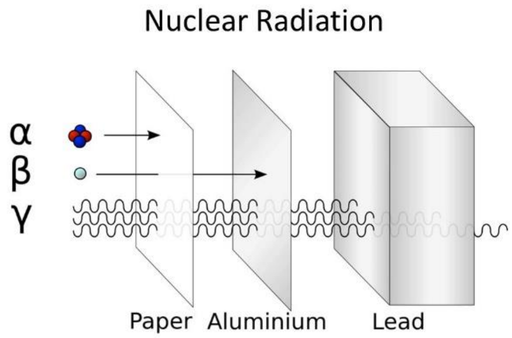
- This test must be completed under supervision.
- The supervisor and student must sign the authentication statements above.
- Answer all questions in the spaces provided.
- Formulas and data are provided in a separate booklet.
- Ruler, pen, pencil, eraser and approved calculator may be used.
- A standard or non-programmable scientific calculator that does not have a full alphabetic display or graphical display may be used.
- No other materials, notes, etc are to be used in the test.
- All working should be shown for calculations. Marks are awarded for working and final answers.
- Time allowed = **60 minutes**

Section	Number of questions available	Your Mark	Marks available	Percentage of Test
Section One: Short answer	5		18	30
Section Two: Extended answer	3		30	50
Section Three: Comprehension and data analysis	1		12	20
			60	**100**

Section One: Short answers

Question 1 **(4 marks)**

The diagram at right illustrates the respective penetrating powers of the three types of nuclear radiation. Explain the pattern shown in terms of the charge and mass of the three different types of nuclear radiation.



Question 2 **(4 marks)**

One method of producing plutonium-238 is by bombarding uranium-238 with deuterium (hydrogen-2), to produce neptunium-238 and two neutrons. The unstable neptunium-238 then decays to produce plutonium-238. Write the nuclear equations for these two reactions, showing all particles involved in each reaction.

Question 3 **(3 marks)**

All elements past bismuth (Z = 83) in the periodic table are radioactive and there are no stable isotopes past bismuth. Briefly explain why there is a limit to the size of stable nuclei.

Question 4 **(3 marks)**

An accident at an experimental nuclear reactor facility exposes an 80 kg scientist to nuclear radiation. He receives 20 mJ of energy from exposure to fast neutrons, and a further 60 mJ of energy from gamma radiation. Calculate his overall dose equivalent from this nuclear radiation exposure.

Question 5 **(4 marks)**

There are 9.00×10^{18} atoms in a sample of a radioactive element. If the element has a half-life of 10.0 minutes, calculate how many atoms of this element remain after 1.00 hour.

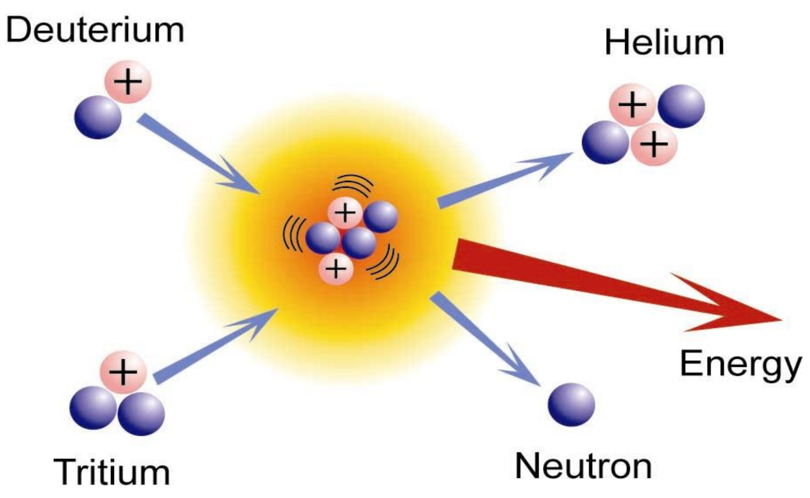
END OF SECTION ONE

Section Two: Problem Solving

Question 6 **(10 marks)**

The fusion of a deuterium nucleus with a tritium nucleus to form helium-4 and a neutron is a possible reaction in future fusion reactors.

$$^{2}_{1}\mathrm{H} + ^{3}_{1}\mathrm{H} \rightarrow ^{4}_{2}\mathrm{He} + ^{1}_{0}\mathrm{n} + \text{energy}$$



(a) Calculate the difference in mass between reactants and products, given the following masses:

deuterium = 3.3435×10^{-27} kg tritium = 5.0074×10^{-27} kg

helium-4 = 6.6447×10^{-27} kg neutron = 1.6750×10^{-27} kg. (2 marks)

(b) Hence use Einstein's mass-energy equivalence to calculate the energy released by a single fusion reaction. (2 marks)

(c) Find the energy released by the fusion of 1.00 kg of reactants (i.e. a combined mass of deuterium and tritium totalling exactly 1.00 kg) (2 marks)

(d) A fusion reactor is designed to have an average power output of 450 MW and an operating efficiency of 60%. Calculate the amount of mass converted into energy by such a reactor over one year of continuous operation. (4 marks)

Question 7 **(10 marks)**

Nuclear reactors use fission reactions to generate electricity. In the nuclear reactor shown in Figure 2 the energy generated by fission heats up the water, the water boils creating steam which turns a turbine creating electricity.

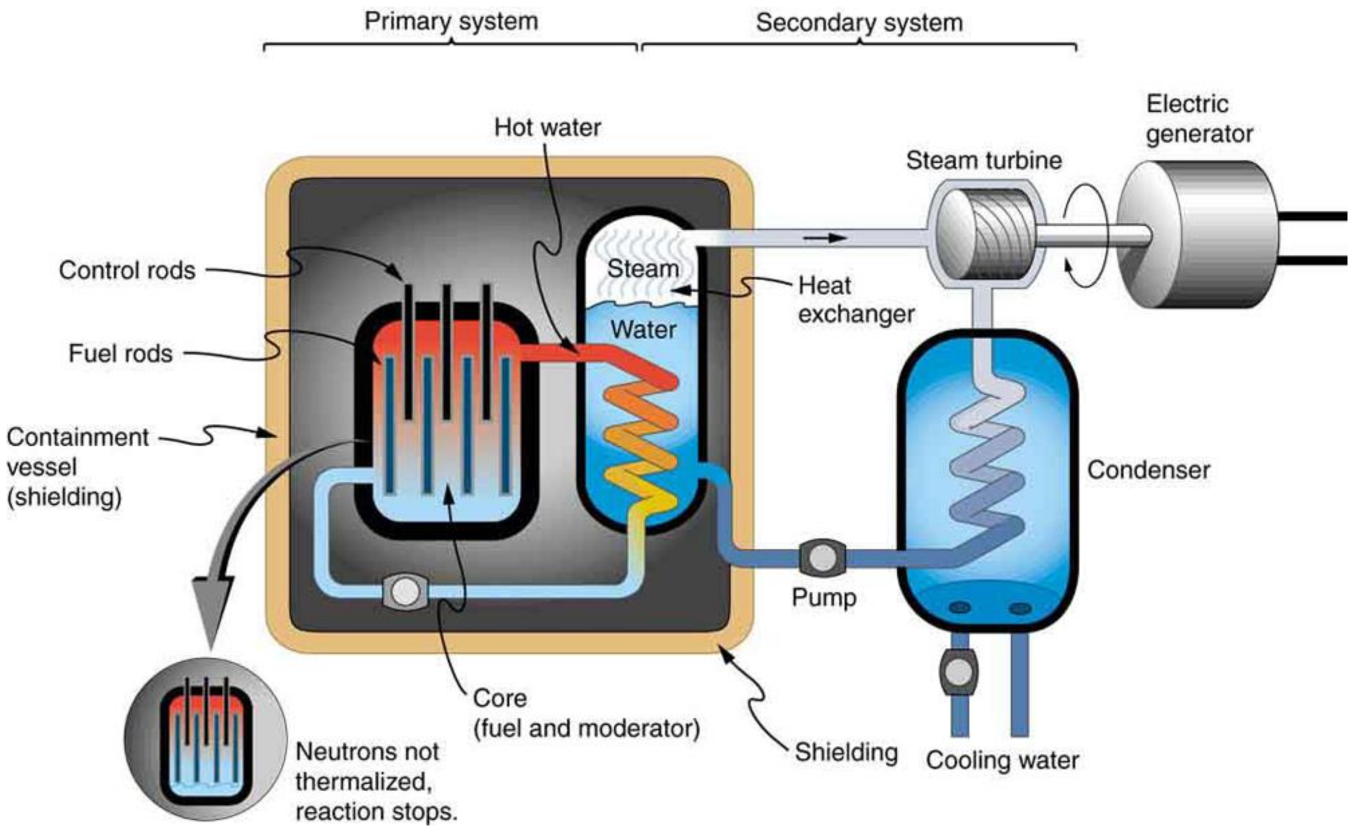


Figure 2: Pressurised water nuclear reactor diagram

The nuclear reactor shown above uses Uranium-238 as a fuel source. The Uranium undergoes fission according to the following equation:

$$^{1}_{0}n + ^{238}_{92}U \rightarrow ^{96}_{38}Sr + ^{140}_{54}Xe + ?\,^{1}_{0}n$$

a) How many neutrons are released as a product of this fission reaction? (1 mark)

b) Calculate the energy (in MeV) released by the fission reaction shown in part a).

(3 marks)

Element	Mass (u)
Uranium-238	238.050784
Strontium-96	95.921750
Xenon-140	139.92164
Neutron	1.008665

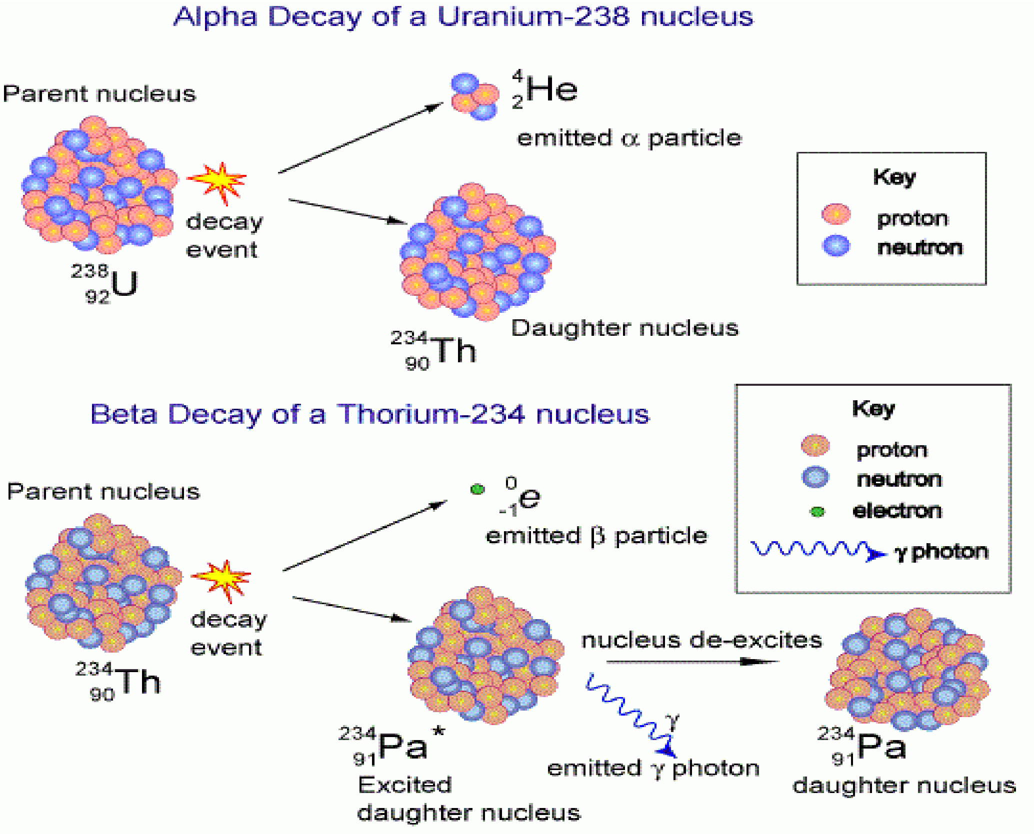
c) Name and describe two safety features used in nuclear reactors. (4 marks)

d) Explain why it is easier for a neutron to enter the nucleus compared to an alpha particle or a proton.

(2 marks)

Question 8 **(10 marks)**

All isotopes of all elements past bismuth (Z = 83) in the periodic table are radioactive; there are no stable nuclei past bismuth. One of the most stable isotopes past bismuth is uranium-238 ($^{238}_{92}U$), which has an extremely long half-life of 4.5 billion years. Uranium-238 nuclei eventually decay into thorium-234 nuclei, as shown in the diagram below. Thorium-234 itself undergoes radioactive decay into protactinium-234 via a two-step process also illustrated below.



(a) What is an isotope? (1 mark)

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___

(b) The half-life of thorium-234 is 24.1 days, while protactinium-234* and protactinium-234 have half-lives of 1.17 minutes and 6.75 hours respectively. Predict the relative abundance of these three radioisotopes (Th-234, Pa-234* and Pa-234) in a sample of uranium ore, from most abundant to least abundant. (1 mark)

Most abundant ___________ > ___________ > ___________ Least abundant

(c) State which of the types of nuclear radiation shown above (3 marks)

(i) is the most penetrating. ______________________

(ii) is the most ionizing. ___________________

(iii) leaves the nucleon composition of the nucleus unchanged. __________________

(d) Briefly describe the nucleon change that occurs inside the thorium-234 nucleus that results in the emission of a β particle. (1 mark)

(e) In terms of the balance of forces within the nucleus, explain why there is a limit to the size of stable nuclei. (4 marks)

END OF SECTION TWO

Section Three: Comprehension

Question 9 **(12 marks)**

Nuclear Imaging with Radioisotopes

Nuclear imaging is a technique that uses radioisotopes to emit radiation from within a patient's body. A radioisotope is given to a patient either orally, by injection or it can be inhaled. Nuclear imaging can provide doctors with information that other techniques can't. For example, X-rays can only image bone but nuclear imaging can take pictures of both bone and soft tissue. With nuclear imaging doctors can detect secondary cancer up to two years before it can be seen in a standard X-ray.

The radioisotopes used in nuclear imaging are usually gamma emitters. Doctors use a special gamma camera to detect the gamma radiation and create an image to help diagnose diseases such as cancer. Different elements are used including isotopes of technetium, gallium, iodine, xenon and thallium. The type of radioisotope used depends on which part of the body is being investigated. For example, Iodine-131 is used to take images of the thyroid.

Nuclear imaging can show the position and concentration of the radioisotope in the patient's body. A 'hot spot', an area where the radioisotope has been absorbed into the tissue or organ may be due to a diseased state, such as infection or cancer.

Iodine Radioisotopes

Iodine radioisotopes are often used to take images of the thyroid, a gland in your neck. Iodine-131 is not used often due to the danger it can pose to the patients' health. Other less-damaging radioisotopes such as Iodine-123 are preferred in most situations.

Iodine-131 contributed to the health problems experienced after the Chernobyl nuclear power plant meltdown. It was also spread through the air after the Fukushima nuclear crisis.

	Iodine-123	Iodine-131
Decays by:	100% Gamma	90% Beta, 10% Gamma
Half-life:	13.22 hours	8.02 days

Figure 3: Nuclear images of a patient's head and chest. The thyroid (circled in the third image) appears as a 'hot spot'.

a) Explain why nuclear imaging usually uses gamma radiation (instead of alpha or beta radiation).
(3 marks)

b) Explain why Iodine-123 is used more often in nuclear imaging than Iodine-131. (3 marks)

c) Iodine-131 is created by Tellurium-130 absorbing a neutron, the Tellurium then beta-decays into Iodine-131. Write the nuclear equations for the creation of Iodine-131
(2 marks)

d) Draw a graph of ‘fraction of sample remaining’ against ‘time’ for Iodine-123. (4 marks)

END OF TEST