Physics Stage 2: Nuclear Physics Test 2014

Name: Solutions (46 marks)

1. Within a nuclear reactor, uranium-235 is bombarded by a neutron to split into two daughter products also emitting two neutrons. Part of the nuclear equation is shown below.

$$^{235}_{92}U + ^{1}_{0}n \rightarrow X + ^{91}_{38}Sr + 2^{1}_{0}n$$

   a. Write the nuclide for the missing daughter product labelled **X**. $^{143}_{54}Xe$

(1 mark)

   b. What is the atomic and mass numbers of the daughter product

   Mass number 143 Atomic number 54 (1 mark)

2. Explain why beta radiation has greater penetration than alpha radiation (e.g. thorough air or paper). (3 marks)

α has higher charge ✓
α has larger mass/size ✓
Thus interacts more with other atoms ✓
Loses KE/velocity faster than β until "absorbed" ✓

any 3 out of 4

3. A radioactive isotope has a count of 3.85 x 10^3 decays in one hour. Calculate the activity of the source. (2 marks)

3.85×10^3 / hr

$= 3.85\times10^3/3600$ per sec

$= 1.07$ Bq ✓ ✓

4. Food can be preserved by irradiating it with nuclear gamma radiation. Meat typically requires an equivalent dose of 1000 Sv to sterilize it. How much energy does 2.0 kg of meat absorb when it undergoes sterilization? (2 marks)

1000 Sv = 1000 ÷ 1 Gy

= 1000 J/kg

i.e. Energy = 2000 J

5.

5. Calculating the binding energy per nucleon in MeV of the helium-3 atom given the mass of He-3 = 5.00 x 10^{-27} kg. (4 marks)

Mass of He 3 individual particles

$= 2\times(1.67\times10^{-27} + 9.11\times10^{-31}) + 1\times(1.67\times10^{-27})$

$= 5.0118\times10^{-27}$ kg ✓

$\Delta m = 5.0118\times10^{-27} - 5\times10^{-27} = 1.1822\times10^{-29}$ kg ✓

$E = mc^2 \Rightarrow E = 1.1822\times10^{-29}\times(3\times10^{8})^2 = 1.06398\times10^{-12}$ J ✓

$1.06398\times10^{-12}\text{ J} = \dfrac{1.06398\times10^{-12}}{1.6\times10^{-19}\times10^{6}} = 6.65$ MeV

$= 6.65 \div 3 = 2.22$ MeV/nucleon ✓

6. Uranium-238 decays via alpha emission to thorium-234.

a. Write the reaction down a balanced equation for this reaction. (1 mark)

$^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$ ✓

b. Calculate the energy released from the decay of one atom in joules. (4 marks) 3

You may need the following information:

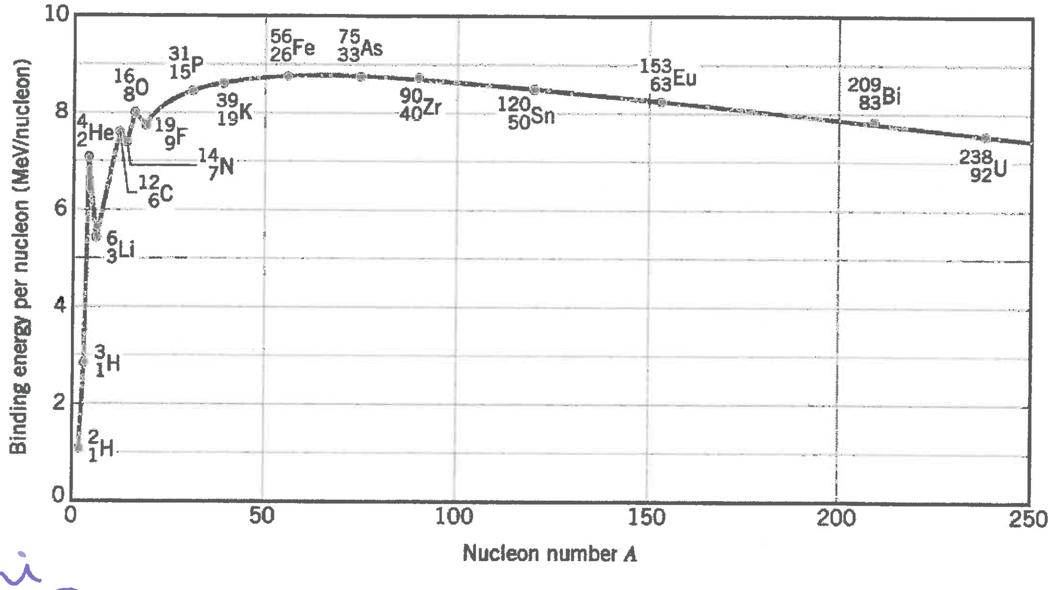
Mass of U-238 atom:	238.05079 u
Mass of α particle:	4.00260 u
Mass of Th-234 atom:	234.04360 u

$\Delta m = 238.05079 - (234.04360 + 4.00260)$

$= 0.00459$ u

$\Rightarrow E = 0.00459 \times 931 = 4.27$ MeV

7. The chart below shows the binding energy per nucleon as a function of nucleon number.



combine

a. Explain why Li-6 could never be used as fuel for a nuclear fission reactor. (2 marks)

Li-6 is a small nuclide. Only large nuclei
fission is a process of splitting a nucleus. Large
nuclei are energetically less favourable than small

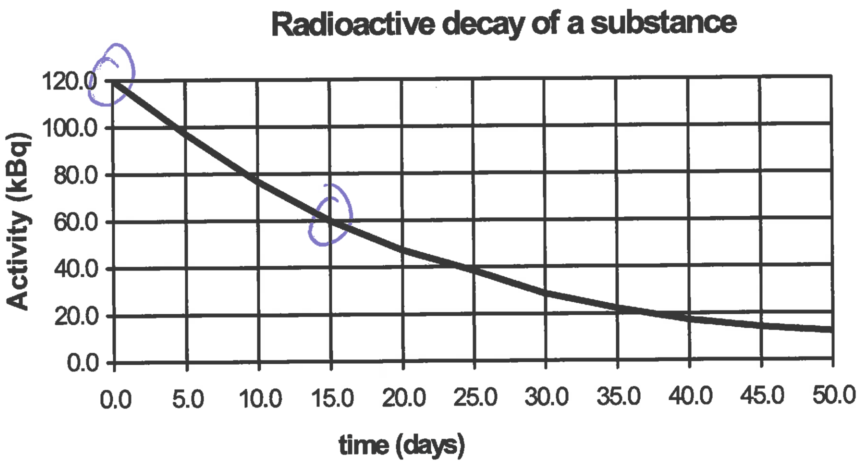
b. Nevertheless, Li-6 could, in theory, be used as a nuclear fuel in a different kind of reactor. Explain. (2 marks)

Energy is theoretically released if 2 Li-6 nucle
where fused. So a fusion reactor

8. The forming of a new element during radioactive decay is called transmutation. Explain why emitting alpha and beta radiation causes a transmutation but emitting gamma radiation does not. (3 marks)

~~α & β radiation are particles.~~
~~The emission of particles from a nucleus~~
+ α emission involve loss of 2 proton
+ β emission involves change of one neutron to proton
+ in Both cases change in proton # ⇒ change of element
+ Not the case with γ.

9. Determine the half-life of the substance from the graph.



a. Half-life = 15 day (1 mark)

b. Use this half-life to calculate as accurately as possible the expected activity of the sample after 63 days. (2 marks)

$$A = A_0\left(\tfrac{1}{2}\right)^{n}$$

$$n = \frac{63}{15} = \underline{4.2}$$

$$A = 120 \times \left(\tfrac{1}{2}\right)^{4.2} = \underline{6.534 \text{ Bq}}$$

10. A miner in a uranium mine does not know that he is exposed to a radon-222 gas leak. The gas is an alpha emitter, and it has a very long half life. The gas he breathes in is not eliminated from the body as it settles into the tissue of his lung. The radon in his body has an estimated activity of 3.40kBq which can be considered constant. Each decay of the isotope releases 3.8×10^{-12} J of energy into his body. One month (30 days) later, the accident is discovered, and management realise that he was been exposed to the gas.

a. Calculate the total energy the miner absorbed into his lungs during the 30 days since he breathed in the radon. (2 marks)

No. of decays: $3.4 \times 10^3 \times 60 \times 60 \times 24 \times 30 = 8.8128 \times 10^9$

total energy $= 8.8128 \times 10^9 \times 3.8 \times 10^{-12} = 0.0334886$ J

$= 3.35 \times 10^{-2}$ J

b. Calculate the absorbed dose he received in one month if he has a mass of 75 kg. (If you were unable to obtain a value for (a) above use 0.035 J) (2 marks)

$AD = \frac{E}{m} = \frac{3.35 \times 10^{-2}}{75} = 4.47 \times 10^{-4}$ Gy ✓ ✓

(4.67×10^{-4} alternative ans)

c. Calculate the dose equivalent. (2 marks)

✓ ✓

$DE = AD \times Q = 4.47 \times 10^{-4} \times 20 = 8.93 \times 10^{-3}$ Sv

(9.33×10^{-3} Sv)

d. Should the miner be concerned about his exposure? Explain. (2 marks)

No, ✓
this is a very small amount of radiation & will almost certainly cause no harm. ✓

Comprehension: ***Read the article then answer the questions.*** (10 marks)

THE BASICS OF NUCLEAR POWER

Nuclear power plants generate electricity from fission, usually of uranium-235 (U-235), the nucleus of which has 92 protons and 143 neutrons. When it absorbs an extra neutron, the nucleus becomes unstable and splits into smaller pieces and more neutrons. The products and neutrons have a smaller total mass than the U-235 and the first neutron; the mass difference has been converted into energy, mostly in the form of heat, which produces steam and in turn drives a turbine generator to produce electricity.

Natural uranium is a mixture of two isotopes, fissionable U-235 (0.7 per cent) and non-fissionable U-238. However, U-238 can absorb neutrons to form plutonium-239 (P-239), which is fissionable, and up to half the energy produced by a reactor can in fact come from fission of P-239. Some types of reactor require the amount of U-235 to be increased above the natural level, which is called enrichment. Pressurized water reactors (PWRs), the most common type of reactor, require fuel enriched to about 3 per cent U-235.

Reactor fuel is made up of fuel pellets or pins enclosed in a tubular cladding of steel, zircaloy, or aluminium. Several of these fuel rods make up each fuel assembly. The fast neutrons released in the fission reaction need to be slowed down before they will induce further fissions and give a sustained chain reaction. This is done by a moderator, usually water or graphite, which surrounds the fuel in the reactor. However, in "fast reactors" there is no moderator and the fast neutrons sustain the fission reaction.

A coolant is circulated through the reactor to remove heat from the fuel. Ordinary water (which is usually also the moderator) is most commonly used but heavy water (deuterium oxide), air, carbon dioxide, helium, liquid sodium, liquid sodium-potassium alloy, molten salts, or hydrocarbon liquids may be used in different types of reactor.

The chain reaction is controlled by using neutron absorbers such as boron, either by moving boron-containing control rods in and out of the reactor core, or by varying the boron concentration in the cooling water. These can also be used to shut down the reactor. The power level of the reactor is monitored by temperature, flow, and radiation instruments and used to determine control settings so that the chain reaction is just self-sustaining.

The main components of a nuclear reactor are: the pressure vessel (containing the core); the fuel rods, moderator, and primary cooling system (making up the core); the control system; and the containment building. This last element is required in the event of an accident, to prevent any radioactive material being released to the environment, and is usually cylindrical with a hemispherical dome on top.

During operation, and also after it is shut down, a nuclear reactor will contain a very large amount of radioactive material. The radiation emitted by this material is absorbed in thick concrete shields surrounding the reactor core and primary cooling system. An important safety feature is the emergency core cooling system, which will prevent overheating and "meltdown" of the reactor core if the primary cooling system fails. See Also Nuclear Fission.

1. The TDS principle for safety when working with radioactive sources is always used in nuclear reactors. T = time, D = distance, S = Shielding. Explain how these factors can be used to minimise exposure to radiation (2 marks)

T = time - minimise time exposed to radiation

D = distance - maintain greatest distance possible

S = shielding - use shielding to absorb radiation

(-1 for each unacceptable answer)

2. Nuclear power plants generate electricity from fission. What is fission and how does this result in a chain reaction? (2 marks)

→ Fission is the splitting of large nuclei into smaller nuclei / fragments ✓

→ neutrons released from fission reaction induce further fissions in a continuing process. ✓

3. Write the nuclear equation for U-238 absorbing a neutron to form Pu-239. (1 mark)

$$^{238}_{92}U + ^{1}_{0}n \rightarrow ^{239}_{94}Pu + 2\,^{0}_{-1}e$$

4. What is "enriched" uranium and why is it necessary to enrich it? (2 marks)

Enriched uranium as a greater % of U-235 than the natural level. ✓

If there is not enough U-235 present in the fuel rods the fission reaction cannot be sustained ✓

5. Chain reactions are controlled by using neutron absorbers. If these were not in place, an uncontrolled chain reaction could take place if the uranium was at critical mass. What is critical mass? (2 marks)

Critical mass is the minimum mass of a fissile material required to sustain a chain reaction. ✓✓

6. Why do fast neutrons need to be slowed down in a nuclear reactor and what is used to do this? (2 marks)

+ Fission of a U-235 nucleus will not be induced if the colliding neutron has too much kinetic energy (velocity) ✓

+ A moderator is used to slow the neutrons. ✓