Physics ATAR - Year 11

Nuclear Physics Unit Test 2017

Mark: / 57

= %

Name: SOLUTIONS

Time Allowed: 50 minutes

Notes to Students:

- You must include **all** working to be awarded full marks for a question.
- Marks will be deducted for incorrect or absent units and answers stated to an incorrect number of significant figures.
- **No** graphics calculators are permitted – scientific calculators only.

Question 1 **(6 marks)**

(a) Complete the following table

(4 marks)

Name of isotope	Atomic Number	Mass Number	Number of Neutrons
Neon - 20	10	20	10
Calcium-40	20	40	20
Lithium - 7	3	7	4
Iron-56	26	56	30

(b) If the isotope Iron-56 gains 4 protons and 5 neutrons, state the name of the isotope it becomes.

(2 marks)

Zinc - 65

(Working out must be displayed for mass number and atomic number)

Question 2 **(4 marks)**

Compare the physical properties of an alpha particle and a beta negative particle in regards to the following:

Property	Alpha	Beta (-)
Charge	**+2e**	**-1e**
Mass (kg)	**6.64×10^{-27}**	**9.11×10^{-31}**
Approximate emission speeds	**~0.1c**	**~0.9c**
Penetration in air	**~ 2cm**	**~1 m**

Question 3 **(8 marks)**

Write balanced nuclear equations for the following events in the space provided.

(a) Uranium-234 emits an alpha particle.

(2 marks)

$${}^{234}_{92}U \rightarrow {}^{230}_{90}Th + {}^{4}_{2}\alpha + energy$$

(b) Carbon-14 emits a beta negative particle.

(2 marks)

$${}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}\beta + \bar{\upsilon} + energy$$

(c) Sodium-23 is bombarded by deuterium (H-2) it produces magnesium-24 and another a. (Identify the other particle produced)

(2 marks)

$${}^{23}_{11}Na + {}^{2}_{1}H \rightarrow {}^{24}_{12}Mg + {}^{1}_{0}n$$

(d) An atom is bombarded by an alpha particle and becomes oxygen-16 and a gamma ray is emitted.

(2 marks)

$${}^{12}_{6}C + {}^{4}_{2}\alpha \rightarrow {}^{16}_{8}O + {}^{0}_{0}\gamma + energy$$

Question 4 **(8 marks)**

Cobalt-59 has an atomic mass of 58.933200 u

Name	Mass of atom (u)
Proton	1.007 276
Neutron	1.008 665
Electron	0.000 548 58
Hydrogen	1.007 825

(a) Calculate the mass defect for a Cobalt-59 atom (3 marks)

m.d. $= 27 \times m({}^1_1H) + 32 \times m(n) - m(\text{Co-59})$ 1

$= 27 \times (1.007825) + 32 \times (1.008665) - 58.933200$ 1

$= 0.555355$ (6.d.p) 1

(b) Calculate the binding energy of the Cobalt-59 atom in both joules and electron volts. (4 marks)

BE = m.d. x 931 1

= 0.555355 x 931 ½

= 517 MeV (3.s.f) ½ $\times 1.60 \times 10^{-13} = 8.27 \times 10^{-11}$ J 1

OR

$= 5.17 \times 10^{8}$ eV 1

(c) Calculate the binding energy per nucleon, in electron volts, of the Cobalt-59. (2 marks)

= 517 / 59 1

= 8.76 MeV / nucleon 1

Question 5 **(18 marks)**

In a thermal nuclear reactor, Uranium-235 absorbs a slow moving neutron to produce Xenon-140 and strontium-94.

Name	Mass of atom (u)
Uranium-235	235.043930
Neutron	1.008 665
Strontium-94	93.915361
Xenon - 140	139.92164

(a) Write the complete nuclear equation for this event.

(2 marks)

$${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{140}_{54}Xe + {}^{94}_{38}Sr + 2{}^{1}_{0}n + energy$$

(b) Calculate the energy, in joules, released in a single fission event.

(6 marks)

m.d. = m(U-235) + m(n) - [m(Xe-140) + m(Sr-94) + 2 x m(n)] 1

= 235.043930 + 1.008665 – [139.92164 + 93.915361 + 2x 1.008665] 1

= 0.198264 (6.d.p) 1

E = m.d. x 931 ½

= 185 MeV 1 x 1.60×10^{-13} ½ = 2.96×10^{-11} J (3.s.f) 1

Xenon-140 and strontium-94 are the most dangerous fission fragments due to their very long half-lives.

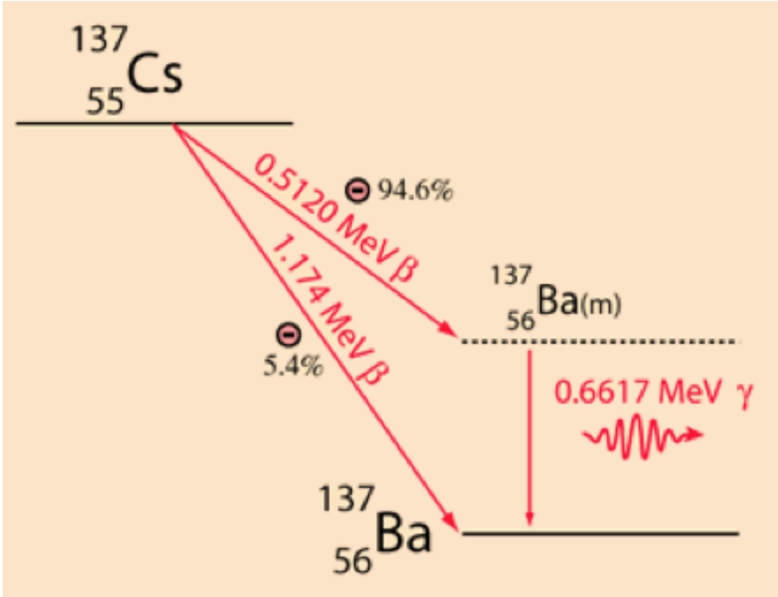
(c) Explain why the fission fragments are, themselves, radioactive.

(3 marks)

- Heavy isotopes require a higher ratio of neutrons to protons to maintain stability
- When fission occurs, the fragments have an excessive ratio of neutrons to protons
- Hence, decay via beta – in an attempt to become stable.

A common fission fragment is caesium-137. Caesium-137 decay has a half-life of 30.07 years and proceeds by both beta decay and gamma emission from an intermediate state. Both the electron and gamma emissions are highly ionizing radiation.

The figure to the right shows the two possible decay pathways for caesium-137. The red text includes the type of decay and the energy of emission.



(d) Choose **one** of the pathways and write a balanced nuclear equation for the decay.

(2 marks)

$$^{137}_{55}Cs \rightarrow {}^{137}_{56}Ba + {}^{0}_{-1}\beta + \bar{\upsilon} + energy$$

OR

$$^{137}_{55}Cs \rightarrow {}^{137m}_{56}Ba + {}^{0}_{-1}\beta + \bar{\upsilon} + energy$$

(no marks for the gamma emission as the question does not ask for it)

Energy is one property that is conserved in the decay pathway.

(e) Using the values in the figure, show through calculation that energy is conserved.

(1 mark)

0.5120 + 0.6617 = 0.1737

= 0.174 rounded.

(f) State one other property that is conserved in the decay pathway

(1 mark)

charge, momentum, lepton number, Baryon number, mass number

(g) Nuclear reactors have very thick concrete shielding around the reactor. Explain why this is required.

(3 marks)

- Thick concrete is required to absorb the gamma rays that are emitted
- as gamma rays are highly penetrating
- this protects the works in the reactor plant from absorbing the energy

Question 6 **(16 marks)**

Brachytherapy is a radiation treatment therapy that involves the precise placement of short-range radioisotopes directly at the site of the cancerous tumor. These are enclosed in a protective capsule or wire, which allows the ionizing radiation to escape to treat and kill surrounding tissue but prevents the charge of radioisotope from moving or dissolving in body fluids.

The capsule may be removed later, or (with some radioisotopes) it may be allowed to remain in place. A feature of brachytherapy is that the irradiation affects only a very localized area around the radiation sources. Exposure to radiation of healthy tissues farther away from the sources is therefore reduced. In addition, if the patient moves or if there is any movement of the tumor within the body during treatment, the radiation sources retain their correct position in relation to the tumor.

Iodine-131 is often used in brachytherapy, it has a half-life of 8.02 days and decays by beta decay (with an energy of 0.606 MeV) to xenon-131m

(a) Explain why "short-range" radioisotopes are preferred over long range,

(3 marks)

- Short range will only effect the cells immediately surrounding it
- Maximising effect on cancerous/tumour cells
- While minimising the effect on healthy cells.

A pellet containing Iodine-131 with an initial activity of 4.05 MBq is inserted into a tumor. The pellet is able to irradiate 20.0 grams of the tumor. It is left inserted in the tumor for 60.0 days.

(b) Calculate the activity of the pellet when it is removed.

(4 marks)

$n = \frac{t}{t_{1/2}}$ ½

$= \frac{8.02}{60}$ ½

$= 7.48$ half lives 1

$A = A_0(1/2)^n$ ½

$= 4.05 \times 10^6 (1/2)^{7.48}$ ½

$= 2.27 \times 10^4$ Bq 1

(c) If the tumor absorbs 1.40 J of energy through beta decay, calculate the absorbed dose.

(3 marks)

m = 20 / 1000

= 0.02 kg 1

A.D. = $\frac{Energy}{mass}$ ½

= $\frac{1.40}{0.02}$ ½

= 7.00 x 10^1 Gy 1

(d) Calculate the dose equivalent the tumor receives.

(2 marks)

D.E. = A.D x Q.F ½

= 7.00 x10^1 x 1 ½

= 7.00 x 10^1 Sv 1

(e) The pellet is considered ineffective when its activity drops below 31.6406 kBq. Calculate the time for this to occur.

(4 marks)

$$\frac{A}{A_0} = \frac{1}{2^n} \frac{31.6406 \times 10^3}{4.05 \times 10^6} = \frac{1}{128.} = \frac{1}{2^7} \quad \therefore n = 7$$

½ ½ 1

(1 mark for full mathematical logic in solving for n)

t = n x $t_{1/2}$ ½

= 7 x 8.02 ½

= 56.1 days 1

End of Test