Christ Church
Grammar School

Science Department
Year 11 2021

ATAR PHYSICS
UNIT 1 – Nuclear Physics
TEST 2021

Student Name:

SOLUTIONS

Teacher: JRM PCW CJO
(Please circle)

Time allowed for this paper
Working time for paper: 50 minutes.

Instructions to candidates:

- You must include **all** working to be awarded full marks for a question.
- Answers should be expressed to 3 significant figures unless otherwise indicated.
- Marks may be deducted if diagrams are not drawn neatly with a ruler and to scale (if specified).
- Marks will be deducted for incorrect or absent units.
- **No** graphics calculators are permitted – scientific calculators only.

Mark:	/ 52
=	%

Question 1 **(9 marks)**

(a) State what is meant by the term “isotope”

(2 marks)

Description	Marks
Atoms of the same element/same number of proton/same chemical properties	1
But different mass number/ number of neutrons/difference physical properties	1
Total	2

(b) Carbon-14 is a radioactive isotope of carbon, whereas carbon-12 is stable. Explain why carbon-14 is radioactive and carbon-12 is not.

(2 marks)

Description	Marks
Carbon-14 has too many neutrons / unstable ratio of n : p.	1
Carbon-12 has a stable number of protons : neutrons	1
Total	2

(c) State what form of radioactive decay carbon-14 is likely to undergo and write a complete nuclear equation for this event.

(2 marks)

Description	Marks
Beta negative	1
$^{14}_{6}C \rightarrow ^{14}_{7}N + ^{0}_{-1}\beta + ^{0}_{0}\bar{\nu}$	1
Total	2

(d) One isotope of zinc is zinc-64. For this isotope, state:

(3 marks)

(i) number of protons: **30**

(ii) number of neutrons: **34**

(iii) the correct element notation in the form $^{A}_{Z}X$: $^{64}_{30}\boldsymbol{Zn}$

Question 2 **(9 marks)**

Heavy elements (Z > 52) are observed to emit alpha particles in an effort to reach nuclear stability. Thorium-228 is a radioactive isotope that undergoes decay via a decay series to eventually reach bismuth-212, a stable isotope. Each of the steps in the series involves the release of ionising radiation.

(a) Determine how many α and β^- particles in total are released in the transitions between these two isotopes. Show your working and logic below.

(3 marks)

Description	Marks
228 – 212 = 16 = loss of 16 nucleons	1
16 / 4 = 4 alpha decays loose 8 protons = 82 (lead)	1
1 β^- decay will transmutate to Bismuth-212	1
Total	3

In an experiment to study radioactive decay, a 100-gram sample of thorium oxide is placed in a sealed container to decay. The initial activity was measured to be 1.43 kBq. After a time period equal to 3 half-lives has transpired, the activity of the sample was measured again and was found to be significantly higher than the theoretical prediction of 0.179 kBq

(b) Explain why the reading was significantly higher.

(2 marks)

Description	Marks
Thorium decays into daughter products that are also unstable	1
Geiger counter would be detecting daughter decays also.	1
Total	2

(c) If given enough time, state and explain how the final mass and final activity will compare to the original.

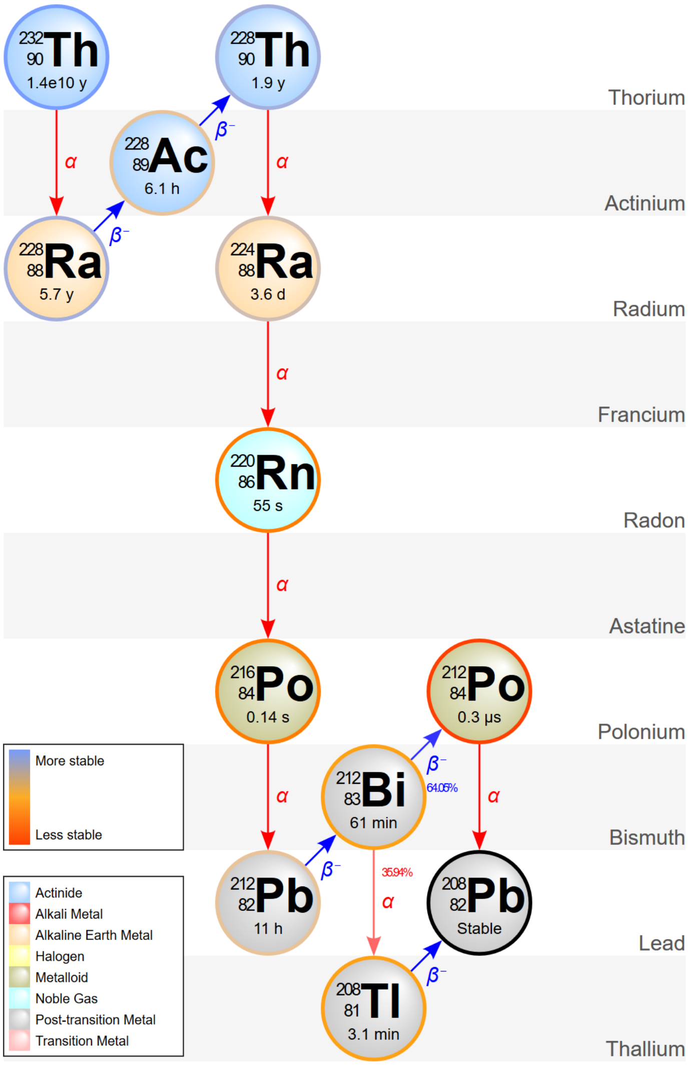
(4 marks)

Description	Marks
Mass defect occurs so mass will reduce	1
as matter has been converted to energy as per $E = mc^2$	1
Accept: Container is sealed, hence no particles have left the container. Mass defect of the events will not be large enough to be measured on the scale.	
Final activity = 0	1
Given sufficient time, all thorium would have decayed to Bi-212	1
Total	4

Question 3 **(6 marks)**

Consider the decay series leading to lead-208 in the diagram below. The time underneath each isotope symbol displays the half-life and the arrow moving away from each displays the decay mode.

(a) To the right of the image, write balanced nuclear equations for the decay of:



(i) Ac-228: (1 mark)

$$^{228}_{89}Ac \rightarrow {}^{228}_{90}Th + {}^{0}_{-1}\beta + {}^{0}_{0}\bar{\nu}$$

(ii) Rn-220 (1 mark)

$$^{220}_{86}Rn \rightarrow {}^{216}_{84}Po + {}^{4}_{2}\alpha$$

(iii) Po-216 (1 mark)

$$^{216}_{84}Po \rightarrow {}^{212}_{82}Pb + {}^{4}_{2}\alpha$$

(b) Calculate the time for the activity of a sample of Radium-224 to drop to 1/16th of its original activity.

(3 marks)

Description	Marks
$A/A_0 = 1/16 = 1/2^4$ n = 4	1
$t = n \times t_{1/2}$ = 4 x 3.6	1
= 14.4 days	1
Total	3

Question 4 **(16 marks)**

When a uranium-235 nucleus absorbs a neutron, many fission products are possible. One such reaction in a nuclear power plant results in the formation of lanthanum-148 (La), bromine-85 (Br) and neutrons.

(a) Write an equation for this reaction and identify the number of neutrons produced.

(2 marks)

Description	Marks
$^{236}_{92}U + ^{1}_{0}n \rightarrow ^{148}_{57}La + ^{85}_{35}Br + 3^{1}_{0}n$	2
Total	2

(b) Calculate the energy released, in joules, from each decay event.

(5 marks)

Particle	**Atomic mass (u)**
Proton	1.007276
Neutron	1.008665
Electron	0.0005486
Hydrogen	1.007825
Uranium-235	235.043930
Lanthanum-148	147.93223
Bromine-85	84.91561

Description	Marks
m.d = m(U-235) + m(n-1) – [m(La-149) + m(Br85) +3xm(n-1)	1
235.043930 + 1.008665 → 147.93223 + 84.91561 + 3 x 1.008665	1
m.d. = 0.17869 u	1
x 931 = 166 MeV	1
x 1.60 $x10^{-19}$ $x10^{6}$ = 2.66 $x10^{-11}$ J	1
Total	5

(c) How do the neutrons released in this reaction differ from those that took part in the initial fission reaction?

(1 mark)

Description	Marks
They are released with higher E^{k} / speed	1
Total	1

(d) State what component of a nuclear reactor overcomes the difference mentioned in (c) and comment on its effect on the criticality of the core.

(2 marks)

Description	Marks
Moderator slows neutrons down so they can be cauptured by U-235	1
This increases likelihood of capture and hence, the criticality increases	1
Total	2

Many of the products of fission reactions are radioactive but are not able to be used in the reactor. This waste is taken from the site and stored permanently in a safe and secure place where its activity can be monitored. The measured activity from some radioactive waste when it was first removed from the reactor was 64.0 Bq above the background count of 0.500 Bq.

(e) Explain what is meant by the term 'background count' and give an example of a source that contributes to it.

(2 marks)

Description	Marks
Naturally occurring sources of radiation in the environment	1
Such as cosmic rays, rocks, atomic testing, nuclear sources, bananas.	1
Total	2

(f) If the average half-life of the waste in part (e) is taken as being 7.50×10^3 years, calculate how long it will take for its activity to reach the same level as the background count.

(4 marks)

Description	Marks
$A/A_0 = 0.5/64 =$	1
$1/128 = 1/2^7$ $n = 7$	1
$t = n \times t_{1/2}$ $= 7 \times 7500$	1
$= 52{,}500$ years	1
Total	4

Question 4 **(12 marks)**

A melanoma is a cancer which can develop in the pigment-producing cells in the skin. A technique called boron capture therapy has been developed to treat melanomas. Researchers have synthesised a boron-containing compound that a person with a melanoma can drink in solution. The molecules of this compound tend to accumulate at the melanoma site. The boron-containing molecules can be absorbed by the melanoma cells. When exposed to a neutron beam the boron atoms capture a neutron.

(a) Determine the identity of 'X' in the equation.

(1 mark)

$${}^{11}_{5}B + {}^{1}_{0}n \rightarrow + X$$

X = **Boron-12**

The radioisotope 'X' has a short half-life. When it decays it gives off a charged particle with a very short range. This particle also deposits a relatively large quantity of energy along its short path. This decay, therefore, occurs within the cell.

(b) State what this particle likely to be.

(1 mark)

Description	Marks
Alpha ${}^{4}_{2}\alpha$	1
Total	1

(c) Hence, write a possible decay equation for radioisotope 'X'.

(1 mark)

Description	Marks
${}^{12}_{5}B \rightarrow {}^{8}_{3}Li + {}^{4}_{2}\alpha$	1
Total	1

(d) How might this treatment be effective in treating a melanoma?

(1 mark)

Description	Marks
Alpha is short range, meaning it will not travel outside the melanoma/only damage the cancerous cells.	1
Total	1

(e) Calculate the initial power that radioisotope 'X' generates.

(3 marks)

Description	Marks
P = E / t = E/n x A	1
= 145000 x 2.30 x 10^{6} x 1.60 x10^{-19}	1
= 5.33 x10^{-8} W	1
Total	3

Over the period of 7 days, 32.3 mJ of energy is provided to the melanoma which has an estimated mass of 3.20 grams.

(f) Calculate the absorbed dose received by the melanoma.

(3 marks)

Description	Marks
A.D = Energy / mass	1
$= \frac{32.3 \times 10^{3}}{3.2 \times 10^{-3}}$	1
= 10.1 Gy	1
Total	3

(g) Hence, calculate the dose equivalent received by the melanoma. (If you could not complete part (f), use a value of 1.00)

(2 marks)

Description	Marks
D.E = A.D x Q.F = 10.1 x 14	1
= 141 Sv	1
Total	2

END OF TEST