(Note: Q7 has been omitted)

BELMONT CITY COLLEGE

PHYSICS 2AB TEST – 2013

NUCLEAR PHYSICS

Student Name: Solutions

/ 42

TIME: 50 minutes

* A data sheet is supplied for student use

NOTE:

1. Calculations must show clear working with answers written in scientific notation stated to **three significant figures unless you are answering a question specifically asking you how many significant figures are technically required**
2. Full Marks will be allocated for clear and logical setting out.
3. To help identify your answer, underline each answer.
4. State **assumptions** if working on open ended type questions.

1. During a fission reaction, uranium-235 is bombarded by a neutron which splits into two daughter products and emits 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 elemental symbol for the missing daughter product labelled **X**.

~~[illegible]~~ Xe

(1 mark) ✓

b. What is the mass number and atomic number of the daughter product **X**:

Mass number 143 (1 mark) ✓ Atomic number 54 (1 mark) ✓

2. In terms of the properties of alpha and beta radiation, explain why alpha radiation cannot penetrate paper but beta radiation can. (4 marks)

α - large particles, interacts with atoms in air ✓
& solids & quickly loses KE ⇒ low penetration ✓

β - much smaller. Less interaction ⇒ less ✓
loss of KE ⇒ higher penetration ✓

3. Why do therapeutic radioisotopes used for cancer need to be alpha, beta, and gamma emitters? (3 marks)

α & β have high ionisation (specially α) ✓

This can kill cancer cells ✓

Gamma can be traced, allowing doctors to ✓
check progress of the radioisotope

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

$\frac{3850}{60 \times 60} = 1.07$ Bq

✓ ✓

5.a. Define what is meant by the "binding energy" of a nucleus. (2 marks)

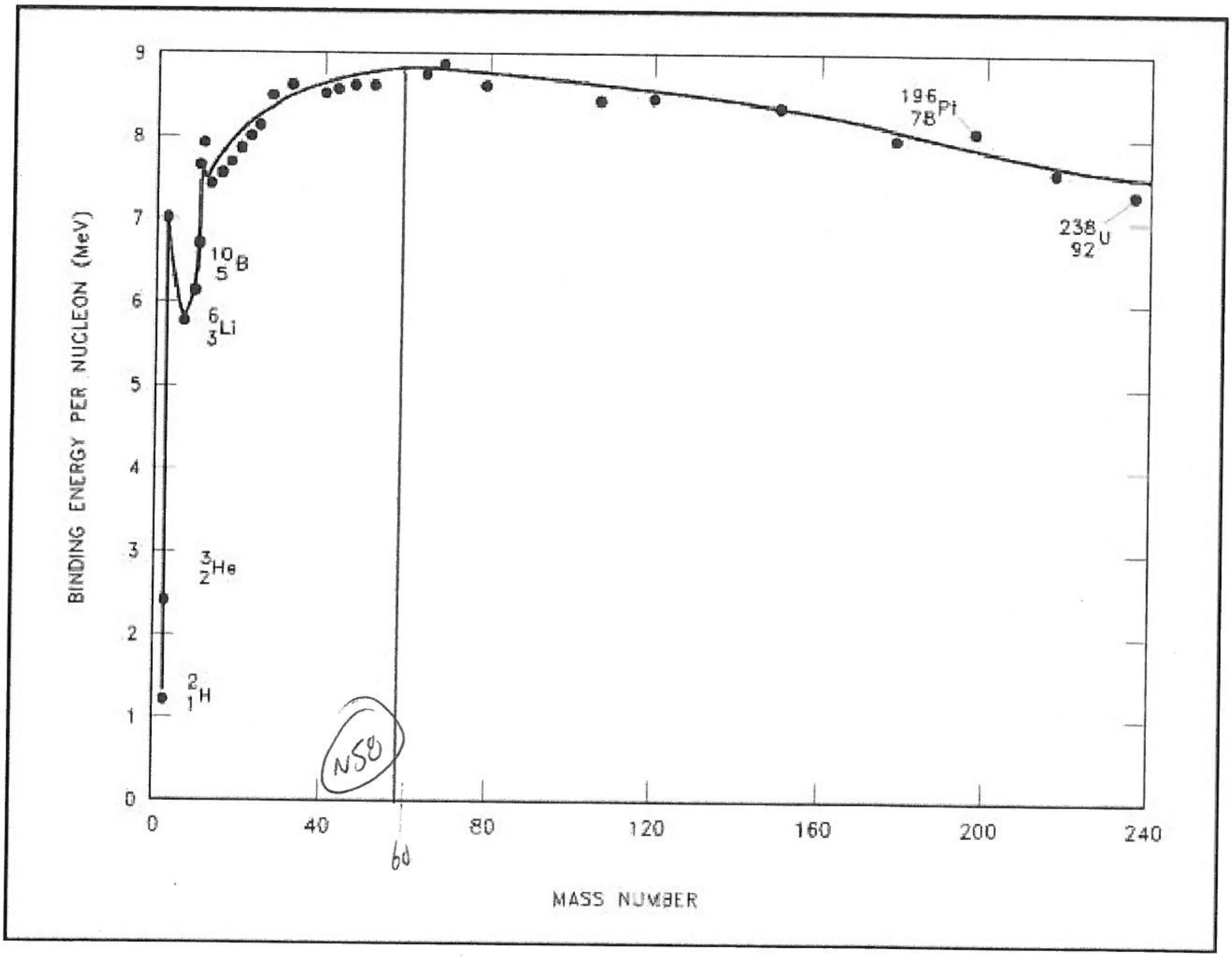
When the particles of an atom 'combine' there is a loss of mass. The equivalent energy of this mass loss ($E = mc^2$) is the 'energy that binds the nucleus'. More correctly, it is the work needed to separate the nucleus.

b. What is the relationship between the binding energy per nucleon of a nucleus and the stability of a nucleus? (2 marks)

The higher the binding energy/nucleon, the more stable the nucleus. ✓✓

c. Use the graph below to approximately determine the mass number of the most stable element. (1 mark)

See below: 55-60



d. Why do some nuclei undergo radioactive decay, or possibly fission or fusion? (2 marks)

Decay is one type of fission.
Fission occurs with large atoms, which tend to break up into smaller atoms which have a higher binding energy per nucleon (more stable)
Smaller atoms fuse together to become larger, more stable atom.

6. If the original activity of a radioactive sample is 42.0 kBq and it has a half-life of 4.00 days, what will be the theoretical activity after 12.0 days? Show all working to arrive at your answer. (3 marks)

12 days = 3 half lives

$42 \xrightarrow{1} 21 \xrightarrow{2} 10.5 \xrightarrow{3} 5.25$

= 5.25 kBq

8. When a plant or animal dies it stops taking in carbon-14 and radioactive decay begins to decrease the amount of carbon-14 in the tissues. The age of the deceased organism can then be predicted by measuring the activity of carbon-14 left in the remnants.

A 30.0 g sample of carbon from a skeleton has a carbon-14 decay rate of 240.0 decays per minute. Considering the activity of carbon-14 in a living organism is 16.0 decays minute^{-1} g^{-1} and the half-life of carbon-14 is 5730 years, what is the approximate age of the skeleton? (4 marks)

240 decays / min in 30g

= 8 decays / min in 1g ✓

Since this is ½ living organism (16), the object is exactly 1 half ~~length~~ life. ✓ ✓

(5730 years) ✓

9. A miner in a uranium mine is unaware that he is breathing in radon-222 gas, which unfortunately is an alpha emitter. The gas has a very long half-life with an activity of 3.40kBq, which will be unchanged during his time in the mine. Each decay of the isotope releases 3.8×10^{-12} J of energy into the body and the radioisotope is not eliminated from the body, as it will settle into the tissue of his lungs. After a month the dangerous gas is discovered and the mine is closed (assume a month is 30 days).

a. Calculate the total energy the miner absorbed into his lungs during this time. (2 marks)

30 days = $30 \times 24 \times 60 \times 60$ seconds = 2592000 s

Total decays = $3400 \times 2592000 = 8.8128 \times 10^{9}$

Total Energy = $8.8128 \times 10^{9} \times 3.8 \times 10^{-12}$

= 0.0334886 J ≈ 0.0335 J

b. Calculate the absorbed dose he received in one month if he has a mass of 75.0 kg. (*If you were unable to obtain a value for part (a), use 0.035 J*)

(2 marks)

$$AD = \frac{0.03348864}{75} = 0.00044651 5 \text{ Gy}$$

$$= 4.47 \times 10^{-4} \text{ Gy}$$

$\boxed{\left(0.035 \text{ gives} \quad 4.67\times10^{-4} \text{ Gy}\right)}$

(one mark for units)

c. Calculate the dose equivalent if the alpha radiation has a quality factor of 20.

(2 marks)

$$DE = 20 \times AD$$

$$= 8.93 \times 10^{-3} \text{ Sv}$$

(one mark for units)

($\approx$ 9 mSv)

(or 9.33×10^{-3} Sv)

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

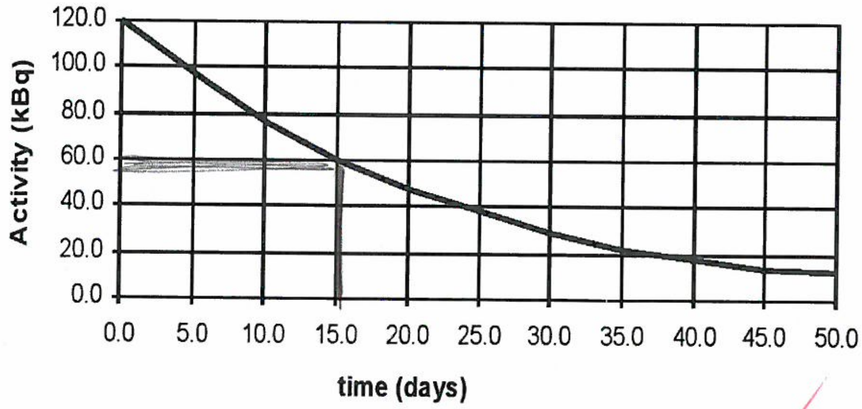
Average annual DEP due to background radiation is around 1-2 mSv

~~Many~~ ~ 50 mSv is not considered a problem (in workers working around nuclear energy)

~~So~~ No, no need to be concerned about 9 mSv.

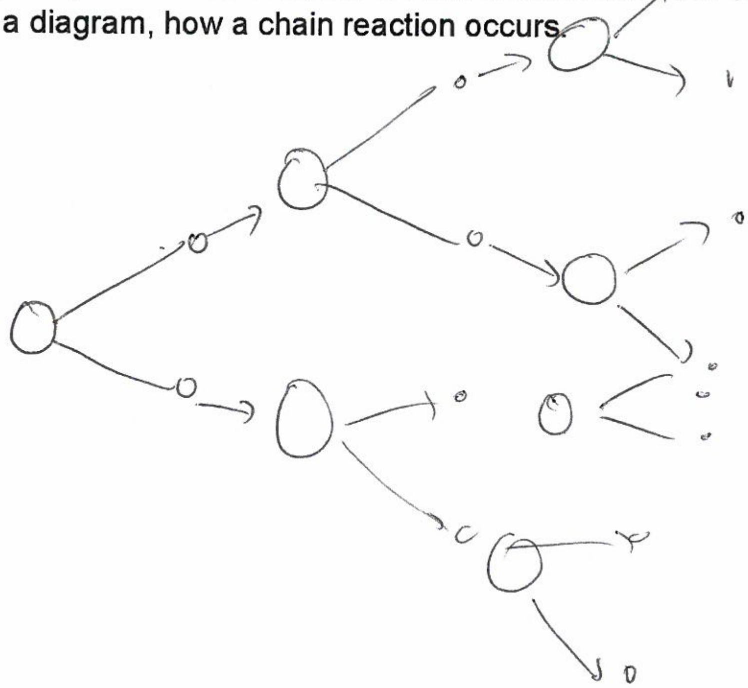
10. Determine the half-life of Dopsonium from the graph.

Radioactive decay of Dopsonium



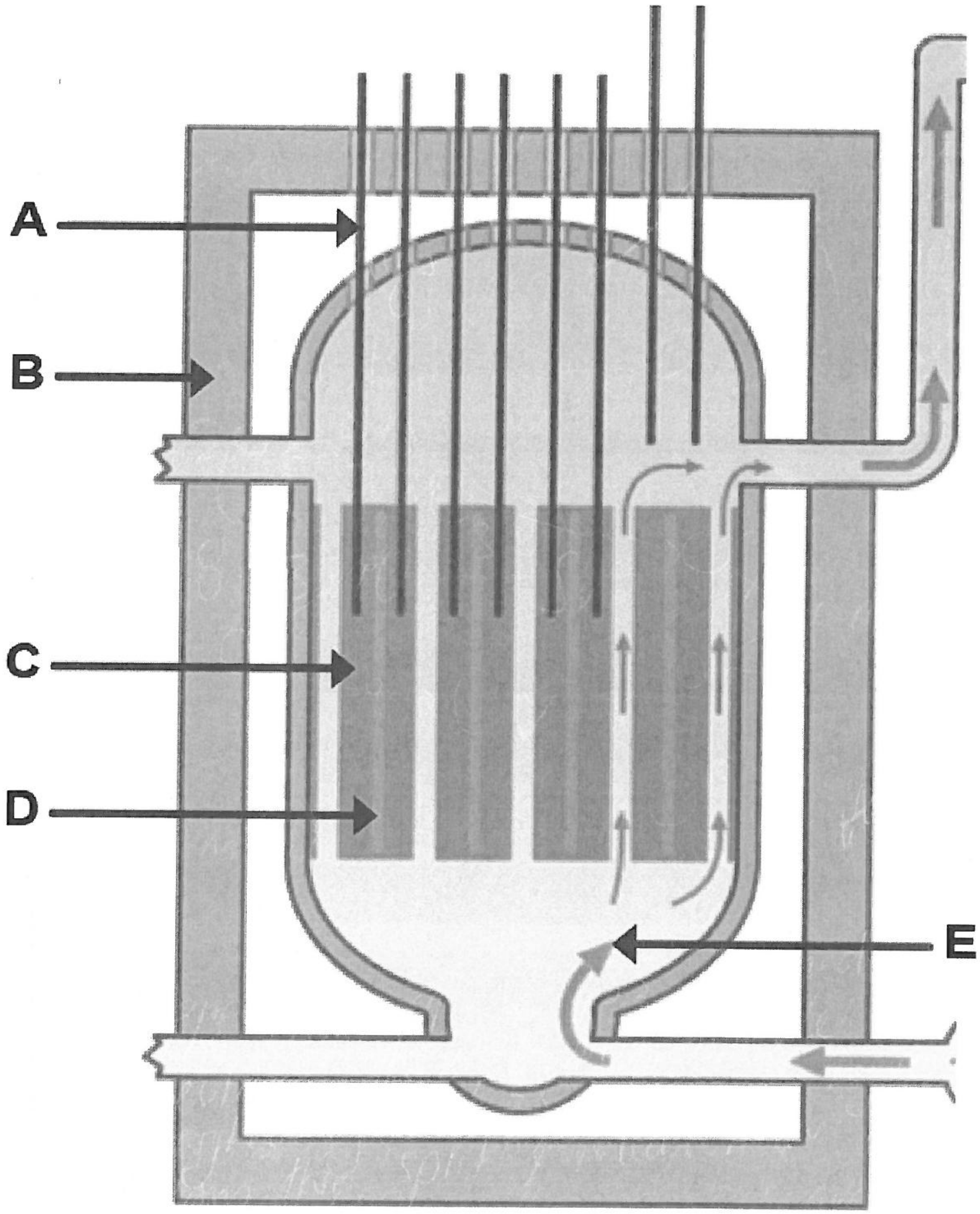
Half-life = 15 days (1 mark)

11. When U-235 undergoes fission it releases energy. If there are enough U-235 nuclei, the process will escalate to form a chain reaction. Describe, with the aid of a diagram, how a chain reaction occurs. (2 marks)



The fission of U-235 released 2-3 neutrons. These, in turn, induce fission in neighbouring U-235 atoms if they collide. These atoms then split & release more neutrons, and so on. The result is a cascading & geometrically increasing rate of reaction, unless it is controlled

12. The diagram below indicates the location of the key parts of a thermal nuclear reactor. Complete the table on the next page by describing the purpose of each component and its composition (*what it is made of*). (5 marks)



½ mark each

Letter Component Name	Purpose of this Component	Component Composition
A Control Rods	To absorb neutrons, slow reaction.	Boron steel Silver, cadmium alloys.
B Radiation Shielding	To protect surroundings from radiation	Concrete, Lead
C Moderator	To slow neutrons to keep reactions going (U-235 needs slow neutrons)	Carbon, water heavy water.
D Fuel Rods	To provide the fissile material used as 'fuel' (usually ~~...~~	enriched U-235 ore Plutonium U-238 in fast breeder
E Coolant	To transfer heat energy to generators for conversion to electricity	Water, CO_2, liquid metal