Test on Nuclear Physics

Examination Time - 40 minutes
Answer all questions in the spaces provided

This whole test involves an imaginary element called Bedlum which has the isotope notation shown below:

$$^{247}_{121}\mathrm{Bd}$$

1. **Bedlum** decays by alpha decay to another element, **tantrum**, Tt :

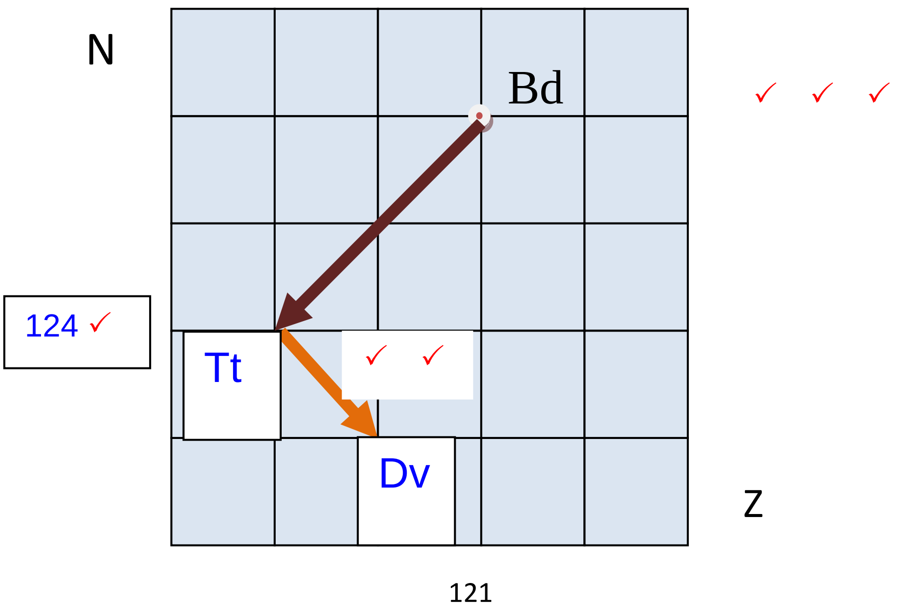
   a. Write a balanced equation in isotope notation to describe this decay. (2)

$$^{247}_{121}Bd \rightarrow ^{243}_{119}Tt + ^{4}_{2}He + Q$$ ✓ ✓

   b. Explain why alpha decay is the most likely decay for this element (2)

It's a very large nucleus ✓
Electrostatic force from all the protons will be stronger than strong force ✓

2. Show this decay on the graph of neutron number (N) against proton number (Z). (3)

3. 

In the box, write down the correct number of neutrons in a tantrum nucleus. (1)

4. Tantrum is unstable, and decays by beta minus decay to an isotope of drivelium, Dv.

   a. Write down a balanced equation for this in isotope notation. (2)

$^{243}_{119}Tt \rightarrow ^{243}_{120}Dv + ^{0}_{-1}e^{-} + \overline{\nu_e}$ ✓

   b. Show the decay from tantrum to drivelium on the graph. (2)

5. A sample of bedlum consists of 3 × 10^{11} atoms. It emits alpha particles and its activity is worked out to be 1 × 10^{8} Bq.

   a. Calculate the decay constant, λ. (2)

λ = ΔN/N = 1 × 10^{8} ÷ 3 × 10^{11} ✓
λ = **3.3 × 10^{-4} s^{-1}** ✓

   b. Calculate the half life of bedlum. (2)

$T_{½}$ = 0.693 ÷ 3.3 × 10^{-4} ✓
$T_{½}$ = **2080 s** ✓

   c. What is the activity of the bedlum sample after 40 minutes? (3)

lnA = ln(1.0 × 10^{8}) + -(3.3 × 10^{-4} × 2400) ✓ = 18.42 – 0.792 = 17.63 ✓
A = $e^{17.63}$ = **4.53 × 10^{7} Bq** ✓

6. Bedlum also emits gamma rays as it decays to tantrum.

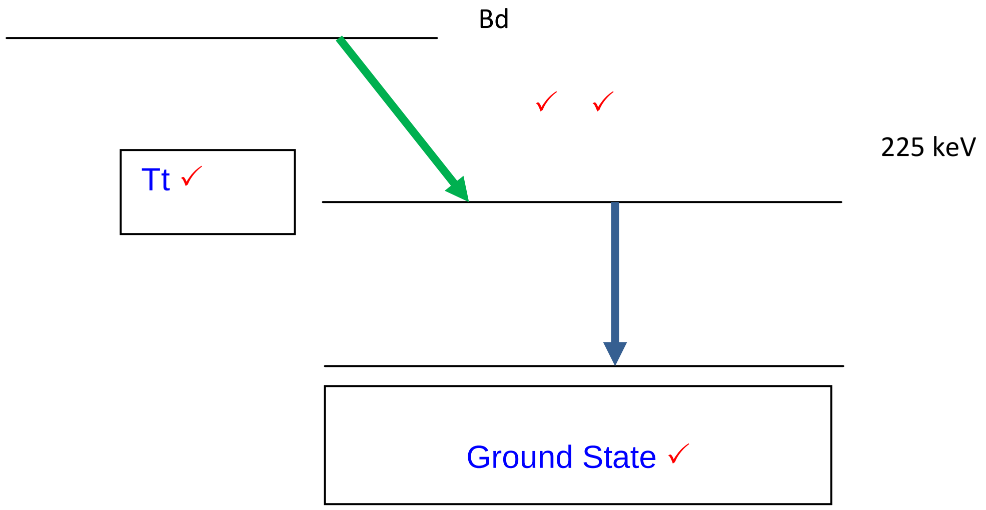
   a. What is a gamma ray? (1)

A photon of very short wavelength electromagnetic radiation ✓

   b. Explain how gamma rays are produced in the daughter nucleus. (2)

Nucleus is excited after a decay event. ✓
It loses energy by emitting a gamma photon. ✓

7. Complete the energy level diagram. (4)



8. Calculate the wavelength of the gamma ray produced. (3)

225 keV = 225000 × 1.6 × 10^{-19} = 3.6 × 10^{-14} J ✓
λ = hc/E = (6.63 × 10^{-34} × 3 × 10^{8}) ÷ 3.6 × 10^{-14} ✓
λ = **5.53 × 10^{-12} m** ✓

9. Drivelium decays to pandemonium (Pm) by another alpha decay. Pandemonium is a metastable nuclide. What is meant by the term metastable? (3)

Metastable refers to a nuclide that can remain excited ✓
for a long period of time. ✓
They release gamma photons randomly ✓

10. Pandemonium is used as a source of gamma. However it decays by an alpha decay to bolocsium (Bs).

a. How can a source of pure gamma be achieved? (1)

Put a sheet of paper over the source. ✓

b. A Geiger-Müller tube has a cross-sectional area of 1.5×10^{-4} m^2. When the source is in its box, the counter records a count rate of 35 counts per minute. It is then placed 10 cm from the pandemonium source. The counter shows a count rate of 1350 counts per minute.

i. Calculate the corrected count rate in Bq. (2)

Corrected rate = 1350 – 35 = 1315 min^{-1} ✓
A = 1315 ÷ 60 = **22 Bq** ✓

ii. Calculate the gamma activity of the pandemonium source. (3)

Work out the area of the sphere: $A = 4\pi r^2 = 4 \times \pi \times 0.1^2 = 0.126$ m^2 ✓
Total activity = $(0.126 \times 1315) \div 1.5 \times 10^{-4}$ ✓
A = 1.01×10^6 min^{-1} = **16800 Bq** ✓

c. The Geiger-Müller tube is now moved to a distance of 45 cm from the source. Calculate the number of counts per minute that is shown by the counter. (2)

The tube is 4.5 times further away, so count rate = $1315 \div 4.5^2$ = 65 min^{-1} ✓
Displayed count rate = 65 +35 = **100 min^{-1}** ✓

11. Alpha particles are fired at bedlum atoms that are in a thin foil in a vacuum:

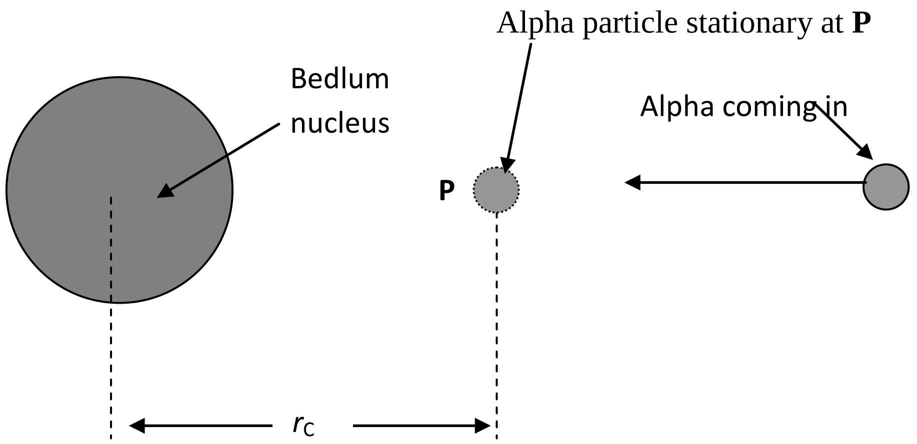
a. What is likely to happen to the alpha particles? (2)

Most will go straight through ✓
But a very small number will be deflected ✓

b. Why is the foil placed in a vacuum? (1)

Alpha is stopped by 1 cm air, or less energy lost by collisions ✓

12. The diagram shows an alpha particle at its closest point to the bedlum nucleus.



The kinetic energy of the alpha particles is initially 7.68 MeV.

c. Explain the energy changes that occur as the alpha particle approaches the nucleus. (2)

Kinetic energy is converted into potential energy. ✓
All the energy at P is potential. ✓

d. Calculate the speed of the alpha particle. (3)

Mass of alpha particle = 4 × 1.67 × 10^{-27} kg = 6.68 × 10^{-27} kg.
Energy = 7.68 × 10^{6} × 1.6 × 10^{-19} = 1.23 × 10^{-12} J ✓
v^2 = (2 × 1.23 × 10^{-12}) ÷ 6.68 × 10^{-27} kg = 3.68 × 10^{14} ✓
v = **1.9 × 10^{7} m s^{-1}** ✓

e. Show that the Rutherford radius is given by the equation:

$$r_c = \frac{Ze^2}{\pi\varepsilon_0 mv^2}$$

where Z is the proton number. (3)

Ek = Ep. ✓
$\frac{1}{2}mv^2 = \frac{1}{4\pi\varepsilon_0}\frac{2Ze^2}{r}$ ✓ $\Rightarrow r_c = \frac{1}{4\pi\varepsilon_0}\frac{4Ze^2}{mv^2}$ ✓ $\Rightarrow r_c = \frac{Ze^2}{\pi\varepsilon_0 mv^2}$

f. The mass of a nucleon = 1.67 × 10^{-27} kg. Calculate the radius of closest approach of an alpha particle to the bedlum nucleus. (2)

$r_c = \frac{121 \times (1.6 \times 10^{-19})^2}{\pi \times 8.85 \times 10^{-12} \times 6.68 \times 10^{-27} \times 3.68 \times 10^{14}}$ ✓
r_c = **4.5 × 10^{-14} m** ✓

13. Electron scattering gives a more reliable estimate of the size of the bedlum nucleus. Explain with reference to fundamental forces why electrons are used in preference to alpha particles. (3)

Alpha particles feel the strong nuclear force and the electromagnetic force. ✓
Strong nuclear force is not well understood. ✓
Electrons are leptons ✓
They only interact by the electromagnetic force. ✓

14. Electrons are

g. What is meant by the de Broglie wavelength? (2)

Moving particles can be shown to have wave properties ✓
de Broglie wavelength is inversely proportional to the momentum ✓

h. Show that $\lambda = \frac{h}{\sqrt{2meV}}$. (2)

E_k = eV, $\lambda = \frac{h}{mv}$ and $v^2 = \frac{2eV}{m} \Rightarrow v = \frac{h}{m\lambda} \Rightarrow v^2 = \frac{h^2}{m^2\lambda^2}$ ✓
$\frac{2eV}{m} = \frac{h^2}{m^2\lambda^2} \Rightarrow \lambda^2 = \frac{h^2}{2meV}$ ✓ $\Rightarrow \lambda = \frac{h}{\sqrt{2meV}}$

i. Calculate the de Broglie wavelength of electrons that are accelerated by a potential difference of 100 kV. (2)

$\lambda = \frac{6.63 \times 10^{-34}}{(2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times 100 \times 10^{3})^{1/2}}$ ✓
λ = **3.9×10^{-12} m** ✓

15. Calculate the nuclear radius of Bedlum

($r_0 = 1.4 \times 10^{-15}$ m) (2)

R = $1.4 \times 10^{-15} \times (247)^{1/3}$ ✓
R = **8.8×10^{-15} m** ✓

16. Explain whether the wavelength you worked out in 4(c) will resolve the bedlum nucleus. (2)

The wavelength of 3.9×10^{-12} m is too long to resolve the nucleus. ✓
The minimum size resolved by this wavelength is 4×10^{-12} m ✓
This is 450 times bigger than the Bd nucleus. ✓

17. The angle of the first minimum of the electron diffraction pattern is given by the equation:

$$\sin\theta = \frac{0.61\lambda}{R}$$

R is the nuclear radius and λ is the de Broglie wavelength.

An electron diffraction pattern for bedlum shows the angle of the first minimum is 30 degrees. Calculate the de Broglie wavelength of the electrons that are diffracted. Hence work out the accelerating potential difference. (4)

$\lambda = R \sin\theta/0.61 = (8.8 \times 10^{-15} \times 0.5) \div 0.61$ ✓
λ = **7.2×10^{-15} m** ✓
$V = \dfrac{h^2}{2me\lambda^2}$
V = $(6.63 \times 10^{-34})^2$ ✓
$2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times (7.2 \times 10^{-15})^2$
V = **2.9×10^{10} V** ✓

Total = 70 marks