TAP 512-3: Practice with nuclear equations

1 The isotope ^{235}U decays into another element, emitting an alpha particle. What is the element?

This element decays, and the next, and so on until a stable element is reached. The complete list of particles emitted in this chain is:

$^{235}_{92}\text{U} \rightarrow [\alpha, \beta, \alpha, \beta, \alpha, \alpha, \alpha, \alpha, \beta, \alpha, \beta] \rightarrow \text{X}$.

What is the stable element X? (You could write down each element in the series, but there is a quicker way.)

2 The following fission reaction can take place in a nuclear reactor:

$^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{137}_{55}\text{Cs} + {}^{95}_{[\ ]}\text{Rb} + [\ ]{}^{1}_{0}\text{n}$.

Complete the equation, showing how many neutrons are produced in the reaction. What is the significance of the number of neutrons produced?

Why are the products of the reaction, caesium-137 and rubidium-95, likely to be radioactive? What type of decay are these isotopes likely to show?

3 Boron absorbs neutrons with results as follows:

$^{10}_{5}\text{B} + {}^{1}_{0}\text{n} \rightarrow {}^{7}_{3}\text{Li} + {}^{4}_{2}\alpha$.

Why is boron suitable for use in a control rod?

4 When the isotope $^{27}_{13}\text{Al}$ is irradiated with alpha particles, the products from each aluminium nucleus are a neutron, and a nuclide that emits positrons to give the stable isotope $^{30}_{14}\text{Si}$. Write nuclear equations for these two processes.

5 Complete the following nuclear equations. In each case describe the decay process:

$^{131}_{53}\mathrm{I} \rightarrow \quad \mathrm{Xe} + \ ^{0}_{-1}\mathrm{e}$

$^{67}_{31}\mathrm{Ga} + \ ^{0}_{-1}\mathrm{e} \rightarrow \quad \mathrm{Zn}$

$^{11}_{6}\mathrm{C} \rightarrow \quad \mathrm{B} + \ ^{0}_{1}\mathrm{e}$

$^{99m}_{43}\mathrm{Tc} \rightarrow \quad \mathrm{Tc} + \gamma.$

6 The Manhattan Project, the development of the atomic bomb, led to the discovery of the transuranic elements (elements beyond uranium in the periodic table). Plutonium, element 94, is formed by the bombardment of uranium-238 with neutrons. The nuclear equations are:

$^{238}_{92}\mathrm{U} + \ ^{1}_{0}\mathrm{n} \rightarrow \ ^{239}_{92}\mathrm{U}$

$^{239}_{92}\mathrm{U} \rightarrow \ ^{239}_{93}\mathrm{Np} + \ ^{0}_{-1}\mathrm{e}$

$^{239}_{93}\mathrm{Np} \rightarrow \ ^{239}_{94}\mathrm{Pu} + \ ^{0}_{-1}\mathrm{e}$

Complete the following nuclear equation for the formation of americium:

$^{239}_{94}\mathrm{Pu} + 2\,^{1}_{0}\mathrm{n} \rightarrow \quad \mathrm{Am} + \ ^{0}_{-1}\mathrm{e}.$

Curium is produced if plutonium-239 is bombarded with alpha particles. If the curium isotope is $^{242}_{96}\mathrm{Cm}$, complete the equation

$^{239}_{94}\mathrm{Pu} + \ ^{4}_{2}\alpha \rightarrow$

If curium is made the target for alpha particle bombardment californium is produced. Complete the nuclear equation to find the atomic number of californium:

$^{242}_{96}\mathrm{Cm} + \ ^{4}_{2}\alpha \rightarrow \ ^{245}\mathrm{Cf} + \ ^{1}_{0}\mathrm{n}.$

By firing heavier particles such as carbon or boron ions at the target materials heavier elements can be synthesised. Complete the nuclear equation (Lw is lawrencium)

$^{252}\mathrm{Cf} + \ ^{9}_{5}\mathrm{B} \rightarrow \quad \mathrm{Lw} + 4\,^{1}_{0}\mathrm{n}.$

One of the transuranic elements is commonly found in the home. Which is this and where is it used?

Practical advice

These questions are intended for homework or practice in class.

Answers and worked solutions

1. The complete decay chain involves the loss of seven alpha particles ($^{4}_{2}\alpha$) and four beta particles ($^{0}_{-1}e$). This represents a loss of 7×4, i.e. 28, in mass number and $(7 \times 2 - 4)$, i.e. 10, in atomic number. X is therefore an isotope with mass number (235 – 28), i.e. 207, and atomic number (92 – 10), i.e. 82. This is lead, $^{208}_{82}Pb$.

2. $^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{137}_{55}Cs + {}^{95}_{37}Rb + 3{}^{1}_{0}n.$

   The reaction produces more neutrons than it absorbs, this will cause a 'chain reaction'. To see why the products of the reaction are likely to be radioactive you need to consult the plot of neutron number against atomic number for the known stable nuclei. For elements with atomic numbers up to about 30 the number of neutrons in the nucleus is the same as the number of protons if the nucleus is stable. For higher atomic numbers the ratio of neutrons to protons gradually increases to 1.5. Look at the position of both $^{137}_{55}Cs$ and $^{95}_{37}Rb$ on the plot and you will see that they both have a considerable excess of neutrons. They are therefore likely to be radioactive. To become more stable the nuclides need to decrease the neutron to proton ratio. The emission of a beta particle does this, increasing the number of protons by one and decreasing the number of neutrons by one. These isotopes are therefore likely to decay by emitting beta particles.

3. When boron captures a neutron it is transformed into a stable isotope. If the control rods are pushed into the reactor more neutrons are absorbed, causing the chain reaction to slow down. If they are pulled out the chain reaction will proceed more vigorously.

4.

$^{27}_{13}Al + {}^{4}_{2}\alpha = {}^{30}_{15}P + {}^{1}_{0}n$

$^{30}_{15}P = {}^{30}_{14}Si + {}^{0}_{1}e$

5.

$^{131}_{53}I \rightarrow {}^{131}_{54}Xe + {}^{0}_{-1}e$ beta decay $\quad {}^{67}_{31}Ga + {}^{0}_{-1}e \rightarrow {}^{67}_{30}Zn$ electron capture

$^{11}_{6}C \rightarrow {}^{11}_{5}B + {}^{0}_{1}e$ positron emission $\quad {}^{99m}_{43}Tc \rightarrow {}^{99}_{43}Tc$ nuclear rearrangement

6.

$^{239}_{94}Pu + 2{}^{1}_{0}n \rightarrow {}^{241}_{95}Am + {}^{0}_{-1}e$

$^{239}_{94}Pu + {}^{4}_{2}\alpha \rightarrow {}^{242}_{96}Cm + {}^{1}_{0}n$

$^{242}_{96}Cm + {}^{4}_{2}\alpha \rightarrow {}^{245}_{98}Cf + {}^{1}_{0}n$

$^{252}_{98}Cf + {}^{9}_{5}B \rightarrow {}^{257}_{103}Lw + 4{}^{1}_{0}n.$

Americium is commonly found in homes where it is used in smoke detectors.

External reference

This activity is taken from Advancing Physics chapter 18, 210S