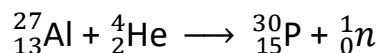


Nuclear Chemistry

Section 137 – Transmutation and nuclear energy

- 137-1 When atoms of aluminum-27 are bombarded with alpha particles, a neutron and an element are produced. Provide the balanced nuclear equation and indicate the element that is produced.

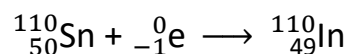
Solution:



The element produced is phosphorus-30.

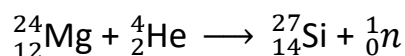
- 137-2 What does the decay of tin-110 by electron capture yield? Write the balanced nuclear equation.

Solution:



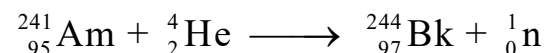
- 137-3 When atoms of magnesium-24 are bombarded with alpha particles, a neutron and an element are produced. What is the element? Write the balanced nuclear equation

Solution:



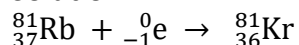
- 137-4 Write the balanced nuclear equation for the production of berkelium-244, made by the bombardment of Am-241 with alpha particles.

Solution



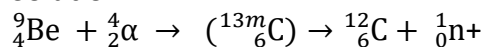
- 137-5 Write the balanced nuclear equation for electron capture by rubidium-81.

Solution:



- 137-6 When atoms of beryllium-9 are bombarded with alpha particles, neutrons are produced (one per beryllium-9 nucleus). What new isotope is also formed? Write the balanced nuclear equation.

Solution:



- 137-7 How does nuclear fission differ from nuclear fusion? Why are both of these processes exothermic?

Solution

Nuclear fission is the conversion of heavy nuclei into two or more lighter nuclei and other fragments. Fusion is the combination of two smaller nuclei into a heavier nucleus. In both cases, the mass of the products is less than the mass of the reactants and the mass lost is converted into energy—thus yielding an exothermic reaction.

- 137-8 Both fusion and fission are nuclear reactions. Why is a very high temperature required for fusion, but not for fission?

Solution

Two nuclei must collide for fusion to occur. High temperatures are required to give the nuclei enough kinetic energy to overcome the very strong repulsion resulting from their positive charges.

- 137-9 Cite the conditions necessary for a nuclear chain reaction to take place. Explain how it can be controlled to produce energy, but not produce an explosion.

Solution

The number of neutrons produced by fission must equal or exceed the number of neutrons absorbed by the nuclei that split plus the number lost to the surroundings. The amount of fissionable material must match or exceed the critical mass. Insertion of a neutron-absorbing material, called a *moderator*, which is encased in a metal tube, into the nuclear fuel can be used to control the reaction.

- 137-10 Describe the components of a nuclear reactor.

Solution

A nuclear reactor consists of the following:

1. A nuclear fuel. A fissionable isotope must be present in large enough quantities to sustain a controlled chain reaction. The radioactive isotope is contained in tubes called fuel rods.
2. A moderator. A moderator slows neutrons produced by nuclear reactions so that they can be absorbed by the fuel and cause additional nuclear reactions.
3. A coolant. The coolant carries heat from the fission reaction to an external boiler and turbine where it is transformed into electricity.

- A control system. The control system consists of control rods placed between fuel rods to absorb neutrons and is used to adjust the number of neutrons and keep the rate of the chain reaction at a safe level.
- A shield and containment system. The function of this component is to protect workers from radiation produced by the nuclear reactions and to withstand the high pressures resulting from high-temperature reactions.

137-11 In usual practice, both a moderator and control rods are necessary to operate a nuclear chain reaction safely for the purpose of energy production. Cite the function of each and explain why both are necessary.

Solution

A moderator slows down neutrons that travel too fast to cause fission. The neutrons must be slowed so that they will be absorbed by the fuel, such as U-235, and produce additional nuclear reactions. Moderators can consist of heavy water (D₂O), graphite, carbon dioxide, or ordinary water. Control rods absorb neutrons. Cadmium or boron-10 are often used to keep the rate of the chain reaction at a safe level by adjusting the number of neutrons that would otherwise strike the fuel rods, causing the production of still more neutrons.

137-12 Describe how the potential energy of uranium is converted into electrical energy in a nuclear power plant.

Solution

fission of uranium generates heat, which is carried to an external steam generator (boiler). The resulting steam turns a turbine that powers an electrical generator.

137-13 The mass of a hydrogen atom (${}^1_1\text{H}$) is 1.007825 amu; that of a tritium atom (${}^3_1\text{H}$) is 3.01605 amu; and that of an α particle is 4.00150 amu. How much energy in kilojoules per mole of ${}^4_2\text{He}$ produced is released by the following fusion reaction: ${}^1_1\text{H} + {}^3_1\text{H} \longrightarrow {}^4_2\text{He}$.

Solution

Calculate the mass change that occurs; then convert this mass to energy:

mass defect = mass ${}^1_1\text{H}$ + mass ${}^3_1\text{H}$ – mass ${}^4_2\text{He}$ = 1.007825 amu + 3.01605 amu – 4.00150 amu = 0.022375 amu. Convert atomic mass units to kilograms:

Mass defect = 0.022375 amu \times $1.6605 \times 10^{-27} \frac{\text{kg}}{\text{amu}}$ = 3.7154×10^{-29} kg

$E = mc^2 = (3.7154 \times 10^{-29} \text{ kg})(2.9979 \times 10^8 \text{ m/s})^2 = 3.339 \times 10^{-12} \text{ kg m}^2/\text{s}^2 = 3.339 \times 10^{-12} \text{ J/nucleus}$; on a per-mole basis:

$$\begin{aligned} E &= \frac{E}{\text{nucleus}} \times \frac{6.022 \times 10^{23}}{\text{mol}} = 3.339 \times 10^{-12} \text{ J/nucleus} \times 6.022 \times 10^{23} \frac{\text{nuclei}}{\text{mol}} \\ &= 2.011 \times 10^{12} \text{ J mol}^{-1} \\ &= 2.011 \times 10^9 \text{ kJ mol}^{-1} \end{aligned}$$