Nuclear Chemistry R and R Worksheet
7/31/24

1) Rank the three types of natural radiation (α, β, γ):

a) In order of increasing mass

γ < β < α

b) In order of increasing penetrating power

α < β < γ

2) The uranium-235 radioactive decay series, beginning with $^{235}_{92}U$ and ending with $^{207}_{82}Pb$, occurs in the following sequence: α, β, α, β, α, α, α, α, β, β, α. Write an equation for each step in this series.

$$^{235}_{92}\mathrm{U} \longrightarrow {}^{231}_{90}\mathrm{Th} + {}^{4}_{2}\alpha$$
$$^{231}_{90}\mathrm{Th} \longrightarrow {}^{231}_{91}\mathrm{Pa} + {}^{0}_{-1}\beta$$
$$^{231}_{91}\mathrm{Pa} \longrightarrow {}^{227}_{89}\mathrm{Ac} + {}^{4}_{2}\alpha$$
$$^{227}_{89}\mathrm{Ac} \longrightarrow {}^{227}_{90}\mathrm{Th} + {}^{0}_{-1}\beta$$
$$^{227}_{90}\mathrm{Th} \longrightarrow {}^{223}_{88}\mathrm{Ra} + {}^{4}_{2}\alpha$$
$$^{223}_{88}\mathrm{Ra} \longrightarrow {}^{219}_{86}\mathrm{Rn} + {}^{4}_{2}\alpha$$
$$^{219}_{86}\mathrm{Rn} \longrightarrow {}^{215}_{84}\mathrm{Po} + {}^{4}_{2}\alpha$$
$$^{215}_{84}\mathrm{Po} \longrightarrow {}^{211}_{82}\mathrm{Pb} + {}^{4}_{2}\alpha$$
$$^{211}_{82}\mathrm{Pb} \longrightarrow {}^{211}_{83}\mathrm{Bi} + {}^{0}_{-1}\beta$$
$$^{211}_{83}\mathrm{Bi} \longrightarrow {}^{211}_{84}\mathrm{Po} + {}^{0}_{-1}\beta$$
$$^{211}_{84}\mathrm{Po} \longrightarrow {}^{207}_{82}\mathrm{Pb} + {}^{4}_{2}\alpha$$

3)

a) Oppenheimer said "theory will only take you so far," but how far can you take theory? Barium-141 and another element with a mass number of 92 are formed when uranium-235 captures a neutron. Write a balanced equation for this nuclear fission reaction, which is the same process that took place in Oppenheimer's bomb.

$$^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3\ {}^{1}_{0}n$$

b) Despite his work on the uranium bomb, Oppenheimer was opposed to the hydrogen bomb, which involves a nuclear fusion reaction often consisting of deuterium and tritium producing helium-4. Write a balanced equation for this reaction.

$$^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + {}^{1}_{0}n$$

4) Copper (II) acetate containing ^{64}Cu is used to study brain tumors. This isotope has a half-life of 12.7 hours. If you begin with 25.0 µg of ^{64}Cu, what mass remains after 63.5 hours?

63.5 / 12.7 = 5

5 half-lives occur

Mass Remaining = 25 µg * (1 / 2^5) = 0.781 µg

5) To test the concept of carbon-14 dating, J. R. Arnold and W. F. Libby applied this technique to analyze samples of acacia and cyprus wood whose ages were already known. (The acacia wood, which was supplied by the Metropolitan Museum of Art in New York, came from the tomb of Zoser, the first Egyptian pharaoh to be entombed in a pyramid. The cyprus wood was from the tomb of Sneferu.) The average activity based on five determinations on one of these wood samples was 7.04 dpm per gram of carbon. Assume (as Arnold and Libby did) that the original activity of carbon-14, A_0, was 12.6 dpm per gram of carbon. The half-life of carbon-14 is 5.73 × 10^3 years. Calculate the approximate age of the sample.

$$k = 0.693/t_{1/2} = 0.693/5730\ \text{yr}$$

$$= 1.209 \times 10^{-4}\ \text{yr}^{-1}$$

$$\ln(A/A_0) = -kt$$

$$\ln\left(\frac{7.04\ \text{dpm/g}}{12.6\ \text{dpm/g}}\right) = (-1.209 \times 10^{-4}\ \text{yr}^{-1})t$$

$$t = 4.81 \times 10^3\ \text{yr}$$

The wood is about 4800 years old.

6) Identify probable mode(s) of decay for each isotope and write an equation for the decay process.

a) oxygen-15

b) uranium-234

c) fluorine-20

d) manganese-56

(a) Oxygen-15 has 7 neutrons and 8 protons, so the neutron-to-proton (n/p) ratio is less than 1—too low for ^{15}O to be stable. Nuclei with too few neutrons are expected to decay by either positron emission or electron capture. In this instance, the process is $^{0}_{+1}\beta$ or positron emission.

$$^{15}_{8}O \longrightarrow {}^{0}_{+1}\beta + {}^{15}_{7}N.$$

(b) Alpha emission is a common mode of decay for isotopes of elements with atomic numbers higher than 83. The decay of uranium-234 is one example:

$$^{234}_{92}U \longrightarrow {}^{230}_{90}Th + {}^{4}_{2}\alpha$$

(c) Fluorine-20 has 11 neutrons and 9 protons, a high n/p ratio. The ratio is lowered by β emission:

$$^{20}_{9}F \longrightarrow {}^{0}_{-1}\beta + {}^{20}_{10}Ne$$

(d) The mass number of ^{56}Mn is higher than the atomic weight of the element (54.85). This suggests that this radioactive isotope has an excess of neutrons (giving a high n/p ratio), in which case it would be expected to decay by β emission:

$$^{56}_{25}Mn \longrightarrow {}^{0}_{-1}\beta + {}^{56}_{26}Fe$$