Chapter 21

Nuclear Chemistry

Concept Check 21.1

You have two samples of water each made up of different isotopes of hydrogen: one contains $^{1}_{1}H_2O$ and the other, $^{3}_{1}H_2O$.

a. Would you expect these two water samples to be chemically similar?
b. Would you expect these two samples to be physically the same?
c. Which one of these water samples would you expect to be radioactive?

Solution

a. Yes. Isotopes have similar chemical properties.
b. No, since the $^{3}_{1}H_2O$ molecule is more massive than $^{1}_{1}H_2O$.
c. $^{3}_{1}H_2O$ should be radioactive.

Concept Check 21.2

Say you are internally exposed to 10 rads of α, β, and γ radiation. Which form of radiation will cause the greatest biological damage?

Solution

For the same radiation dosage (10 rads) the form of radiation with the highest RBE will cause the greatest biological damage. Therefore, the α particle will cause the most damage, since it has the highest RBE (10).

Concept Check 21.3

Why do you think that carbon-14 dating is limited to about 50,000 years?

Solution

After 50,000 years, enough half-lives have passed (about 10) so there would be almost no carbon-14 present to detect and measure (about 0.1% would be left).

Conceptual Problem 21.19

When considering the lifetime of a radioactive species, a general rule of thumb is that after 10 half-lives have passed, the amount of radioactive material left in the sample is negligible. The disposal of some radioactive materials is based on this rule.

a. What percentage of the original material is left after 10 half-lives?
b. When would it be a bad idea to apply this rule?

Solution

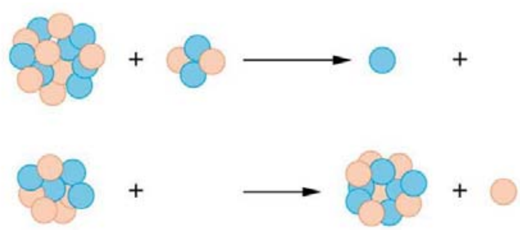
a. After 10 half-lives have passed, the percentage of the original material that is left is

$$\left(\frac{1}{2}\right)^{10} \text{ x } 100\% = 0.0976 \cong 0.1\%.$$

b. If you had a large quantity of material, 0.1% still would be a significant quantity. Also, if the material were particularly toxic in addition to being radioactive, even small amounts would be a problem.

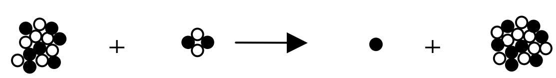
Conceptual Problem 21.20

Use drawings to complete the following nuclear reactions (orange circles represent neutrons and blue circles represent protons). Once you have completed the drawings, write the nuclide symbols under each reaction.

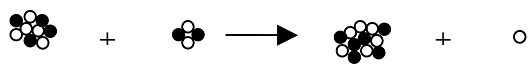


Solution

In the following drawings, a white ball represents a neutron, and a black ball represents a proton.



$$^{14}_{7}N + ^{4}_{2}He \rightarrow ^{1}_{1}p + ^{17}_{8}O$$



$$^{9}_{4}Be + ^{4}_{2}He \rightarrow ^{12}_{6}C + ^{1}_{0}n$$

Conceptual Problem 21.21

Sodium has only one naturally occurring isotope, sodium-23. Using the data presented in Table 21.3, explain how the molecular weight of sodium is 22.98976 amu and not the sum of the masses of the protons, neutrons, and electrons.

Solution

An atom of sodium-23 has 11 protons, 12 neutrons, and 11 electrons. Using the values in Table 21.3, the atomic mass of sodium-23 would be

(11)(1.00728 amu) + (12)(1.008665 amu) + (11)(0.000549 amu) = $23.1900\underline{9}9$ amu.

Since the observed atomic weight is 22.98976 amu, it is not the same as the sum of the masses of the protons, neutrons, and electrons. Some of the expected mass is in the form of energy: the mass defect.

Conceptual Problem 21.22

Identify the following reactions as fission, fusion, or a transmutation, or radioactive decay.

a. $4\,^{1}_{1}H \rightarrow ^{4}_{2}He + 2\,^{0}_{1}e$

b. $^{14}_{6}C \rightarrow ^{14}_{7}N + ^{0}_{-1}e$

c. $^{1}_{0}n + ^{235}_{92}U \rightarrow ^{140}_{56}Ba + ^{93}_{36}Kr + 3\,^{0}_{1}e$

d. $^{14}_{7}N + ^{4}_{2}He \rightarrow ^{17}_{8}O + ^{1}_{1}H$

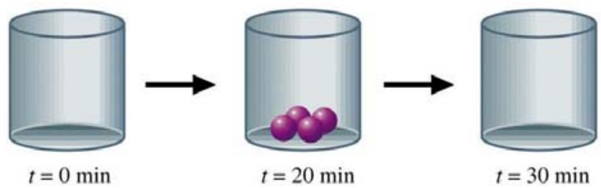
Solution

a. fusion
b. radioactive decay
c. fission
d. transmutation

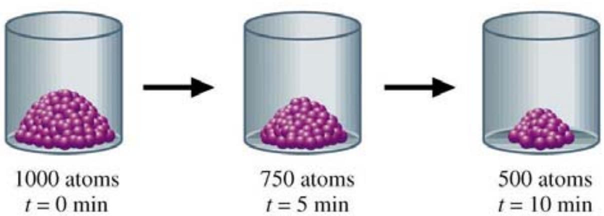
Conceptual Problem 21.23

A radioactive sample with a half-life of 10 minutes is placed in a container.

a. Complete the pictures below depicting the amount of this sample at the beginning of the experiment (t=0) and 30 minutes into the experiment (t=30). Each sphere represents one radioactive nuclide of the sample.



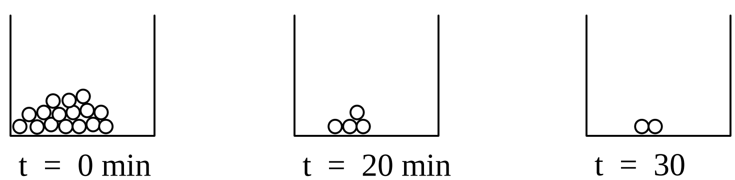
b. A friend working with 1000 atoms of the same nuclide represents the amount of nuclide at three time intervals in the following manner.



Is his drawing correct? If not, explain where and why it is incorrect.

Solution

a. The container in the middle is depicted after 20 minutes have passed. This is equivalent to two half-lives ($t_{1/2}$ = 10 min). At this time, one-quarter of the original material remains present. Since there are four nuclides after 20 minutes, the original sample (t = 0) must have consisted of 16 nuclides. After 30 minutes have passed (three half-lives), one-eighth of the original material, or two nuclides, would be present. The pictures are



b. The middle picture is not correct. The pile on the right (t = 10 min) containing 500 nuclides is one-half the original 1000 nuclides, so the half-life of the material is ten minutes. The pile in the middle (t = 5 min) contains 750 nuclides, which represents one-quarter of the original material reacted. This is 1/2 x 1/2, which is not the correct way to determine the number of remaining nuclides. Instead, it is $(1/2)^{1/2}$, or 0.707. Thus, there should be 707 nuclides remaining after five min.

Conceptual Problem 21.24

You have a mixture that contains 10 g of Pu-239 with a half-life of 2.4×10^4 years and 10 g of Np-239 with a half-life of 2.4 days. Estimate how much time must elapse before the quantity of radioactive material is reduced by 50%.

Solution

The total amount of radioactive material at the start is 10 g Pu-239 + 10 g Np-239 = 20 g total. In order to reduce this by 50%, the total mass must be reduced to 10 g. Since the half-life of Pu-239 (2.4×10^4 years) is long compared to the half-life of Np-239 (2.4 days), all of the Np-239 will have decomposed before any measurable amount of Pu-239 decays. This would require approximately 10 half-lives, or about 24 days.

Conceptual Problem 21.25

Come up with an explanation as to why α radiation is easily blocked by materials such as a piece of wood, where γ radiation easily passes through.

Solution

The large, positively charged He nucleus that makes up alpha (α) radiation is unable to pass through the atoms that make up solid materials such as wood without coming into contact or being deflected by the nuclei. Gamma (γ) radiation, however, with its small wavelength and high energy, can pass through large amounts of material without interaction, just like x-rays can pass through skin and other soft tissue.

Conceptual Problem 21.26

You have an acquaintance who tells you that he is going to reduce his radiation exposure to zero. What examples could you present that would illustrate that this is an impossible goal.

Solution

Examples of elements and compounds that would be impossible to avoid include: radioactive ^{40}K that is in bananas and any food that contains potassium, H_2O that contains $^{3}_{1}H$, CO_2 that contains carbon-14, and radon gas that comes from soil and rocks.

Conceptual Problem 21.27

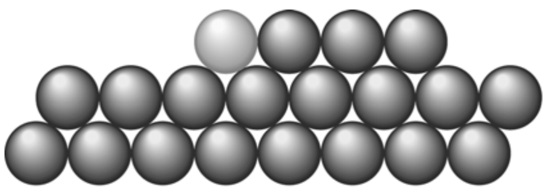
In Chapter 7 (*A Chemist Looks At: Zapping Hamburger with Gamma Rays*) there is a discussion of how gamma radiation is used to kill bacteria in food. As indicated in the feature, there is concern on the part of some people that the irradiated food is radioactive. Why is this not the case? If you wanted to make the food radioactive, what would you have to do?

Solution

Irradiation of food atoms with gamma radiation does not result in the creation of radioactive elements; therefore, the food cannot become radioactive. The addition of a radioactive element directly to the meat would make the meat radioactive. Under the right conditions, nuclear bombardment could also lead to the production of radioactive elements.

Conceptual Problem 21.28

You have a pile of I-131 atoms with a half-life of 8 days. A portion of the solid I-131 is represented below. Can you predict how many half-lives will occur before the lighter colored (green in text) I-131 atom undergoes decay?



Solution

No, half-life can only tell you the quantity of material that will undergo decay, not the identity of the individual atoms.