



## Nuclear Chemistry

Nuclear chemistry deals with the chemistry of the nucleus of an atom. The key property discussed in nuclear chemistry is **radioactivity**, the spontaneous emission of particles or rays from the nucleus of an atom. If an element has this property, it's **radioactive**.

In nuclear chemistry, we use isotopic notation frequently:

$${}^A_Z X, \text{ where } A = \text{the mass number (sum of protons and neutrons)}$$

$$Z = \text{atomic number (number of protons)}$$

$$X = \text{Symbol of element or particle}$$

So  ${}^{14}_6\text{C}$  is an isotope of carbon used in dating of archeological artifacts that contains 8 neutrons and 6 protons. We can also express this isotope as “carbon-14” or “C-14” (element symbol followed by mass number).

Two new terms are **nucleons** and **nuclide**. Nucleons are how we refer to protons and neutrons as a group. **Nuclide** is similar to isotope (atoms of the same element with different masses) but broader in definition—it includes ANY isotope of ANY atom.

### PARTICLES INVOLVED IN NUCLEAR REACTIONS

The three principal emissions from the nuclei of radioactive elements are alpha particles, beta particles, and gamma rays. There are also other particles that show up in nuclear reactions like neutrons and protons. It is important to know the mass number, charge, and symbol for all of these.

PARTICLE	MASS NUMBER	CHARGE (Atomic Number)	SYMBOL
alpha particle	4	2+	${}^4_2\text{He}$ or $\alpha$
beta particle	0	1-	${}^0_{-1}\text{e}$ or $\beta$
gamma ray	0	0	${}^0_0\gamma$ or $\gamma$
neutron	1	0	${}^1_0\text{n}$
proton	1	1+	${}^1_1\text{H}$ or ${}^1_1\text{p}$

Alpha particles are the same as the nucleus of a helium atom since they have 2 protons and 2 neutrons. We can use the symbol alpha,  $\alpha$ , or He.

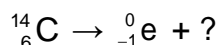
Beta particles are identical to an electron, which is why they have a mass number of zero (no protons or neutrons) and an atomic number (charge) of  $-1$ . The symbol is beta,  $\beta$ , or e for electron.

Gamma rays are a type of electromagnetic radiation (like light waves) that have no mass and no charge. We use the symbol gamma,  $\gamma$ .



## RADIOACTIVE DECAY

When radioactive elements undergo **radioactive decay**, they form different elements. When a nuclide loses an alpha or beta particle, the atomic number of the nuclide changes. This means a *new* element results. We call these processes **decays** or **emissions**. We can write a nuclear equation showing the process. For example, carbon-14 undergoes beta decay:



Carbon-14 is our reactant and goes on the left side. Beta decay means a beta particle is produced (product side). How do we find the other product of the decay?

**In balancing nuclear equations, both the total of the atomic numbers (the subscripts) and the total of the mass numbers (the superscripts) must be balanced on both sides.** The 14 in the superscript on the left-hand side must equal the sum of the superscripts on the right-hand side. The beta particle has a mass number of 0, so the mass number of the other product is 14.

The 6 in the subscript on the left-hand side must equal the sum of the subscripts on the right-hand side.  $? - 1 = 6$ ,  $? = 7$  so the atomic number of our other product is 7. We look up the atomic number in the periodic table to find out what element the missing nuclide is. The element with an atomic number of 7 is nitrogen. The missing nuclide is nitrogen-14:  ${}^{14}_7\text{N}$ .

## HALF-LIFE

The **half-life** of a radioactive isotope tells us how quickly it decays. Every isotope has its own unique half-life, expressed in units of time. The half-life is the time it takes for exactly one half of the original amount of the radioactive element to decay no matter how much there was to start with. We use the symbol  $t_{1/2}$  for half-life.

For instance, say we have 10.0 g of carbon-14, which has a half-life of 5,730 years. After exactly 5,730 years, 5.00 g of C-14 will have decayed (to nitrogen) and 5.00 g of C-14 will remain. After another 5,730 years, 2.50 g more of the C-14 will have decayed and 2.50 g of C-14 will remain, and so on. This is an exponential decay process.

*Example 1:* Iodine-131 has a half-life of 8 days. If the original sample of I-131 was 8.00 g, how much remains after 24 days?

*Solution:* The time period in question is 24 days, but more importantly we need to know how many half-lives have passed.  $24 \text{ days} \div 8 \text{ days} = 3$  half-lives. If three half-lives have passed, then the sample has decayed by 50% three times. The formula for half-life calculations is:

$$\text{Amount remaining} = \text{original amount} \times (1/2)^n$$

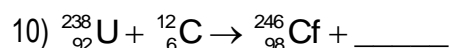
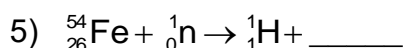
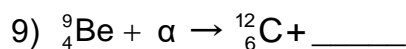
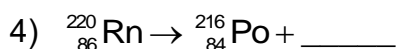
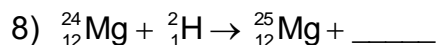
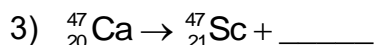
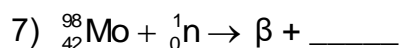
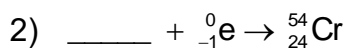
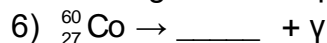
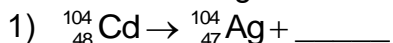
where  $n$  is the number of half-lives that have passed (not the half-life itself!) Here,  $n = 3$ , (not 8 days), so we're essentially multiplying the original amount by  $1/2$ , three times over.

$$8.00 \text{ g} \times (1/2)^3 = 8.00 \times 1/2 \times 1/2 \times 1/2 = 1.00 \text{ g} \quad \leftarrow \text{amount of I-131 remaining.}$$

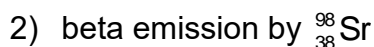
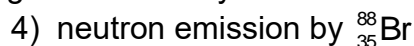


## EXERCISES

A. Fill in the missing nucleus or particle in the following nuclear equations:



B. Write balanced equations for the following nuclear decay reactions:



C. Lead-214 decays to bismuth-214. What type of radiation results?

D. When uranium-235 absorbs a neutron (so that the neutron appears on the reactant side of the equation with U-235), it produces an unstable isotope of uranium.

(a) Write the equation for the above process.

(b) The product of the above equation undergoes fission and produces strontium-90, three neutrons, and one other product. Write the equation including the missing product.

E. Potassium-42 has a half-life of 12.5 hours. If the original amount is 22.4 mg, how much remains after 100 hours? What fraction is the remainder of the original amount?

F. How much of a sample of barium-141 ( $t_{1/2} = 18$  minutes) was present originally if after 90 minutes 0.250 g remains?

G. A skull was found buried in a cave. When tested, its carbon-14 content was found to be 12.5% of the carbon-14 content in a recent skull sample. How old is the skull? (Remember the half-life of C-14 is 5,730 years).



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## SOLUTIONS

A. (1)  ${}^0_1\text{e}$  (2)  ${}^{54}_{25}\text{Mn}$  (3)  ${}^0_{-1}\text{e}$  or  $\beta$  (4)  ${}^4_2\text{He}$  or  $\alpha$  (5)  ${}^{54}_{25}\text{Mn}$  (6)  ${}^{60}_{27}\text{Co}$  (7)  ${}^{99}_{43}\text{Tc}$   
(8)  ${}^1_1\text{H}$  or  ${}^1_1\text{p}$  (9)  ${}^1_0\text{n}$  (10)  $4\ {}^1_0\text{n}$

B. (1)  ${}^{11}_5\text{B} \rightarrow {}^4_2\text{He} + {}^7_3\text{Li}$  (2)  ${}^{98}_{38}\text{Sr} \rightarrow {}^0_{-1}\text{e} + {}^{98}_{39}\text{Y}$  (3)  ${}^{107}_{47}\text{Ag} + {}^1_0\text{n} \rightarrow {}^{108}_{47}\text{Ag}$   
(4)  ${}^{88}_{35}\text{Br} \rightarrow {}^1_0\text{n} + {}^{87}_{35}\text{Br}$  (5)  ${}^{41}_{19}\text{K} \rightarrow {}^1_1\text{p} + {}^{40}_{18}\text{Ar}$  (6)  ${}^{131}_{53}\text{I} \rightarrow {}^0_{-1}\text{e} + {}^{131}_{54}\text{Xe}$

C. beta radiation D. (a)  ${}^{235}_{92}\text{U} + {}^1_0\text{n} \rightarrow {}^{236}_{92}\text{U}$  (b)  ${}^{236}_{92}\text{U} \rightarrow {}^{90}_{38}\text{Sr} + 3\ {}^1_0\text{n} + {}^{143}_{54}\text{Xe}$

E. 0.0875 mg,  $\frac{1}{256}$  of the original amount remains

F. 8.00 g Ba-141

G. 17,190 yrs old

