(After teaching the alpha-particle symbol, we do this)

Balancing Nuclear Reactions

Nuclear reactions do not balance in the same manner as chemical reactions, but they balance relatively easily. The rule is:

> In nuclear reactions, mass numbers and nuclear charge must be conserved.
>
> In a balanced *nuclear* reaction, on both sides of the arrow,
>
> - The *sum* of the *mass numbers* (A, on top) must be the same, and
> - The sum of the *nuclear charge*s (Z, on the bottom) must be the same.

The result is that nuclear reaction equations can be balanced by simple addition and subtraction.

Example: In the alpha decay of U-238, the mass numbers on both sides of the reaction equation total 238 and the nuclear charges total 92.

$$^{238}_{92}\text{U} \xrightarrow{\alpha} {}^{234}_{90}\text{Th} + {}^{4}_{2}\text{He}$$

Apply the nuclear balancing rule to this problem.

Q. Use the nuclear balancing rule to write below the symbol for the nucleus remaining after the alpha decay of plutonium-242.

$$^{242}_{94}\text{Pu} \xrightarrow{\alpha} \underline{\qquad\qquad} + {}^{4}_{2}\text{He}$$

* * * * * * (the * * * mean cover below, finish above, then check below)

The nuclear charges on the bottom must total 94 on both sides. The nuclear charge on the missing particle must be 92, which means the atom is uranium. The mass numbers on top add up to 242 on both sides, so the mass number of the missing nucleus must be 238. The balanced nuclear reaction is:

$$^{242}_{94}\text{Pu} \xrightarrow{\alpha} {}^{238}_{92}\text{U} + {}^{4}_{2}\text{He}$$

Try one more.

Q. Which isotope is produced by the alpha decay of radium-226?

* * * * *

A key to balancing nuclear reactions is to write the isotope symbols in A-Z notation. Start there for Ra-226.

* * * * *

Radium by definition has a nucleus with 88 protons, so this reaction begins

$$^{226}_{88}\text{Ra} \xrightarrow{\alpha}$$

Fill in the missing symbols.

* * * * *

In alpha decay, one product is always an alpha particle. Add its symbol on the right.

* * * * *

$$^{226}_{88}\text{Ra} \xrightarrow{\alpha} {}^{4}_{2}\text{He} \quad +$$

Use the balancing rule to write the isotopic formula for the remaining particle: the nucleus left behind after the alpha particle is expelled.

* * * * *

$$^{226}_{88}\text{Ra} \xrightarrow{\alpha} {}^{4}_{2}\text{He} \quad + \quad {}^{222}_{86}\text{Rn}$$

After the decay, the nucleus has 86 protons, so it must be radon (Rn). For the mass numbers to balance, the Rn nucleus must have a mass number of 222.

Practice 39.2.A

1. Write a balanced equation for the alpha decay of radon-219.
2. How many protons and how many neutrons are in ^{219}Rn??
3. How many protons and how many neutrons are in the nucleus left behind after the alpha decay of radon-219? How many protons and neutrons are lost in the decay?
4. Lead-206 can be formed by the alpha decay of which radioactive isotope?

(Here is an example from a later lesson in Nuclear Chemistry):

To solve decay calculations, we need equations that relate the fraction remaining, half-life, time, and rate constant. Several combinations of the equations above can be used, but the best equations are those that are easy to remember. In these lessons, we will follow this rule.

Radioactive Decay Prompt

If a *radioactive decay* or any first-order rate calculation includes *half-life* and *fraction* or *percentage* of a sample, and the answer cannot be calculated using simple multiples, write in the DATA:

$$\textbf{ln}(\text{fraction } \textit{remaining}) = -kt \quad \text{and} \quad \ln(\mathbf{1/2}) = -k\, t_{1/2}$$

and use the math of natural logs to solve.

Note that the second equation is simply a special case of the first: when the fraction remaining is 1/2, the time is equal to the half-life.

When using the radioactive decay prompt, we solve for the common variable ***k***.

- First solve the equation that can be solved for ***k*** given the data provided, then
- Use that ***k*** to solve for the variable WANTED.

Commit the radioactive decay prompt to memory, then apply it to solve this problem.

Q. Iodine-131, the radioactive isotope used to treat thyroid disorders, has a half-life of 8.1 days. What percentage of an initial [I-131] remains after 48 hours?

* * * * *

WANT: Percent $[\text{I-131}]_{48\ \text{hrs.}}$ = % remaining

DATA: 8.1 **days** = radioactive half-life = $t_{1/2}$

48 hours = 2.0 **days** = t (choose a *consistent* time unit)

Strategy: Write the equations that relate the symbols in the problem.

For radioactive decay calculations that include half-life and fraction or *percentage*, write and use

$\ln(\text{fraction } remaining) = -kt$ and $\ln(1/2) = -k\,t_{1/2}$

Percentage remaining = fraction remaining x 100%

If needed, adjust your work and solve from here.

* * * * *

The variable that links the prompt equations is k

Since we know the half-life, the second equation will find k

Knowing k and t, the first prompt equation will find **ln**(fraction remaining**)**.

Knowing **ln**(fraction remaining), the fraction remaining can be found using

Fraction = $e^{\ln(\text{fraction})}$ and Percentage = Fraction x 100%

Apply those steps and solve.

* * * * *

$$k = \frac{-\ln(1/2)}{t_{1/2}} = \frac{-(-0.693)}{t_{1/2}} = \frac{+0.693}{8.1\text{ days}} = \mathbf{0.0856\ day^{-1}}$$

$$\ln(\text{fraction remaining}) = -kt = -(0.0856\text{ day}^{-1})(2.0\text{ days}) = \mathbf{-0.171}$$

Fraction = $e^{\ln(\text{fraction})} = e^{-0.171}$ = 0.843 = **84 %** of I-131 *remains* after 2.0 days

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Practice 39.5.B: Add the equations of the decay prompt to your flashcards and practice the cards for this module, then try the problems below. Save one problem for your next practice session.

1. The rate constant for the decay of the tritium isotope of hydrogen is 0.0562 years^{-1}. Calculate the half-life of tritium.

2. Strontium-90 is a radioactive nuclide found in **fallout**: dust particles in the cloud produced by the atmospheric testing of nuclear weapons. In chemical and biological systems, strontium behaves much like calcium. If dairy cattle consume crops exposed to dust or rain containing fallout, dairy products containing calcium will also contain

^{90}Sr. Similar to calcium, ^{90}Sr will be deposited in the bones of dairy product consumers, including children. In part for this reason, most (but not all) nations conducting nuclear tests signed a 1963 treaty which banned atmospheric testing.

Strontium-90 undergoes beta decay with a half-life of 28.8 years. What percentage of an original [^{90}Sr] in bones will remain after 40.0 years?

a. Estimate the answer. b. Calculate the answer.

c. Write the equation for the beta decay of strontium-90.

3. The element Polonium was first isolated by Dr. Marie Sklodowska Curie and named for her native Poland. Radioactive ^{210}Po is found in significant concentrations in tobacco. If 20.0% of ^{210}Po remains in a sample after 321 days of alpha decay,

   a. Estimate the half-life of ^{210}Po.

   b. Calculate a precise half-life of ^{210}Po. Compare it to your *part a* estimate.

4. In a sample of radon-222, 10.0% remains after 12.6 days of alpha decay.

   a. What is the composition of the radon-222 nucleus?

   b. Write the decay reaction.

   c. Estimate the half-life for ^{222}Rn.

   d. Calculate a precise half-life of ^{222}Rn. Compare to your *part a* estimate.

5. If the half-life of carbon-14 is 5,730 years, what fraction of the original carbon-14 in a sample has decayed after 1650 years? Estimate, then calculate.

ANSWERS

Practice 39.5.B

1. WANTED: $t_{1/2}$ for tritium

   DATA: $0.0562\ \text{yr}^{-1} = k$

   Strategy: In radioactive decay calculations that include half-life and fraction or percentage, write

   $\ln(\text{fraction remaining}) = -kt$ and $\ln(1/2) = -k\,t_{1/2}$

   The second equation relates the symbols in the WANTED and DATA.

   SOLVE: $t_{1/2} = \dfrac{\ln(1/2)}{-k} = \dfrac{-0.693}{-0.0562\ \text{yr}^{-1}} = \mathbf{12.3\ years}$ $[\ 1/\text{yr}^{-1} = (\text{yr}^{-1})^{-1} = \text{yr}\ ]$