

Student Packet: 10.1: Nuclear Chemistry: Student Handout AP[®] Chemistry

Nuclear stability

- There are some “back of an envelope” rules that can be used to predict nuclear stability. What you do is look at the ratio of neutrons to protons in a nucleus.

$\frac{n}{p^+}$ ratio = 1 for small atoms (up to 20) are stable.

$\frac{n}{p^+}$ ratio > 1 for large atoms are stable.

This is called the
belt of stability

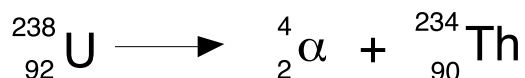
Nuclei with higher or lower $\frac{n}{p^+}$ ratios will be unstable.

Also, all isotopes of elements beyond Bi are unstable and radioactive.

- Radioactivity** can be naturally occurring or artificially induced by bombarding a nucleus with neutrons.

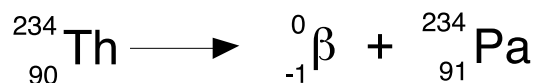
There are three types of naturally occurring radioactivity. You have to know how to write chemical reactions for each, and you also have to know the strength of each type (how severely it can nuke you).

- Alpha emission** (α = alpha). An α particle is just a helium nucleus --> 2 protons, 2 neutrons so that when an α particle is emitted the atomic # decreases by 2 and the atomic mass decreases by 4:



Alpha radiation can't make it through the upper epidermal layer (skin deep) but it can ionize organics and thus is dangerous (chemical ionizing power has to do with how carcinogenic it can be).

- Beta emission** (β = beta). A β particle can be thought of as an electron. When a nucleus emits a β particle a neutron turns into a proton so the atomic # goes up by 1 and the atomic mass stays the same:

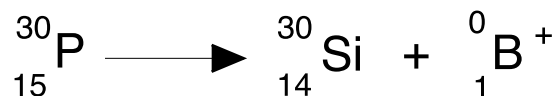


β particles can make it about 1 cm into tissue.

- Gamma emission** (γ = gamma). A γ isn't a particle like α and β : it's a highly energetic photon. There's no change in the atomic number or atomic mass since it's just the emission of light. This is really dangerous. This is the one that vaporizes everything and gives radiation poisoning. Gamma rays are a little stronger than x-rays.

You can also have artificially induced radiation and in such you get another type of radioactivity.

1. **Positron emission** is essentially the opposite of β emission. A positron is a positively charged β particle so it converts a proton into a neutron.



Radioactive decay makes for good little math problems. It's a 1st order process (the rate of change is proportional to the amount present) so,

$$\ln \frac{X_0}{X} = k t \quad \text{and} \quad t_{1/2} = \frac{.693}{k}$$

Carbon-14 dating uses this to determine the age of organic material. The assumption of C-14 dating is that while something's living it has a constant $^{14}\text{C}/^{12}\text{C}$ ratio. When it dies its intake of ^{14}C stops. So you can look at how much ^{14}C something (fossil or some such old organic matter) has and estimate how much has decayed and thus how long since it died. The 1/2-life of C-14 = 5,720 years.

For example, how old is something that has a carbon-14 to carbon -12 ratio equal to 60% of that of a living plant?

$$\ln \frac{X_0}{.6 X_0} = k t$$

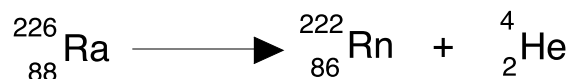
$$t_{1/2} = \frac{.693}{k} = 5720$$

$$t = \ln \frac{1}{.6} \left(\frac{5720}{.693} \right)$$

$$t = 4,216 \text{ years old}$$

Mass=Energy Relations: There are a whole bunch of things we can look at using Einstein's $E = mc^2$. This just gives us a relationship to convert energy to mass or vice versa. (Use joules-kilograms and meters/second.) Here are a couple of problems.

1. **During decay reactions you lose a little mass**



$$\Delta m = 221.9703 + 4.00150 - 225.9971$$

$$\Delta m = -0.0053\text{g} \quad \text{<----- You lost this mass during the decay}$$

$$E = (-0.0053\text{g})\left(\frac{1\text{ Kg}}{1000\text{g}}\right)(3 \times 10^8 \text{ m/s}) = -4.8 \times 10^8 \text{ kJ}$$

That's how much energy is released, thus the A-bomb and H-bomb. When you turn a little mass into energy you get a lot of energy.

2. **Estimate Nuclear Binding Energy** --> Nuclei weigh less than the sum of their neutrons and protons; the difference is called the mass defect.

$$\text{mass proton} = 1.00728 \text{ g}$$

$$\text{mass neutron} = 1.00867 \text{ g}$$

Just find the net mass and use $E = mc^2$ to get the binding energy.

3. **Nuclear Fission** --> Breaking heavy nuclei (${}^{235}\text{U}$) into smaller nuclei <-- A-bombs and nuclear power plants. It's the same problem, just find the missing mass and convert it into energy.

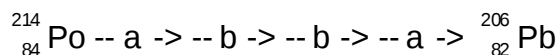
4. **Nuclear Fusion** --> Fusing two deuterium atoms (hydrogen with two neutrons) to get a helium atom. <-- This is H-bombs and the sun. Fusion is tough to get started; in H-bombs a fission rxn is used to supply the activation energy for the fusion reaction. Since the fuel is hydrogen (lots of it around) nuclear fusion is thought to hold the promise of an inexhaustible energy source. Controlled efficient fusion has yet to be done. Fusion has been done but so far it takes more energy to do it than it gives off. (Not such a good quality in an energy source.)

Student Packet: 10.1: Nuclear Chemistry: AssessMe questions

- 1) If there are two isotopes of Cl, ^{17}Cl and ^{19}Cl , how many different molecular masses are possible for a chlorine molecule?
- A) 1 B) 2 C) 3 D) 4 E) I'm clueless
- 2) Atom X has three isotopes, ^{44}X , ^{46}X and ^{49}X , with relative abundances of 23%, 57%, and 20% respectively. What is the atomic weight of X?
- A) 46 B) 46.1 C) 48.2 D) 44.9 E) I'm clueless
- 3) The mass of a proton is _____ the mass of a neutron?
- A) about equal to
B) much less than
C) much greater than
D) exactly equal to
E) I'm clueless
- 4) If an atom is without charge, then it
- A) has an equal number of protons and neutrons.
B) has an equal number of electrons and neutrons.
C) has an equal number of protons and electrons.
D) has more protons than neutrons.
E) I'm clueless
- 5) Alpha decay occurs with the loss of
- A) an electron.
B) a hydrogen nucleus.
C) a helium nucleus.
D) a neutron.
E) I'm clueless
- 6) Beta decay occurs with the loss of
- A) an electron.
B) a hydrogen nucleus.
C) a helium nucleus.
D) a neutron.
E) I'm clueless

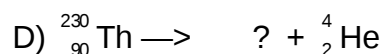
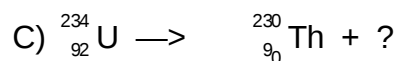
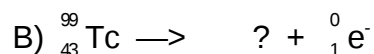
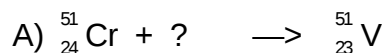
Student Packet: 10.1: Nuclear Chemistry: ShowMe questions

- 1) In 1919, the first nuclear transformation was observed by Lord Rutherford. He observed the formation of $^{17}_8\text{O}$ and deuterium when he bombarded $^{14}_7\text{N}$ with particles. Write a balanced reaction for this process.
- 2) In annihilation, a positron collides with an electron, and the matter is converted to high-energy electromagnetic radiation, or gamma rays. Write a balanced reaction for this process.
- 3) $^{234}_{90}\text{Th}$ decays via β emission to form protactinium. It is also possible to ionize Th to Th^+ . Both of these processes involve the loss of an electron, but they result in different products. Write balanced reactions for these two processes, and explain how they are different.
- 4) $^{214}_{84}\text{Po}$ is an unstable nuclide. It decays to form $^{206}_{82}\text{Pb}$, a stable nuclide, through the following series of steps:



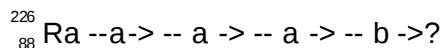
Write a balanced reaction for each of the four decay steps.

- 5) In each of the following nuclear reactions supply the missing particle or nuclide:



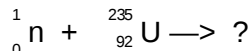
Student Packet: 10.1: Nuclear Chemistry: TestMe questions

- 1) $^{226}_{88}\text{Ra}$ decays through the following series of steps. What is the product?



- A) ${}_{92}^{238}\text{U}$ B) ${}_{89}^{224}\text{Ac}$ C) ${}_{77}^{220}\text{Ir}$ D) ${}_{83}^{214}\text{Bi}$ E) ${}_{83}^{210}\text{Bi}$

- 2) Which of the following are possible products of the fission of $^{235}_{92}\text{U}$ following bombardment by neutrons?



- A) ${}^{141}_{56}\text{Ba} + {}^{92}_{36}\text{Kr} + 3 {}^1_0\text{n}$
 B) ${}^{143}_{56}\text{Ba} + {}^{92}_{36}\text{Kr} + 3 {}^1_0\text{n}$
 C) ${}^{137}_{52}\text{Te} + {}^{95}_{40}\text{Zn} + 2 {}^1_0\text{n}$
 D) ${}^{137}_{52}\text{Te} + {}^{95}_{40}\text{Zn}$
 E) ${}^{137}_{52}\text{Te} + {}^{92}_{36}\text{Kr} + 2 {}^1_0\text{n}$

- 3) $^{210}_{84}\text{Po}$ produces lead in one step via a decay. Which of the following represents this process?

- A) ${}_{84}^{210}\text{Po} \longrightarrow {}_{82}^{206}\text{Pb} + {}_0^0\text{g}$
- B) ${}_{84}^{210}\text{Po} \longrightarrow {}_{82}^{206}\text{Pb} + {}_2^0\text{p}$
- C) ${}_{84}^{210}\text{Po} + 2{}_1^0\text{e}^- \longrightarrow {}_{82}^{210}\text{Pb}$
- D) ${}_{84}^{210}\text{Po} \longrightarrow {}_{82}^{206}\text{Pb} + {}_2^4\text{He}$
- E) ${}_{84}^{210}\text{Po} + {}_0^0\text{g} \longrightarrow {}_{82}^{206}\text{Pb}$

- 4) $^{214}_{83}\text{Bi}$ is an unstable nuclide. It decays to $^{206}_{82}\text{Pb}$ through five decay steps. Which of the following represents a possible decay pathway?

- A) b a a a a B) a b a b a C) b a b b a D) b a a a b E) b b b b a

- 5) Lawrencium-257 may be produced by bombarding californium-249 with boron-10. Which of the following is a balanced reaction representing this process?

- A) ${}_{98}^{249}\text{Cf} + {}_5^{10}\text{B} \longrightarrow {}_{103}^{257}\text{Lr} + 2{}_0^1\text{n}$
- B) ${}_{98}^{249}\text{Cf} + 2{}_5^{10}\text{B} \longrightarrow {}_{103}^{257}\text{Lr}$
- C) ${}_{98}^{249}\text{Cf} + {}_5^{10}\text{B} \longrightarrow {}_{98}^{257}\text{Lr}$
- D) ${}_{98}^{249}\text{Cf} + {}_5^5\text{B} \longrightarrow {}_{103}^{257}\text{Lr} + 2{}_0^1\text{n}$
- E) ${}_{98}^{249}\text{Cf} + {}_5^{10}\text{B} \longrightarrow {}_{98}^{259}\text{Lr}$