

VIII. Nuclear Chemistry

- A. Nuclear reactions involve changes in the number of neutrons and protons in the nucleus whereas chemical reactions involve changes in the number of electrons only.
- B. Radiation - Radioactivity first observed by Henri Becquerel in 1896
1. can be defined as energy or particles that come from one place and travel through things to get to another place.
EX. light, heat, alpha particle, beta particle, gamma rays, cosmic rays
 2. alpha particle, α , is a helium nucleus ${}^4_2\text{He}$ 2 protons and 2 neutrons
beta particle, β , is a high speed electron ${}^0_{-1}\text{e}$ 0 protons, 0 neutrons
gamma rays, γ , are high energy rays
cosmic radiation, high energy charged particles

alpha particle	penetrating power 1	stopped by clothing
beta particle	penetrating power 10	stopped by skin
gamma rays	penetrating power 100	stopped by lead; passes straight through living tissue

3. Classification
 - a. ionizing radiation - produces ions, free radicals, from atoms and molecules - x-rays, gamma rays, cosmic rays
 - b. nonionizing radiation - lower energy - light, radio
 - c. damage to organism that receives radiation directly is somatic damage - burns, rashes, cataracts, cancer
 - d. damage to reproductive organs is called genetic damage - birth defects
4. We are being bombarded at this moment by atomic nuclei, sub atomic particles, high energy rays, all kinds of stuff. This type of radiation is called background radiation
5. Measuring radiation
 - a. SI unit is the Becquerel
 - b. more common is the Curie, Ci. 1 Ci = # of disintegrations per second per gram radium. This doesn't correspond to the level of damage done. 1 Ci of α is harmless, but 1 Ci of γ is devastating.
 - c. rem (roentgen equivalent for man) - named for Wilhelm Roentgen, discovered X- rays. Used to measure exposure to humans. Rem includes both amount of energy transferred by radiation and the sensitivity of the body to that type of radiation. 150 rem causes some tissue damage whether its α , γ . 1000 + rem is fatal; <1000 rem is eventually fatal. 100 mrem / year = avg. dose
 - d. detection - Geiger counter (pg. 991 for diagram) - positive wire in a negative cylinder filled with argon. α, β, γ easily ionize Ar, ions are attracted to either wire or cylinder which creates an electrical pulse.
 - e. Radiation Doses - use a dosimeter that measures total amount of radiation a person receives. Badge most people wear contains

photographic film. Film is developed every so often and amount of darkening is translated to the amount of radiation exposure.

6. Source - unstable nuclei - stability range is a ratio of 1:1 or 1:1.5 of protons to neutrons. The larger the element the more likely it is to be unstable. Unstable nuclei decay and emit radiation in different ways
 - a. alpha emission - an alpha particle, α , is emitted

$${}^{230}_{90}\text{Th} \implies {}^4_2\text{He} + {}^{226}_{88}\text{Ra}$$
 (mass numbers and atomic numbers must be equal on both side of reaction)

Th is the parent nuclide; He is alpha particle; Ra is the daughter nuclide.
 - b. beta emission - emission of a beta negative particle, β^- , which is an electron from the nucleus. ${}^{234}_{91}\text{Pa} \implies {}^0_{-1}\text{e} + {}^{234}_{92}\text{U}$ The decay of the neutron provides a proton to the nucleus.

A beta positive, β^+ , could also be emitted.

$${}^{251}_{98}\text{Cf} \implies {}^0_{+1}\text{e} + {}^{251}_{97}\text{Bk}$$
 - c. K capture - an electron is captured from the K - shell

$${}^{234}_{92}\text{U} + {}^0_{-1}\text{e} \implies {}^{234}_{91}\text{Pa}$$
 - d. Some elements decay naturally in a decay series, until a stable nuclide is reached. Uranium - 238 decays in 14 steps to Lead - 206. The steps are : (overhead)

$\alpha, \beta, \beta, \alpha, \alpha, \alpha, \alpha, \alpha, \beta, \alpha, \beta, \beta, \alpha, \beta$ or $\alpha, \beta, \beta, \alpha, \alpha, \alpha, \alpha, \beta, \beta, \alpha, \beta, \beta, \alpha$.
 - e. Some nuclear reactions are induced by bombardment with other particles. ${}^{14}_7\text{N} + {}^4_2\text{He} \implies {}^{17}_8\text{O} + {}^1_1\text{H}$ (transmutation)

$${}^{98}_{42}\text{Mo} + {}^1_0\text{n} \implies {}^{99}_{43}\text{Tc} + {}^0_{-1}\text{e}$$

Neutrons are very effective since a zero charge can approach the nucleus easier and disrupt stability.

C. Half- life and Geological dating

1. By knowing the half life of an element we can determine the age of a substance containing that element.
2. The half - life, ($T_{1/2}$) of a substance is the time it takes for $\frac{1}{2}$ the nuclei in a radioactive sample to decay.
3. Carbon - 14 has a half life of 5730 years. ${}^{14}_6\text{C} \implies {}^{14}_7\text{N} + {}^0_{-1}\text{e}$ (Carbon - 14 is produced when cosmic rays bombard nitrogen - 14.) Ex. If we had 100 carbon - 14 atoms, after 5730 years there would only be 50; after another 5730 there would only be 25 and so on.
4. Carbon - 14 is used for dating since almost every living organism contains carbon. This method is only reliable for things that 30,000 years old or younger. The β^- emission is too slow to be measured reliably after that.
5. How does this work ? Since radioactivity is measured in # of disintegrations that occur per min per gram. A living plant gives off 15.3 ± 0.1 disint/min/gram. So by measuring the # of disint/min/g being given off something no longer living we can determine the age of the material. Ex. How old is a piece of wood that is emitting 1.9 ± 0.1 disint/min/g of β^- particles ?

An organism living 5730 years ago would be emitting $\frac{1}{2} \times 15.3$
 disint/min/g = 7.65 d/m/g ; another $T_{\frac{1}{2}} \frac{1}{2} \times 7.65$ d/m/g = 3.82 d/m/g;

another $T_{1/2} \times 3.82 \text{ d/m/g} = 1.91 \text{ d/m/g}$; thus this wood has gone through three half lives , $3 \times 5730 \text{ years} = 17,190 \text{ years old}$.

D. Uses of Nuclear Chemistry

1. Development of synthetic elements. this process is called transmutation. The elements are called transuranium.
 - a. Most were made at Lawrence Radiation Lab at the University of California, Berkley. The team was led by Glen Seaborg and Albert Ghiorso.
 - b. The first synthetic element was $^{98}_{43}\text{Tc}$ in Italy in 1937.
 - c. Production of transuranium elements
 - d. Massive amounts of energy are needed to accelerate particles fast enough so they will combine in a nuclear reaction.
 - e. Accomplished with particle accelerators. Cyclotron uses alternating currents in the "Dee" rods. Synchrotron uses electromagnets. Both use the push pull effect to accelerate particles. Synchrotrons are very large (6.3 km circ.) Linear accelerators are also used.
2. Radioactive Isotopes as Tracers
 - a. Used to trace functions in the body, air flow, industry, river currents.
 - b. In the body ; Iodine - 131 is used to trace proper functions of the thyroid, lungs and kidneys. Technetium - 99 is used for the brain, lungs, liver, spleen and bones. Cobalt - 58 is used to trace the body's ability to absorb B_{12} . Also some are used to kill cancerous cells by being injected into tumor and decay very quickly to give pulse of radiation. $^{192}_{77}\text{Ir}$ in metal seed of Pt so Ir can't escape and keeps α , β^- contained. $^{60}_{27}\text{Co}$ used as an external treatment. Chemo attacks fast growing cells like stomach lining and hair thus hair loss and nausea. Radon has a $T_{1/2}$ of minutes. The gas itself is not harmful, but when breathed into lungs it decays before being exhaled. Limit is 4 picocuries/L air.
 - c. Instruments used to diagnose are PET (positron emission tomography) and the SPECT (single photon emission computed tomography).
 - d. $^{32}_{15}\text{P}$ is used to study uptake of nutrients by plant cells.
 - e. $^{140}_{56}\text{BaSO}_4$ is used to follow movement of silt in rivers.
3. Nuclear Energy
 - a. Nuclear reactions involve amounts of energy about 1×10^6 greater than the energy derived from chemical reactions.
 - b. In nuclear reactions it seems as if some matter is lost. This matter has been transformed into energy as Einstein predicted with his $E = mc^2$ equation. "Matter and energy are two different interchangeable forms of a single more fundamental quantity."
 - c. $E =$ energy in joules ($1\text{J} = 1\text{kg m}^2 / \text{s}^2$)
 $m =$ mass in kg
 $c =$ speed of light ($3.00 \times 10^8 \text{ m / s}$)
Thus the quantity of Energy released from a small amount of matter can be determined.
 - d. Example - $^{226}_{88}\text{Ra} \implies ^{222}_{86}\text{Rn} + ^4_2\text{He}$ let's use 1 mole of Ra

Molar mass of Radium - 226 = 225.9771g

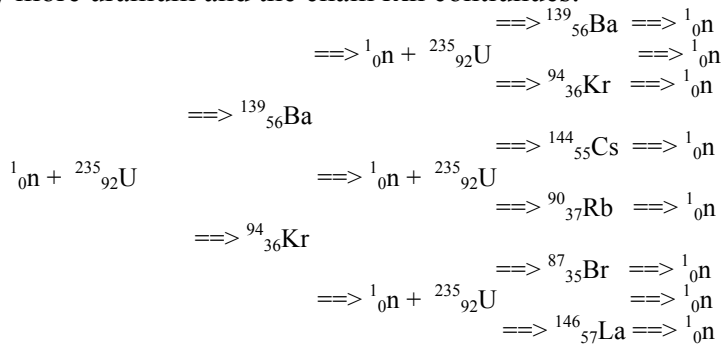
Molar mass of Radon - 88 = 221.9703g

Molar mass of Helium - 4 = 4.0015g

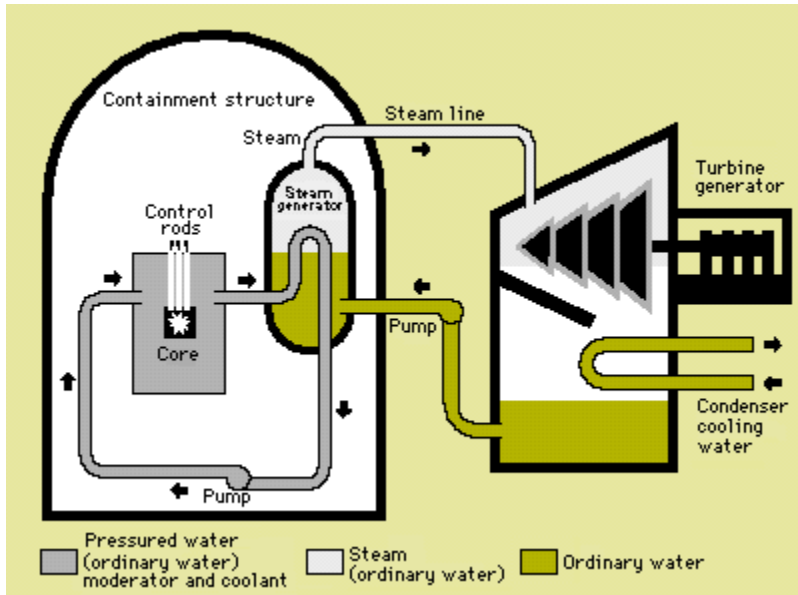
Difference in mass is the mass defect. The amount of energy equal to this mass is the binding energy (energy needed to break up nucleus, often measured in J / particle). This reaction releases 4.77×10^{11} J. This is enough energy to melt all the steel beams and girders in a 30 story building !

4. Fission

- a. Splitting of atoms into smaller nuclei by bombardment with low energy neutrons.
- b. Occurs through a self propagating rxn called a chain rxn.
- c. The uranium - 235 absorbs a neutron and becomes unstable and breaks into 2 smaller nuclei plus more neutrons. The neutrons produced are absorbed by more uranium and the chain rxn continues.



- d. Minimum amount of matter needed to sustain a chain reaction is called the critical mass . 4.5 g of ${}^{235}_{92}\text{U}$ satisfies 1 persons energy need for 1 year whereas, 15 tons of coal will accomplish same task.
- e. Nuclear Power plant (See Diagram page 795 also Laser Disc) fuel is ${}^{235}_{92}\text{U}$ and ${}^{239}_{94}\text{Pu}$. European are called Breeder Reactors because they make their own fuel.



f. Problems - Nuclear waste - what do we do with it ? Bury it in Salt mines? Ocean dumping? Incinerate? Send it to space / sun? Reuse the rods / remaining waste is then converted into a solid glass by a process known as vitrification?

5. Fusion

- More powerful than fission. Its when small nuclei join to form larger nuclei. This is the energy in the sun.
- $^2_1\text{H} + ^3_1\text{H} \implies ^4_2\text{He} + ^1_0\text{n} + 1.7 \times 10^9 \text{ KJ / mole}$
deuterium + tritium must be in plasma phase so the electrons don't get in the way and they are moving fast enough.
- To accomplish this 40 million K are needed. A Tokamak reactor creates plasma and uses a magnetic field to hold the plasma in a
- In one day the energy reaching the earth from the sun equals all the energy ever used by humans on this planet.
- Reasons to explore fusion - Deuterium and Tritium are available from the sea. Helium is a safe by product. Reaction can be stopped instantly.

doughnut shape

6. Quarks

- Theoretical particle with a fractional charge of either 1/3 or 2/3
- | | |
|-----------------|------|
| up | +2/3 |
| down | -1/3 |
| charmed | +2/3 |
| strangeness | -1/3 |
| top (truth) | +2/3 |
| bottom (beauty) | -1/3 |
- Most matter is made of ups and downs

proton		neutron	
up	+2/3	up	+2/3
up	+2/3	down	-1/3

down $-1/3$

down $-1/3$

- d. Electrons are made of leptons
- f. Antimatter - Antiparticles , electrons and positrons , when they meet they completely annihilate each other and are turned completely into energy.