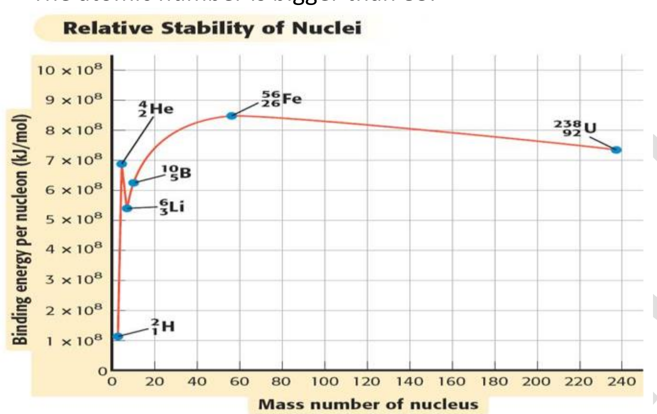
RADIOACTIVITY

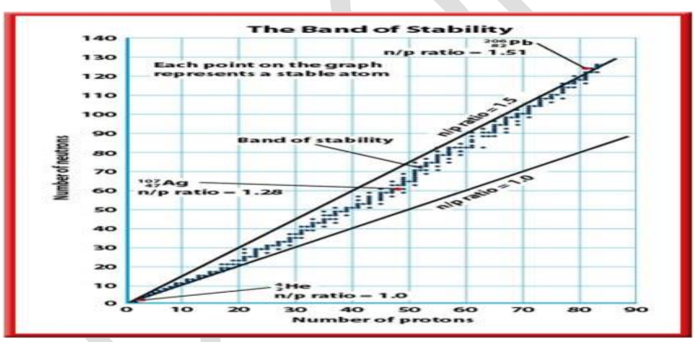
A Comparison of Nuclear and Ordinary Chemical Reactions

1. Both types of reactions require activation energy.
2. Total energy is conserved in both reactions.
3. In nuclear reactions nucleus changes.
4. In nuclear reactions number and types of atoms change.
5. Total mass is not conserved in nuclear reactions.
6. The factors like temperature, pressure affecting rates of ordinary reactions do not affect the nuclear reactions.
7. The amount of energy released in nuclear reactions is tremendously higher than that of ordinary chemical reactions.

1. Radioactivity

- The spontaneous emission of radioactive rays by an unstable nucleus is called radioactivity.
- Spontaneously disintegrating atoms are called radioactive atoms. Most radioactive atoms have the following properties;
- $N_n/N_p>1.5$
- The atomic number is bigger than 83.





2. Types of Radioactive Decays

- There are mainly three types of emissions by radioactive atoms; alpha, beta and gamma.
- These radiations have various effects;

1. They can ionize substances,
2. They can cause substances to phosphoresce and fluoresce,
3. They can affect photographic film.
4. They affect the living cells and cause them to suffer cancer.
5. Glass, porcelain and ceramics can be colored when they are exposed to radiation.

1. Alpha (α) Particles

- They are identical to the nuclei of helium atoms. $^{4}_{2}He^{2+}$
- Their speed is approximately 1/10 of the speed of light.
- Since they have 2+ charged particles they are shown as
- They are deflected by magnetic and electric fields.
- Its penetrating power is low it can be stopped by a paper.
- The nucleus of an atom undergoing an alpha decay loses He^{2+} particles and it emits two protons and two neutrons.

$$^{238}_{94}U \rightarrow ^{234}_{90}Th + ^{4}_{2}He$$

Example 1

A radioactive isotope emits one α particle and transmutes to the atom X. Find the atomic number, atomic mass number and the symbol of the atom X.

Solution

$$^{218}_{84}Po \rightarrow ^{214}_{82}X + ^{4}_{2}He$$

$^{214}_{82}$X is Pb

2. Beta (β) Particles

- They are identical to electrons. $(^{0}_{-1}e)$
- Their speed is approximately the speed of light.
- They are negatively charged particles.
- Since they have 1- charged particles they are shown as $^{0}_{-1}e$ or β^{-}
- They are deflected by magnetic and electric fields.
- Its penetrating power is stronger than alpha particles.
- An atom undergoing beta emission loses one neutron and gains one proton, therefore its atomic number increases by one and mass number remains unchanged.

$$^{1}_{0}n \rightarrow ^{1}_{1}p + \beta^{-}$$

Example 2

A radioactive $^{238}_{93}Np$ isotope emits one β particle and transmutes to the atom Pu. Find the atomic number and atomic mass number Pu.

Solution

$$^{238}_{93}Np \rightarrow ^{238}_{94}Pu + ^{0}_{-1}e$$

3. Gamma (γ) Rays

- They are electromagnetic radiation with a very high energy. Generally they are produced after alpha and beta radiations as energy.
- They are electrically neutral particles.
- It has no mass and charge.
- Its penetrating power is one hundred times greater than that of beta rays.

$$^{234}_{92}U \rightarrow ^{230}_{90}Th^{*} + \alpha$$

$$^{230}_{90}Th^{*} \rightarrow ^{230}_{90}Th + ^{0}_{0}\gamma$$

4. Positron Emission

- It is the transmutation of one proton into one neutron in the nucleus of atom. As a result a positively charged particle with a same mass as a beta particle is emitted.
- It is shown as $_{+1}^{0}e$ or β^{+}
- As a result of positron emission the atomic number of an element decreases by one, whereas the atomic mass remains unchanged.

$$_{1}^{1}\mathrm{p} \rightarrow {}_{0}^{1}n + {}_{+1}^{o}e$$

$$_{12}^{23}Mg \rightarrow {}_{11}^{23}Na + {}_{+1}^{0}e \quad , \quad {}_{15}^{30}P \rightarrow {}_{14}^{30}\mathrm{Th} + {}_{+1}^{0}e$$

Example 3

A radioactive $_{56}^{141}Ba$ isotope transmutes into Cs by decaying through one β^+ emission. Find the atomic number of Cs.

Solution

$$_{56}^{141}Ba \rightarrow {}_{55}^{141}\mathrm{Cs} + {}_{+1}^{0}e$$

5. Electron Capture

- It has the same effect as positron emission. It happens when one electron from inner shell is captured by the nucleus. As a result one proton transmutes into one neutron. In electron capture atomic mass number remains unchanged and atomic number decreases by one

$$_{-1}^{o}e + {}_{1}^{1}\mathrm{p} \rightarrow {}_{0}^{1}n$$

$$_{47}^{106}Ag + {}_{-1}^{0}e \rightarrow {}_{46}^{106}Pd \quad , \quad {}_{81}^{202}Tl + {}_{-1}^{0}e \rightarrow {}_{80}^{202}Hg$$

Example 4

$$_{56}^{141}Ba + {}_{-1}^{0}e \rightarrow \mathrm{X}$$

Find the number of neutrons in X atom.

Solution

$$_{56}^{141}Ba + {}_{-1}^{0}e \rightarrow {}_{55}^{141}\mathrm{X}$$

$$\mathrm{n} = 141 - 55 = 86$$

6. Neutron Emission

- It occurs by removal of a neutron from a nucleus.
- Isotope of the original element is formed.
- Atomic number remains unchanged and atomic mass number decreases by one.

$$_{47}^{106}Ag \rightarrow {}_{47}^{105}\mathrm{Ag} + {}_{0}^{1}n$$

$$_{36}^{87}Kr \rightarrow {}_{36}^{86}\mathrm{Ag} + {}_{0}^{1}n$$

Example 5

A radioactive nucleus $_{92}^{234}U$ transmutes into one of its isotope through three neutron emission. What is the neutron/proton ration in the new nucleus produced?

Solution

$$_{92}^{234}\mathrm{U} \rightarrow {}_{92}^{231}\mathrm{U} + 3{}_{0}^{1}\mathrm{n}$$

No. of neutrons = 231 - 92 = 139

$$\frac{neutron}{proton} = \frac{139}{92} = 1.51$$

Particle	Mass (amu)	Charge	Symbol	Stopped by
Proton	1.007 276 47	+1	$p, p^+, {}_{+1}^{1}p, {}_{1}^{1}\mathrm{H}$	a few sheets of paper
Neutron	1.008 664 90	0	$n, n^0, {}_{0}^{1}n$	a few centimeters of lead
β particle (electron)	0.000 548 580	−1	$\beta, \beta^-, {}_{-1}^{0}e$*	a few sheets of aluminum foil
Positron†	0.000 548 580	+1	$\beta^+, {}_{+1}^{0}e$*	same as electron
α particle (He-4 nucleus)	4.001 474 92	+2	$\alpha, \alpha^{2+}, {}_{2}^{4}\mathrm{He}$	skin or one sheet of paper
Gamma ray	0	0	γ	several centimeters of lead

3. Natural Radioactivity

- Between 1852-1908 Henry Becquerel studied about radioactive substances. He discovered an uranium salt, uranyl sulfate, $K_2UO_2(SO_4).2H_2O$.
- In 1895 X-rays were discovered by Wilhelm Roentgen.
- Most of the studies about radioactivity have been done by Curie Family.
- They discovered many other radioactive elements, Polonium, Radium and Thorium. They got Nobel Prize, but died due to severe radioactive radiation of these elements.

4. Artificial Radioactivity

- Some non-radioactive substances can undergo radioactive changes by bombarding them with various particles. This process is known as artificial radioactivity.

The first non-radioactive element $_{8}^{17}O$ was produced by Ernest Rutherford in 1919.

$$\alpha + {}_{7}^{14}N \rightarrow {}_{8}^{15}\mathrm{O} + {}_{1}^{1}H$$

In 1932 James Chadwick obtained free neutrons by bombarding $_{4}^{9}Be$ atoms with alpha particles.

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

Example 6

What is the particle X produced by the nuclear reaction below?

$$_{3}^{7}\mathrm{Li} + {}_{1}^{1}\mathrm{p} \rightarrow {}_{4}^{7}\mathrm{Be} + \mathrm{X}$$

Solution

$$_{3}^{7}\mathrm{Li} + {}_{1}^{1}\mathrm{p} \rightarrow {}_{4}^{7}\mathrm{Be} + {}_{0}^{1}n$$

1. Nuclear Fission

- The disintegration of a heavier nucleus into lighter nuclei by neutron bombardment is called nuclear fission.
- In 1938, Otto Hahn and Fritz Strassman of German invented nuclear fission reaction.

$$^{235}_{92}\mathrm{U} \;+\; ^{1}_{0}n \longrightarrow ^{92}_{36}\mathrm{Kr} \;+\; ^{141}_{56}Ba \;+\; 3^{1}_{0}\mathrm{n}$$

- The continuous chain reaction results huge amount of energy. By using this property atomic bomb is prepared.
- The chain reaction was first achieved by Enrico Fermi in 1942 in Chicago.

2. Nuclear Fusion

- The combination of two or more lighter nuclei to form a heavier nucleus is called nuclear fusion.
- The amount of energy released by the fusion reaction is much more greater than that of fission reaction. But it needs huge amount of activation energy.
- Nuclear fusion is the basis of the hydrogen bomb.

$$^{2}_{1}\mathrm{H} \;+\; ^{3}_{1}H \rightarrow ^{4}_{2}\mathrm{He} \;+\; ^{1}_{0}\mathrm{n} \;+\; \text{energy}$$

$$^{2}_{1}\mathrm{H} \;+\; ^{2}_{1}\mathrm{H} \;\rightarrow\; ^{4}_{2}\mathrm{He} \;+\; \text{energy}$$

5. The Rate of Radioactive Decay

- The changing of radioactive elements into other elements through radioactive emissions is called either radioactive decay or radioactive disintegration.
- Geiger-Muller counter is used to detect the intensity of radiation.
- Rate of radioactive decay is the number of atoms emitting a radioactive ray per a unit time. The rate of decay is directly proportional to the initial amount of substance and the structure of nuclei. It is independent of physical and chemical properties.
- The period of time required for half of the initial amount of the substance to disintegrate is called half-life. The shorter the half-life the higher the rate of radioactive decay.

$$m = \frac{m_0}{2^n}, \quad \mathrm{n} = \frac{t}{t_{1/2}}$$

m: mass remained, m_0 : initial mass,

n: number of half-lives

t: time passed, $t_{1/2}$: half-life

Example 7

How many grams of one mole of ^{214}Bi will remain undecayed after 80 minutes if its half-life is 20 minutes?

Solution

$$\mathrm{n} = \frac{t}{t_{1/2}} \Rightarrow n = \frac{80}{20} = 4$$

$$m = \frac{m_0}{2^n} \Rightarrow \mathrm{m} = \frac{214g}{2^4} = 13.375\mathrm{g}$$

Example 8

The amount of a 40 g sample of ^{222}Rn remaining after 16 days is 2.5 g.

Solution

$$m = \frac{m_0}{2^n} \Rightarrow 2.5 = \frac{40}{2^n} \Rightarrow 2^n = 16 = 2^4 \Rightarrow n = 4$$

$$4 = \frac{16}{t_{1/2}} \Rightarrow t_{1/2} = 4\ days$$

6. The Effects of Radiation on Living Organisms

- There are many different types of uses of radiation such as TV, cellphones, photocopy machines, x-ray machines.
- Nuclear reactions; fission and fusion, also produce radiations although the reactions stop.
- The radiation produced by stars, sun and explosions in the space is called cosmic rays.
- These radiations are dangerous when at higher intensities. They damage the cells and cause carcinogenic tumors. The further damage is change in genetic structure or it is called mutation.
- Although radiation has very harmful effects it has many applications in medicine, in household items, in food and petroleum industries as well as in archeology.