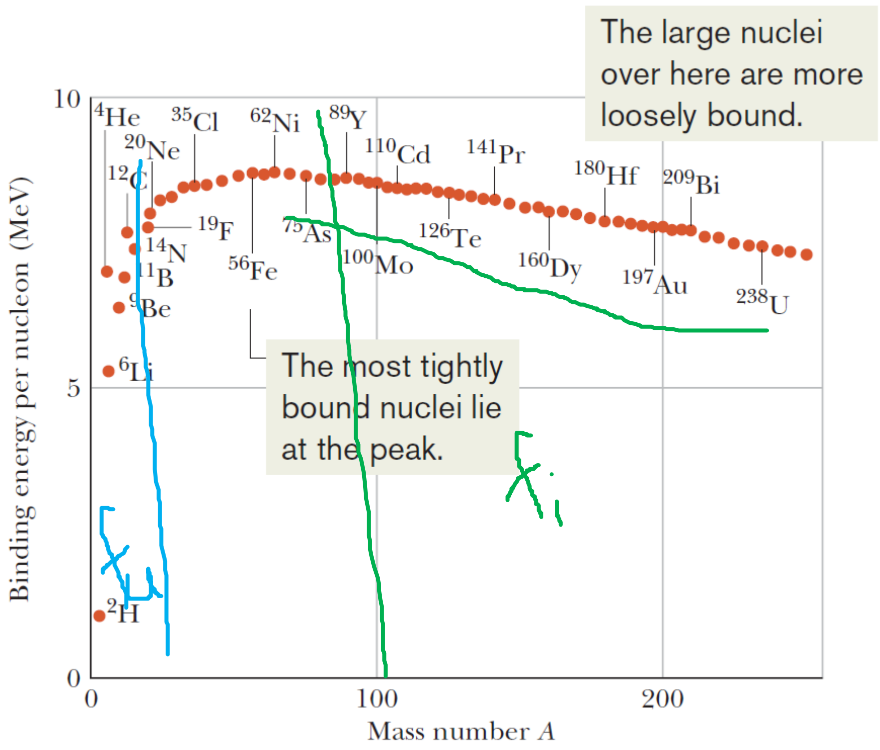
Nuclear Stability

Lecture 29

PH-122

Nuclear Stability

- Nuclear stability depends upon multiple factors.
- Two that will be discussed here are Binding energy per nucleon and neutron to proton ratio.



Neutron to Proton ratio

- Nucleus has energy levels and as nucleons are also half spin particles so these obey Poly's exclusion principle.
- Therefore, each energy-level contains 2 neutrons (opposite spin) and 2 protons (opposite spin).
- Energy-levels are filled in sequence, just like atomic levels (for electrons), to achieve configuration of minimum energy and therefore maximum stability.
- Protons are positively charged particles and hence repel each other. For a proton number of 10 or greater the repulsive force becomes overwhelming (neutrons will increase stability in this case).
- Usually elements having even-even nuclei are stable.

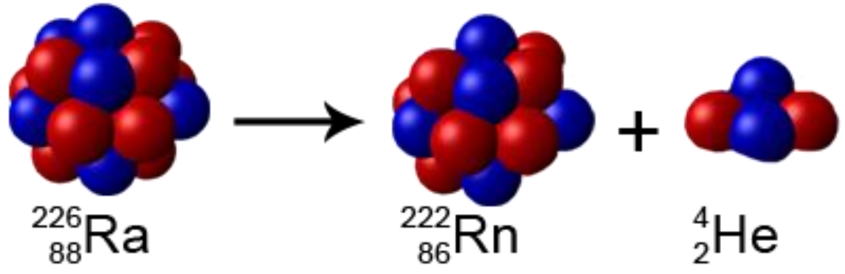
Radioactive Decay

- Unstable nuclei undergo radioactive decay in order to gain stability.
- It is the process of spontaneous emission of a particle from nucleus that transforms the nucleus into a different nucleus.
- There are three types of radioactive decay: alpha, beta and gamma decay.

Alpha Decay

- It occurs when nucleus has too many protons which cause excessive repulsion.
- In an attempt to reduce repulsion, a Helium nucleus is emitted.
- He nuclei are in constant collision with the walls of nucleus, as it energy and mass so there are non-zero chances of transmission (tunneling).
- Example: Am241 transforms to Np237 through alpha decay.

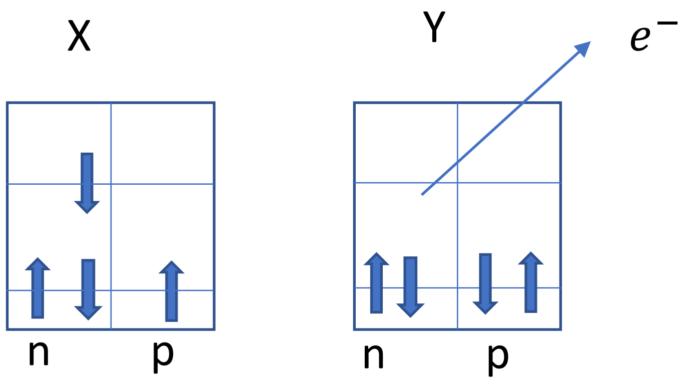
  Ra226 changes to Rn222.



The nucleus of an atom of radium-226 contains 88 protons and 138 neutrons. A radium-226 nucleus undergoes alpha decay to form a different element, radon-222, and an alpha particle.

Beta Decay

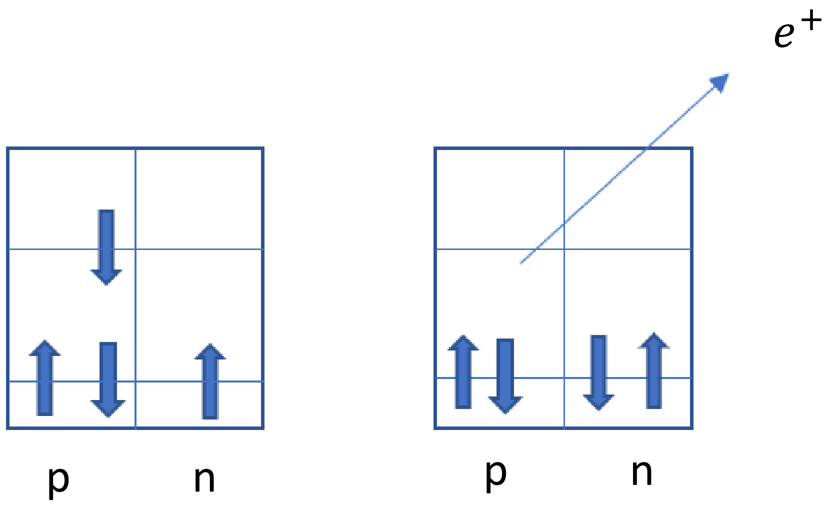
- Three types of beta decay; electron emission, positron emission and electron capture.
- When neutron to proton ration is too high, it causes instability.
- In order to gain stability a neutron is converted into a proton and electron. Electron is then emitted out.
- Example: H3 converts to He3 to gain stability.

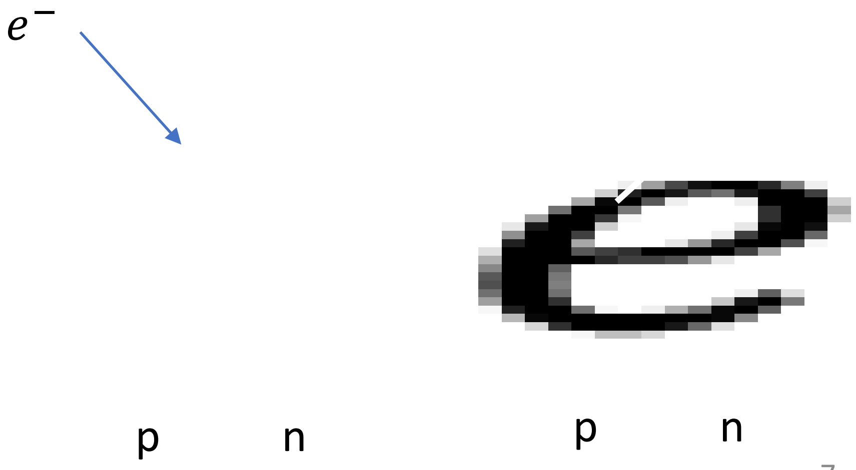


Beta Decay

If neutron to proton ration is too small, positron emission takes place.
Example: C11 converts to B11 through positron emission.

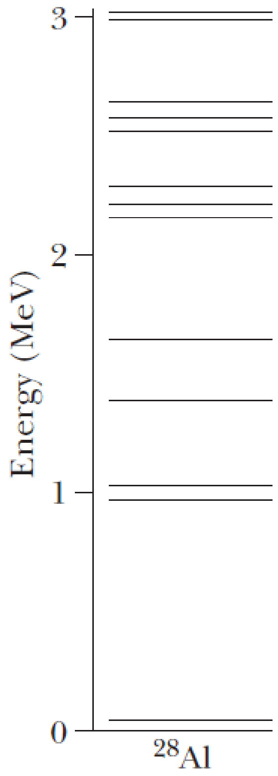
If neutron to proton ration is too small, electron capture can takes place.
Example: Be7 converts to Li7 through electron capture.





Gamma decay

- Gamma decay occurs because the nucleus is at too high energy. The nucleus falls to a lower energy state and in process emits a high energy photon known as gamma particle.
- Beta decay is always accompanied by gamma decay.



Law of Radioactivity

$$N = N_0 e^{-\lambda t}$$

$$R = R_0 e^{-\lambda t}$$

$$T_{1/2} = \frac{\ln 2}{\lambda}.$$

Problem

- Of 600 mg of potassium in a large banana, 0.0117% is radioactive K^{40}. It has a half-life of $1.25X10^9$ y. What is the activity of banana?

- By definition: $R = -\frac{dN}{dt}$
- But, $N = N_0 e^{-\lambda t}$
- Therefore, $R = \lambda N_0 e^{-\lambda t}$ or $R = \lambda\mathrm{N}$.
- We know that; $T_{1/2} = \frac{ln2}{\lambda}$ or $\lambda = \frac{ln2}{T_{1/2}}$.
- $=> R = \frac{Nln2}{T_{1/2}}$ (1)

Problem

- N is the number of nuclei and hence can be found by using Avogadro's number as $N = (1.17X10^{-4})X \frac{massX\ Avogadro's\ no.}{Molar\ mass}$

$$N = (1.17X10^{-4})X \frac{(600X10^{-3}\ g)(6.02X10^{23} mol^{-1})}{39.102\ g/mol}$$

$$N = 1.081X10^{18}$$

- Therefore, eq. (1) becomes:
- $R = \frac{(1.081X10^{28})ln2}{(1.25X10^{9}y)(3.16X10^{7}\frac{s}{y})} = 18.96\ Bq.$