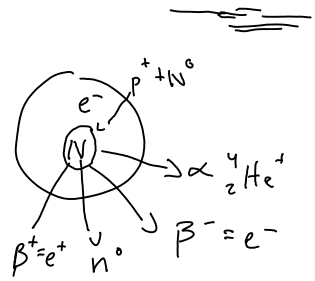
Notes: Chapter 24

Wednesday, January 10, 2007
12:04 AM

Chapter 24: NUCLEAR Reactions and their Applications



Homework:

Within the nucleus of the atom is a tremendous amount of energy. The release of this energy can range from the barely noticeable to the catastrophic.

Discovery of Radioactivity

This discovery of radioactivity belongs to Antone Henri Becquerel who showed that particles emitted from uranium salts could pass through paper to expose photographic film in the absence of light.

Marie Curie coined the term 'Radioactivity' for the spontaneous emission of particles or rays from the nucleus of atoms. In 1898 Marie Curie and her husband Pierre Curie discovered two radioactive elements; polonium and radium.

In 1899 Ernest Rutherford discovered that two different types of rays emitted from the nucleus, alpha and beta rays. Alpha rays consisted of streams of helium nuclei where beta rays consisted of streams of electrons. The third type of nuclear emission, gamma rays, was discovered by Paul Villard in 1900.

Isotopic Notation

$^{14}_{6}C$ 6protons 8neutrons 14g/mol

Isotopic notation describes the nuclear composition of a particular isotope of an element. For example:

In the nucleus of carbon-14, there are 6 protons and 8 neutrons. **Neutrons** and protons are called nucleons. Carbon-14 is a particular **nuclide** of carbon.

Natural Radioactivity

Radioactive nuclides disintegrate spontaneously over time. The length of time required for 1/2 of the atoms to disintegrate is called the **half-life**. The half-life equation is derived from first order kinetic arguments exactly like those for rates of chemical reactions.

Rate = $-\Delta N/\Delta t = k N_t$

If we assume a differential and integrate:

$-dN/dt = kN$

- $dN/N = -k\int dt$

$\ln(N_t/N_o) = -kt$

or for base 10 logs

$\log(N_t/N_o) = -kt/2.303$

It is a simple matter to derive the half-life expression:

$t_{1/2} = .693/k$

Problem:

1,000,000 carbon-14 atoms will disintegrate to about 500,000 carbon-14 atoms in 5668 years. What is k for carbon? $k = \frac{.693}{t_{1/2}} = \frac{.693}{5668} = 1.22\times10^{-4}\ yr^{-1}$

Problem:

How long will it take for 1,000,000 carbon-14 atoms to disintegrate to 10,000 carbon-14 atoms. $\ln\frac{10,000}{1,000,000} = -1.22\times10^{-4}t$ $t = 37747$ Yr

Problem:

A 1.0000 g sample of fresh carbon gives 575 disintegrations/second, while a 1.0000 g sample of carbon from a mummy gives 366 disintegrations/second. How old is your mummy? Note: only a small fraction of naturally occurring carbon is radioactive carbon-14. rate $= kN_t$ $1.22\times10^{-4}yr \times \frac{1\ Yr}{31{,}557{,}600}$

$\frac{575\ dis}{sec}\ \frac{3600\ sec}{1h} \times \frac{24hr}{1day} \times 365.25$ $= 31557600$ sec in 1yr

$C_{Fresh}\ N_0 = 1.48\times10^{14}$ $C_{mummy}\ N_t = 9.47\times10^{13}$ $t = \frac{\ln\frac{N_t}{N_0}}{-k} = 3700\ yrs$

Radioactive Decay Processes

When a nucleus decays all the conservation laws must be observed-conservation of mass, charge and energy. The sum of charges and particles will be the same on each side of the equation.

Consider the decay of the uranium-235 nuclei:

$$^{235}_{92}U \rightarrow ^{231}_{90}Th + ^{4}_{2}He$$

where

$^{4}_{2}He$

is an alpha (α) particle.

Write the equation for the α disintegration of thorium-231.

$^{231}_{90}Th \rightarrow ^{227}_{88}Ra + ^{4}_{2}He$

Consider the following β emission example and complete the equation:

$^{14}_{6}C \rightarrow ^{14}_{7}N + ^{0}_{-1}e$

Where

$^{0}_{-1}e$

is a beta (β) particle or simply an electron.

Complete the following equation for the β decay of

$^{231}_{90}Th \rightarrow ^{0}_{-1}e + ^{231}_{91}Pa$

There are two ways for gamma rays to be produced in nuclear reactions: electron capture and positron emission.

Example: Electron capture usually occurs with heavy nuclei having too many protons to be stable.

$^{118}_{54}Xe + ^{0}_{-1}e \rightarrow ^{118}_{53}I + 2\gamma$

where γ is a gamma photon of high-energy light given off when an electron cancels the charge on a proton.

Complete the following equation for the electron capture of mercury-197

$^{197}_{80}Hg + \beta \rightarrow$

Example: Positron emission usually occurs with light elements having too many protons to be stable.

$^{118}_{54}Xe \rightarrow ^{118}_{53}I + ^{0}_{1}e$

where

$^{0}_{1}e$

is a positron or positive electron.

Show the positron emission of Magnesium-23

$^{23}_{12}Mg \rightarrow$

Stability of Isotopes

Most stable isotopes have an even number of protons and neutrons 157 total. Several have an odd number of protons OR neutrons, 52 and 50 respectively. Only 5 stable isotopes have an odd number of protons and neutrons.

Predicting Nuclear Reactions

To determine the type of radiation likely for a particular element we must look at a chart of stable elements on page 795. This chart shows a band of stable isotopes; all other isotopes are unstable.

- emission: Usually occurs when the atomic number, Z, is greater than 83.
- emission: Usually occurs when the element is above the belt of stability. N/Z too large

$^{0}_{1}e$

emission: Usually occurs for **light** elements below the belt of stability. N/Z too small

$^{0}_{-1}e$

capture: Usually occurs for **heavy** elements below the belt of stability. N/Z too small

- emissions: Occur when the $_{-1}°e$ capture occurs or when a $_{+1}°e$ annihilates an electron.

Measurement of Radioactivity

Radiation units

Curie (Ci) 1Ci = $3.7x10^{10}$ disintegrations /sec which is how much 1 gram of radium gives off.

Roentgen (R) 1R = $2.1x10^{9}$ ions of air molecules/cm^3 of air.

Rad Radiation Absorbed Dose which is a measure of the amount of energy absorbed/kg of matter. 1 rad = .01 J/kg

Rem Roentgen Equivalent to Man. 1(0) rem= 1rad x factor where the factor is 1 for beta and gamma radiation and alpha a factor of 10 determine by the biological harm caused by the particular type of radiation.

Nuclear Fission

The fat man and little boy atomic bombs dropped on Hiroshima and Nagasaki were the only two nuclear weapons used in any war. In less than 10 seconds 4.5 square miles of Hiroshima was destroyed and 70,000 people died and as many were injured. 35,000 died in the explosion over Nagasaki. The enormous amount of energy released is the result of a conversion of a tiny fraction of mass into energy. When uranium -235 is struck by a neutron it splits into two fragments such as krypton and barium and releases 2 neutrons which in turn strike two uranium atoms which release 2 neutrons each for a total of 4 neutrons. Those 4 neutrons produce 8 -> 16 -> 32 -> 64 -> 128 -> 256 -> 512 -> 1024 -> 2048 -> 4096 -> 8192 etc.

So long as the neutrons can escape as fast as they are produced everything is fine, and you have a sub-critical mass of uranium. However, if the rate of production of neutrons becomes larger than the rate at which the neutrons can escape, a nuclear explosion can result.

Problem:

How much energy is released when 1 kg of uranium-235 undergoes a chain reaction? Assume the reaction:

$$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{139}_{56}Ba + ^{94}_{36}Kr + 3^{1}_{0}n$$

Masses in amu.

U =235.0439, Ba =138.9048, Kr =93.9128, n=1.00867

236.0526 total → 235.8436 total

Nuclear Power

Electricity is nearly always produced by boiling water to turn a turbine (exceptions are hydroelectric and solar voltaic cells). Coal, oil or nuclear fission can be used to boil the water. A nuclear reactor is simply the source of heat to boil water to turn turbines, which turn generators to produce electricity.

Nuclear Fusion

Fusion is the putting together of nuclei to produce heavier nuclei. Nuclear fusion takes place naturally in stars and in our sun. It is quite interesting to consider that every element on earth was once formed in the center of a star billions of years ago and thrown out into space when that star exploded as a nova or super nova. Fusion occurs most readily between light elements such as hydrogen or helium.

Problem:

Calculate the amount of energy given off when .25 kg of hydrogen is reacted with .75 kg of tritium.

$$^{3}_{1}H = 3.01550,\ ^{1}_{1}H = 1.00728,\ ^{4}_{2}He = 4.0015$$

This source of energy holds great promise as a non-polluting source of energy from seawater... the source of tritium and deuterium. If not that, at least it makes good bombs.

Mass Defect (Or Where the Energy IS)
The helium nucleus consists of 2 protons and 2 neutrons. The total mass of 2 protons and 2 neutrons is slightly greater than the mass of one helium nuclei! Where did the excess mass go? The excess mass was released as energy when the helium nuclei was formed and it is the energy that is responsible for holding the positive charges of the nuclei together. This energy is called the **binding energy.**

Problem :

Calculate the binding energy for Helium. Look up the mass of 2 protons and 2 neutrons and the mass of the helium-4 nuclei. Take the difference and convert to SI (mks) units. Use $E=mc^2$.

Biological Effects of Radiation
X-ray or gamma radiation is damaging to the genetic material within the nucleus of living cells. The damage is most severe to cells, which are rapidly dividing such as cancer cells. By far the most damaging radiation is alpha radiation. This is due to the fact that alpha particles are very massive and can inflict greater damage to individual cells; however, alpha particles are not very penetrating because of their size and maximum damage can only occur if the alpha source is ingested or inhaled. Gamma or x-ray radiation does much less damage than alpha; however, it is extremely penetrating and can cause damage deep within the body from outside the body. Long-term exposure to low level radiation shortens the average life span of mankind.

Some Application of Nuclear Chemistry
Tracers for following a chemical process
Dating organic and inorganic materials
Diagnosis of thyroid with ^{131}I
Pet scans by positron emission of C-11, O-15 and N-13.
Radiation therapy and Chemotherapy

Pasted from <http://fp.academic.venturacollege.edu/doliver/chem1b/notes/Chap24new.htm>