

Nuclear Chemistry Background

Atom = electrons and nucleus

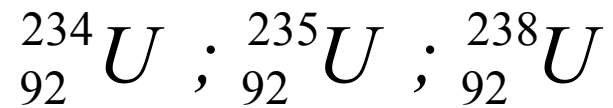
Nucleus = neutrons and protons = nucleons

Atomic number = number of protons in nucleus

Mass number = number of nucleons in nucleus

Isotopes = same atomic number but different mass number

mass number
atomic number X



Nuclide	a specific nucleus
Radionuclides	radioactive nuclides
Radioisotopes	Atoms containing a radionuclide

Types of Radioactive Decay

Alpha Particle emission

An Alpha particle (α) is a Helium 4 nucleus

Beta particle emission

A beta particle (β) is an electron

Gamma ray emission

A gamma (γ) ray is a photon

Types of Radioactive Decay (continued)

Positron emission

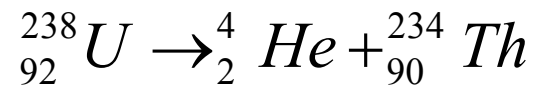
A positron is a positively charged electron

Electron Capture

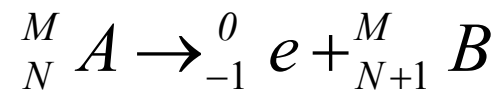
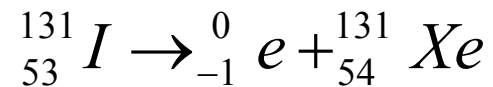
Capture by the nucleus of an atomic electron

Nuclear Equations

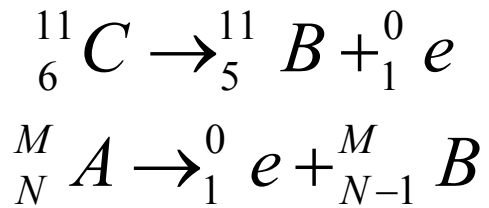
Alpha decay



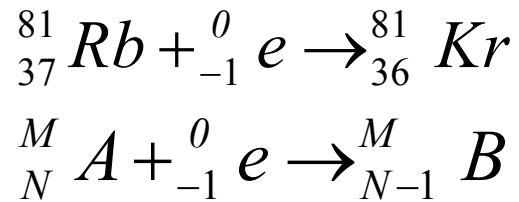
Beta Decay



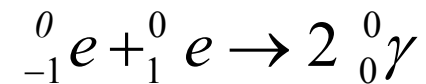
Positron Emission



Electron Capture



Gamma Emission

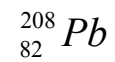
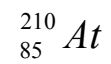
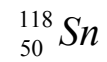
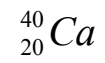


Assumptions

$${}^0_{-1}e + {}^1_1p \rightarrow {}^1_0n$$

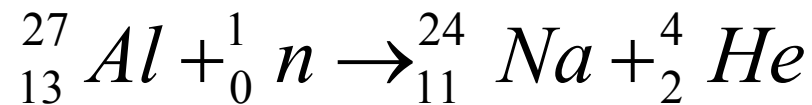
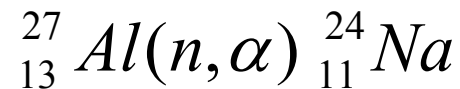
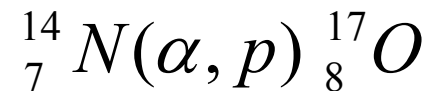
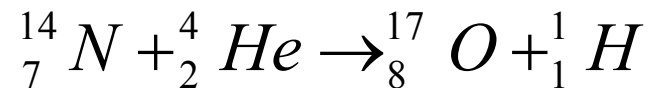
$${}^0_1e + {}^1_0n \rightarrow {}^1_1p$$

Predicting Nuclear Stability

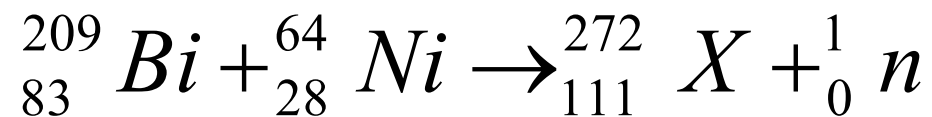
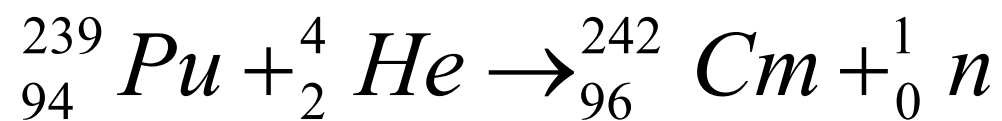


Nuclear Transmutations

Nuclear reactions that are not spontaneous but induced by the interaction with another nucleus or nucleon



Transuranium Elements (continued)



Rates of Radioactive Decay

Nuclear decay is a first order process

$$\frac{dN}{dt} = -kN$$

$$N(t) = N(0)e^{-kt}$$

$$\text{half life} = t_{1/2} = \frac{\ln 2}{k} = \frac{0.693}{k}$$

$$\text{Rate of decay} = -\frac{dN}{dt} = kN$$

Rate of decay (disintegrations per second) is also called activity

Units of activity

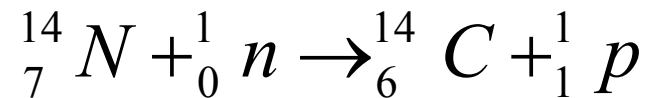
Becquerel (Bq) one nuclear disintegration per second

Curie (Ci) the rate of decay of 1 g of Radium or 1.5×10^8 disintegrations per second

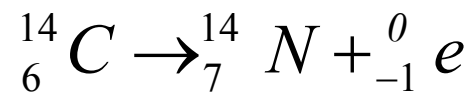
Carbon Dating

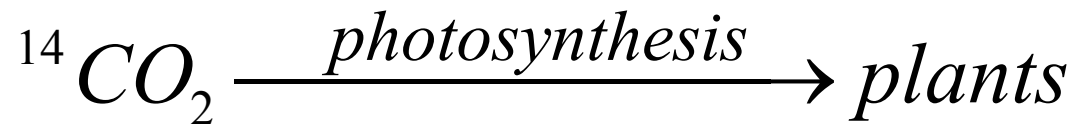
Use of carbon-14 half life to determine the age of an organic material

Carbon 14 is formed in the upper atmosphere



and has a half life of 5715 years





Ratio of ^{14}C to ^{12}C begins to decrease once plants die

If one knows the current ratio and the ratio just before death
one can calculate how long plant has been dead

Basic Assumption

The ratio of ^{14}C to ^{12}C has been constant in the atmosphere for 50,000 years.

Carbon Dating Example

A wooden artifact has a ^{14}C activity of 24.9 counts/minute as compared with an activity of 32.5 counts/minute for a standard of zero age.

How old is the artifact?

Potassium-40 Dating

Potassium-40 decays to argon-40 with a half-life of 1.27×10^9 years. What is the age of a rock in which the mass ratio of argon-40 to potassium-40 is 3.6?

Moles of K initially = moles of (K +Ar)

$$\frac{N_K(t)}{N_K(0)} = \exp(-kt) = \frac{N_K(t)}{N_K(t) + N_{Ar}(t)}$$

$$n_{Ar} = \frac{m_{Ar}}{40.0} \quad \& \quad n_K = \frac{m_K}{39.0}$$

$$\frac{N_K(t)}{N_K(t) + N_{Ar}(t)} = \frac{1}{1 + \frac{N_{Ar}(t)}{N_K(t)}} = \frac{1}{1 + \frac{n_{Ar}(t)}{n_K(t)}}$$

$$\frac{n_{Ar}(t)}{n_K(t)} = \frac{39.0}{40.0} \frac{m_{Ar}}{m_K} = 3.6 \frac{39.0}{40.0} = 3.5$$

$$0.222 = \exp(-kt)$$

$$k = \frac{\ln 2}{t_{1/2}}$$

$$t = 2.173 t_{1/2} = 2.76 \times 10^9 \text{ years}$$

Mass Defect

The mass of an **atom** is not the sum of the masses of its components.

The mass of a **nucleus** is not the sum of the masses of its component nucleons.

$$m({}_1^1p) = 1.00728 \text{ amu} \ \& \ m({}_0^1n) = 1.00866 \text{ amu}$$

$$m({}_2^4He) = 4.00150 \text{ amu}$$

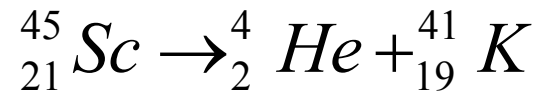
$$\Delta m({}_2^4He) = m({}_2^4He) - 2m({}_1^1p) - 2m({}_0^1n)$$

$$\Delta m({}_2^4He) = 0.03038 \text{ amu} \equiv 5.0447 \times 10^{-29} \text{ kg}$$

$$E = \Delta m({}_2^4He)c^2 = 4.534 \times 10^{-12} \text{ J} \equiv 28.30 \text{ MeV}$$

$$\text{Binding Energy/nucleon} = 7.075 \text{ MeV}$$

Consider the fission reaction



$$m(\text{Sc}) = 44.955914 \text{ amu}$$

$$m(\text{He}) = 4.00150 \text{ amu}$$

$$m(\text{K}) = 40.961825 \text{ amu}$$

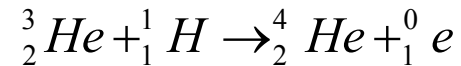
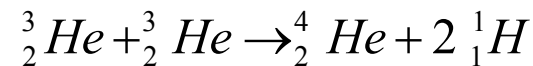
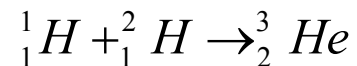
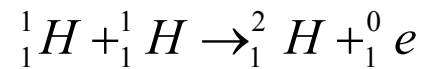
$$\Delta m(\text{amu}) = 40.961825 + 4.00150 - 44.955914$$

$$\Delta m(\text{amu}) = +0.007411 \text{ amu}$$

Nuclear Fusion

Form heavier nuclei from lighter nuclei via thermonuclear reactions.

Source of sun's energy



Requires temperatures of **40,000,000K**

Equivalence of mass and energy

$$E = mc^2$$

m in kilograms

$$c = 2.99792458 \times 10^8 \text{ m/s}$$

E in Joules

$$\text{Electron mass } 9.10938188 \times 10^{-31} \text{ kg}$$

$$E = 8.18710414 \times 10^{-14} \text{ J} = 5.109989 \times 10^5 \text{ eV}$$

$$E = 0.511 \text{ MeV}$$

What is the rest mass-energy of the proton?

$$\frac{m_p}{m_e} = 1836.15266$$

$$E_p^0 = E_e^0 \times 1836.15266$$

$$E_p^0 = 938.27199 \text{ MeV}$$

What is the rest mass-energy of a H atom?

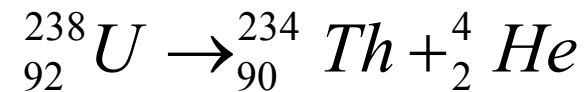
$$E(H) = E_p^0 + E_e^0 - IP(H)$$

$$E(H) = 938.782 \text{ MeV} - 13.6 \times 10^{-6} \text{ MeV}$$

$$E(H) = 938.782 \text{ MeV} - 0.0000136 \text{ MeV}$$

Energy Changes in Nuclear Reactions

Fission



$$m(\text{U}) = 238.0003 \text{ amu}$$

$$m(\text{Th}) = 233.9942 \text{ amu}$$

$$M(\text{He}) = 4.0015 \text{ amu}$$

$$\Delta E = E(\text{products}) - E(\text{reactants}) = -4.28 \text{ MeV}$$

