Radioactivity and radiation

Introduction

• Radioactive decay

• Properties of alpha, beta and gamma radiations

• Radioactive decay law

• Half life

• Units of radioactivity

• Nuclide chart

• Interactions of nuclear radiations

• Penetrating powers of nuclear radiations

Atomic Instability

• Atoms of a few naturally-occurring elements are unstable - undergo spontaneous transformation into more stable atoms by a process known as radioactive decay

• Such substances are said to be radioactive

• In radioactive decay three main types of radiation are emitted: alpha, beta and gamma

• Natural radioactivity was first recognized by Becquerel in 1896. He gives his name to the SI unit of activity (see later lecture)

Alpha, Beta, Gamma Radiations

• **Alpha (α)** radiation consists of helium nuclei (2 protons + 2 neutrons)

• **α particle** – mass 4 u, charge +2

• **Beta (β)** radiation consists of high-speed electrons originating in nucleus

• **β particle** - mass 1/1840 u, charge -1

• **Gamma (γ)** radiation results from changes in nucleus: consists of quanta of energy

• **Gamma rays** - electromagnetic radiation, energy inversely proportional to wavelength, $E \alpha 1/\lambda$

Wavelengths of EM Radiations

Type of radiation	Wavelength, λ (m)
Radio waves, long wave	1500
Radio waves, VHF	3
Visible light	10^{-6} to 10^{-7}
X-rays, 50 keV energy	2.5×10^{-11}
γ-rays, 1 MeV energy	1.2×10^{-12}

Radiation Energy

• Radiation energy: in electron volts(eV)

• One eV - energy gained by electron passing through electrical potential of 1 volt

• 1 keV = 1000 eV

• 1 MeV = 1000 keV = 10^6 eV

• Energies of other radiations also expressed in eV

• Kinetic energy (E_k) of particle of mass m travelling with velocity v is $E_k = \frac{1}{2} mv^2$

Radioactive Decay Mechanisms

• α-emission in which number of protons and neutrons in nucleus are each reduced by 2

• β-emission - a neutron changes into a proton by emitting a high-speed electron(β particle):

+ β –

• Positron emission - proton in nucleus ejects positive electron(β +) to become neutron

• Electron capture - an inner electron is captured by nucleus resulting in conversion of a proton into a neutron:

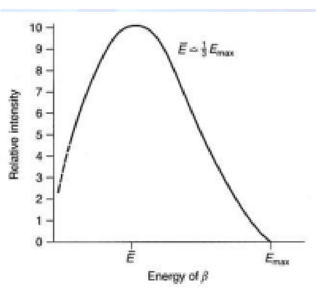
e-

Typical β Spectrum

• Electrons emitted during β-decay have a continuous energy distribution from zero to E_{max}

• E_{max} is characteristic of the particular nuclide

• Most probable β energy is about 1/3 E_{max}



Natural Radioactive Series

Series name	Final stable nucleus	Longest-lived member
Thorium	208Pb	^{232}Th ($T_{½}$ = 1.39 x 10^{10} y)
Uranium-radium	206Pb	^{238}U ($T_{½}$ = 4.50 x 10^{9} y)
Actinium	207Pb	^{235}U ($T_{½}$ = 8.52 x 10^{8} y)
Neptunium	209Pb	^{237}Np ($T_{½}$ = 2.20 x 10^{6} y)

Induced Radioactivity

• Lighter elements can be made radioactive by bombarding them with nuclear particles, e.g. neutrons in a nuclear reactor

• A neutron may be captured by a nucleus, with the emission of a γ-photon, known as an (n,γ) reaction

• An important example is

$$^{59}\boldsymbol{Co}\quad (\boldsymbol{n},\boldsymbol{Y})^{60}\boldsymbol{Co} \overset{\boldsymbol{\beta^{-}_{60}}}{\rightarrow} \boldsymbol{Ni}$$

Radioactive Decay Law

• Radioactive decay - a random, statistical process governed by the mathematical law

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

• The half-life ($T_{½}$) of a radioactive species is the time required for ½ of nuclei in sample to decay

$T_{½} = 0.693/\lambda$

The disintegration rate (activity) is proportional to the number of unstable nuclei

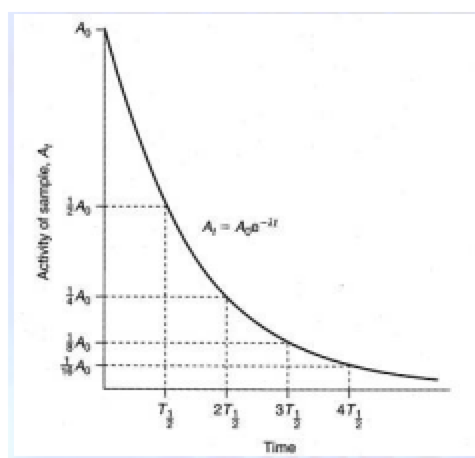
$A_t = A_0 e^{-\lambda t}$

Variation of Activity with Time

• In one half-life activity decays to ½ A0

• In two half-lives activity decays to ¼ A0

• Half-life of a particular radioactive isotope is constant and its measurement helps to identify unknown samples



The Unit of Radioactivity

• Original unit of radioactivity was the **curie (Ci)**

• The **curie** was originally related to the activity of 1 gram of radium but it was later standardized to 1Ci = 3.7 x 1010 disintegrations/sec

• Modern, SI unit is **becquerel (Bq)**

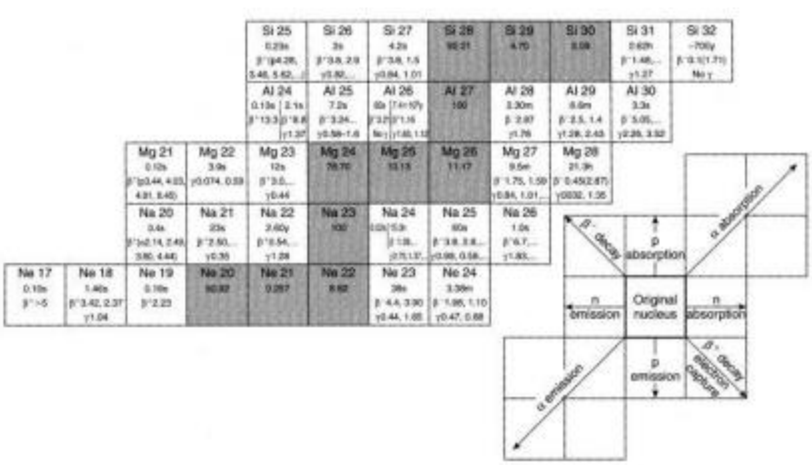
1Bq = 1 disintegration/sec

1kBq = 10^3 Bq = 10^3 dis/s

1MBq = 10^6 Bq = 10^6 dis/s

1TBq = 10^{12} Bq = 10^{12} dis/s

The Nuclide Chart



Interaction of Radiation with Matter

• Charged particles (α, β) lose energy mainly by interacting with atomic electrons. Transferred energy causes either excitation or ionization

• Bremsstrahlung X-rays: released when charged particles slow down rapidly in vicinity of nucleus

• X and γ radiation interactions: photoelectric effect, Compton scattering and pair-production

• Neutrons cannot cause ionization directly. They lose energy through elastic and inelastic scattering and various capture processes

Interaction of Nuclear Radiations

Radiation	Process	Remarks
Alpha	Collisions with atomic electrons	Leads to excitation and ionization
Beta	(a) Collisions with atomic electrons b) Slowing-down in field of nucleus	Leads to excitation and ionization Leads to emission of bremsstrahlung X-rays
X and Y radiation	(a) Photoelectric effect (b) Compton scattering (c) Pair-production	Photon is totally absorbed Only part of photon energy is absorbed in (b) and (c)
Neutron	(a) Elastic scattering (b) Inelastic scattering (c) Capture processes	These processes will be discussed in a later lecture

Penetrating Powers of Nuclear Radiations

• α particles – massive, travel slowly, high probability of interacting with atoms along their path. Lose energy rapidly and only travel very short distances

• β particles - very much smaller than α particles, travel much faster. Undergo fewer interactions per unit length of path and travel further than α's in dense media

• X and Y radiation loses energy mainly by interacting with atomic electrons. Travels very large distances and is very difficult to absorb completely

• Neutrons – interactions are energy dependent. Very penetrating - travel large distances even in dense media

Properties of Nuclear Radiations

Radiation	Mass (u)	Charge	Range in air	Range in tissue
Alpha	4	+2	0.03m	0.04mm
Beta	1/1840	-1 (positron +1)	3m	5mm
X,Y radiation	0	0	Very large	Through body
Fast neutron	1	0	Very large	Through body
Thermal neutron	1	0	Very large	0.15 m

Summary

• Radioactive decay - α, β particles and γ rays emitted

• α particle - helium nucleus, 2p + 2n, mass 4u, charge +2

• β particle - high-speed electron originating in nucleus, mass 1/1840u, charge -1 (+1 for positron)

• Y radiation - electromagnetic radiation, very short
wavelength, E α 1/λ, mass 0, charge 0

• Radioactive decay law $N_t = N_0 e^{-\lambda t}$

• Half-life $T_{½} = 0.693/\lambda$

• Becquerel (Bq) - SI unit of radioactivity, equal to1 dis/s

• Nuclide chart - compilation of data on all known nuclides

• Interactions of nuclear radiations - depend on various factors such as mass, energy, charge