Introduction to Radiation Physics

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INTRODUCTION TO RADIATION PHYSICS

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What do you think of when you hear the word Radiation?
What is Radiation?

RADIATION is an emission or propagation of energy through a medium or space in form of electromagnetic waves or particles.

Type of radiation based on physical properties

1. Particle
   a. Charged particle (alpha, beta)
   b. Uncharged particle (neutron)

2. Electromagnetic waves
   - All spectra of electromagnetic waves (Gamma ray, X-ray, Radio waves, visible light etc.)
Type of Radiation based on Ionization capability

Non-Ionizing

Ionizing

• Directly Ionizing (charged particles)
  • Electron, proton, alpha, etc.
• Indirectly Ionizing (neutral particle)
  • Photon, neutron
Ionizing photon radiation is classified into four categories:

- **Characteristic x ray**
  
  Results from electronic transitions between atomic shells.

- **Bremsstrahlung**
  
  Results mainly from electron-nucleus Coulomb interactions.

- **Gamma ray**
  
  Results from nuclear transitions.

- **Annihilation quantum (annihilation radiation)**
  
  Results from positron-electron annihilation.
Non-Ionizing Radiations

- MR Imaging (FM Region)
- Ultrasound.
- Microwave.
- Lasers used for various treatments.
- Visible Light to read images.
Is radiation Hazard?

Not All Radiation is hazardous

- IONIZING RADIATION → HAZARDOUS
- NON-IONIZING RADIATION → UN-HAZARDOUS
RADIATION

ELECTROMAGNETIC WAVES SPECTRA

LOW ENERGIES
(Non-Ionizing Radiation)

HIGH ENERGIES
(Ionizing Radiation)
# Electromagnetic Spectrum

## Learn the Order

<table>
<thead>
<tr>
<th>R</th>
<th>M</th>
<th>I</th>
<th>V</th>
<th>U</th>
<th>X</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>I</td>
<td>N</td>
<td>I</td>
<td>L</td>
<td>R</td>
<td>A</td>
</tr>
<tr>
<td>D</td>
<td>C</td>
<td>F</td>
<td>S</td>
<td>T</td>
<td>A</td>
<td>M</td>
</tr>
<tr>
<td>I</td>
<td>R</td>
<td>I</td>
<td>R</td>
<td>Y</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>V</td>
<td>A</td>
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<td>O</td>
<td>R</td>
<td>L</td>
<td>V</td>
<td>I</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>E</td>
<td>E</td>
<td>I</td>
<td>O</td>
<td>L</td>
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</tr>
<tr>
<td>V</td>
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<td>E</td>
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<tr>
<td>E</td>
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</tbody>
</table>
Electromagnetic Spectrum

LOW ENERGIES
(Non-Ionizing Radiation)

HIGH ENERGIES
(Ionizing Radiation)
Why Radiation happen?

Unstable nuclide will spontaneously change into stable nuclide. The change process is called radioactive decay where in each of the decay process the radiation will be emitted (alpha, beta and gamma).
### Characteristics of Radiation

<table>
<thead>
<tr>
<th>Type of Radiation</th>
<th>Ionization</th>
<th>Penetration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha</td>
<td>large</td>
<td>low</td>
</tr>
<tr>
<td>Beta</td>
<td>medium</td>
<td>medium</td>
</tr>
<tr>
<td>X-ray</td>
<td>Small</td>
<td>large</td>
</tr>
<tr>
<td>Gamma ray</td>
<td>Small</td>
<td>More large</td>
</tr>
</tbody>
</table>
Characteristic of Nuclear Radiation

NUCLEAR RADIATION

- Invisible
- Senseless
- Colourless
- not influenced by temperature and pressure
- Ionize
Atomic Models

Thomson atomic model

Positive charge
Negative electrons

Rutherford atomic model

Positive charge
Negative electrons
Drawback of Rutherford’s Model
Atomic structure:
- **Nucleus**: proton and neutron
- **Electron**: that revolve around the nucleus in orbit or a certain distance
Shortcoming of Bohr’s theory

(i) The theory could not account for the spectra of atoms more complex than hydrogen.

(ii) The theory does not give any information regarding the distribution and arrangement of electrons in an atom.

(iii) It does not explain, the experimentally observed variations in intensity of the spectral lines of the element.

(iv) When the spectral line of hydrogen atom is examined by spectrometers having high resolving power, it is found that a single line is composed of two or more close components. This is known as the fine structure of spectral lines. Bohr’s theory could not account for the fine structure of spectral lines.

(v) It is found that when electric or magnetic field is applied to the atom, each of the spectral line split into several lines. The former effect is called as Stark effect, while the latter is known as Zeeman effect. Bohr’s theory could not explain the Stark effect and Zeeman effect.
NUCLEUS

Consisting of protons and neutrons

\[ X : \text{Atomic Symbol} \]
\[ Z : \text{Atomic Number} \ (\text{number of proton}) \]
\[ A : \text{Atomic Mass} \ (\text{number of proton} + \text{neutron}) \]
Examples

Element: Helium
Proton (Z) = 2
Neutron (N) = 2

Element: Cobalt
Proton (Z) = 27
Neutron (N) = 32
There is no basic relation between the atomic mass number $A$ and atomic number $Z$ of a nucleus but the empirical relationship:

$$Z = \frac{A}{1.98 + 0.0155A^{2/3}}$$

furnishes a good approximation for stable nuclei.
Nucleus Stability

Depends on the composition of proton and neutron in the nucleus

In general:
- Light nucleus $\Rightarrow N = Z$
- Heavy nucleus $\Rightarrow N = 1\frac{1}{2} \cdot Z$
## Nucleus Stability

<table>
<thead>
<tr>
<th>Proton</th>
<th>Neutron</th>
<th>No. of stable Nucl.</th>
<th>Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Odd</td>
<td>Odd</td>
<td>4</td>
<td>least stable</td>
</tr>
<tr>
<td>Odd</td>
<td>Even</td>
<td>50</td>
<td>more stable</td>
</tr>
<tr>
<td>Even</td>
<td>Odd</td>
<td>57</td>
<td>even more stable</td>
</tr>
<tr>
<td>Even</td>
<td>Even</td>
<td>168</td>
<td>most stable</td>
</tr>
</tbody>
</table>
Stability curve

- Belt of stability
- (1.5:1 ratio) $^{200}_{80}$Hg
- (1.4:1 ratio) $^{120}_{50}$Sn
- (1.25:1 ratio) $^{90}_{40}$Zr

Number of neutrons vs. Number of protons
Examples of stable nuclides

Stable nuclides are shown in black boxes.
PROTON RICH SIDE, "LOW" N/Z, POSITRON (β⁺) OR EC INSTABILITY.
(p → n + e⁺)

N = Z

Z = \frac{2A}{4 + \frac{a_c}{a_a} A^{2/3}}

ISOBAR LINE

NEUTRON RICH SIDE, "HIGH" N/Z, NEGATRON (β⁻) INSTABILITY,
(n → p + e⁻)

NEUTRON NUMBER N

ATOMIC (PROTON) NUMBER Z

A = 60

A = 137
Radioactive decay

Nuclear Transformation

Ionizing Radiation: α, β, or γ
Alpha decay

Emission of alpha particle alpha that is identical to the nucleus of Helium atom

$$\alpha \approx _2^4\text{He}$$

Charge: + 2 elementer charge
Mass: 4 amu

Contoh: $^{90}_{\phantom{0}}\text{Th}^{230} \rightarrow ^{88}_{\phantom{0}}\text{Ra}^{226} + \alpha$
Alpha Particles

$Z - 2, \ M - 4$

$Z, \ M$

$^4_2\alpha \ \leftrightarrow$

Alpha Particle (Helium Nucleus)
Beta decay

Emission of beta particle

\[ \beta^+ \approx +1e^0 \]
\[ \beta^- \approx -1e^0 \]

Charge: + or – 1 elementer charge
Mass: 0 amu

Contoh:
\[ _4\text{Be}^{11} \rightarrow _5\text{B}^{11} + \beta^- \]
\[ _6\text{C}^{10} \rightarrow _5\text{B}^{10} + \beta^+ \]
Beta Particles

$Z + 1, M$ → $Z, M$ → $^{0}_{0}\nu$, Antineutrino → $^{0}_{-1}\beta^-$, Beta Particle
Gamma decay

Emission of electromagnetic wave

Charge $\gamma : 0$

Mass $\gamma : 0$

Example: $^{56}\text{Ba}^{137*} \rightarrow ^{56}\text{Ba}^{137} + \gamma$
**Gamma Rays**

Gamma rays are electromagnetic radiation resulting from nuclear transformation.
Production of X-Rays

Electron or beta → Target Nucleus (Heavy metal) → X-Ray
Example: Radioactive Decay

\[ 90^{230}\text{Th} \rightarrow 88^{226}\text{Ra} + \alpha \]
\[ 4^{11}\text{Be} \rightarrow 5^{11}\text{B} + \beta^- \]
\[ 6^{10}\text{C} \rightarrow 5^{10}\text{B} + \beta^+ \]
\[ 56^{137}\text{Ba}^{*} \rightarrow 56^{137}\text{Ba} + \gamma \]
Decay scheme

$^{55}\text{Cs}^{137}$

$T_\frac{1}{2}$ 30 Th

1176 keV

$\beta_2$ 6 %

$^{56}\text{Ba}^{137*}$

$T_\frac{1}{2}$ 2.5 mnt

662 keV

$\gamma$ 85 %

$^{56}\text{Ba}^{137}$
What Activity of Radiation?

Number of disintegration per time unit

Determine the number of radionuclide which is not stable change to become stable nuclide in one second

Unit:

- Currie (Ci) old unit
- Bequerel (Bq) new unit (SI)

\[ A = A_0 e^{-\lambda \cdot t} \]

1 Ci = 3,7 \times 10^{10} Bq or
1 \mu Ci = 3,7 \times 10^{4} Bq = 37.000 Bq
1 Bq = 1 disintegration per second
Activity of Radiation

Activity (A) vs. Time (t)

Initial Activity (Ao)

\[ A = A_0 e^{-\lambda \cdot t} \]
Half-life

$T^{1/2} = \frac{0.693}{\lambda}$
Utilization of $T_{1/2}$

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$Ao$</td>
</tr>
<tr>
<td>1 x $T_{1/2}$</td>
<td>0,5 x $Ao$</td>
</tr>
<tr>
<td>2 x $T_{1/2}$</td>
<td>0,25 x $Ao$</td>
</tr>
<tr>
<td>3 x $T_{1/2}$</td>
<td>0,125 x $Ao$</td>
</tr>
<tr>
<td>4 x $T_{1/2}$</td>
<td>0,0625 x $Ao$</td>
</tr>
<tr>
<td>5 x $T_{1/2}$</td>
<td>0,03125 x $Ao$</td>
</tr>
<tr>
<td>6 x $T_{1/2}$</td>
<td>0,0156 x $Ao$</td>
</tr>
</tbody>
</table>

$$A = \left(\frac{1}{2}\right)^n \cdot A_0$$

$n = \text{time} : T_{1/2}$
Charged Particles Interactions

Alpha
1. Ionization
2. Excitation
3. Nuclear reaction

Beta
1. Ionization
2. Excitation
3. Brehmsstrahlung
Ionization

Charged Particle

Electron emitted

Inti Atom

Elektron

Lintasan Elektron

Elektron

Elektron

Elektron
Excitation

Charged Particle

Inti Atom

Elektron

Lintasan Elektron

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Nuclear reaction

\[ _4^{9}\text{Be} + \alpha \rightarrow _6^{12}\text{C} + n \]
Brehmsstrahlung

F = 3,5 \times 10^{-4} \cdot Z \cdot E_{\text{max}}

High energy Beta

Inti Atom

Elektron

Kulit K

Kulit L

Sinar-X

X-ray
Neutral particle

- Elastic collision
- Inelastic collision
- Nuclear reaction
- Fission
Elastic collision

Before collision

After collision
Inelastic Collision

Before collision: Neutron collides with an Atom.

After collision: The Atom is deformed, and a new particle is emitted.
Nuclear Reaction

Before collision	After collision

Neutron Thermal

Nuclei

$ZX^A$

$ZX^{A+1}$

radiation
Fission

\[ \text{U}^{235} + n_t \rightarrow Y_1 + Y_2 + (2-3)n + Q \]

\[ {}^{92}\text{U}^{235} + n_t \rightarrow {}^{54}\text{Xe}^{140} + {}^{38}\text{Sr}^{94} + 2_0n^1 + Q \]
Electromagnetic waves

- Photoelectric
- Compton
- Pair Production
Photoelectric

Electromagnetic waves

Electron emitted
Compton effect

Electromagnetic waves

Electron emitted

Electromagnetic waves
Pair production

Electromagnetic waves

Elektron

Inti Atom

Electron

Positron
# Characteristics of radiation

<table>
<thead>
<tr>
<th>Types</th>
<th>Ionization</th>
<th>Penetration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Beta</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Gamma</td>
<td>Low</td>
<td>Very High</td>
</tr>
<tr>
<td>X-ray</td>
<td>Low</td>
<td>High</td>
</tr>
</tbody>
</table>
Absorption of Gamma / X-ray

\[ I = I_0 e^{-\mu \cdot x} \]

Narrow beam

\[ I = B \cdot I_0 e^{-\mu \cdot x} \]

Broad beam
Radiation Sources

**Nature:**
- Cosmic (high energy radiation from cosmic \(10^{17}\text{eV}\), produced: C-14, Be-7, Na-22 and H-3.)
- Terrestrial (primordial radiation \(T1/2 = 10^9\) years; Ra-222 (Radon), Ra-220 (Thoron), K-40.)
- Internal (inside the body: K-40, C-14, H-3.)

**Artificial:**
- Radioactive material (for industry, medical etc: Co-60, Cs-137, I-131, Mo-99.)
- X-ray Machine (for industry and medical)
- Accelerator (to accelerate charge particles: LINAC, Cyclotron.)
- Reactor (for research and power plan)
X-ray Machine

Configuration of Radioflex Series

X-Ray Generator

1. Low voltage cable 20m
2. Power cable 20m

Controller

1. Gilt
2. Flashlight to indicate X-ray generation
3. Spare lamps
4. Spare tubes
5. Direction indicator
6. Storage bag for accessories
Radioactive sources

Source

Connector
Radioisotope Sources

<table>
<thead>
<tr>
<th>Type</th>
<th>Energy (MeV)</th>
<th>Half live</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-60</td>
<td>1.17</td>
<td>5.3 years</td>
</tr>
<tr>
<td>Tm-170</td>
<td>0.07</td>
<td>127 days</td>
</tr>
<tr>
<td>Se-75</td>
<td>0.4</td>
<td>118 days</td>
</tr>
<tr>
<td>Ir-192</td>
<td>0.31</td>
<td>74 days</td>
</tr>
<tr>
<td>Cs-137</td>
<td>0.66</td>
<td>30 years</td>
</tr>
<tr>
<td>Yb-169</td>
<td>0.17</td>
<td>30 days</td>
</tr>
</tbody>
</table>
Thank you. Question?
Terima Kasih