Radioactivity = particles emitted from nucleus as result of nuclear instability.

Classified by range in matter:

$\alpha$: He$^+$ heavy, doubly charged
stopped by piece of paper

$\beta$: $e^-$ stopped by Al foil

$\gamma$: highly penetrating, penetrate concrete wall
stopped by block of lead

$\nu$: neutron, massive, no charge
highly penetrating
molested (slowed) by nearly equal mass protons
hydrogen-rich materials like water, wax

\[ \alpha \rightarrow \beta \rightarrow \gamma \]
Measure of source "strength" or activity:

1 Curie = $3.7 \times 10^{10}$ decay/second

Decay according to exponential law:

\[
\frac{N(t)}{N(0)} = \frac{1}{2} e^{-\frac{t}{\tau}}
\]

where $\tau$ is the "lifet ime".

Half-life $T_{\frac{1}{2}} = \ln(2) \tau = 0.69 \tau$

After $n$ half-lives,

\[
N(nT_{\frac{1}{2}}) = N(0) \left(\frac{1}{2}\right)^n
\]
\( \alpha \) decay

\[
\text{He}^{++} = 2p, 2n \quad \text{Very tightly bound}
\]

Enormous range of half lives

Fraction of second \( \approx 8 \text{ MeV} \) \( \alpha \)

billion of years \( \approx 4 \text{ MeV} \) \( \alpha \)

Result of Q.M. tunneling.

Nuclear force has short range

\[ F = 0 \]

\[ \Delta \text{ stat} \]

Classically forbidden region

\( \text{Strong force range} \)

Tunneling gives exponential dependence on thickness of barrier
Example: Atomic mass (# protons + neutrons)

\[ ^{238}_{92} \text{U} \]

\( ^{238}_{92} \text{U} \rightarrow ^{234}_{90} \text{Th} \rightarrow ^{206}_{82} \text{Pb} \text{ (stable)} \)

\( ^{232}_{90} \text{Th} \rightarrow ^{228}_{88} \text{Ra} \quad 1.4 \times 10^9 \text{ years} \)

\( ^{222}_{86} \text{Rn} \rightarrow ^{218}_{84} \text{Po} \quad 3.8 \text{ days} \)

Rn is inert gas.

Inhaled deposits energy in lung tissue - carcinogenic.

U, Th naturally occurring in rock. Created in supernovae.

Ratio \( ^{206}_{82} \text{Pb} : ^{238}_{92} \text{U} \) used to date age of Earth = 4.55 billion yrs.
Beta decay

$\beta^+ : e^+ \text{ electron, positron}$

Free neutron $n \rightarrow p + e^- + \bar{\nu}_e$

$T_{1/2} = 600 \text{ s}$

$\bar{\nu}_e$ neutral weakly interacting particle

Inside nuclei, $n$ can be stable.

In heavy nuclei, $n \rightarrow p$ can be unstable.

$\beta^-$ decay $\quad \overline{n} \rightarrow p + e^- + 2\bar{\nu}_e \quad Z \rightarrow Z+1$

$\beta^+$ decay $\quad p \rightarrow n + e^+ + \nu_e \quad Z \rightarrow Z-1$

e$^{-}$-capture $\quad p + e^- \rightarrow n + \nu_e \quad Z \rightarrow Z-1$
$\gamma$-decay

disruption of nucleus in $\alpha$/$\beta$ decay

often leaves daughter nucleus in excited state - deexcite by

emitting mev-"ish" photon $\gamma$-ray

Just like atom, nucleus has discrete

energy states.

Detector

thin window

Geiger counter $\rightarrow$ +V (keV)

Ar gas

primary ionization multiplied by

secondary ionization in high E field

near wire.
$\gamma$-detector

Scintillating Crystal inside Al Shield

H.V. → PMT → e$^+$ → e$^-$ → e$^0$

$\gamma$-rays

Scintillation photons detected by PMT which multiplicit $e^-$ from photo-cathode (photo-electric effect)
Effects of ionizing radiation

Ionization causes cell damage, cell mutation, cell death.

Cells that are dividing are most susceptible.

Unit of absorbed dose:

\[1 \text{ rad} = \frac{1}{100} \text{ Joule/Kg}\]

Biological damage:

\[1 \text{ rem} = (\text{weighting factor}) \text{ rad}\]

<table>
<thead>
<tr>
<th>Radiation</th>
<th>Weighting Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>X, Y, \beta</td>
<td>1</td>
</tr>
<tr>
<td>Neutron</td>
<td>5-20 depending on energy</td>
</tr>
<tr>
<td>Proton</td>
<td>5</td>
</tr>
<tr>
<td>\alpha, fission fragments</td>
<td>20</td>
</tr>
</tbody>
</table>
Naturally occurring radiation sources

<table>
<thead>
<tr>
<th>Source</th>
<th>2 x 10^{-3} rem/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cosmic rays (sea level)</td>
<td>30</td>
</tr>
<tr>
<td>@ ABQ</td>
<td>60</td>
</tr>
<tr>
<td>Interior (Carbon-14, Potassium-40)</td>
<td>40</td>
</tr>
<tr>
<td>Radon</td>
<td>~200</td>
</tr>
</tbody>
</table>

~300 mrem/yr total

Radiation worker limit (U.S.) = 5000 mrem/yr

Lethal dose (50% mortality in 30 days) = 250-450 rad

Cancer induction probability: 5% per 100 rad on average