The Atomic Nucleus

Discovery of Radioactivity
Lead block
Alpha particle (helium nucleus)
Beta particle (electron)
Gamma ray
(ultra-high energy nonvisible light)
Radioactive Source

α

Paper

Aluminum

Lead
Radioactive Source

Paper

Aluminum

Lead
Radioactive Source

Paper

Aluminum

Lead

γ

γ
Radioactivity Is a Natural Phenomenon
Origins of radiation exposure
Origins of radiation exposure

Natural Background (cosmic rays, earth minerals) 81%

Medicine and Diagnostics 15%

Consumer Products (televisions sets, smoke detectors) 4%
Unit of radiation exposure
Unit of radiation exposure

rad
Unit of radiation exposure

\[
\text{rad} = \frac{0.01 \text{ joule}}{\text{kilogram of tissue}}
\]
Some forms of radiation are more harmful to living organisms than others...
Ability to cause harm is given in “rem”

\[ \text{rem} = \text{rad} \times \text{factor} \]
<table>
<thead>
<tr>
<th>Particle</th>
<th>Dosage</th>
<th>Factor</th>
<th>Health effect</th>
</tr>
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<tr>
<td>alpha</td>
<td>1 rad</td>
<td>$\times 10$</td>
<td>10 rem</td>
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</table>
1 rem = 1000 millirem

(mrem)
Average annual exposure per person in the United States

about 360 mrem

Major Source

Radon - 222
## Typical Annual Radiation Exposure

<table>
<thead>
<tr>
<th>Source</th>
<th>Typical Amount Received in 1 Year (millirems)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Natural Origin</strong></td>
<td></td>
</tr>
<tr>
<td>Cosmic radiation</td>
<td>26</td>
</tr>
<tr>
<td>Ground</td>
<td>33</td>
</tr>
<tr>
<td>Air (radon-222)</td>
<td>198</td>
</tr>
<tr>
<td>Human tissues (postassium-40; radium-226)</td>
<td>35</td>
</tr>
<tr>
<td><strong>Human Origin</strong></td>
<td></td>
</tr>
<tr>
<td>Medical procedures</td>
<td></td>
</tr>
<tr>
<td>Diagnostic X rays</td>
<td>33</td>
</tr>
<tr>
<td>Nuclear medicine</td>
<td>15</td>
</tr>
<tr>
<td>Television tubes, other consumer products</td>
<td>11</td>
</tr>
<tr>
<td>Weapons-test fallout</td>
<td>1</td>
</tr>
</tbody>
</table>
Radioactive Isotopes Are Useful as Tracers and for Medical Imaging
<table>
<thead>
<tr>
<th>Isotope</th>
<th>Usage</th>
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<tbody>
<tr>
<td>Calcium-47</td>
<td>Study of bone formation in mammals</td>
</tr>
<tr>
<td>Californium-252</td>
<td>Inspect airline luggage for explosives</td>
</tr>
<tr>
<td>Hydrogen-3 (tritium)</td>
<td>Life-science and drug-metabolism studies to ensure safety of potential new drugs</td>
</tr>
<tr>
<td>Iodine-131</td>
<td>Diagnose and treat thyroid disorders</td>
</tr>
<tr>
<td>Iridium-192</td>
<td>Test integrity of pipeline welds, boilers, and aircraft parts</td>
</tr>
<tr>
<td>Thallium-201</td>
<td>Cardiology and for tumor detection</td>
</tr>
<tr>
<td>Xenon-133</td>
<td>Lung-ventilation and flood-flow studies</td>
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*Source: Nuclear Regulatory Council*
Radioactivity Results from an Imbalance of Forces in the Nucleus
Helium nucleus
Strong Nuclear Force

An attractive force that acts between all nucleons
These protons are not normally attracted to each other
Neutrons are needed to create the strong nuclear force.
There is a limit to the number of neutrons that can be added to an atomic nucleus...
...neutrons need to have protons around them in order to remain stable...
...with too many neutrons, and not enough protons, something most bizarre occurs...
A lone neutron...
...converts to a proton!
Proton to Neutron ratios
Proton to Neutron ratios

Optimum 1 to 1
Proton to Neutron ratios

Optimum \hspace{2cm} 1 \text{ to } 1

Limit \hspace{2cm} 1 \text{ to } 1.4
A nucleus with “too many neutrons”
A nucleus with “too many neutrons”
Hmm...extra proton?
The size of the nucleus is limited

1) The nucleus cannot hold a very large number of protons together.

2) There cannot be an unlimited number of neutrons.
A Radioactive Element Can Transmute to a Different Element
Transmutation

The changing of one element to another
$^{234}_{90} Th \rightarrow ^{4}_{2} He$
$^{238}_{92}U$
$^{234}_{90}Th^{4}_{2}He$
$^{234}_{90}Th$ $^4_2He$
238
92

U

234
90

Th

+ 4
2

He
$^{234}_{90}Th \rightarrow ^{234}_{91}Pa + 0^\text{e} - 1^\text{e}$
Radioactive Half-Life

The time it takes for one-half of a radioactive sample to decay
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<tr>
<td>Polonium-214</td>
<td>$1.6 \times 10^{-4}$ sec</td>
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Sample of radium-226
Sample mass (kg)

$rac{1}{2}$

1620

Years

Sample of radium-226
Radioactive Half-Life

The time it takes for one-half of a radioactive sample to decay

Look at factors of 2
One half-life (1/2)
Two half-lives (1/4)
Three half-lives (1/8)

For Example: A material has decreased by 1/4 of its original amount; it has gone through two half-lives
N-14
N-14

7

7
C-14
C-14
C-14
C-14
C-14
$^{14}\text{CO}_2$
Carbon-14 is a radioactive isotope that is naturally incorporated from carbon dioxide into living organisms, the amount remains relatively constant during the life of the organism.

When the living organisms dies the carbon 14 is no longer being replaced in the organism and will start to decay. The amount of loss from the that compared to living organisms can be used to determine when the organism died.
22,920 years ago
17,190 years ago
11,460 years ago
5730 years ago
Problem: The carbon-14 radioactivity in the bones of a body was measured to be 1/8 of that compared to a living person. How long ago did the person live?
Calculate Age

Calculation of Age:
The carbon-14 has decreased by 1/8 which is three half lives (1/2 times 1/2 times 1/2 = 1/8)

Carbon-14 half life = 5730 years

3 times 5730 = 17,190 years
One Half-Life
5730 years ago
Two Half-Lives
11,460 years ago
Three Half-Lives
17,190 years ago