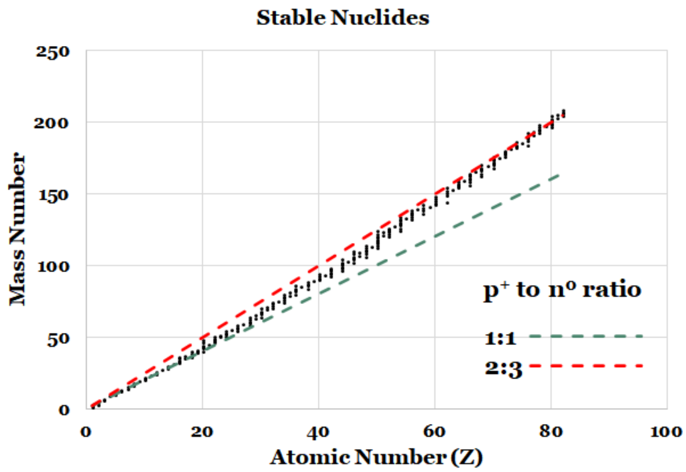
Nuclear Chemistry

Stable Nuclides

- stability is related to the ratio of protons to neutrons (p^+ to n^o)
  stable light elements (Z ≤ 20) have a p^+:n^o ratio of 1:1
  stable heavy elements (Z > 75) have a p^+:n^o ratio of 2:3



- stability is related to the size of the nucleus
  no stable nuclides with Z > 83 (Bi)
  no long lasting nuclides with Z > 92
- stability is related to the numbers of even or odd p^+ or n^o

p^+:n^o	E:E	E:O	O:E	O:O	Totals
Stable	148	53	48	5	254
Long Lived	22	4	5	4	35
Primordial	170	57	53	9	289

Types of Radioactive Decay Particles (Table O)

Name	Notation	Symbol
alpha particle	${}^{4}_{2}He$ or ${}^{4}_{2}\alpha$	α
beta particle	${}^{0}_{-1}e$ or ${}^{0}_{-1}\beta$	β
gamma	${}^{0}_{0}\gamma$	γ
neutron	${}^{1}_{0}n$	n
proton	${}^{1}_{1}H$ or ${}^{1}_{1}p$	p
positron	${}^{0}_{+1}e$ or ${}^{0}_{+1}\beta$	β^+

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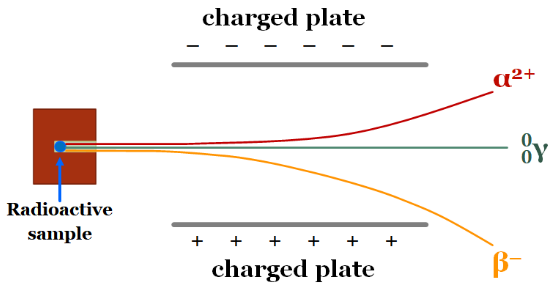
Separate and Identify Radioactive Decay Particles



Identify decay particles using Table N

What type of radioactive decay particle is emitted from cobalt-60?

An electron or β– particle (also γ radiation which is not shown on Table N)

What is the decay mode of tritium, ${}^3H$?

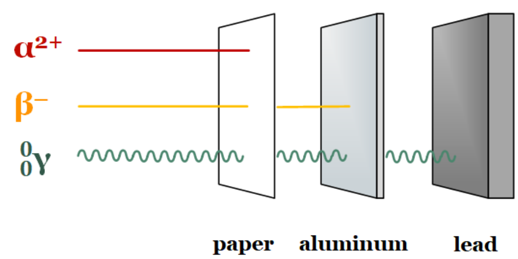
An electron or β– particle

What is the decay mode of U-235?

An alpha particle or α particle

The Penetrating Power of Radioactive Decay Particles

Name	Penetrating Power	Mass	Speed	Charge
α particle	very slight	high	low	+2
β particle	slight	low	high	−1
γ radiation	very high	0	c	0



Half-Life

The time required for one-half of the original mass of a radioisotope to decay (Table N)

Radioactive decay is a first order reaction – the reaction rate does not depend on effective collisions, but *only* on the total number of radioisotopes present

Example: How much of a 6.00 gram sample of I-131 would remain after 40.105 days?

$t_{1/2}$ = 8.021 d (from Table N)

40.105 d ÷ 8.021 d / $t_{1/2}$ = 5 $t_{1/2}$

6.00 g ÷ 2^5 = 6.00 ÷ 32 = 0.188 g

Example: How old is a wood sample containing 12.5% of the C-14 in living trees?

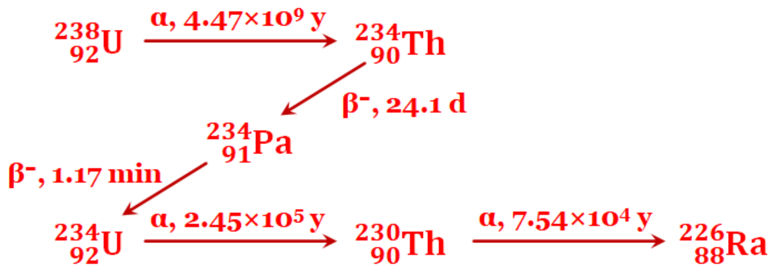
$t_{1/2}$ = 5715 y (from Table N)

12.5 % = 0.125 = 2^{-3} or 3 $t_{1/2}$

5715 y × 3 = 17 150 y

Radioactive Series – successive elements formed by the decay of a long lived parent isotope

Radioisotopes that begin a series are called parent material and the products are called daughter material



Transmutation

Two types of transmutation

Radioactive decay: a *spontaneous* nuclear breakdown

- natural transmutation
- a new element forms
- only one element or particle appears before the yields arrow

Artificial transmutation: the nucleus is bombarded to *cause* a nuclear breakdown

- nonspontaneous
- requires bombardment to begin the reaction
- an element and a bombardment particle appear before the yields arrow

Laws of Conservation must be maintained in nuclear reactions

- conservation of mass – the sum of the mass numbers of the reactants (to the left of the arrow) must equal the sum of the mass numbers of the products (to the right of the arrow)
- conservation of charge – the sum of the atomic numbers of the reactants must equal the sum of the atomic numbers of the products

Natural transmutation example

$^{210}_{84}Po \rightarrow {}^{206}_{82}Pb + {}^{4}_{2}He$ 210 = 206 + 4; 84 = 82 + 2

Artificial transmutation example

$^{27}_{13}Al + {}^{4}_{2}He \rightarrow {}^{30}_{15}P + {}^{1}_{0}He$ 27 + 4 = 30 + 1; 13 + 2 = 15 + 0

Transmutation Reactions by Decay Particle

Alpha decay:	$^{210}_{84}Po \rightarrow {}^{206}_{82}Pb + {}^{4}_{2}He$
Beta decay (β⁻):	$^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$
Positron emission (β⁺):	$^{23}_{12}Mg \rightarrow {}^{23}_{11}Na + {}^{0}_{+1}e$
Electron capture:	$^{81}_{37}Rb + {}^{0}_{-1}e \rightarrow {}^{81}_{36}Kr + \nu_e$
Gamma emission:	$^{60}_{27}Co \rightarrow {}^{60}_{28}Ni + {}^{0}_{-1}e + {}^{0}_{0}\gamma$ (2 possible ${}^{0}_{0}\gamma$)

Transmutation Reactions (using Table N)

$^{85}_{36}Kr \rightarrow {}^{0}_{-1}e + {}^{85}_{37}Rb$ ${}^{0}_{-1}e$ obtained from Table N, ${}^{85}_{37}Rb$ derived from mass and charge

$^{232}_{90}Kr \rightarrow {}^{4}_{2}He + {}^{228}_{88}Ra$ ${}^{4}_{2}He$ obtained from Table N, ${}^{228}_{88}Ra$ derived from mass and charge

Radioisotopes

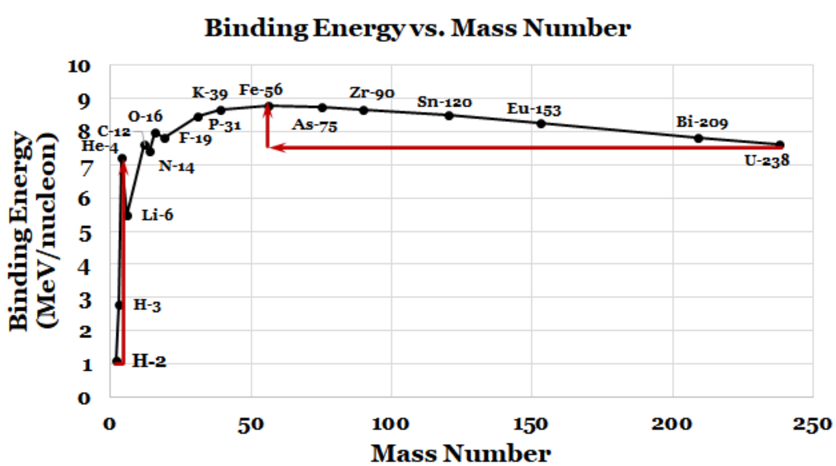
Uses for radioisotopes:

- medical
  - iodine-123: diagnose thyroid disorders
  - iodine-131: treat thyroid disorders
  - cobalt-16: γ-ray source for cancer treatments or sterilizing instruments or food
- tagging
  - oxygen-18: determine oxygen source in reactions
- dating
  - carbon-14: determine the age of wood
  - uranium-238: date rocks, age of the earth
- gauging
  - krypton-85: measure thickness of thin plastic films
- Nuclear Power
  - fission: splitting heavy nuclei keep the 'i's together – split = fission

    $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{92}_{36}Kr + ^{141}_{56}Ba + 3\,^{1}_{0}n$
  - fusion: unite (combine) light nuclei keep the 'u's together – unite = fusion

    $^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$

Fission vs. Fusion and Energy: the Einstein equation, $E=mc^2$



Fission gives a maximum of 1.2 MeV

Fusion gives a maximum of 6.0 MeV

Nuclear Energy

Nuclear reactions can generate thousands of times more power than coal, gas, or oil

The binding energy vs. mass number graph reveals why energy comes from fusion of light elements and fission of heavy elements

The energy comes from converting nuclear mass to energy, $E = mc^2$

Iron, Fe, has the highest conversion of mass to energy

Light elements must combine to move toward Fe

Heavy elements must be split to move toward Fe

Even though fusion can generate more energy, experiments using fusion have not been able to be controlled

Nuclear reactors in use today therefore use fission to generate heat to turn a steam turbine to generate electricity

The artificial transmutation reaction used is fission of uranium-235 by neutron bombardment

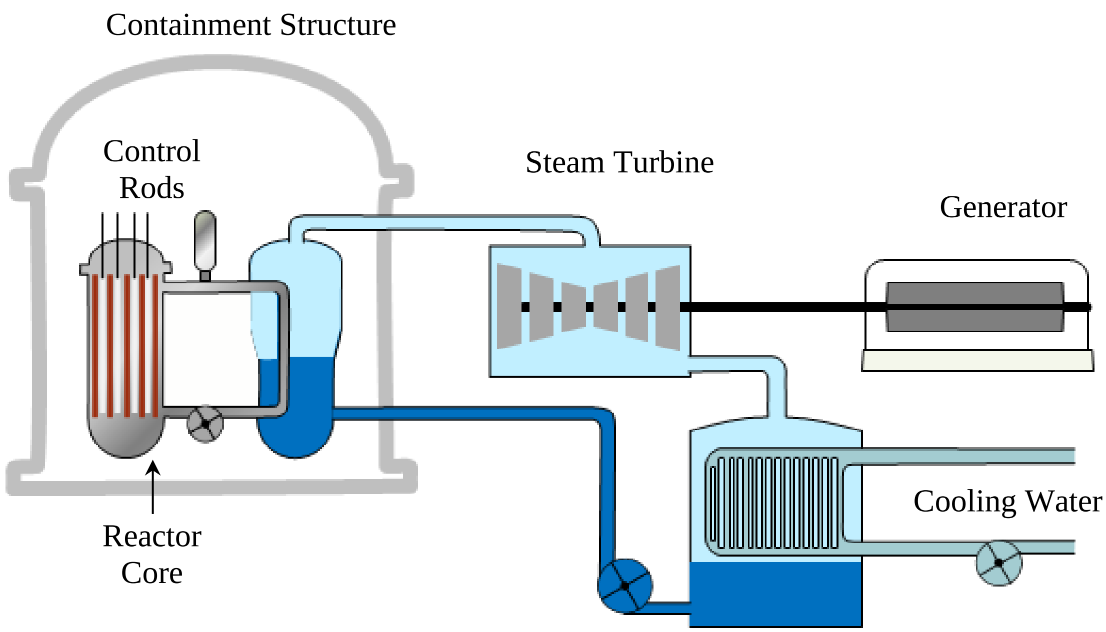
$${}^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{92}_{36}\text{Kr} + {}^{141}_{56}\text{Ba} + 3\,{}^{1}_{0}\text{n}$$

If the amount of U-235 is small, most of the neutrons generated by the reaction do not strike more U-235 and the reaction dies out, below *critical mass*

Critical mass occurs when the number of neutrons generated strike enough U-235 to sustain a continuous reaction or chain reaction

If the amount of U-235 is large, most of the neutrons generated by the reaction strike more U-235 and the reaction rapidly builds to a nuclear explosion (atom bomb)

Nuclear Reactor (cut-away view)



The water in the reactor core, the water in the steam system, and the cooling water are confined to three separated system to prevent escape of ionizing radiation

Nuclear Reactor Risks:

- biological exposure to ionizing radiation (may cause death)
- long term storage of radioactive daughter materials
- nuclear accidents – radioactive steam escapes, core melt down, or uncontrolled chain reaction