Radioactivity and Radioactive Decay

Nevada Site Specific Advisory Board

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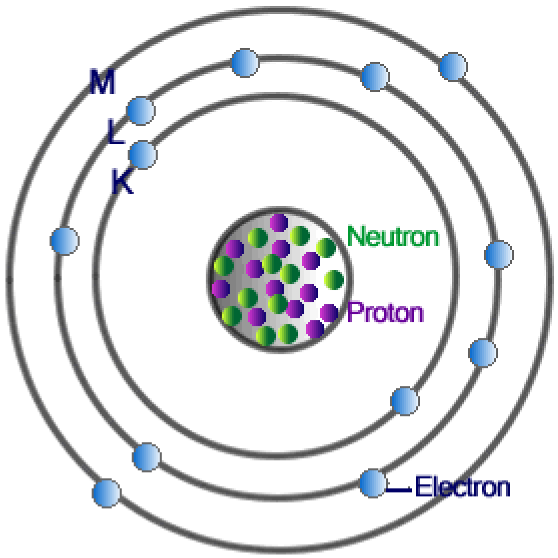
Radioactivity and Radioactive Decay

- Radioactivity originates in the nucleus of an atom.
- Therefore, radioactivity (half-life) is not affected by the chemical or physical state of the atom.

Bohr Model of Atom

Electrons create chemical bonds with other atoms to form compounds.



Nucleus contains protons and neutrons.

Proton mass is = 1 amu, charge = +1

Neutron mass is = 1^{+} amu, charge 0

(amu = atomic mass unit)

Nucleus

Number of protons designated by Z.

Z determines the element.

Changing number of protons creates a new element.

Total mass of nucleus designated by A.

Therefore, number of neutrons N equals A – Z.

Changing the number of neutrons creates a new isotope of the same element.

Such a change generally (though not always) creates an unstable or radioactive nucleus.

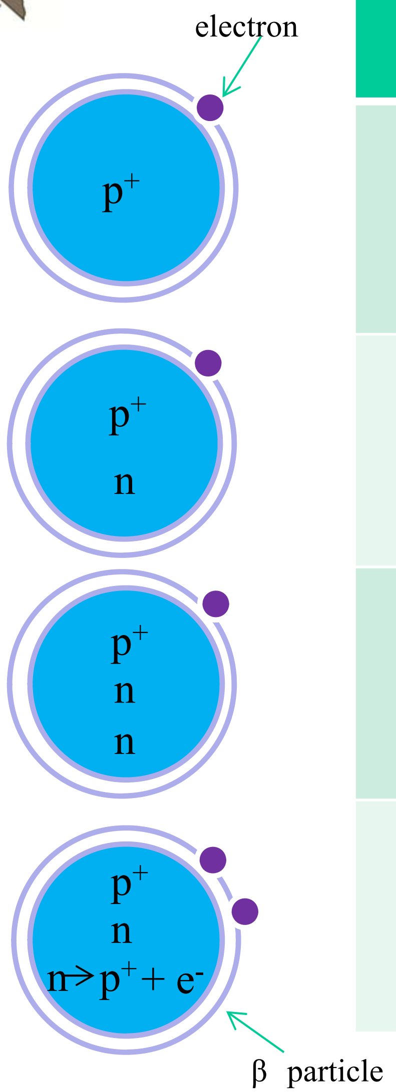
Nomenclature: $_{92}U^{235}$

Z = 92 = element uranium

A = 235 = atomic mass

N = 143 (A – Z)

Hydrogen to Tritium
Example of Isotope* Production



Z	AMU	Name	Common Chemical Compound
1	1	Hydrogen	H_2O
1	2	Deuterium	D_2O
1	3	Tritium (Radioactive) ($T_{½}$ is 12.33 yr)	T_2O
2	3	Helium (New element)	Noble Gas

*Only case where isotopes have distinct names

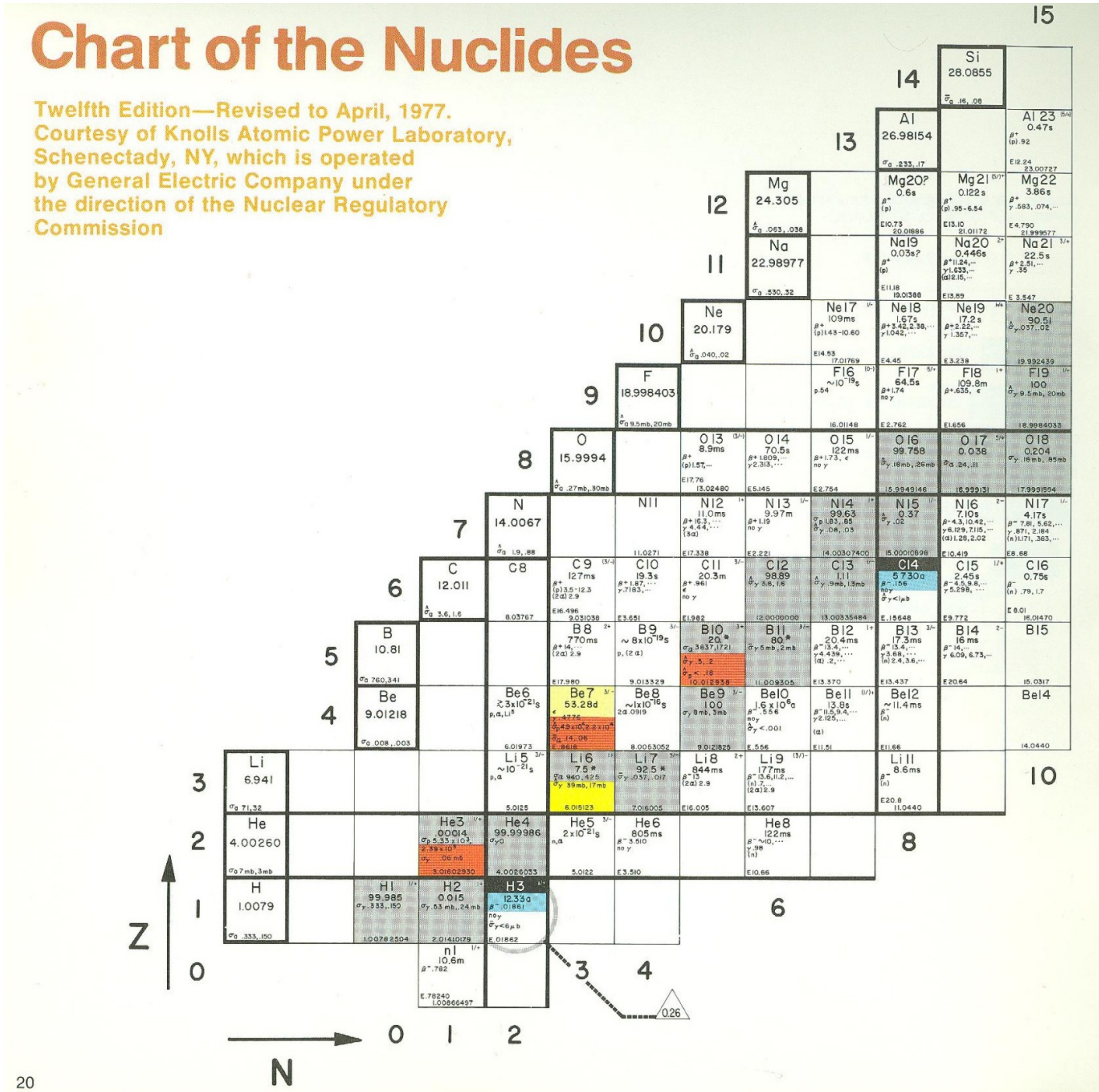


Chart of the Nuclides
Twelfth Edition—Revised to April, 1977.
Courtesy of Knolls Atomic Power Laboratory,
Schenectady, NY, which is operated
by General Electric Company under
the direction of the Nuclear Regulatory
Commission
Z
N
20

Radioactivity

All elements with Z less than or equal to 82 (lead) have a stable form of the nucleus.

Above Z of 82, no stable nuclei exist, although there are some elements (e.g. Uranium, thorium) that have quasi-stable states, that is very long radioactive half lives.

Half life of Uranium-238 is 4.468 x 10^9 years.
Approximately the age of the earth.

As the number of neutrons in the nucleus changes up or down from the stable number(s) the nucleus becomes more and more unstable.

Radioactive Decay

An unstable nucleus emits some particle to move toward a stable configuration.

Typically (though again not always) these emissions will be:

- α Alpha particle
- β Beta particle
- γ Gamma ray emission requires the emission of a particle

Names are the first three letters of the Greek alphabet and denote the order of discovery of these radiations.

For the case of U-235 almost all of the decays necessary to reach a stable isotope of Pb are alpha decays accompanied by one or more gammas.

Radioactive Decay (continued)

ALPHA particle is 2 protons and 2 neutrons.

Hence mass = 4 amu and charge = +2

This particle is actually the nucleus of a He atom.

BETA particle is 1 electron.

Mass = very small (approx. 1/1836 of a proton) and charge = -1.

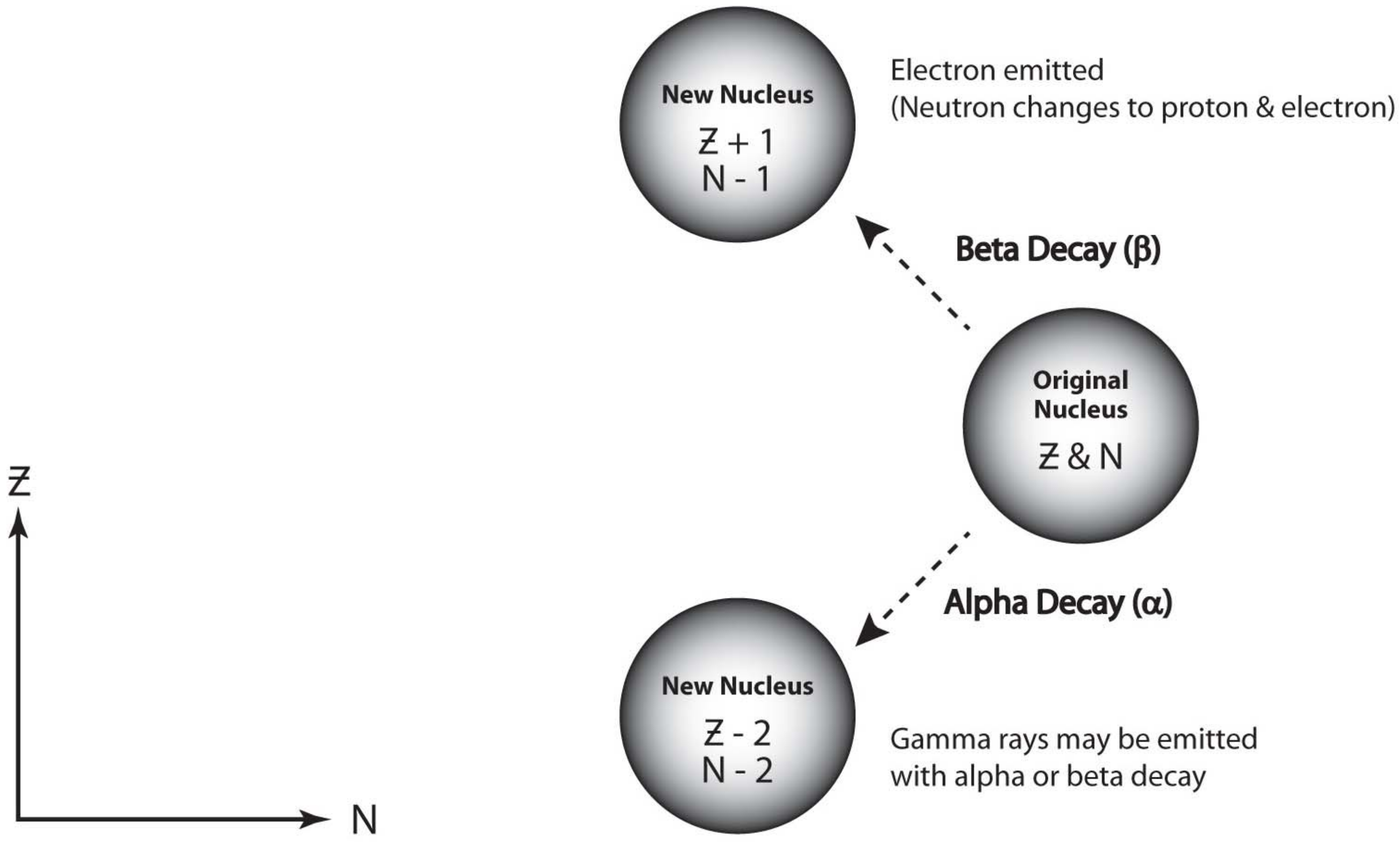
GAMMA RAY is pure electromagnetic wave.

Mass = 0, charge = 0

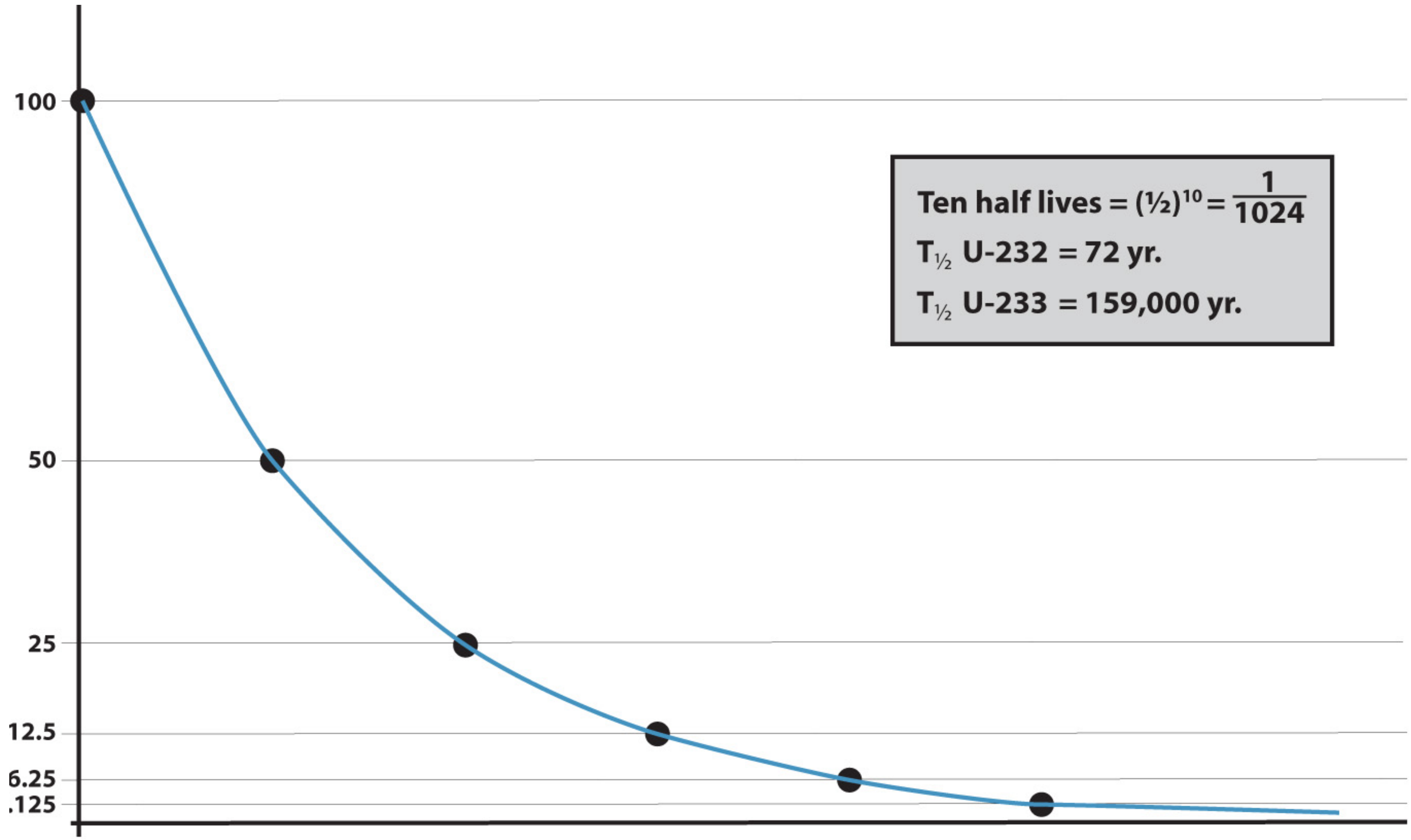
A gamma ray is exactly like an X-ray and interacts with matter the same as an X-ray. The name difference is used to denote the origin of the radiation. Gammas come from the nucleus and X-rays come from the atomic electrons.

Note that both alpha and beta decay change the Z of the nucleus and hence result in a new element being formed.

Diagram of Alpha and Beta Decay



Half Life Decay



Uranium Isotope Series

Decay Series for U-235

Parent Nuclide

U-235 $T_{1/2} = 7x10^8$ y

↓ α

Th-231 $T_{1/2} = 25.52$ h

↓ β

Pa-231 $T_{1/2} = 3.28x10^4$ y

γ ↓ α

Ac-227 $T_{1/2} = 21.72$ y

↓ β

Th-227 $T_{1/2} = 18.72$ d

γ ↓ α

Ra-223 $T_{1/2} = 11.43$ d

γ ↓ α

Rn-219 $T_{1/2} = 3.96$ s

γ ↓ α

Po-215 $T_{1/2} = 1.78$ ms

γ ↓ α

Pb-211 $T_{1/2} = 36.1$ m

γ ↓ β

Bi-211 $T_{1/2} = 2.14$ m

γ ↓ α

Tl-207 $T_{1/2} = 4.77$ m

γ ↓ β

Pb-207 Stable

Daughter Nuclides

ms = milliseconds
s = seconds
m = minutes
h = hours
d = days
y = years

Decay Series for U-235 (continued)

There are seven alpha decays in this chain indicating a mass change of 28, i.e. from U-235 to Pb-207.

The seven alpha decays represent 14 protons, offset by the four beta decays for a net change of 10 protons, i.e. from Z=92 to Z=82.

Most of the alpha decays are accompanied by one or more gamma rays. The most energetic gamma accompanies the transition from Tl-207 to Pb-207 (stable).

Interesting Sidebar

- Approximately 1.7 billion years ago the abundance of U-235 in natural Uranium would have been 3% or higher, as compared to 0.72% today (due to radioactive decay).
- This abundance is high enough that with sufficient water present (as a moderator), a natural nuclear reactor could have occurred.
- During the French mining of natural uranium in Oklo in the Gabon Republic in Africa just such a natural reactor was found. This "reactor" has been estimated to have generated a total of 15,000 megawatt years. (A large modern nuclear reactor generates approximately this much energy in 4 years of operation.)
- This natural reactor generated Pu-239 and studies of the deposit indicate that this Pu was "locked up" in the grains of the ore for a time comparable to its 24,110 year half-life. Further, at least half of the fission product elements have remained immobilized in the ore.
- All this with no help from man.