The Quest for Gold Exploring Nuclear Transmutation

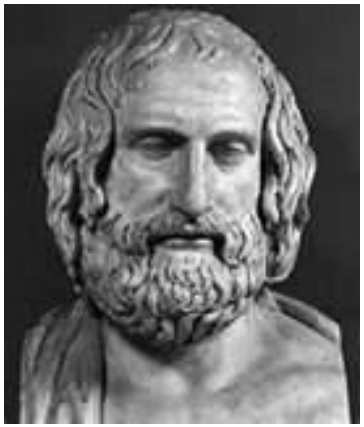
January 2025

Presented by Candace Davison, M.Engr.

Alchemy

A brief history of atoms and alchemy

Anaxagoras



- Greek, born 500 B.C.
- Infinite divisibility of matter

“Of what is small, there is no smallest part, but always a smaller.”

Empedocles

- Greek, born 490 B.C.
- Four basic elements: earth, air, fire, water
- Conservation of mass

“Nothing new comes or can come into being; the only change that can occur is a change in the arrangement of the elements.”

A brief history of atoms and alchemy

Democritus

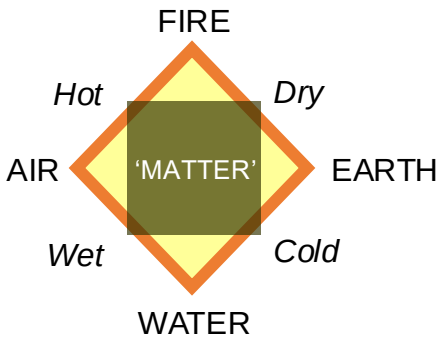
- Greek, Born 460 B.C.
- Everything is composed of atoms
  - Indestructible, indivisible
  - Empty space between them
  - Always in motion
- Origin of the universe
  - Atoms came together to form larger substances
- More than four elements

“Nothing exists but atoms and space, all else is opinion.”

A brief history of atoms and alchemy

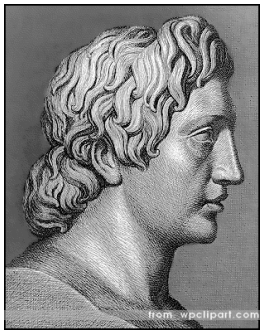
Aristotle and Plato

- Believed there were only four elements
- Elements can transform to other elements

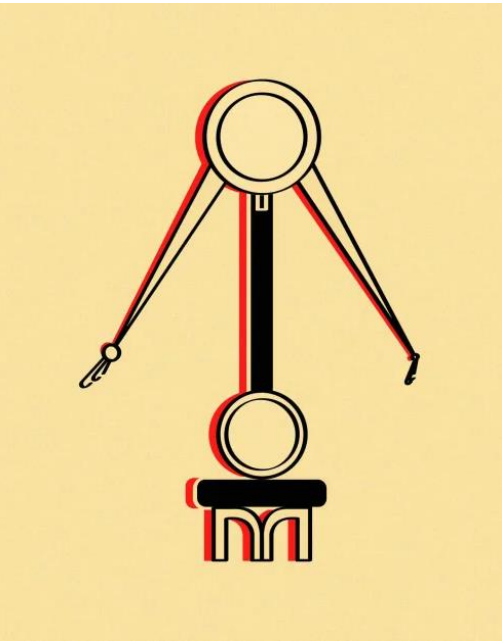


Alexander the Great

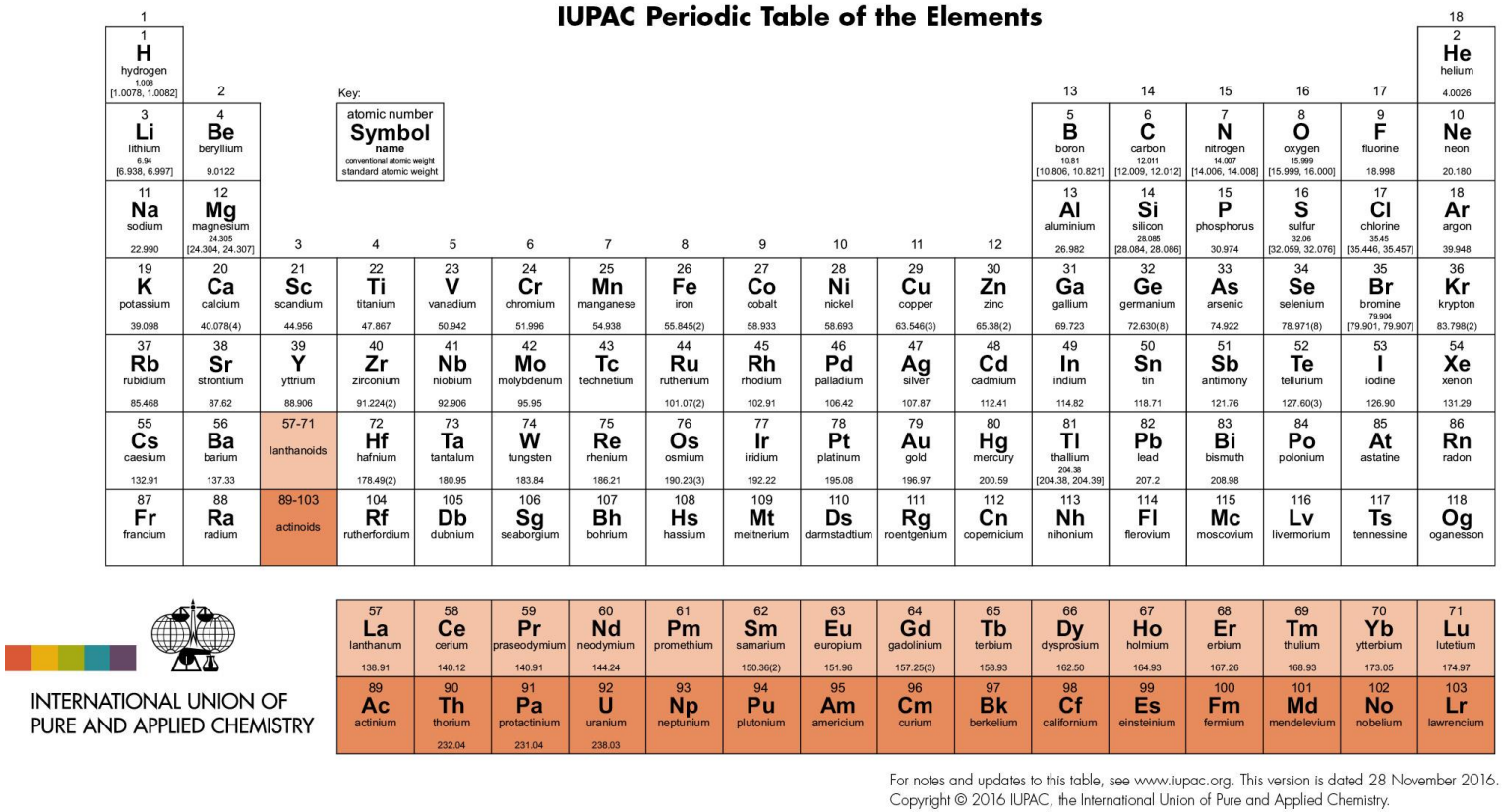
- King of Macedon
- Tutored by Aristotle
- Alchemy was deemed only science worth pursuing



Cleopatra Chrysopoeia



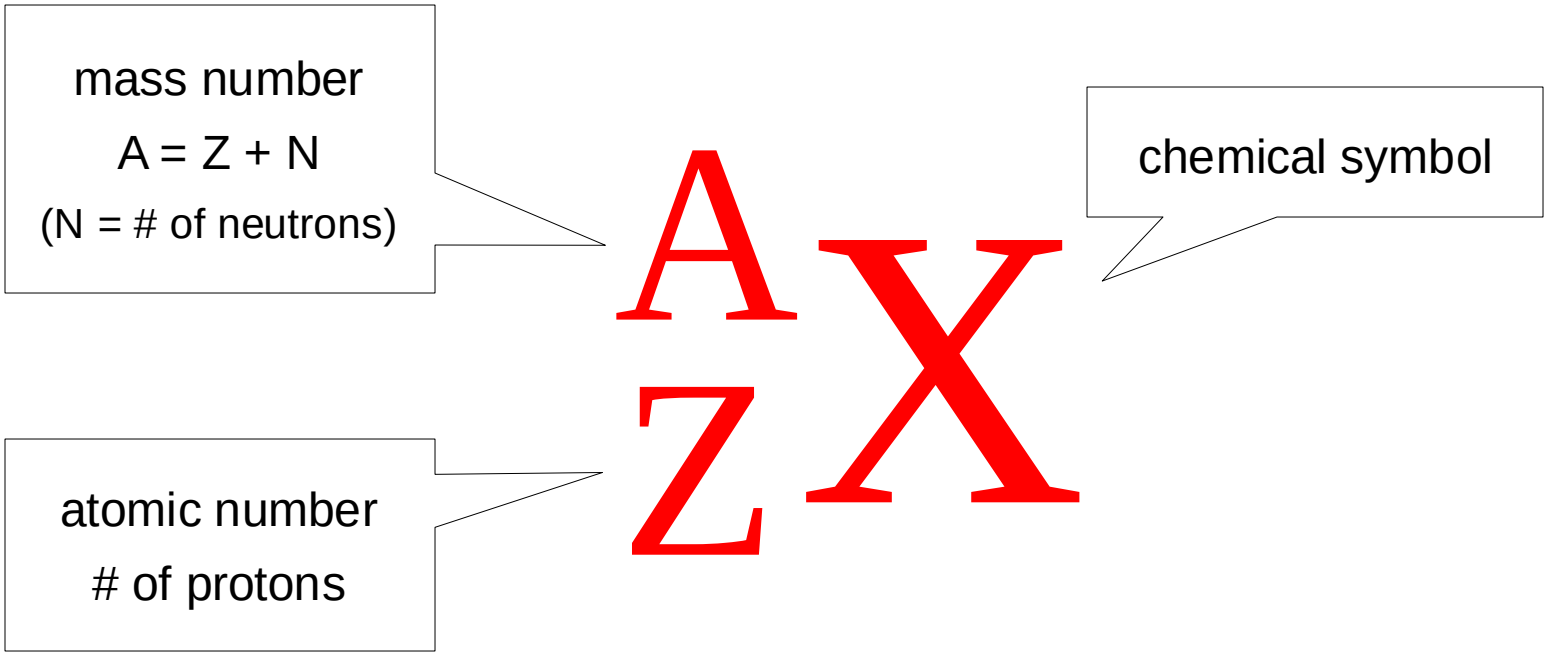
Periodic Table of the Elements



INTERNATIONAL UNION OF PURE AND APPLIED CHEMISTRY

For notes and updates to this table, see www.iupac.org. This version is dated 28 November 2016.

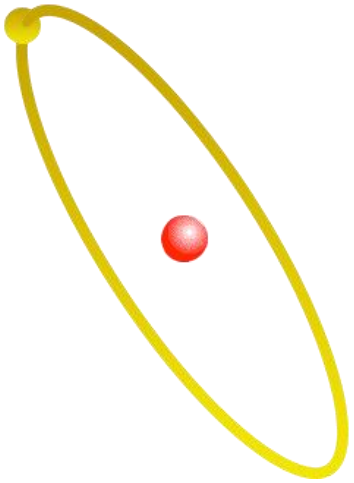
Standard nuclear notation



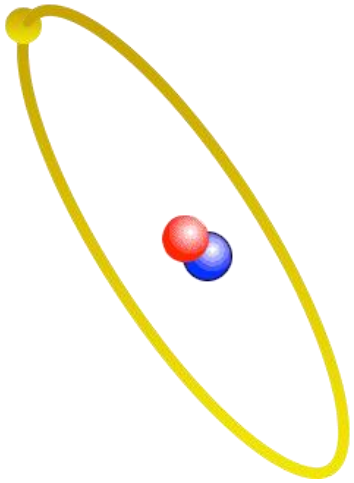
$^{12}_{6}C$ $^{13}_{6}C$ $^{14}_{6}C$ or ^{12}C ^{13}C ^{14}C

Isotopes

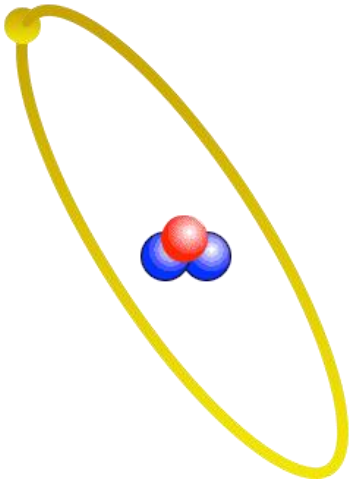
Three isotopes of hydrogen



Hydrogen
H-1

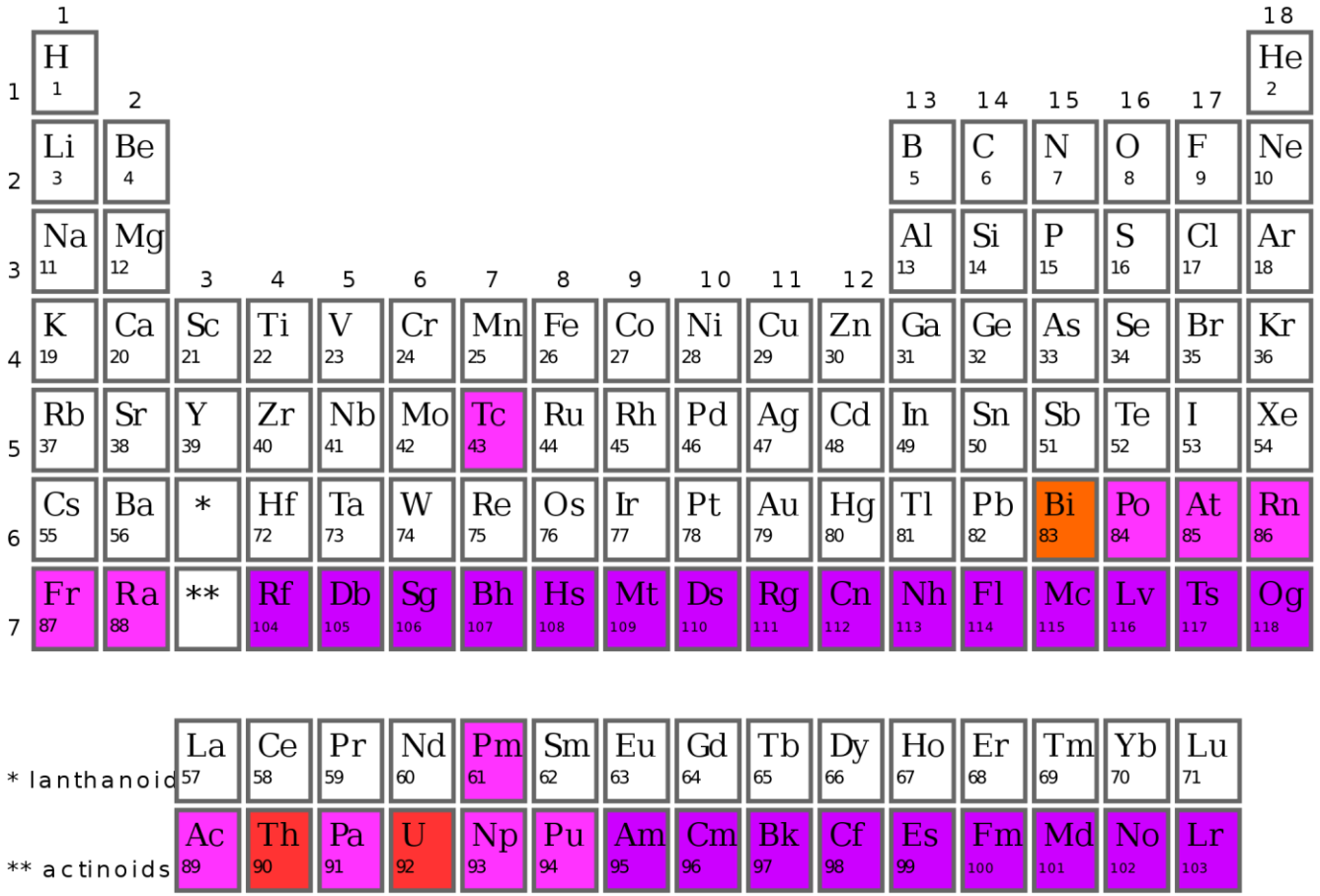


Deuterium
H-2



Tritium
H-3

Why are atoms radioactive?

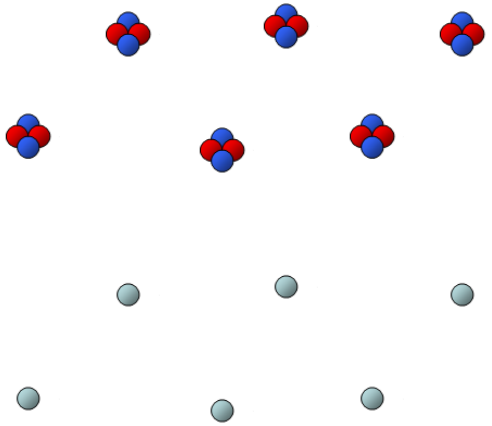


Nuclear stability

- An unstable nucleus becomes more stable by rearranging its nuclear structure and emitting *radiation*.
- If unstable after radioactive decay, further decay is possible.

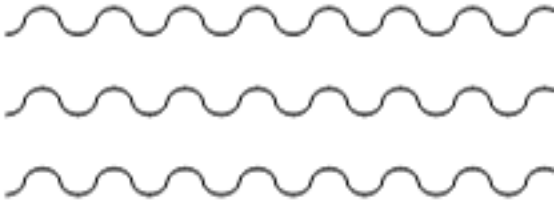
What is radiation?

Transmission of energy via:



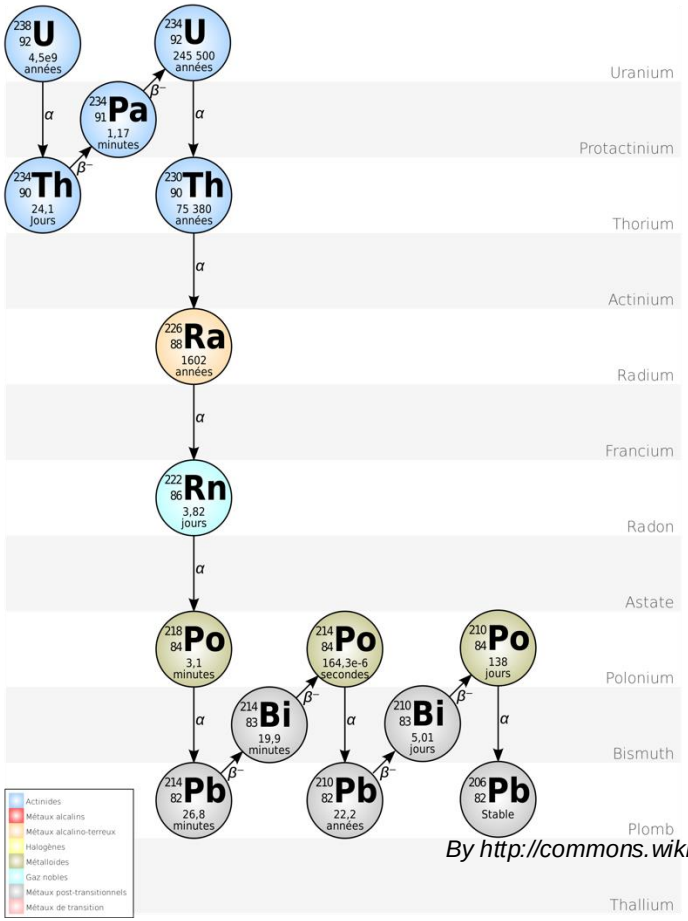
Particles

or



Waves

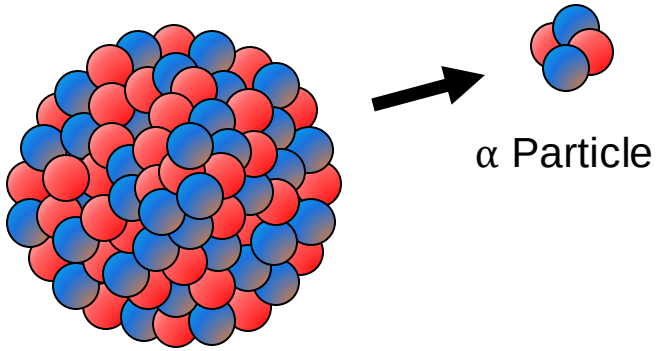
Radioactive decay - transmutation



By http://commons.wikimedia.org/wiki/User:BatesIsBack

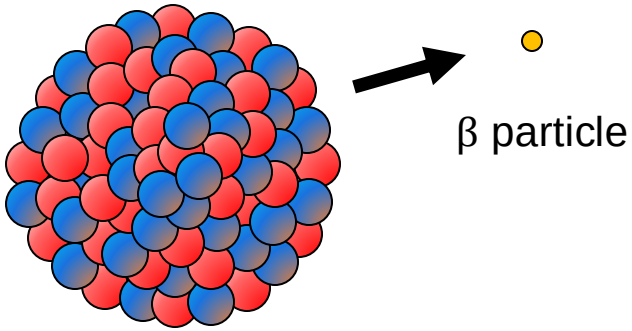
Alpha particle α

Helium nucleus that is emitted from a radioactive atom's nucleus



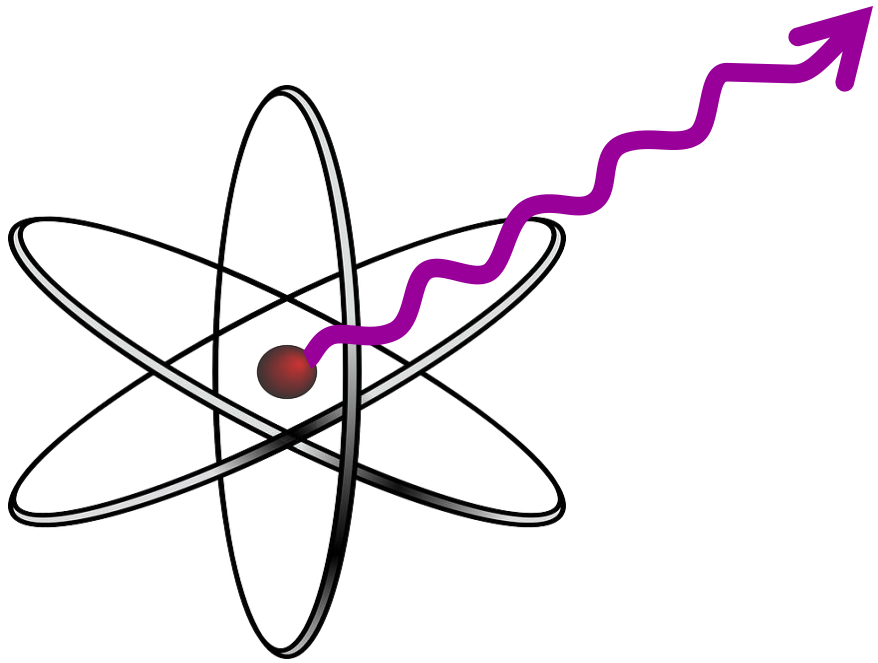
Beta particle β^-

Electron emitted from an atom's nucleus when a neutron converts to a proton

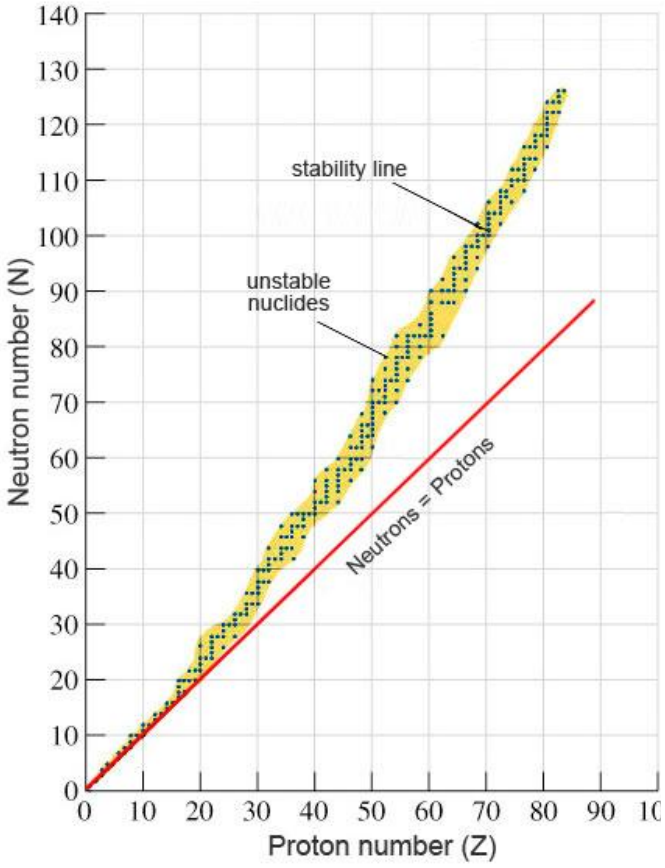


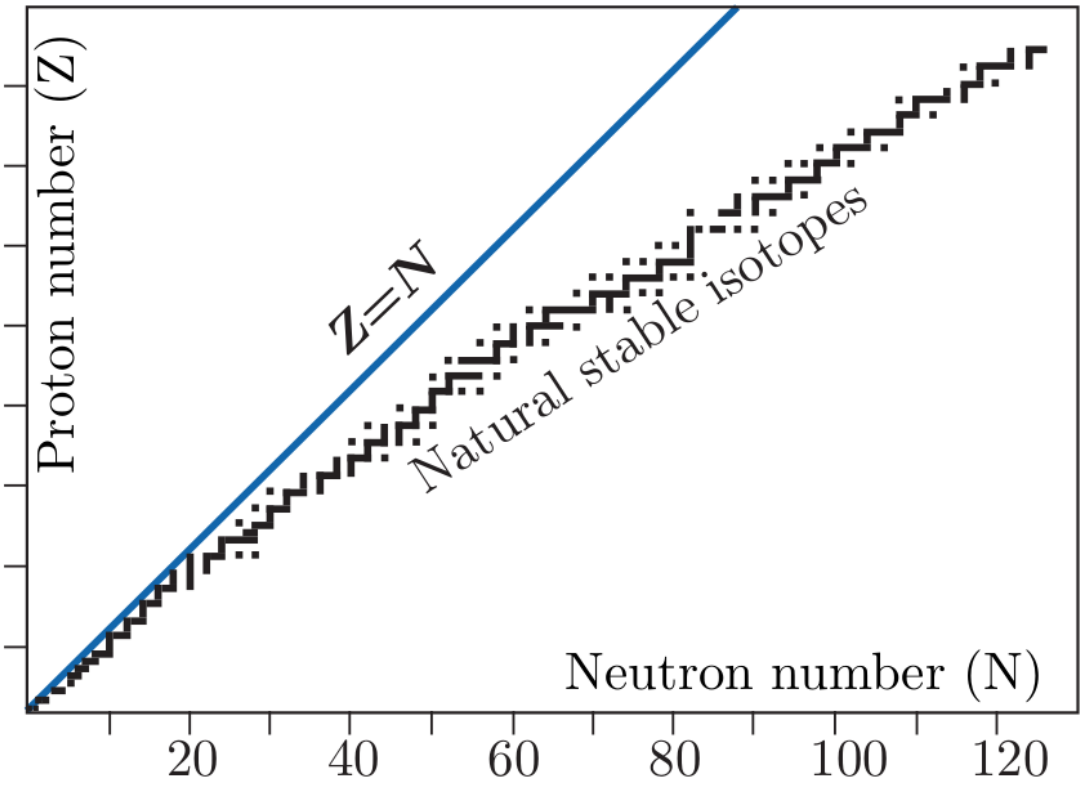
Gamma ray γ

High-energy photon emitted from an atom's nucleus



What make a nucleus unstable?





Nuclear stability

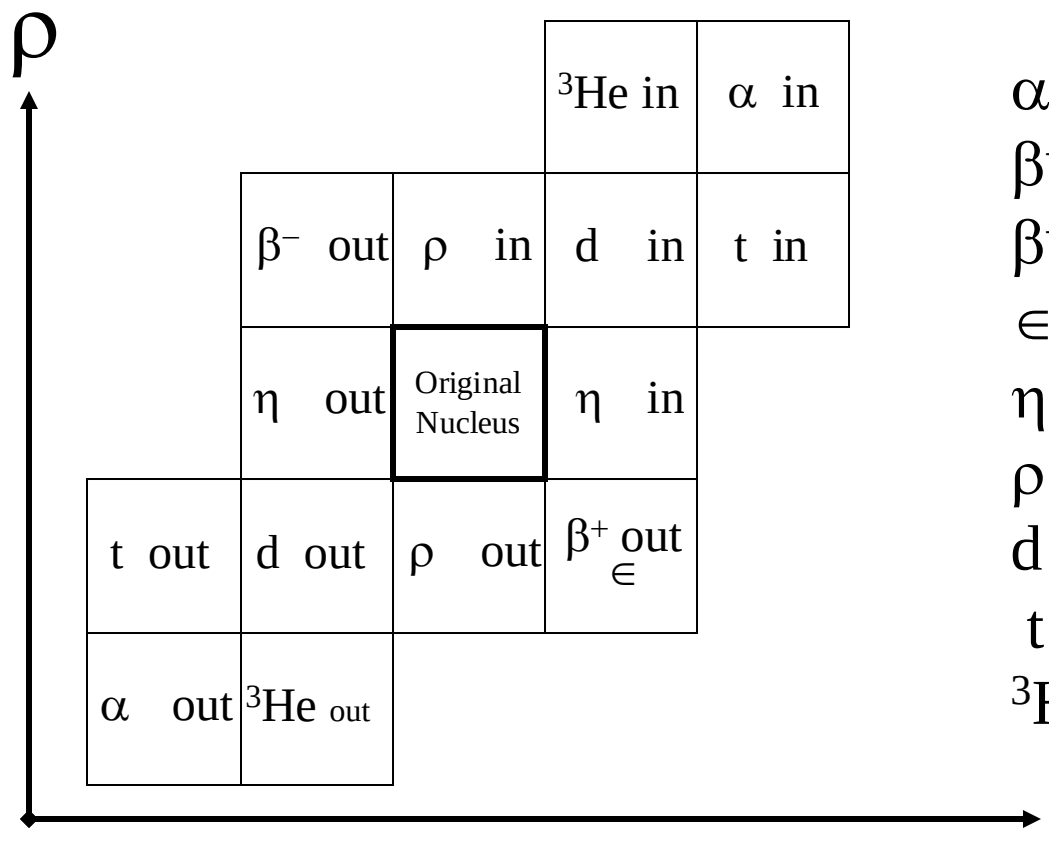
- Only certain combinations of neutrons and protons lead to a stable atom.

- In a stable atom, the attractive and repulsive forces in the nucleus balance.

Nuclear stability

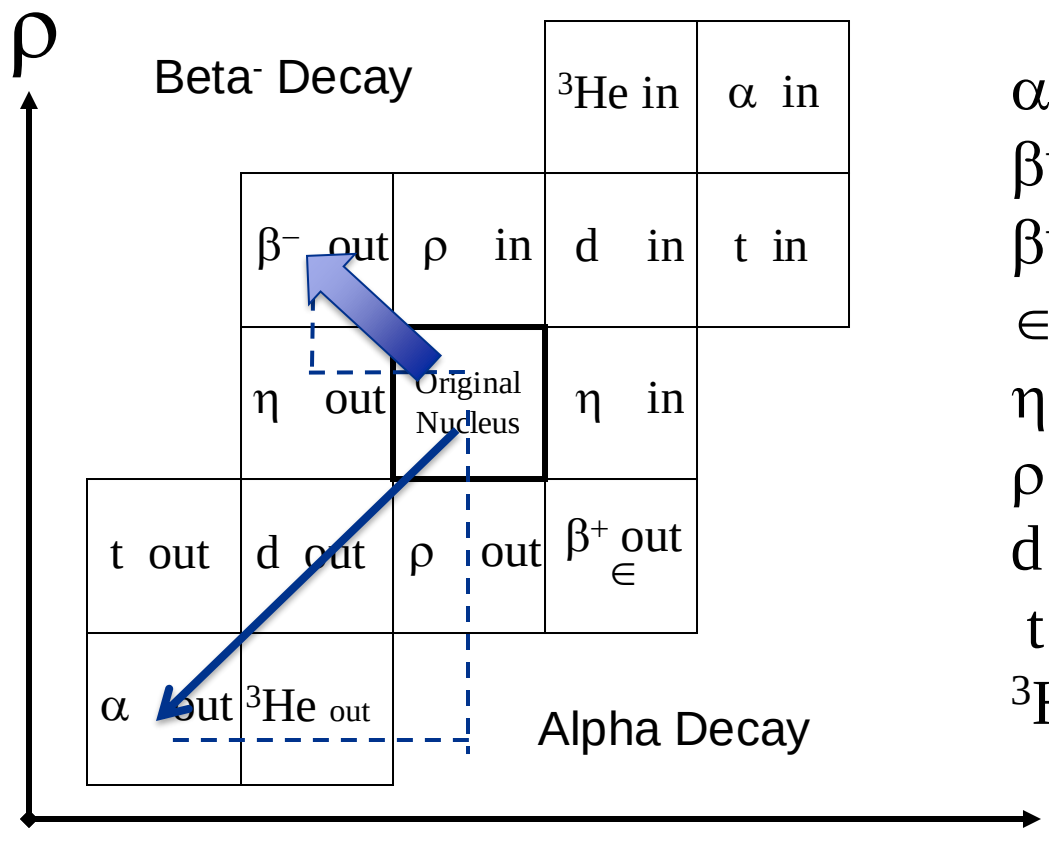
- Atoms with unstable nuclei are radioactive.
- If unstable after radioactive decay, further decay is possible.
- Nuclei decay toward the line of stability.

Relative locations of products of various nuclear processes



α	alpha particle
β$^-$	negative electron
β$^+$	positron
∈	electron capture
η	neutron
ρ	proton
d	deuteron
t	triton (H-3 nucleus)
^{3}He	helium-3 nucleus

Relative locations of products of various nuclear processes



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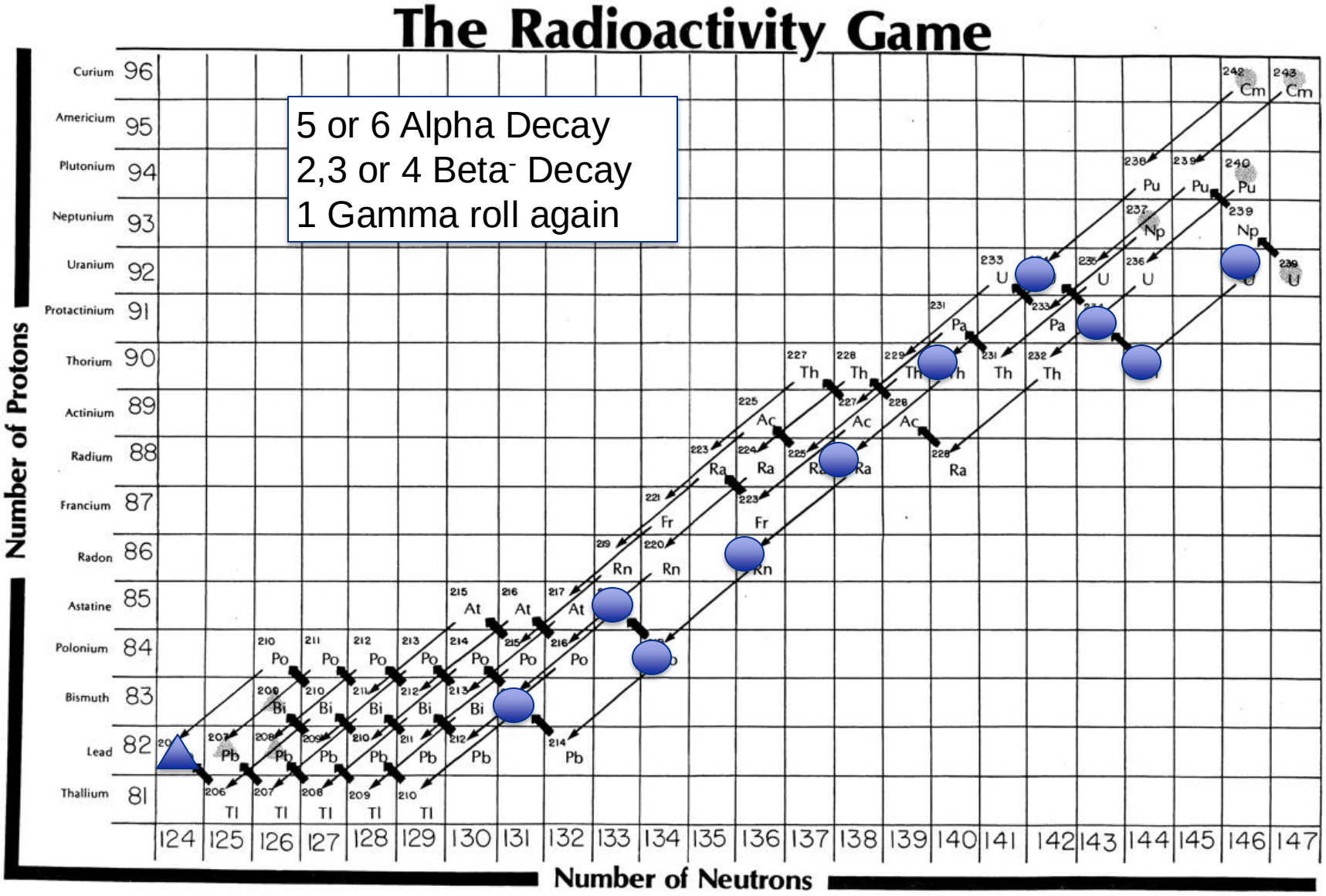
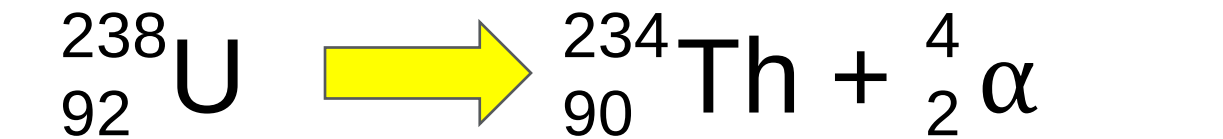
^3He	helium-3 nucleus

The Radioactivity Game

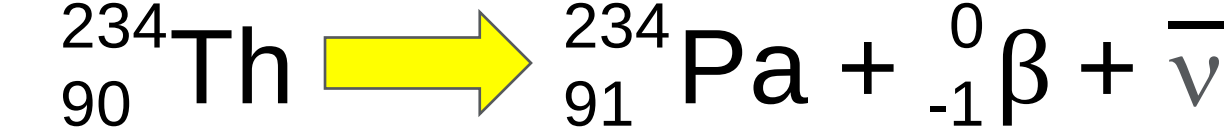


Radioactive decay equations

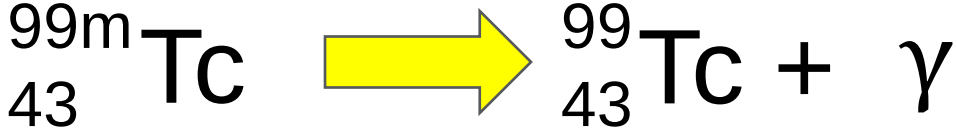
Alpha Decay



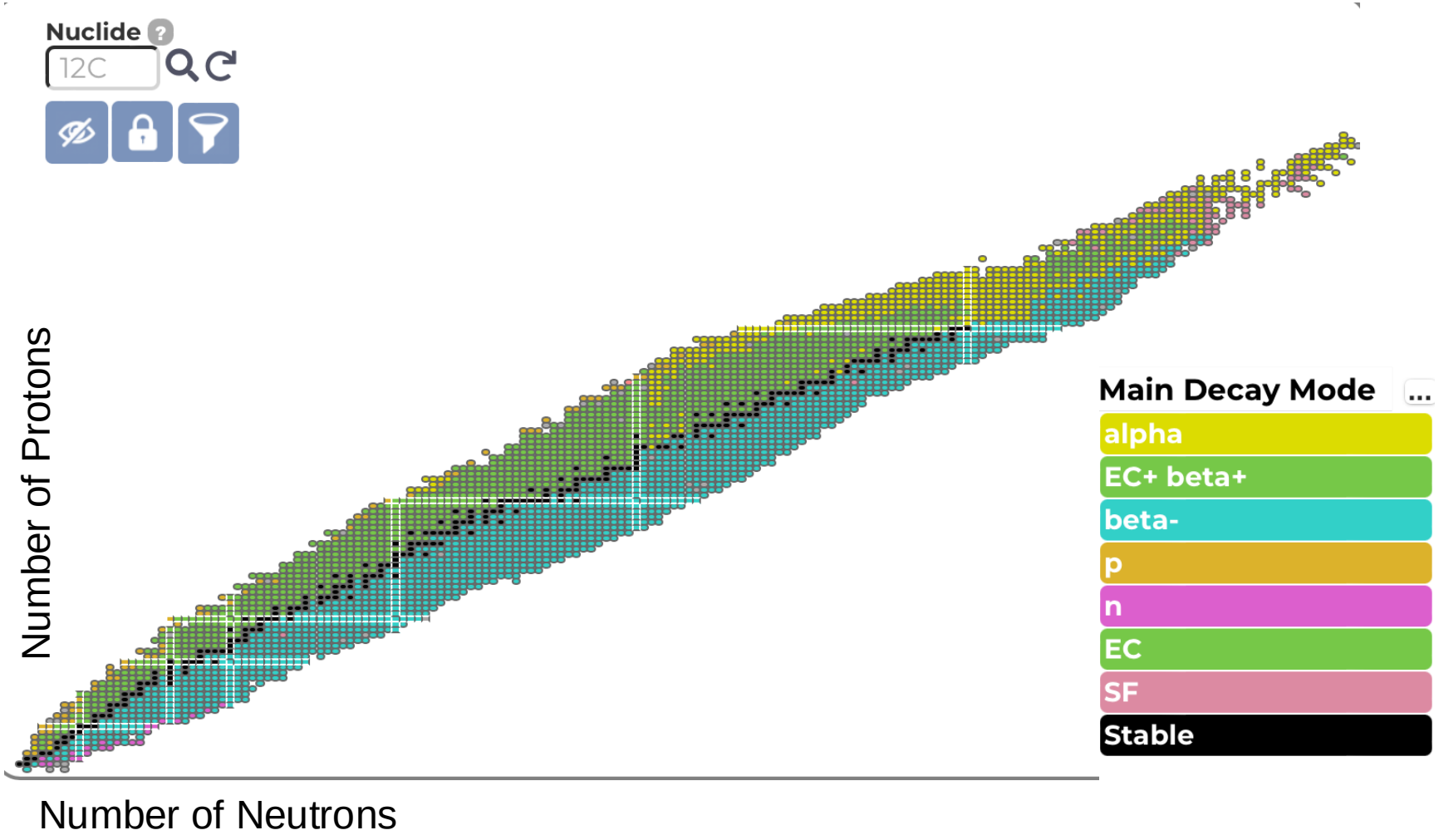
Beta Decay



Gamma Decay

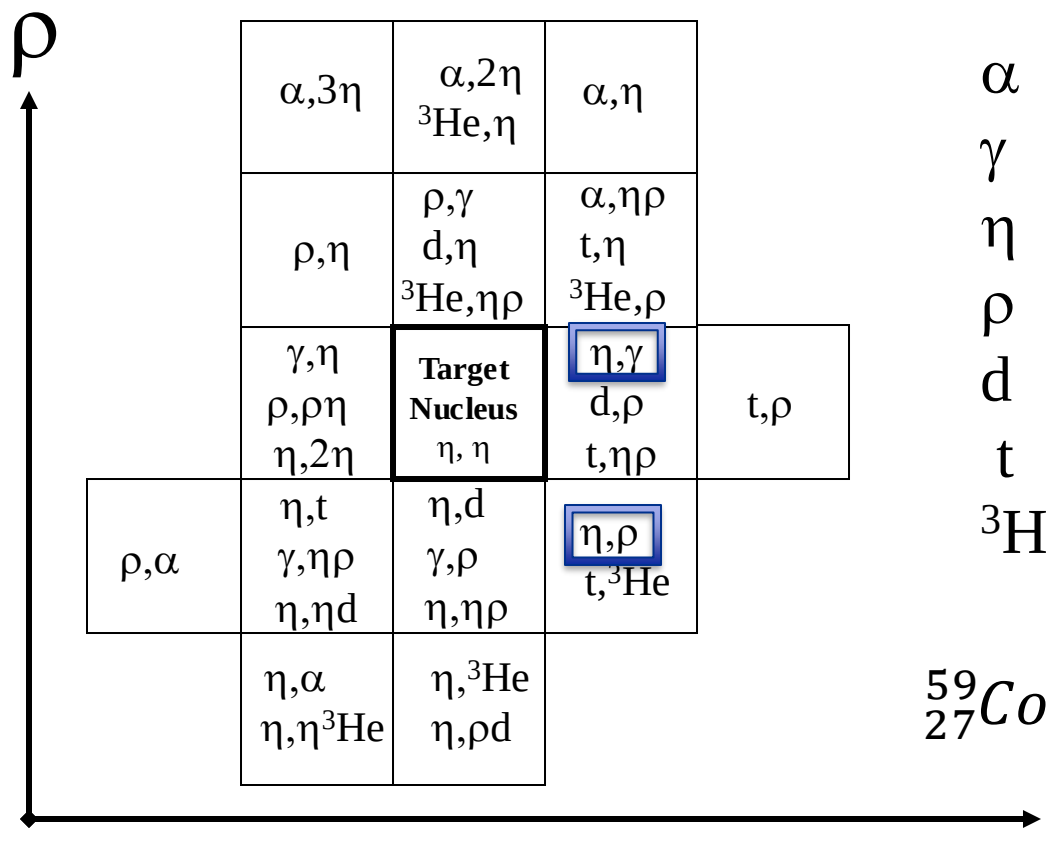


IAEA Chart of Nuclides



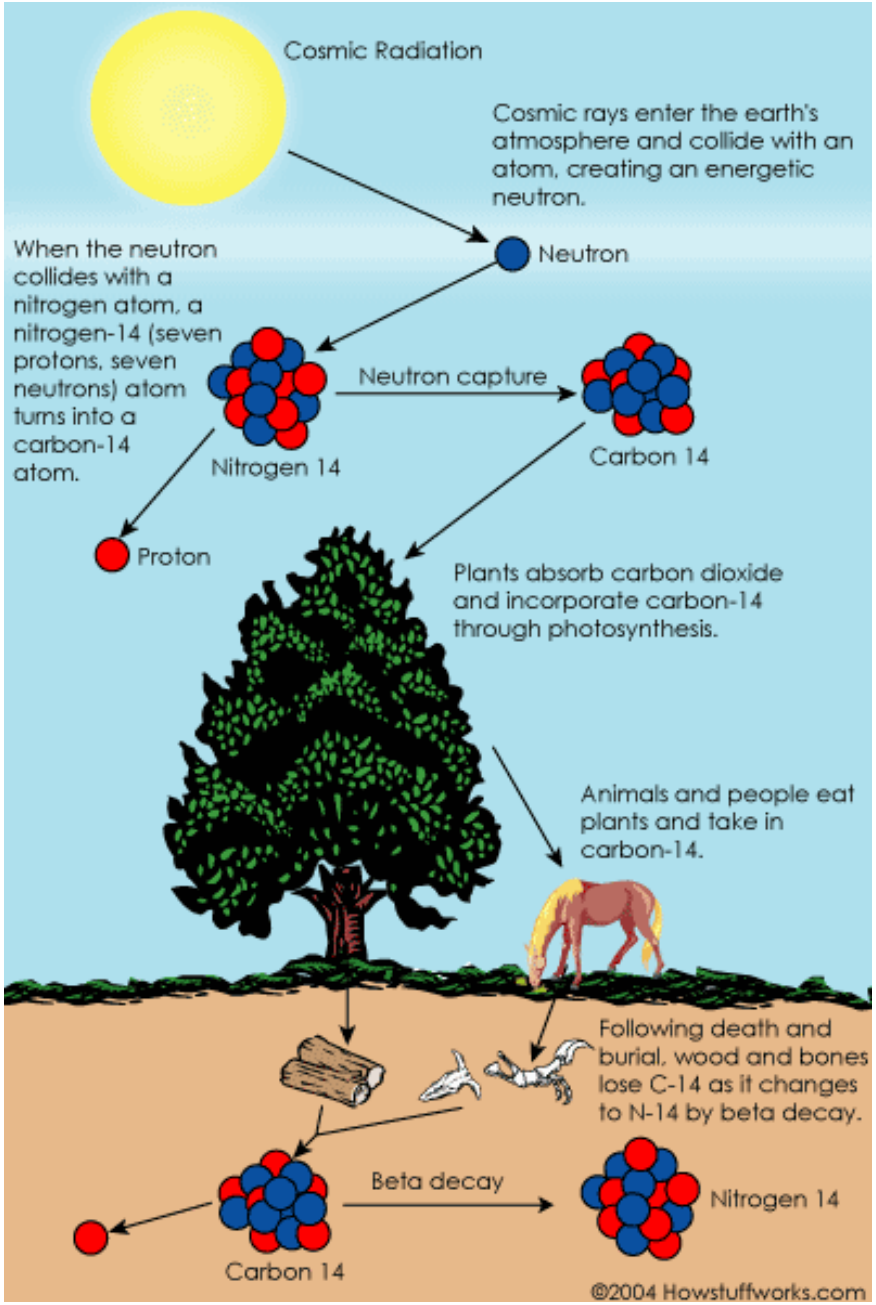
https://www-nds.iaea.org/relnsd/vcharthtml/VChartHTML.html

Nuclear Reactions



α	alpha particle
γ	gamma
η	neutron
ρ	proton
d	deuteron (^{2}H nucleus)
t	triton (^{3}H nucleus)
^{3}He	helium-3 nucleus

$$^{59}_{27}Co + ^{1}_{0}n \rightarrow ^{60}_{27}Co + \gamma$$



Carbon-14

Production

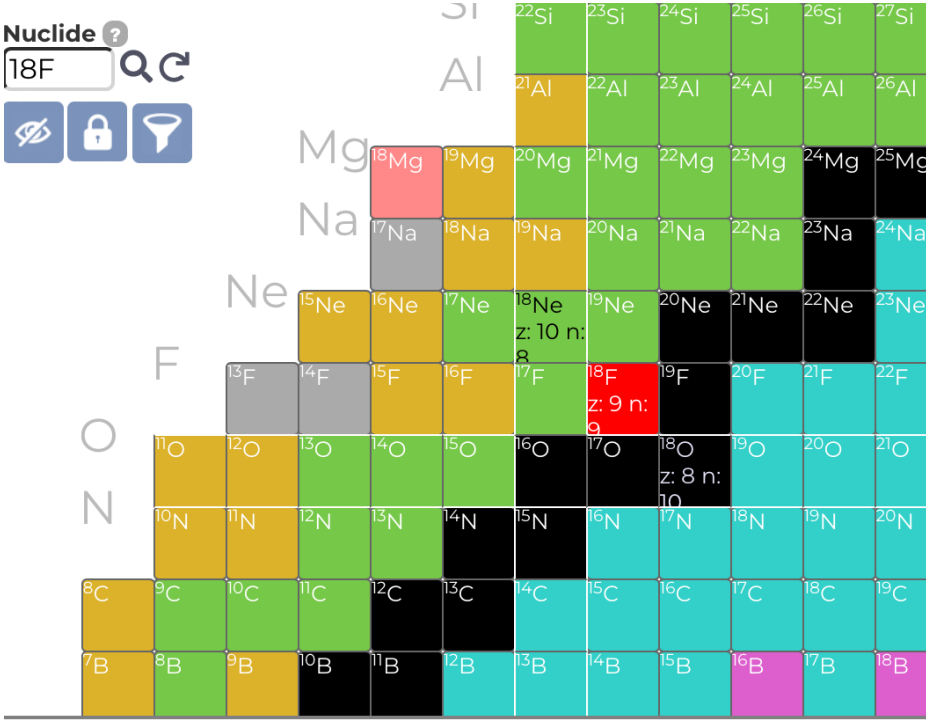
N-14 Target (n,p)

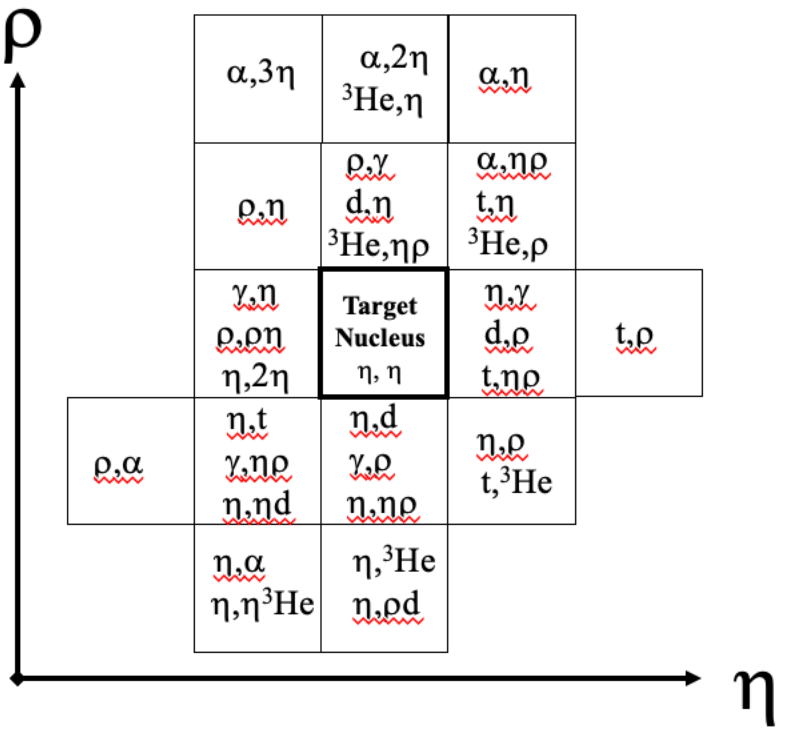
$$^{14}_{7}N + ^{1}_{0}n \rightarrow ^{14}_{6}C + ^{1}_{1}p$$

Radioactive Decay

$$^{14}_{6}C \rightarrow ^{14}_{7}N + ^{0}_{-1}\beta^{-} + ^{0}_{0}\bar{\nu}$$

How can we make Fluorine-18?

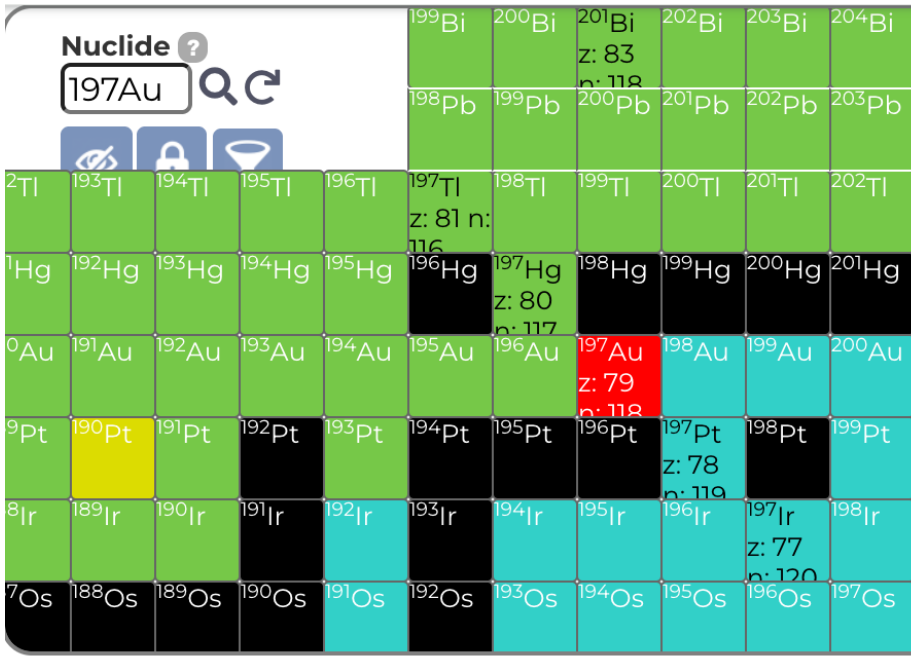


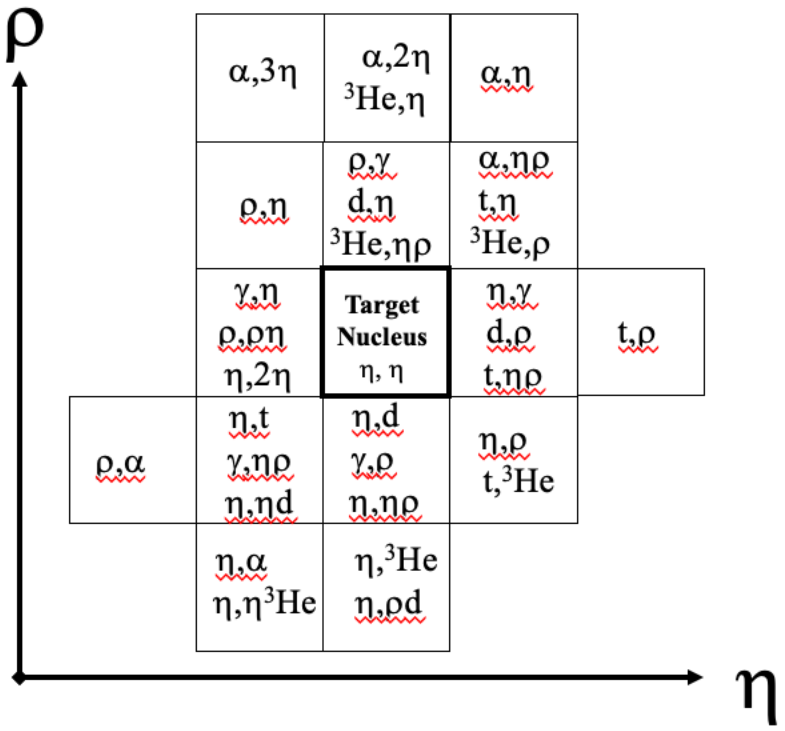


$^{18}O(p,n)^{18}F$ $^{16}O(^{3}He,p)^{18}F$ $^{16}O(\alpha,np)^{18}F$

Screenshot from: https://www-nds.iaea.org/relnsd/vcharthtml/VChartHTML.html#lastnuc=18F

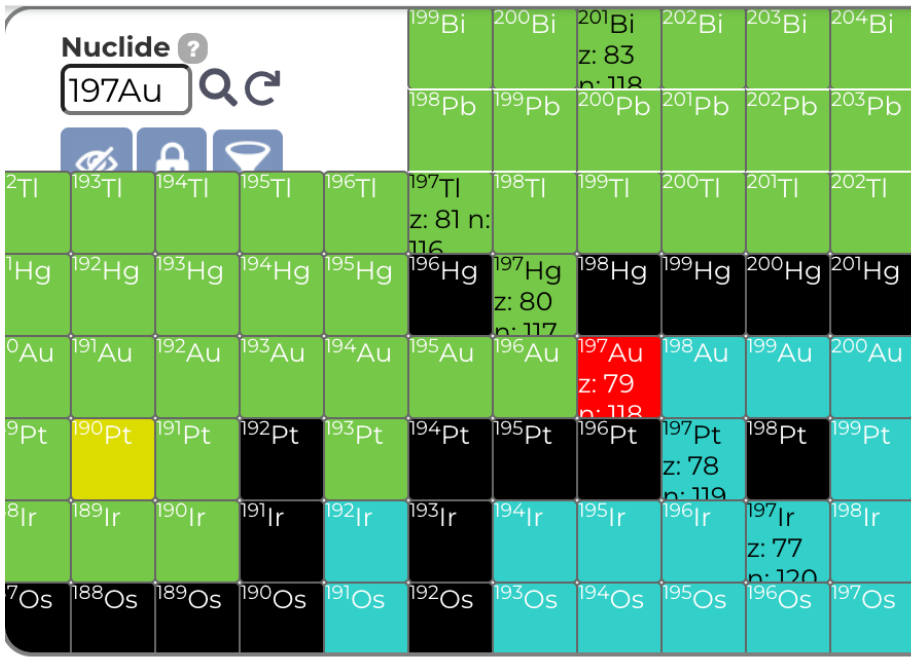
What reactions can we use to make gold?

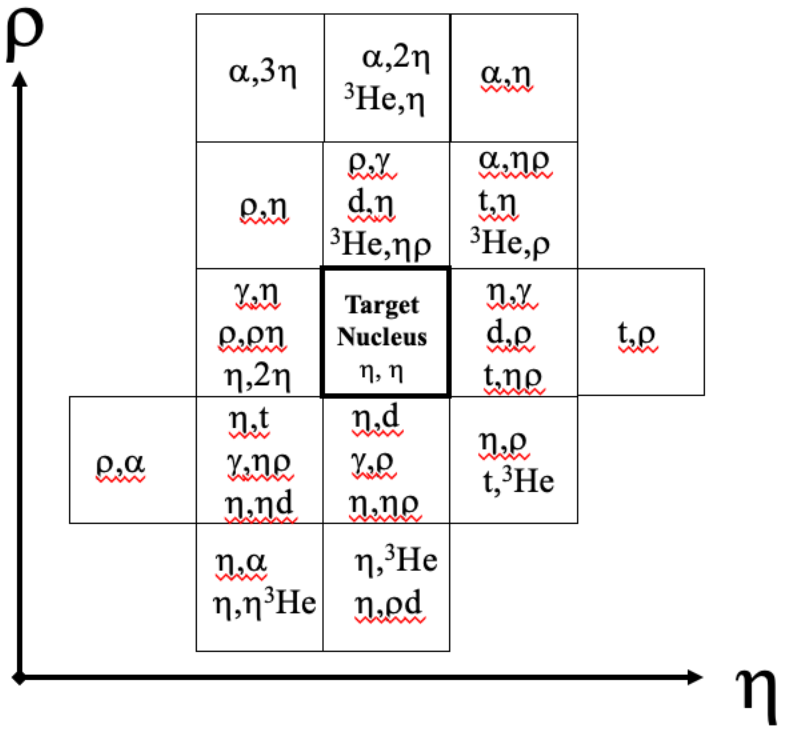




Screenshot from:
https://www-nds.iaea.org/relnsd/vcharthtml/VChartHTML.html#lastnuc=197Au

Possible Reactions to Produce Gold





Survey Answers

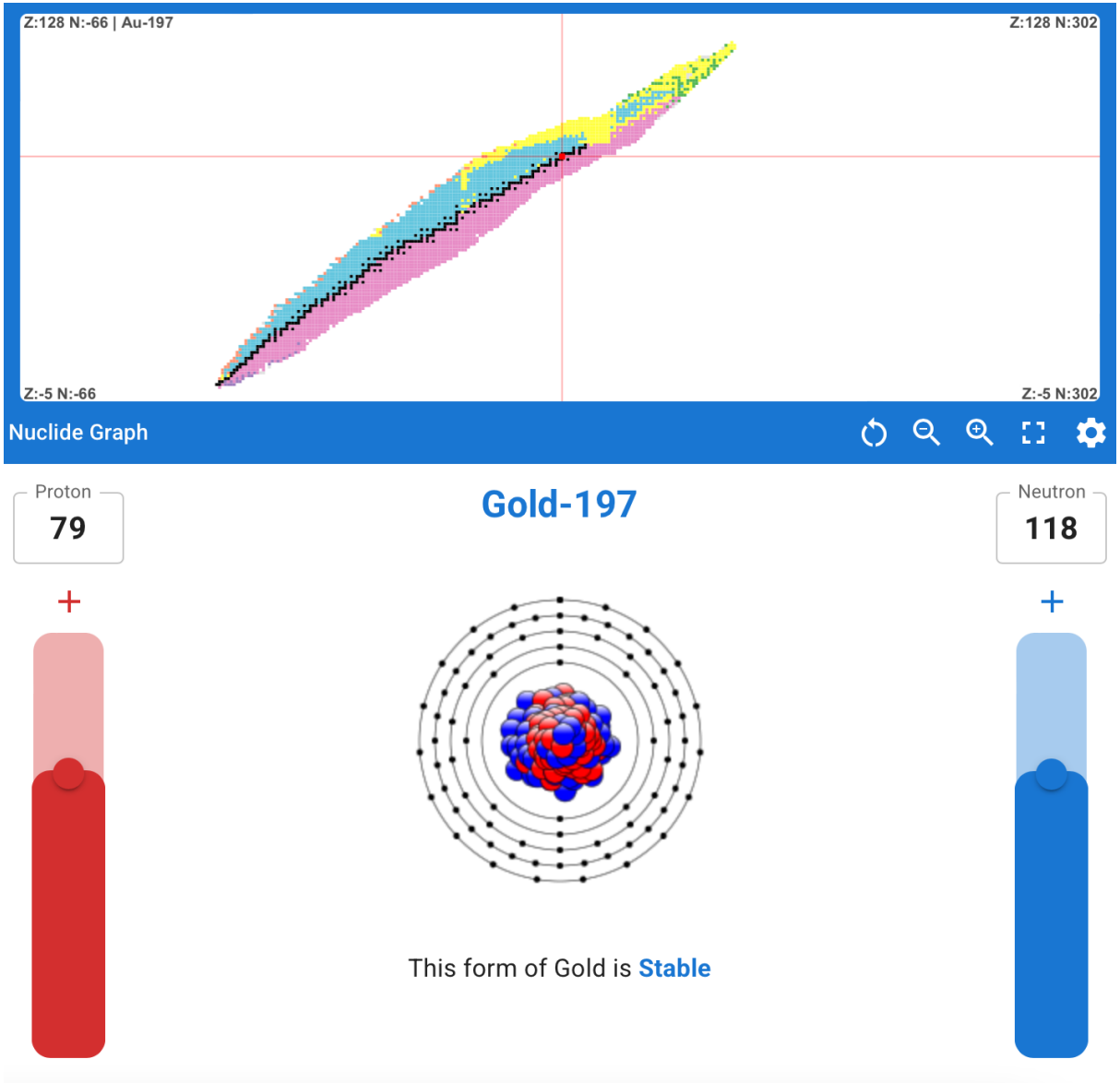
$^{196}Pt(p,\gamma)$

$^{198}Hg(\gamma,p)$

$^{199}Hg(n,t)$

Screenshot from:https://www-nds.iaea.org/relnsd/vcharthtml/VChartHTML.html#lastnuc=197Au

ANS Isotope Discovery App



Demo

ANS Resources

ANS Educational Resources
ans.org/nuclear

Navigating Nuclear (nuclear science curriculum for grades 3-12)
ans.org/nuclear/navigatingnuclear

ANS Isotope Discovery App
(link in chat)

Educator Training Webinars
ans.org/nuclear/k12programs/educator/

Build a Nucleus: K-12 Classroom Investigations
ans.org/webinars/view-edbn2024/

Decoding Radioactive Decay: Alpha, Beta, Gamma, and More
ans.org/webinars/view-etdd23/

Radioisotopes:
Nuclear Applications Beyond Energy
ans.org/webinars/view-ediso2023/

Resources

Office of Nuclear Energy/ Department of Energy https://www.energy.gov/ne/office-nuclear-energy

International Atomic Energy Agency IAEA. https://www.iaea.org
Nuclear Explained
https://www.iaea.org/newscenter/nuclear-explained

PhET Simulations https://phet.colorado.edu/sims/html/build-an-atom/latest/build-an-atom_en.html

Contemporary Physics Education Project CPEP
https://www.cpepphysics.org

International Atomic Energy Agency IAEA. https://www.iaea.org
Nuclear Explained
https://www.iaea.org/newscenter/nuclear-explained

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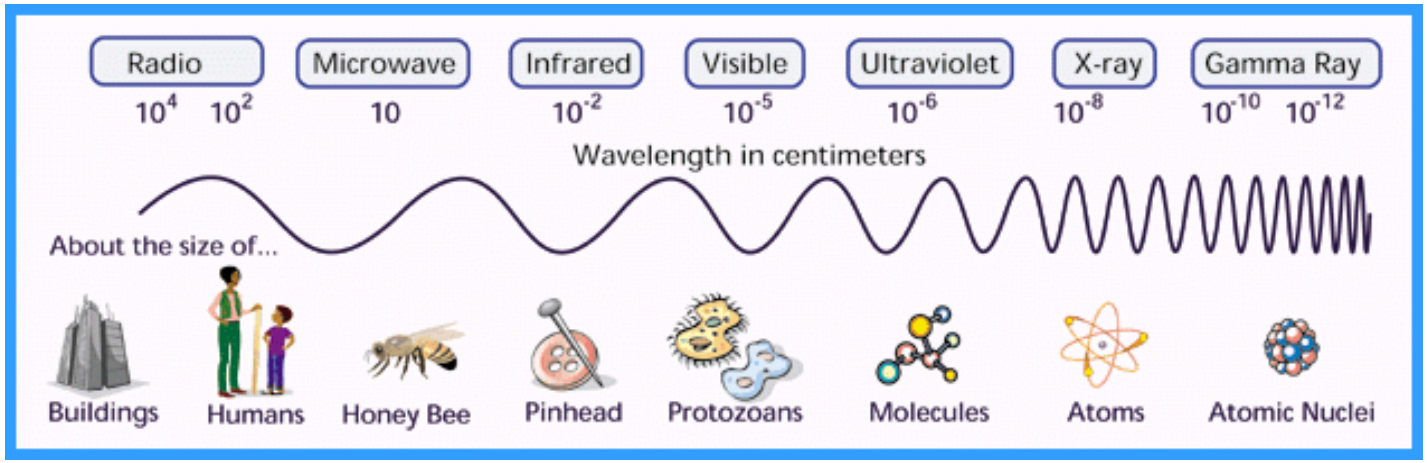
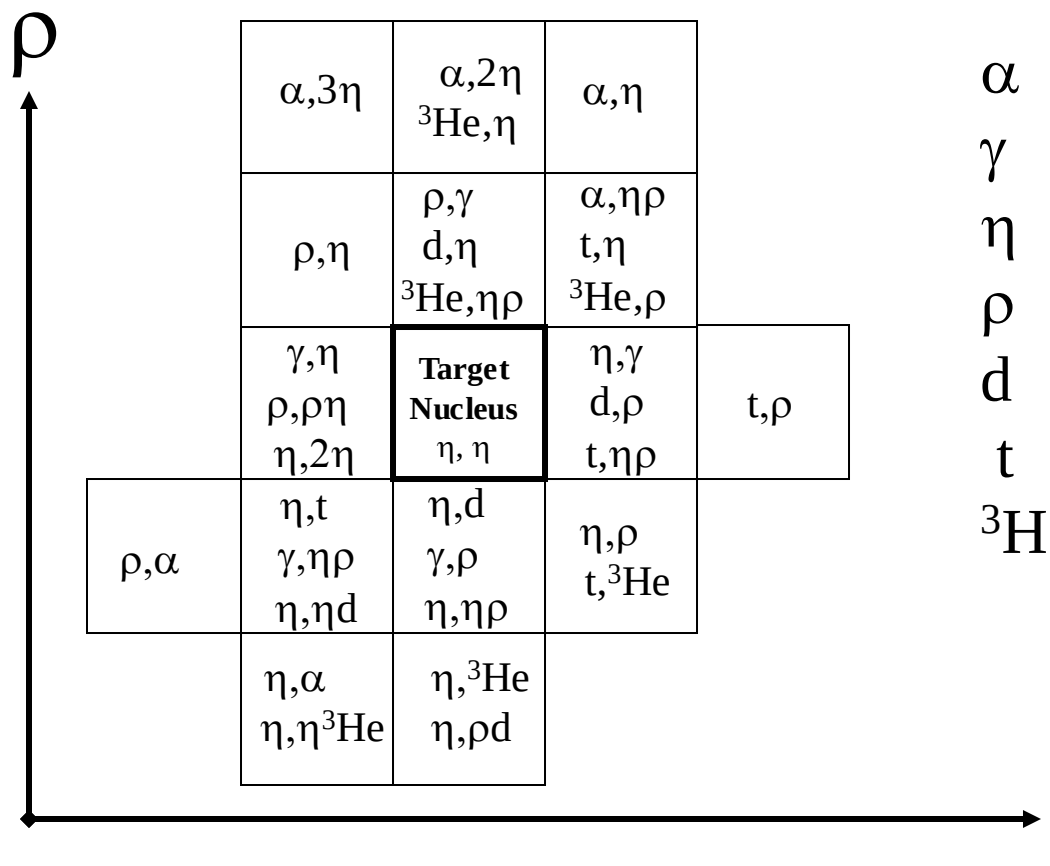
Cole EL, Stewart MN, Littich R, Hoareau R, Scott PJ. Radiosyntheses using fluorine-18: the art and science of late stage fluorination. Curr Top Med Chem. 2014;14(7):875-900. doi: 10.2174/1568026614666140202205035. PMID: 24484425; PMCID: PMC4140448.

Questions?

Electromagnetic spectrum



Nuclear Reactions



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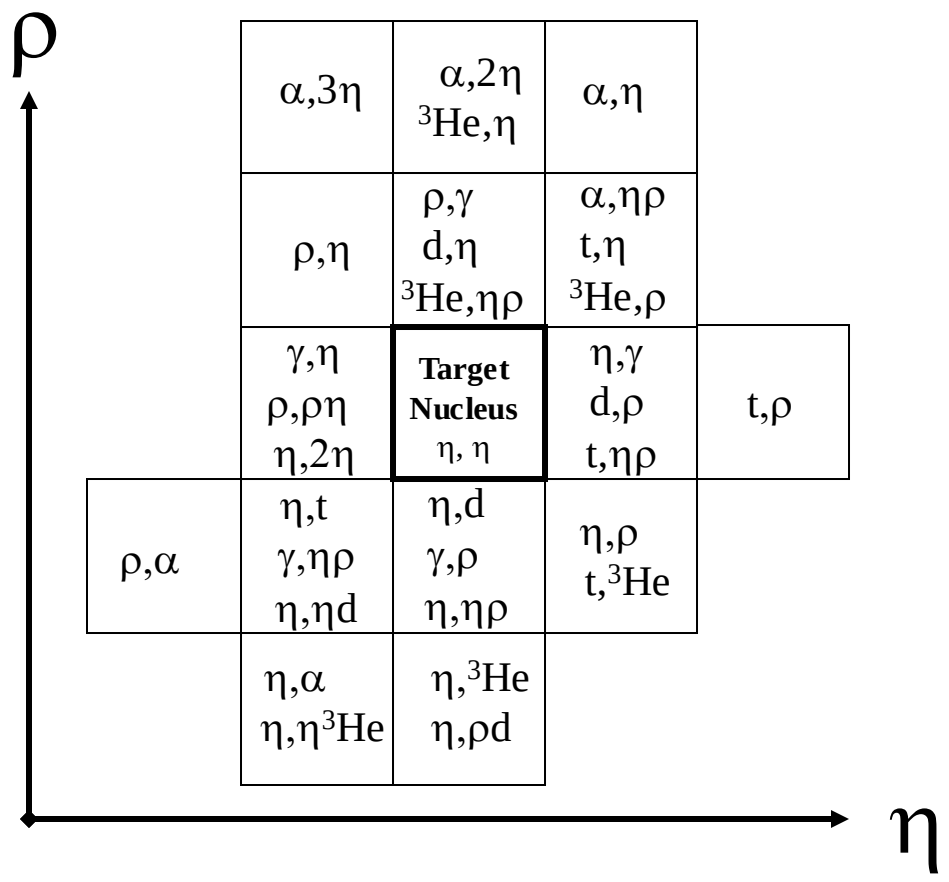


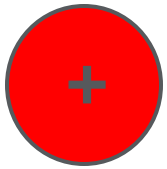
More on this helium *isotope* . . .

total number of
protons and neutrons
MASS NUMBER

$^{4}_{2}He$

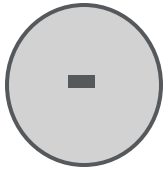
ELEMENT
SYMBOL

ATOMIC NUMBER
number of protons



Protons have a large mass and a positive charge. The number of protons identifies an element.

Neutrons have a large mass approximately equal to a proton's mass. Neutrons have no charge.



Electrons have a very small mass and a negative charge. Electrons travel outside the nucleus.