# BASICS OF NUCLEAR CHEMISTRY

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- The Basics
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- What is Nuclear Chemistry?
- Radioactivity
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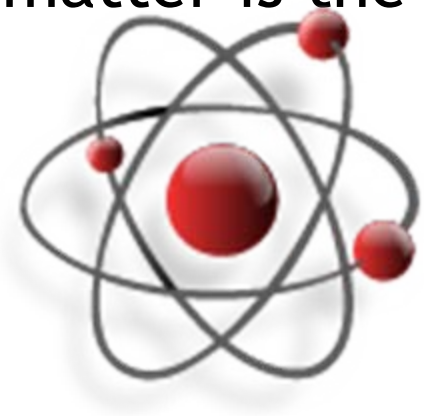
# WHAT IS CHEMISTRY?

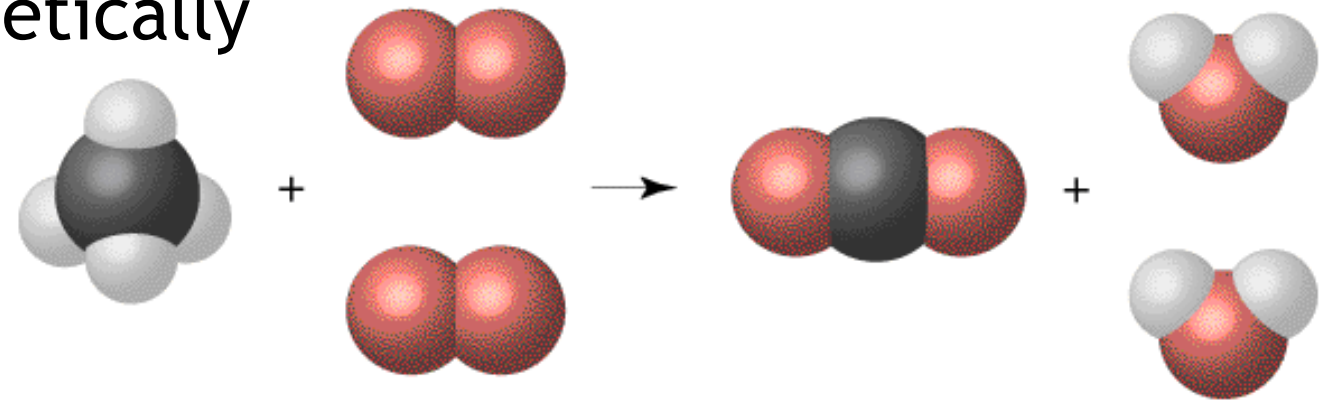
- Chemistry is the study of **matter** and the changes that it can undergo
- Matter is anything that has mass and takes up space
- Can be made up of pure or a mixture of pure substances in any state
- The smallest unit of matter is the **atom**



Lithium Atom

# CHEMISTRY - THE CENTRAL SCIENCE

- The goal of chemistry is to understand atomic and molecular interactions – both naturally and synthetically



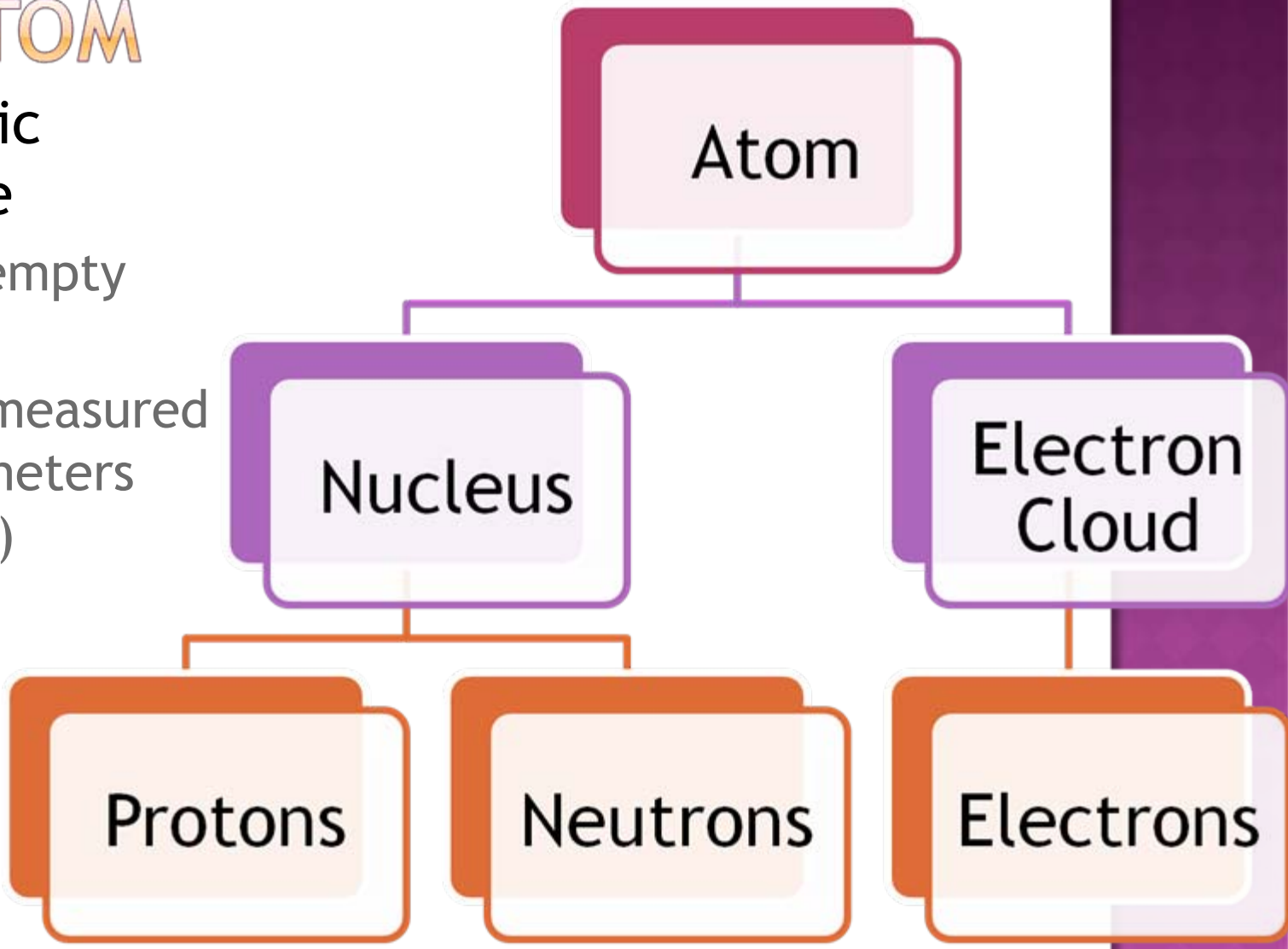
One methane molecule + Two oxygen molecules → One carbon dioxide molecule + Two water molecules

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

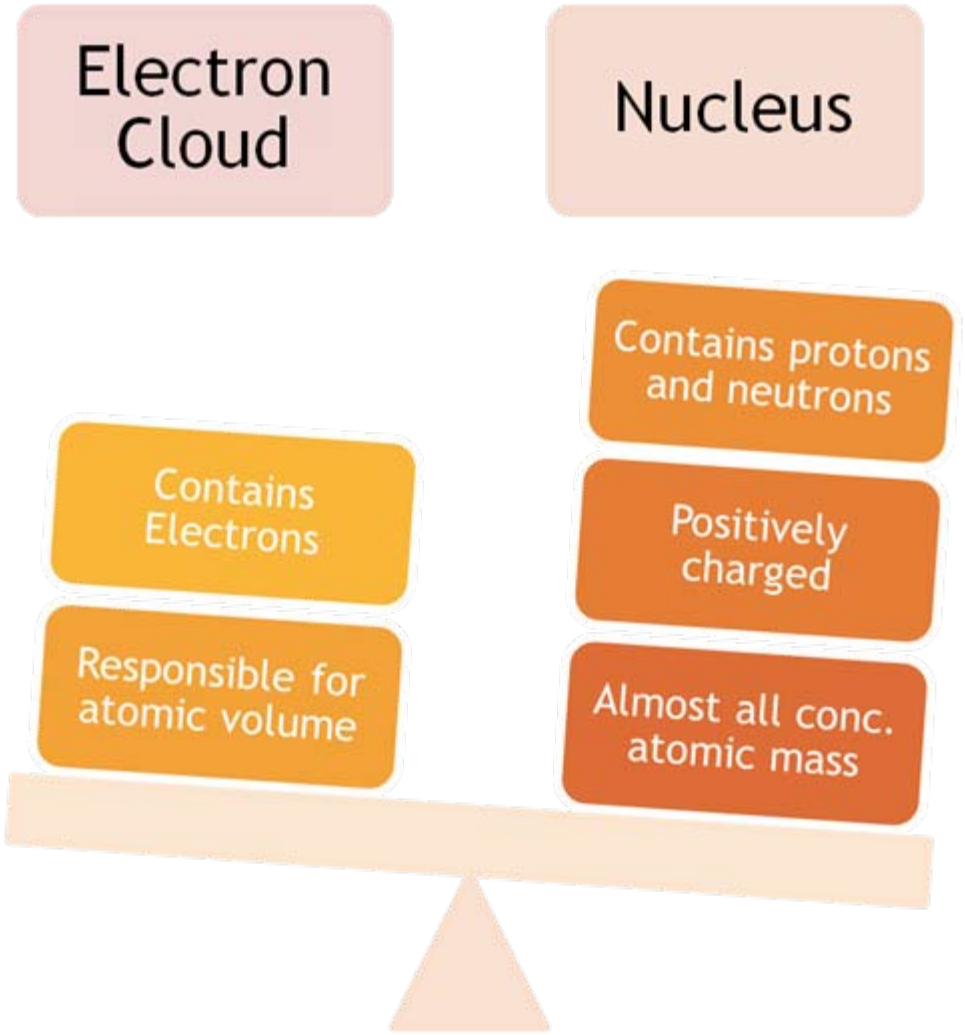
(1 C, 4 H) (4 O) (1 C, 2 O) (2 O, 4 H)

# THE ATOM

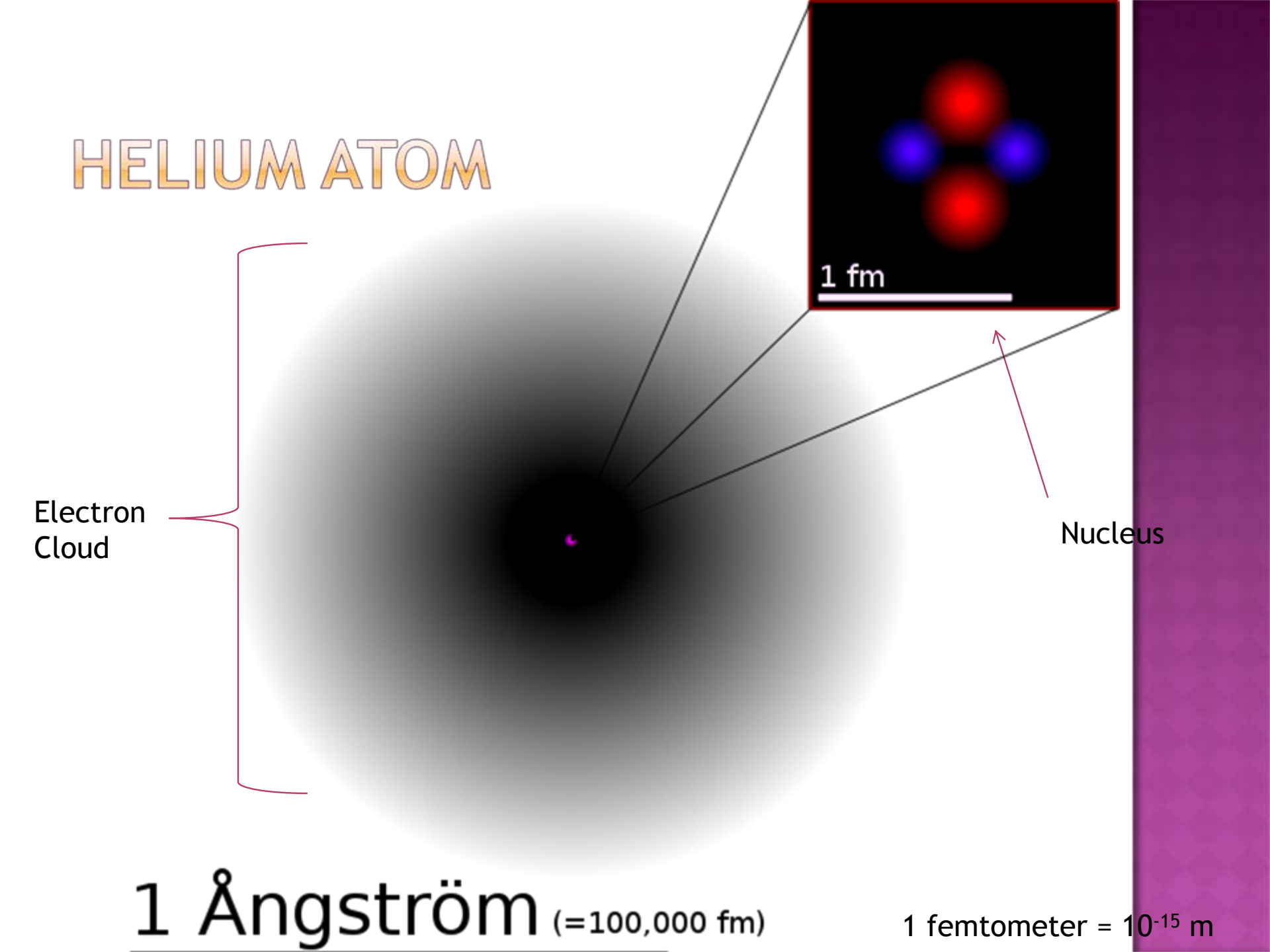
- Very basic structure
  - Mostly empty space
  - Radius measured in picometers ($10^{-12}$ m)



# REGIONS OF THE ATOM



# HELIUM ATOM




1 femtometer = $10^{-15}$ m

# SUBATOMIC PARTICLES

## Protons

- Symbol
  - $p^+$
- Charge
  - +1
- Relative Mass
  - 1
- Actual Mass
  - $1.67 \times 10^{-24}$

## Neutrons

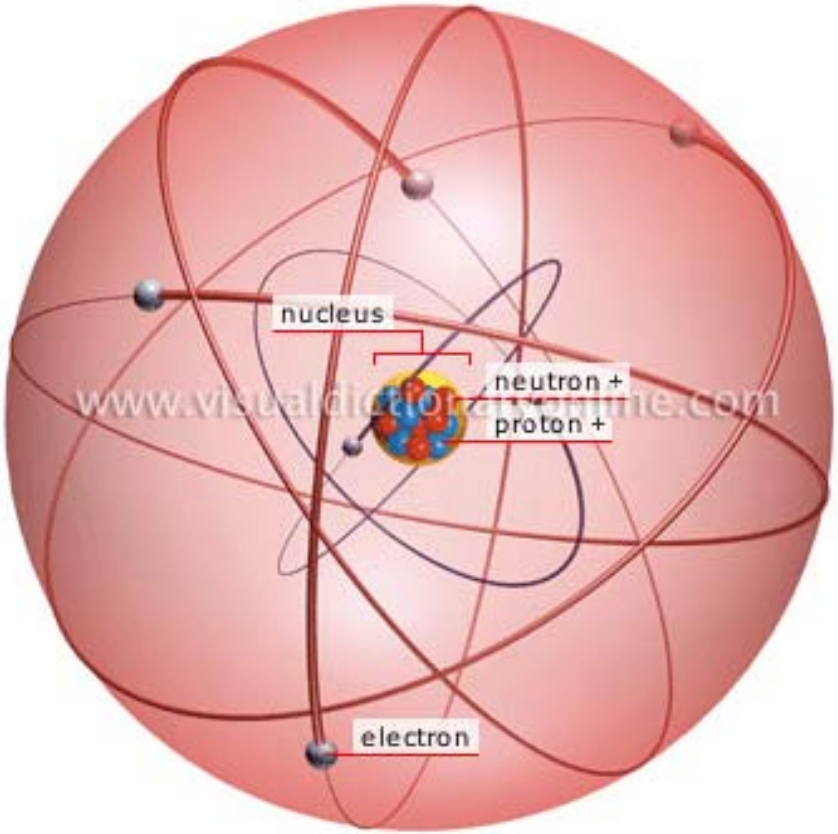
- Symbol
  - $n^0$
- Charge
  - 0
- Relative Mass
  - 1
- Actual Mass
  - $1.67 \times 10^{-24}$

## Electrons

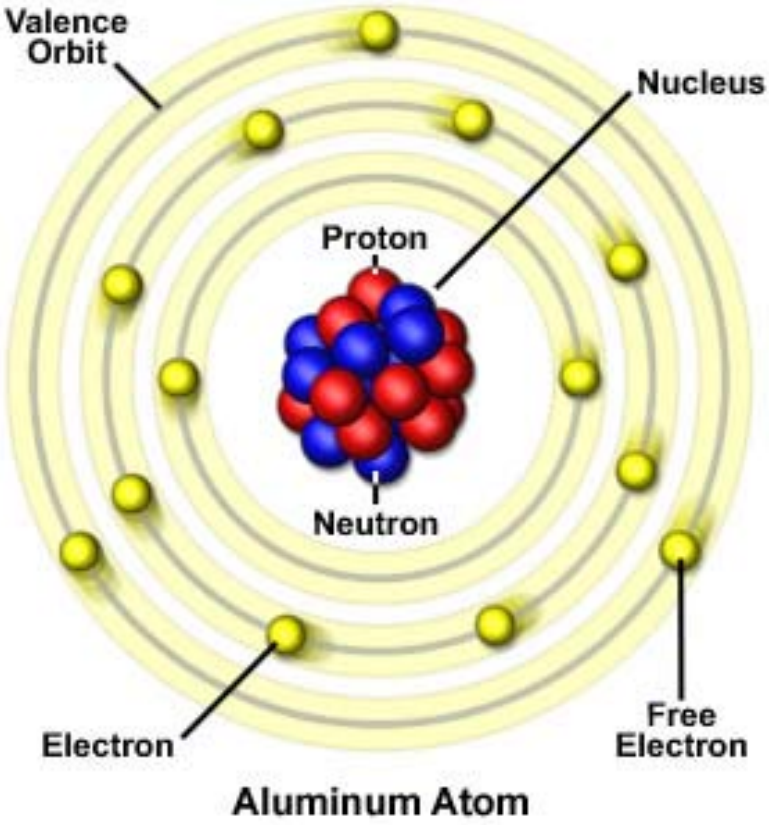
- Symbol
  - $e^-$
- Charge
  - -1
- Relative Mass
  - 1/1840
- Actual Mass
  - $9.11 \times 10^{-28}$

# CARBON ATOM

6 electrons,
6 protons,
6 neutrons



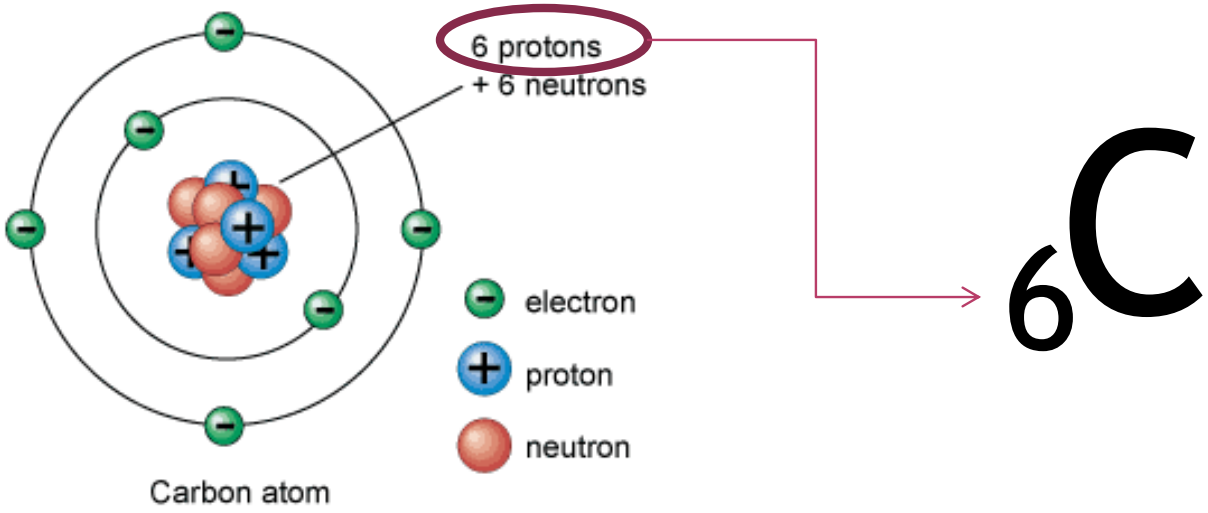

# ALUMINUM ATOM



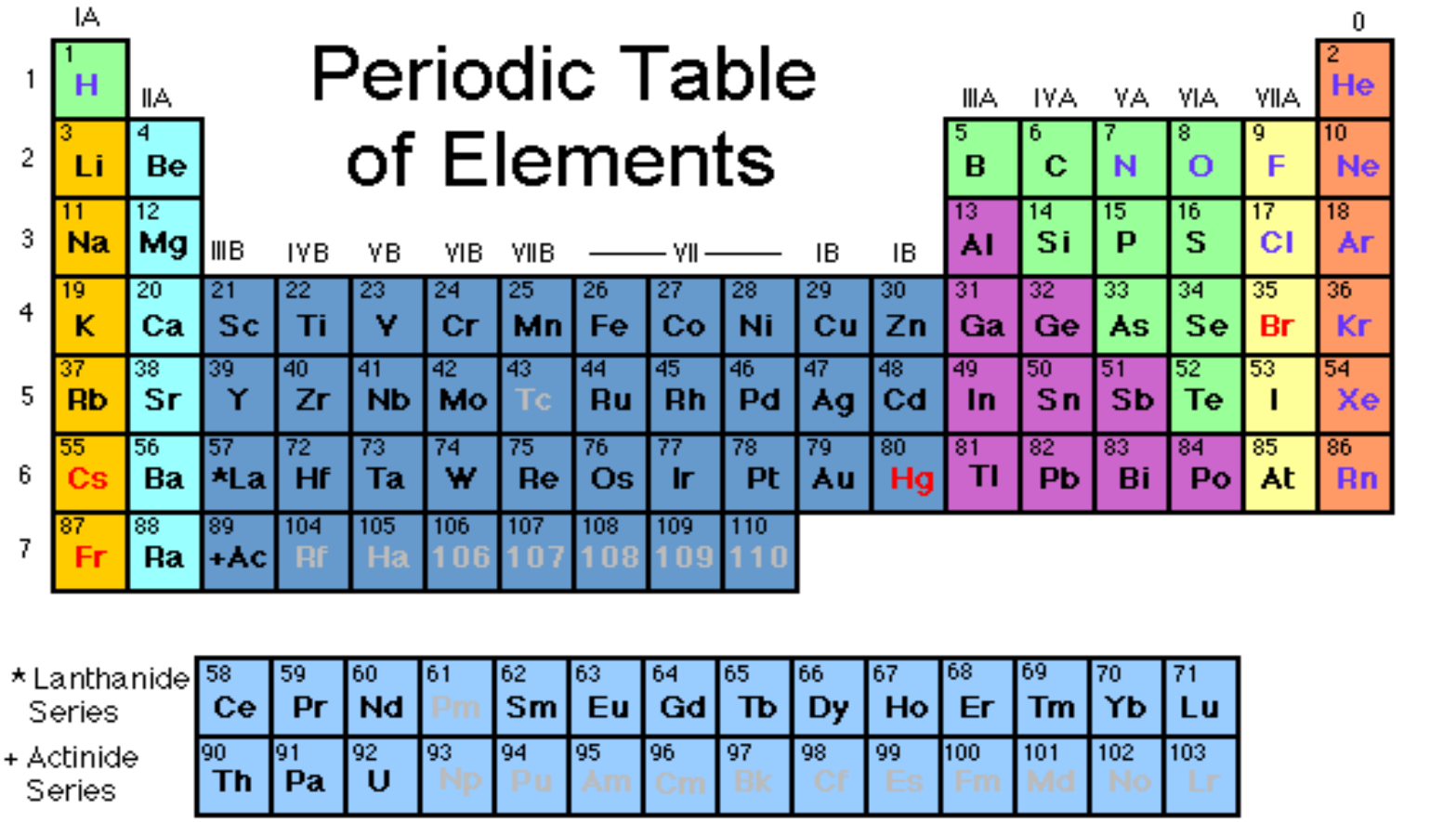

13 electrons,
13 protons,
14 neutrons

# HOW WE TELL ATOMS APART

- Atoms differ depending upon the number of protons in the nucleus and as they are discovered, they are named and become **elements**
- Each element is given an **atomic number** which corresponds with its proton number
- They are now organized by increasing atomic number in the **Periodic Table of Elements**



# PERIODIC TABLE




**Legend - click to find out more...**

**H - gas** **Li - solid** **Br - liquid** Tc - synthetic

Non-Metals

Transition Metals

Rare Earth Metals

Halogens

Alkali Metals

Alkali Earth Metals

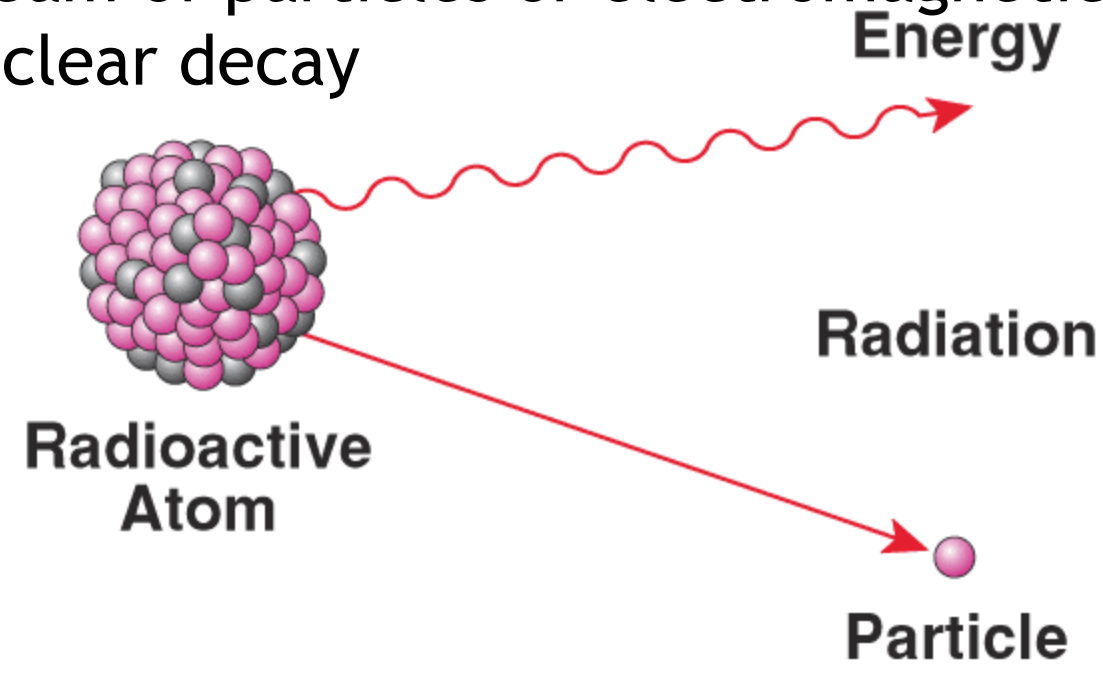
Other Metals

Inert Elements

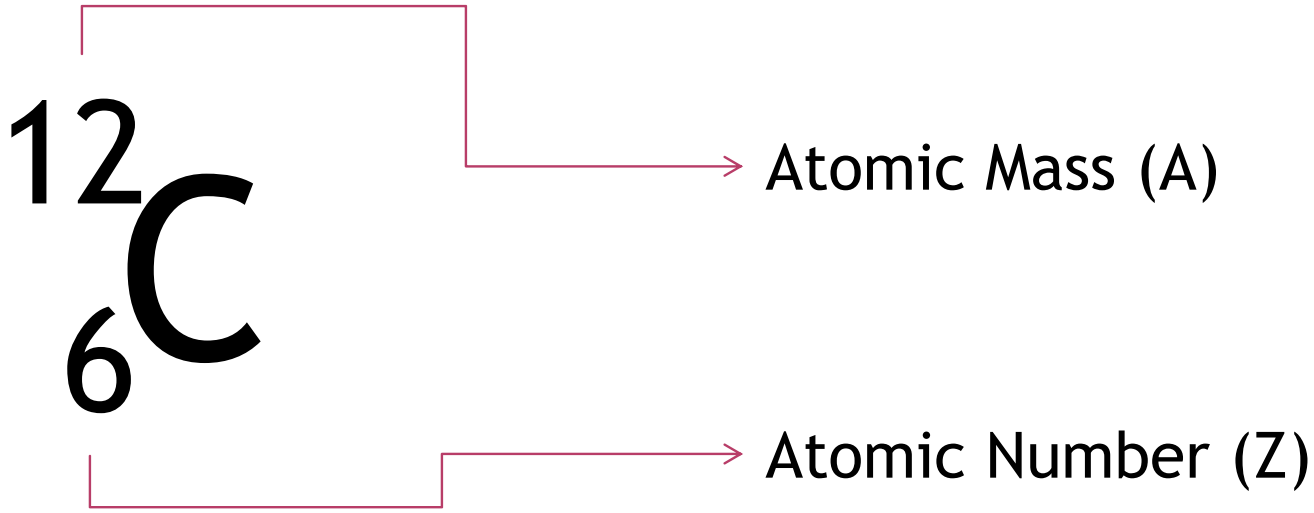
# WHAT IS NUCLEAR CHEMISTRY?

- Nuclear Chemistry is the division dealing with the atomic nucleus, radioactivity, and nuclear reactions
- **Radioactivity** - the spontaneous emission of a stream of particles or electromagnetic rays in nuclear decay

Any atom with 84 or more protons is radioactive

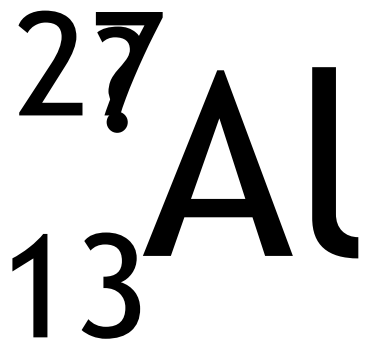


# BACK TO THOSE ELEMENTS - CHEMICAL SYMBOLS




Atomic Mass = Proton Number + Neutron Number

Aluminum: 13 $p^+$, 13 $e^-$, 14 $n^0$



# ISOTOPES

- Atoms of the same element may have different neutron numbers, thus different mass numbers

$^{12}_{6}C$ Carbon-12

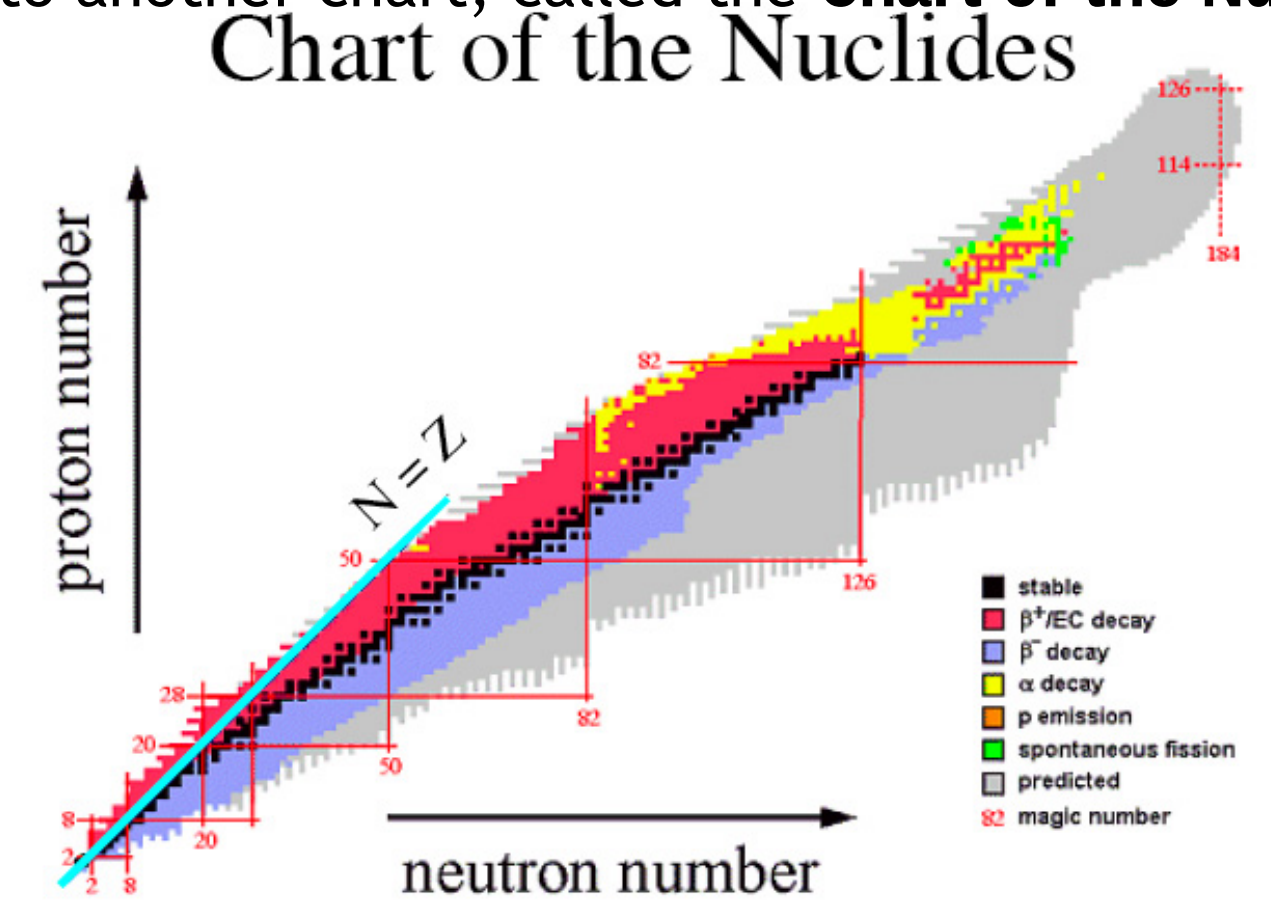
6 electrons,
6 protons,
6 neutrons

$^{14}_{6}C$ Carbon-14

6 electrons,
6 protons,
8 neutrons

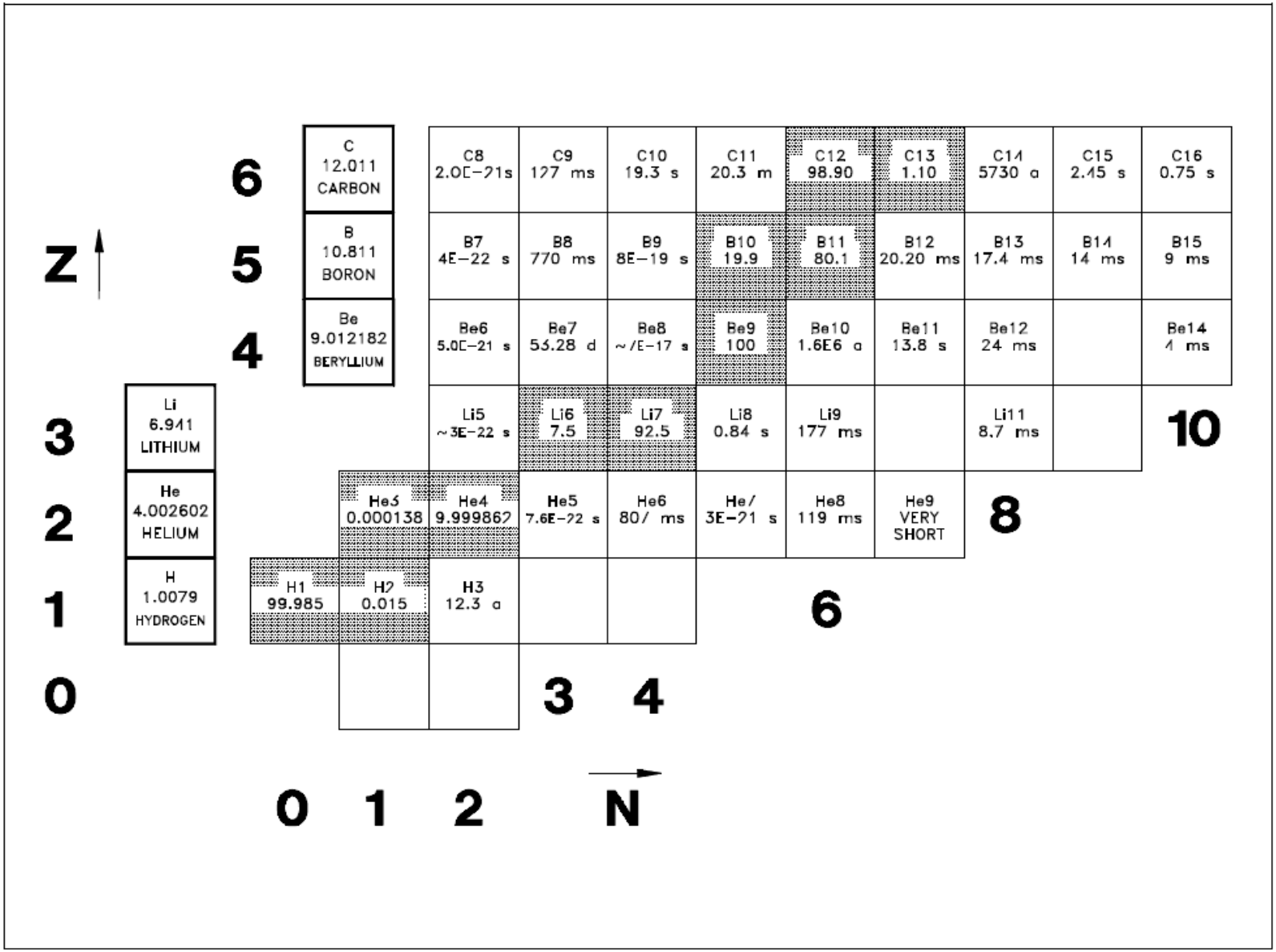
# CHART OF THE NUCLIDES

- We organize all the known isotopes of the elements into another chart, called the **Chart of the Nuclides**




Symmetric: Equal numbers of protons and neutrons
Asymmetric: Unequal numbers of protons and neutrons

# CHART OF THE NUCLIDES



# NUCLEAR REACTIONS

- Nuclear reactions involve changes in an atom's nucleus
- Isotopes with an unstable nucleus are radioactive and will spontaneously undergo a nuclear reaction
- A stable isotope will not spontaneously undergo a nuclear reaction
- Different isotopes undergo different types of changes
- A nucleus will gain or lose protons and/or neutrons
- High energy particles or electromagnetic radiation will be given off
- The new atom may be stable or radioactive
- Several types of reactions

# TYPES OF RADIATION

## Alpha Particles

- Made up of 2 protons & 2 neutrons, the nucleus of a He atom (2+ charge)
- Can emit from a radioactive atom
- Symbolized as $\alpha$

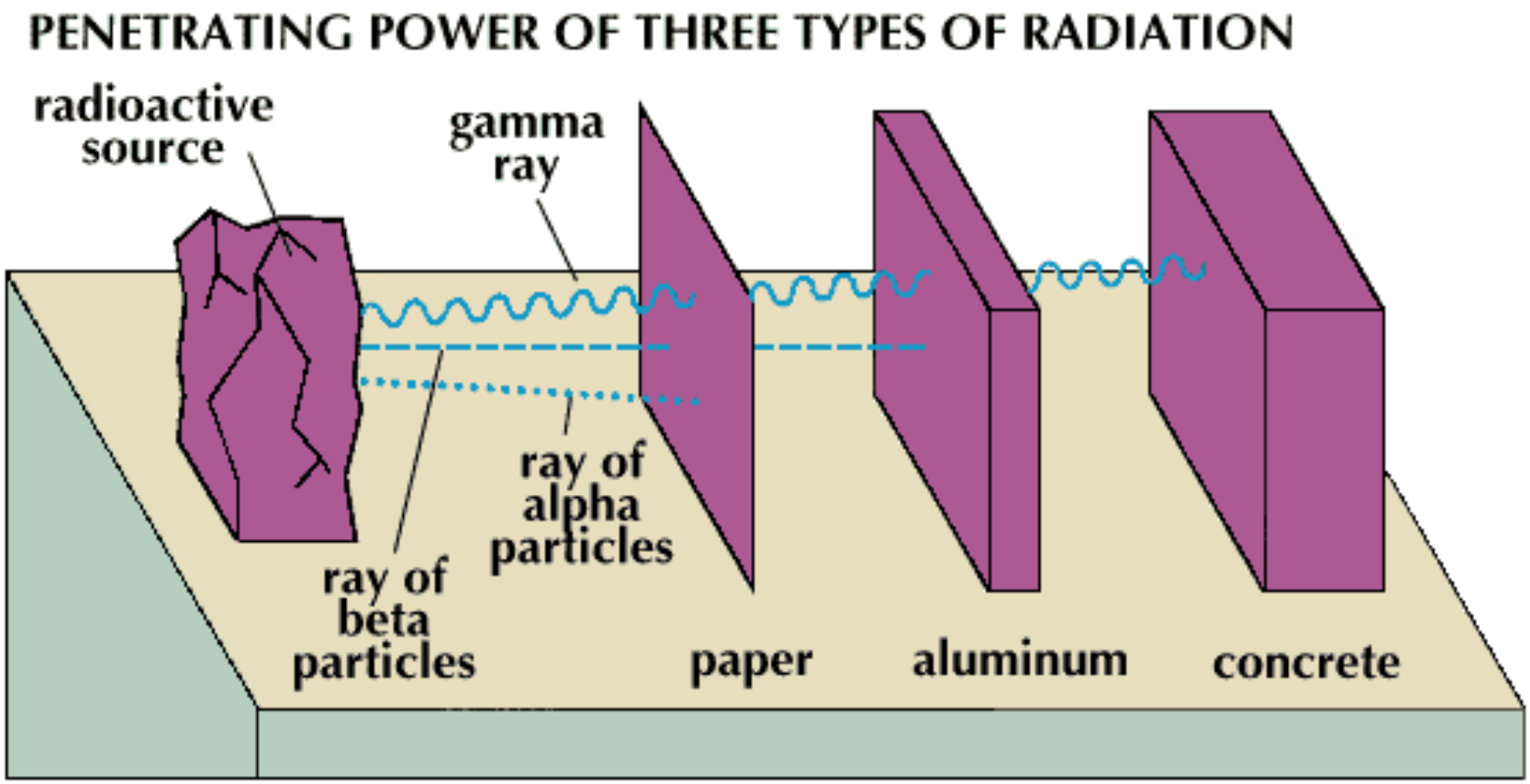
## Beta Particles

- 2 types of beta decay w. 2 types of particles
- Fast moving electrons
- Symbolized as $\beta$

## Gamma Rays

- High energy electromagnetic radiation from an excited nucleus
- No mass and no charge
- Symbolized as $\gamma$

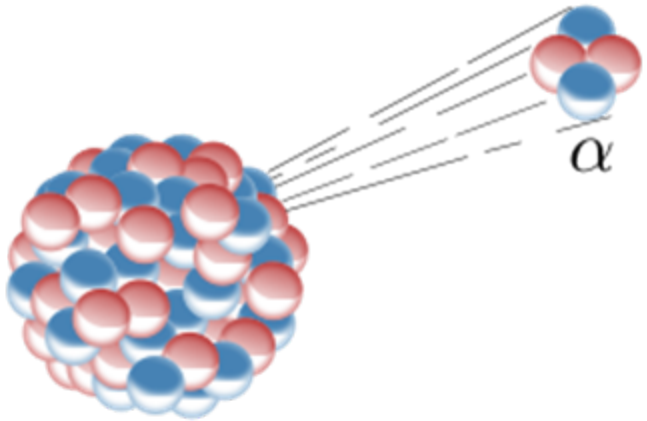
# RADIATION POWER



# ALPHA DECAY

- When a nucleus undergoes α decay, it loses 2 protons and 2 neutrons
- A new element is produced, with an atomic number 2 less than and an atomic mass 4 less than the original

$$ {}^{A}_{Z}X \rightarrow {}^{4}_{2}\alpha + {}^{A-4}_{Z-2}Y $$

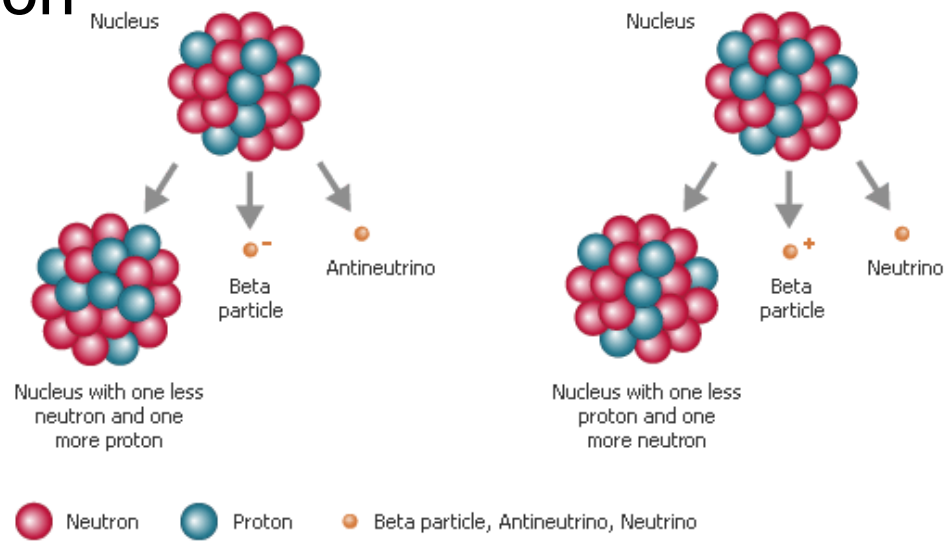



$$ {}^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}\alpha $$

Uranium-238 into Thorium-234

# BETA DECAY

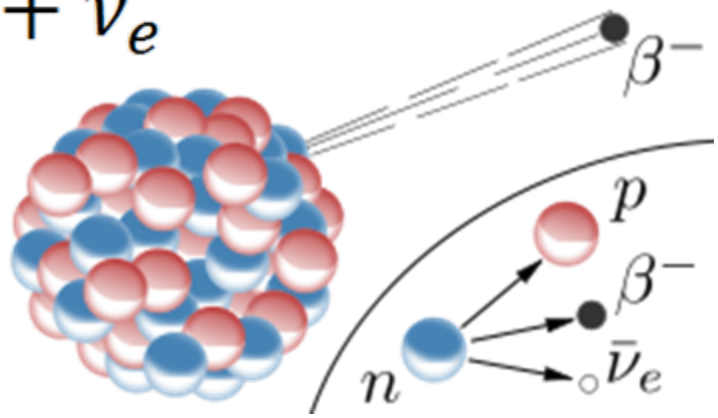
- There are 2 types of Beta Decay
  - $\beta^-$ decay
  - $\beta^+$ decay also called positron emission
- In $\beta^-$ decay, a neutron decomposes into a proton and a beta particle
- In $\beta^+$ decay a proton is converted to a neutron and a positron



# BETA NEGATIVE DECAY

- Occurs when there are too many neutrons
- A neutron decomposes into a proton, antineutrino, and a beta particle (electron)

$$ {}^{A}_{Z}X \rightarrow {}^{0}_{-1}\beta + {}^{A}_{Z+1}Y + \bar{\nu}_e $$

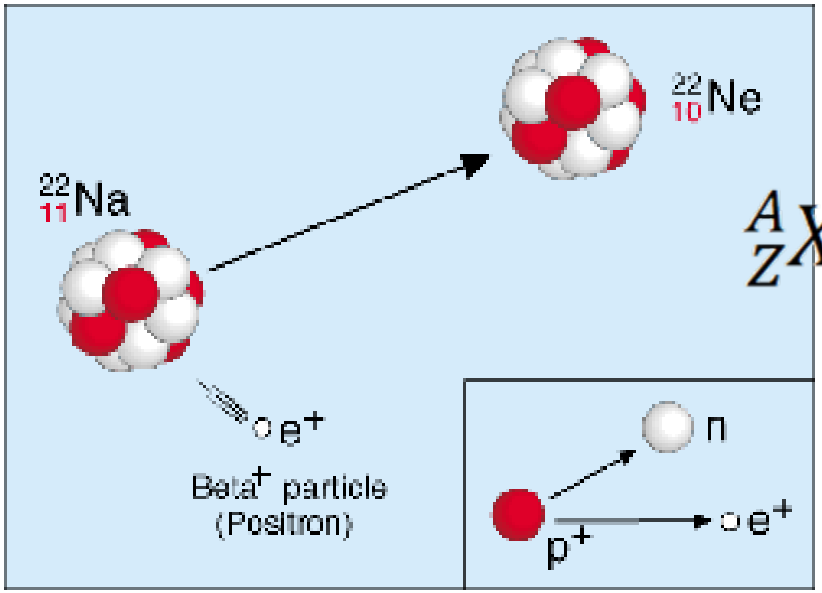



$$ {}^{14}_{6}C \rightarrow {}^{0}_{-1}\beta + {}^{14}_{7}N + \bar{\nu}_e $$

Carbon-14 into Nitrogen-14

# BETA POSITIVE DECAY

- Occurs when there are too many protons
- A proton is converted to a neutron, neutrino, and a positron (a positive electron)



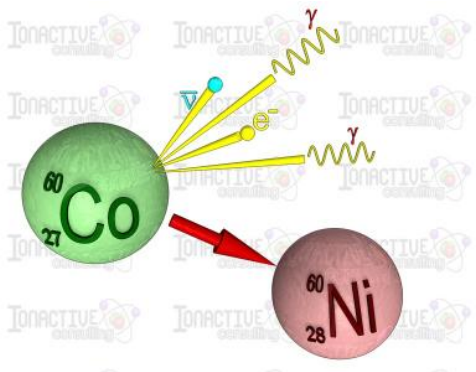

$$^{A}_{Z}X \rightarrow {}^{0}_{+1}\beta + {}^{A}_{Z-1}Y + \nu_e$$

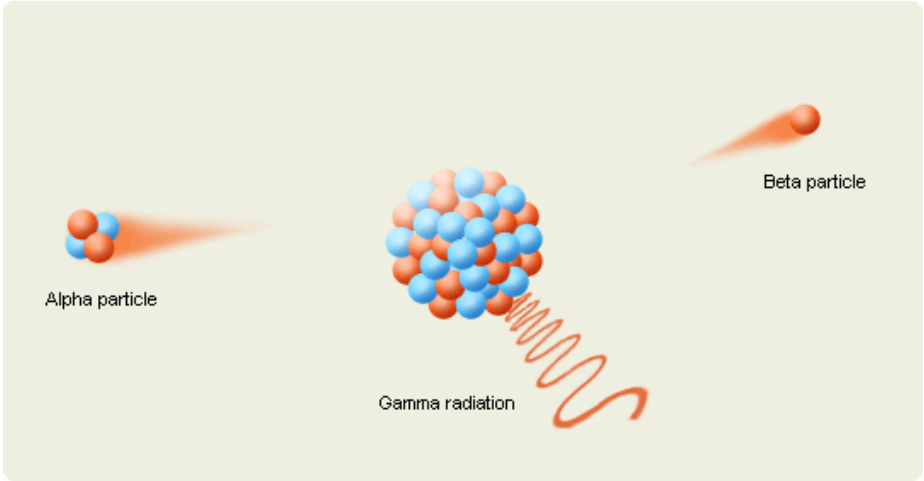
$$^{10}_{6}C \rightarrow {}^{0}_{+1}\beta + {}^{10}_{5}B + \nu_e$$

Carbon-10 into Boron-10

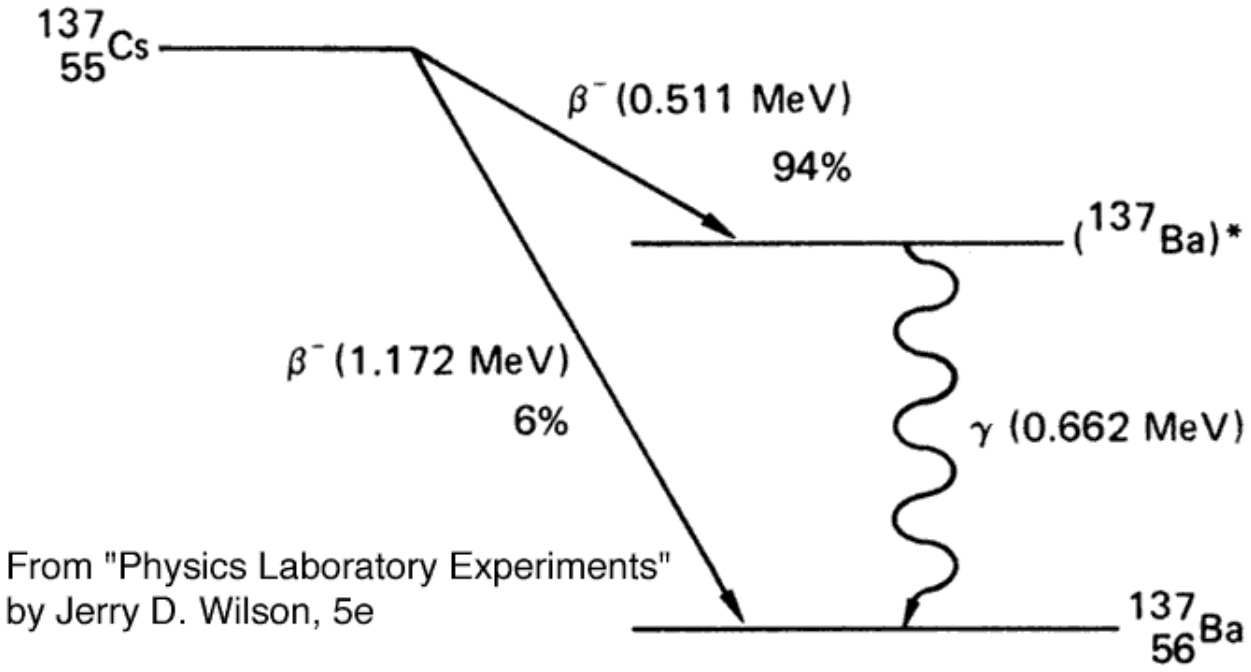
# GAMMA RAY EMISSION

- Emission of high energy electromagnetic radiation from an excited nucleus
- Often occurs with alpha or beta decay as a way to release energy



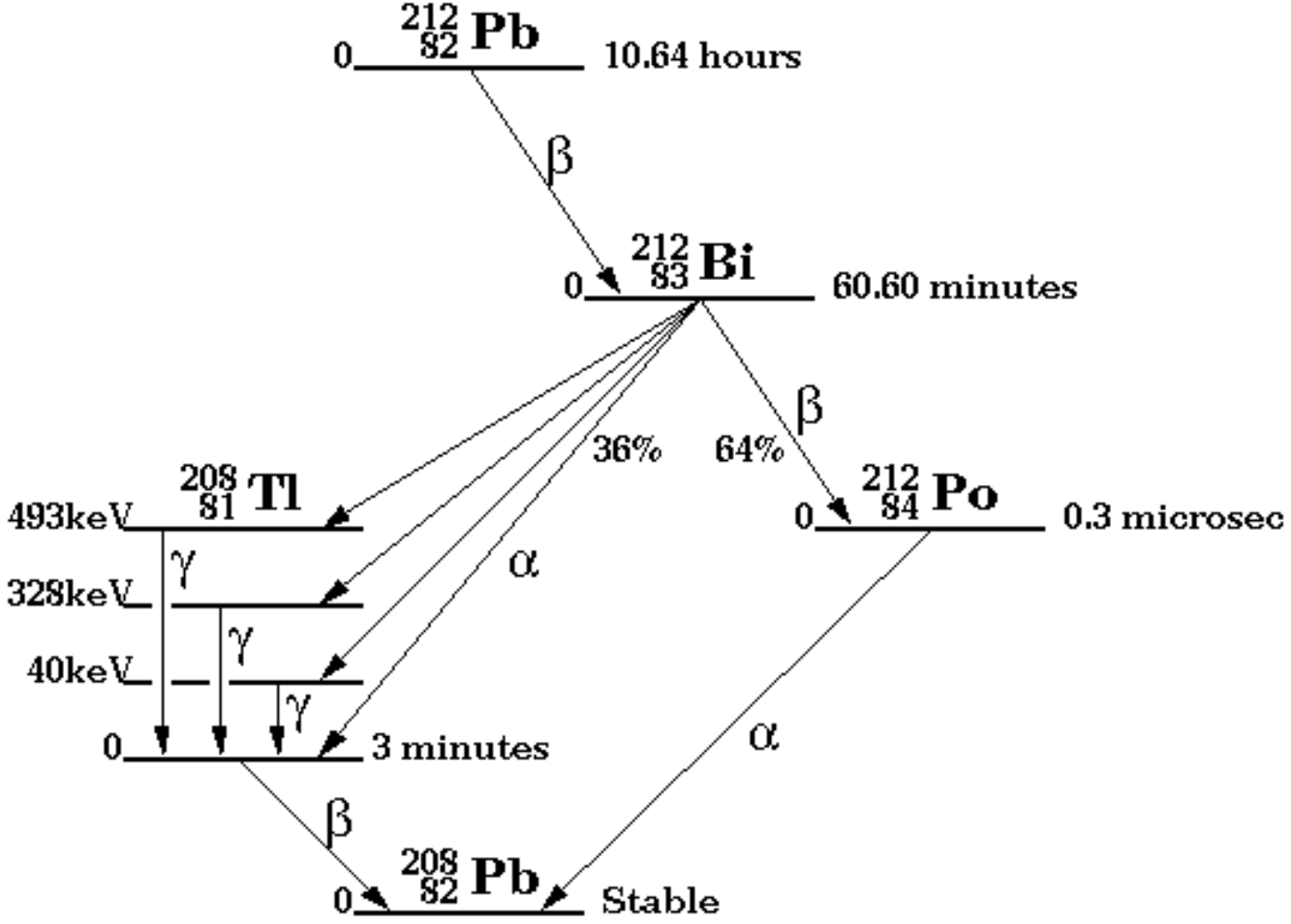
# DECAY SCHEMES



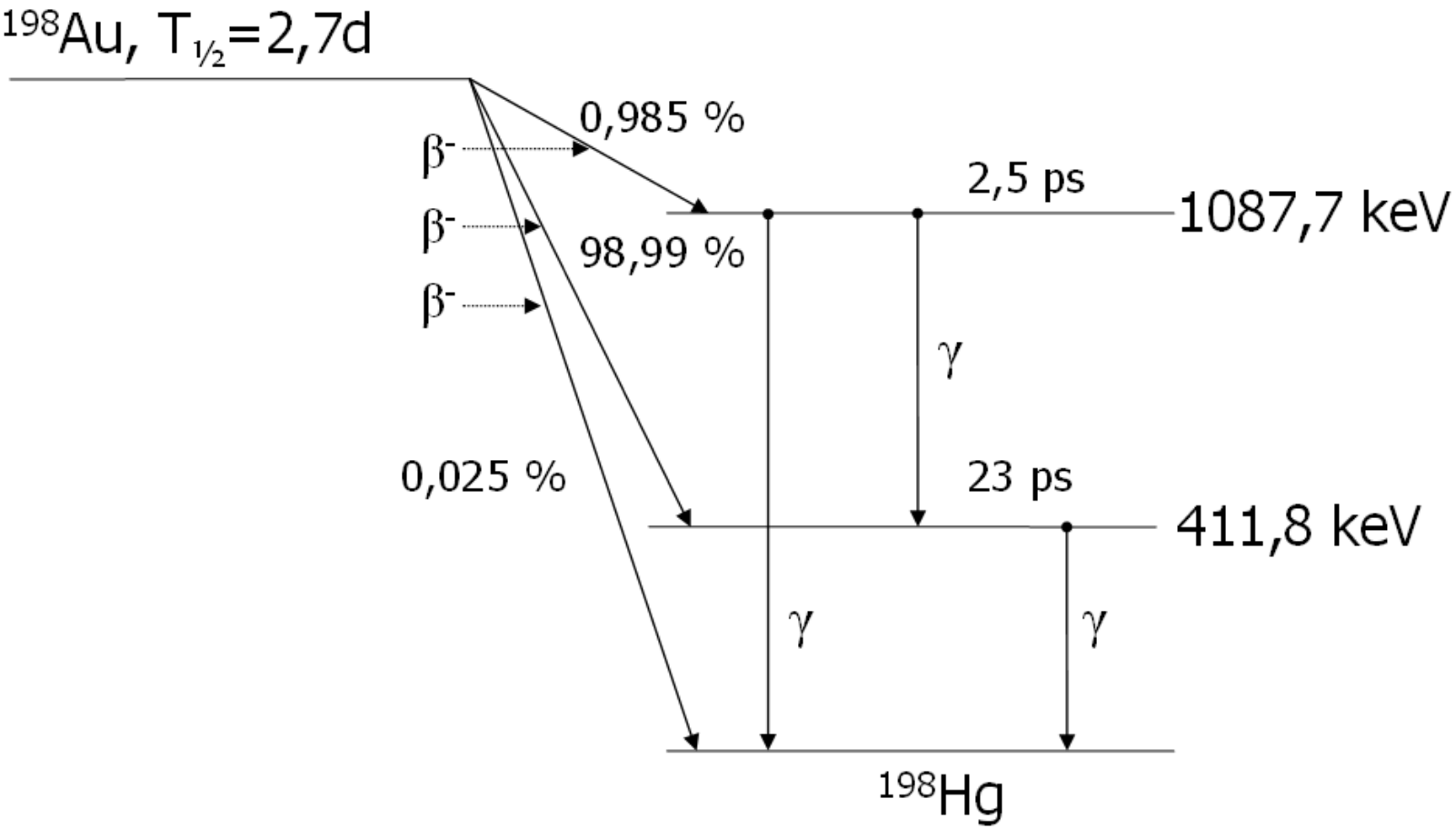

From "Physics Laboratory Experiments"
by Jerry D. Wilson, 5e

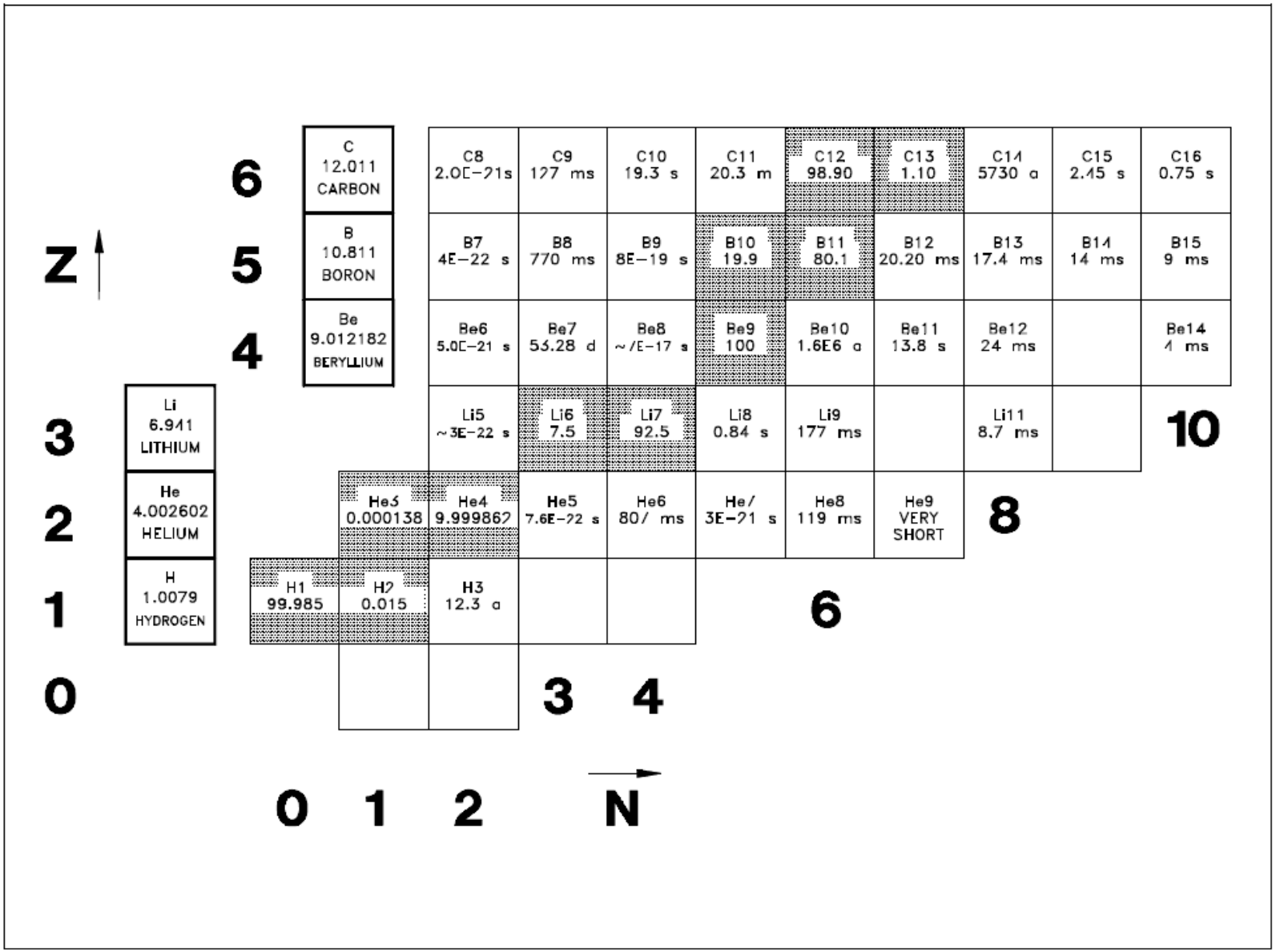
**Figure 49.2 Decay scheme of Cs-137.** Most of the cesium-137 (Cs-137) nuclei (94%) decay to an excited state of barium-137 ($^{137}$Ba*), which then gamma decays to a stable state.

# DECAY SCHEMES



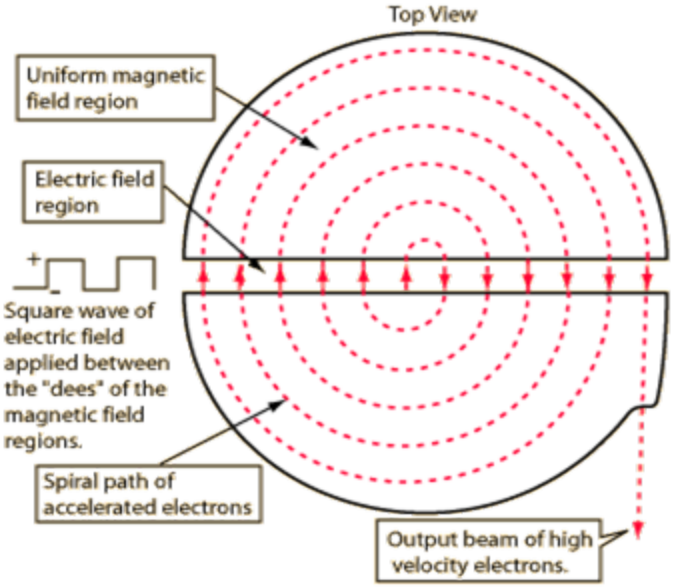
# DECAY SCHEMES

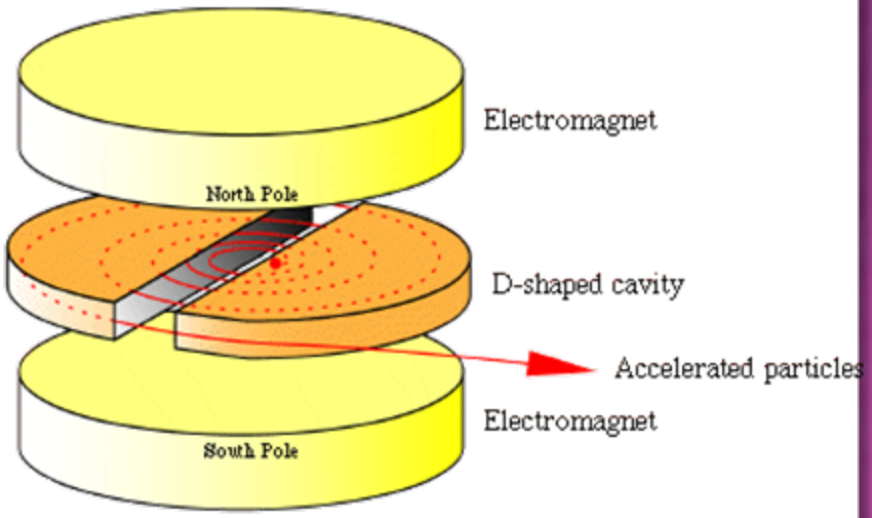



C
12.011
CARBON
B
10.811
BORON
Be
9.012182
BERYLLIUM
Li
6.941
LITHIUM
He
4.002602
HELIUM
H
1.0079
HYDROGEN
C8 2.0E−21s
C9 127 ms
C10 19.3 s
C11 20.3 m
C12 98.90
C13 1.10
C14 5730 a
C15 2.45 s
C16 0.75 s
B7 4E−22 s
B8 770 ms
B9 8E−19 s
B10 19.9
B11 80.1
B12 20.20 ms
B13 17.4 ms
B14 14 ms
B15 9 ms
Be6 5.0E−21 s
Be7 53.28 d
Be8 ~7E−17 s
Be9 100
Be10 1.6E6 a
Be11 13.8 s
Be12 24 ms
Be14 4 ms
Li5 ~3E−22 s
Li6 7.5
Li7 92.5
Li8 0.84 s
Li9 177 ms
Li11 8.7 ms
He3 0.000138
He4 9.999862
He5 7.6E−22 s
He6 807 ms
He7 3E−21 s
He8 119 ms
He9 VERY SHORT
H1 99.985
H2 0.015
H3 12.3 a
Z
6
5
4
3
2
1
0
10
8
6
3
4
0 1 2
N

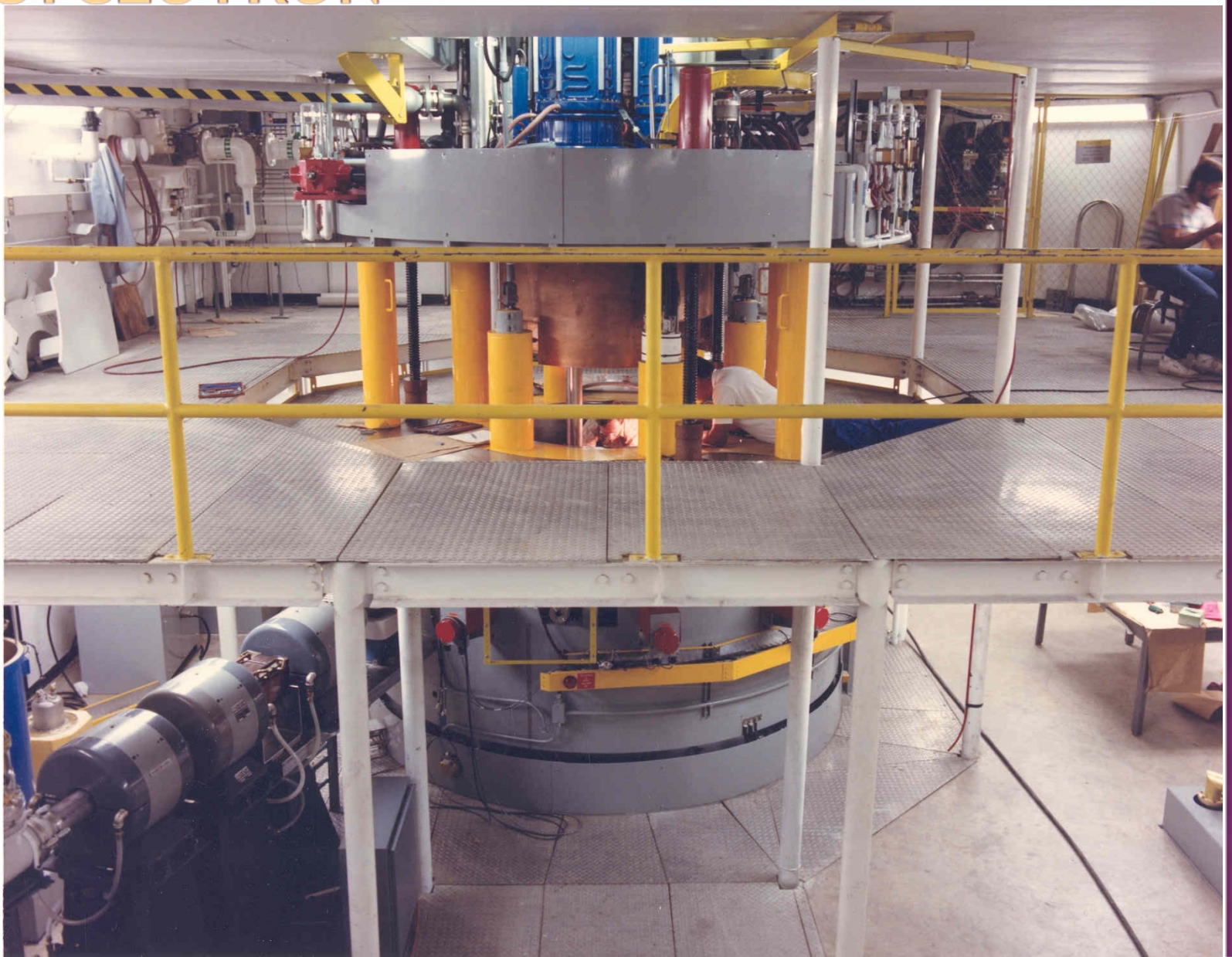
# WHAT DO WE DO AT THE CYCLOTRON?

- The Cyclotron is a particle accelerator
  - Accelerates charged particles using a high-frequency, alternating voltage, and a magnetic field
- The Cyclotron produces a beam of particles that we can use to shoot at other particles to create and study isotopes and measure decays

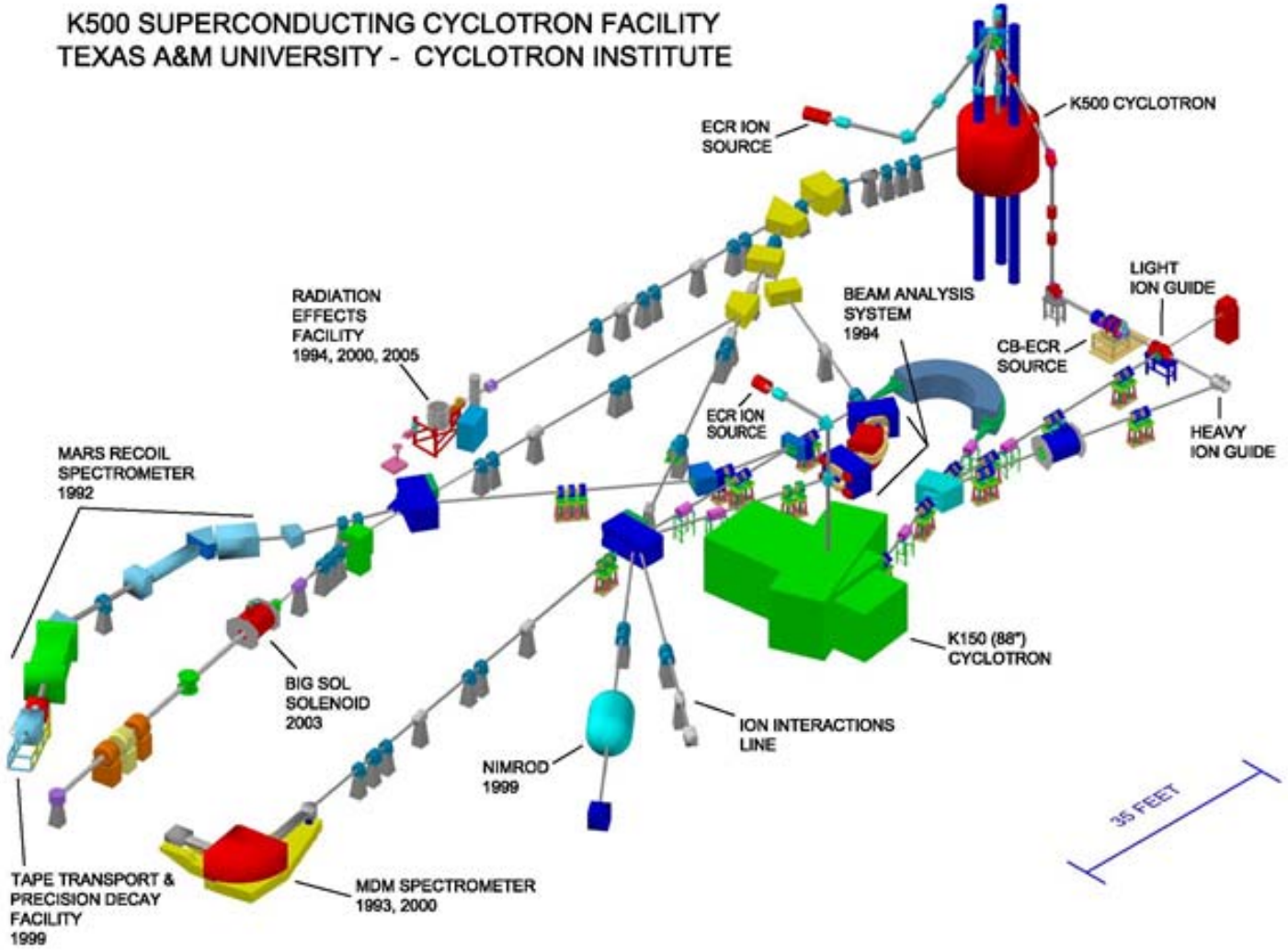


# K500 SUPERCONDUCTING CYCLOTRON



# TAMU CYCLOTRON INSTITUTE



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