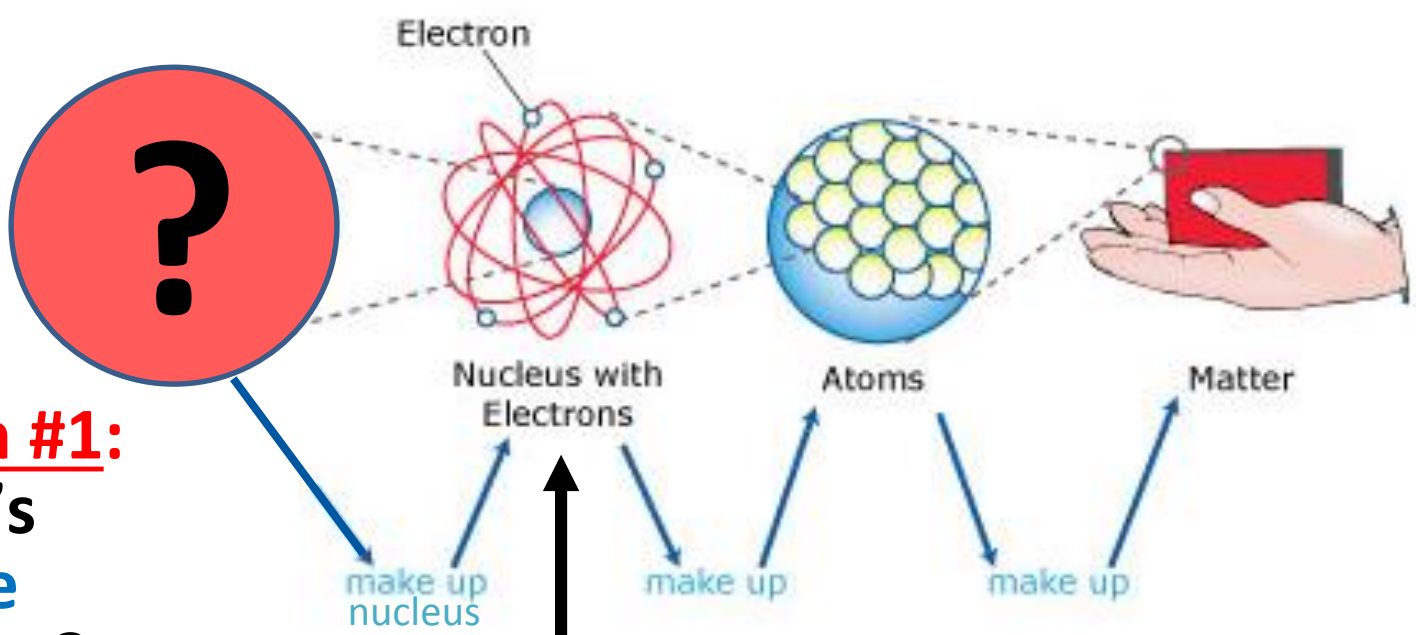
Structure of Matter

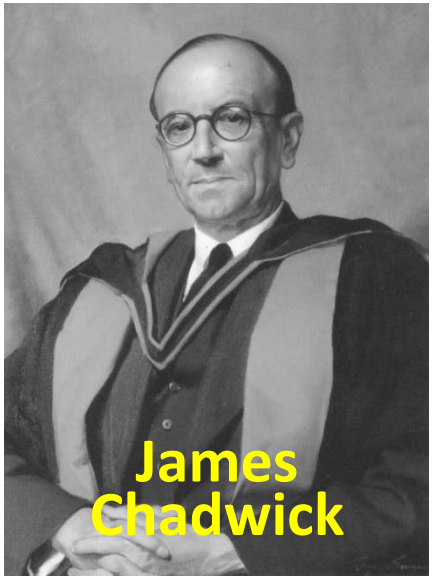


Question #1: What's inside a nucleus?

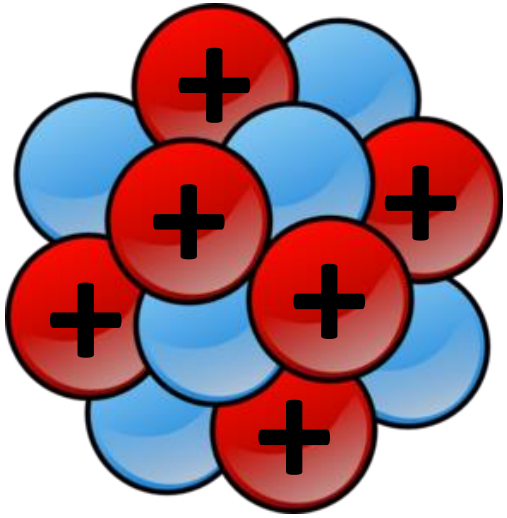
Question #2: Is planetary model of the atom *good enough* to explain all experimental observations?

Inside a Nucleus

- **Rutherford, 1920: discovery of a proton (Greek: "first"), a positively charged subatomic particle.**
- **1920-1932: search for a *neutral* particle.**
- **Chadwick, 1932: detected zero charged particles with about the same mass as the proton, eventually called neutron (1935 Nobel Prize in Physics).**



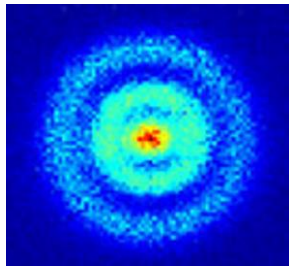
Atomic Nucleus Structure



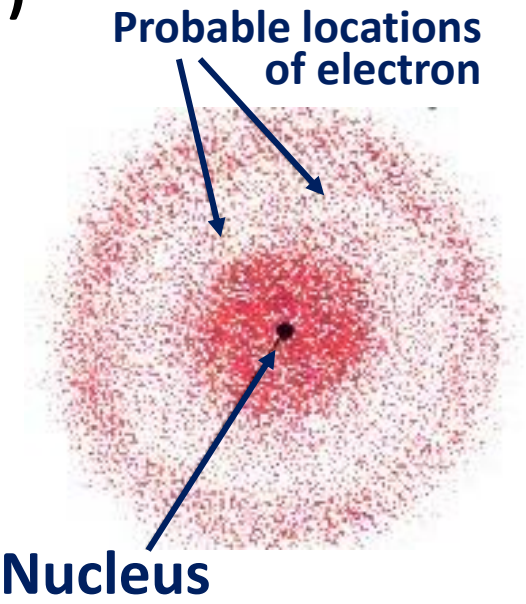
Atom ~10^{-10}m

Nucleus ~10^{-14}m
Proton ~10^{-15}m
Neutron ~10^{-15}m

Wave Model of the Atom (contemporary model)

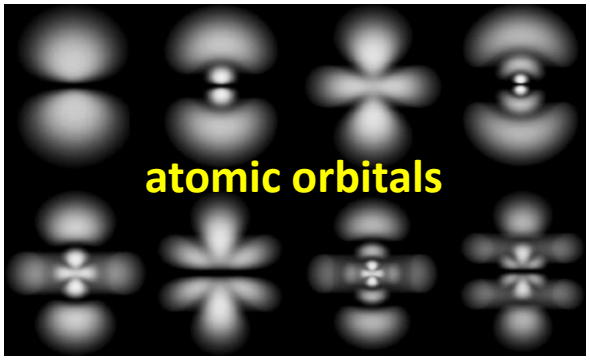


Atom has a small positively charged nucleus surrounded by a large region (*"electron cloud"*) in which there are enough electrons to make an atom neutral.

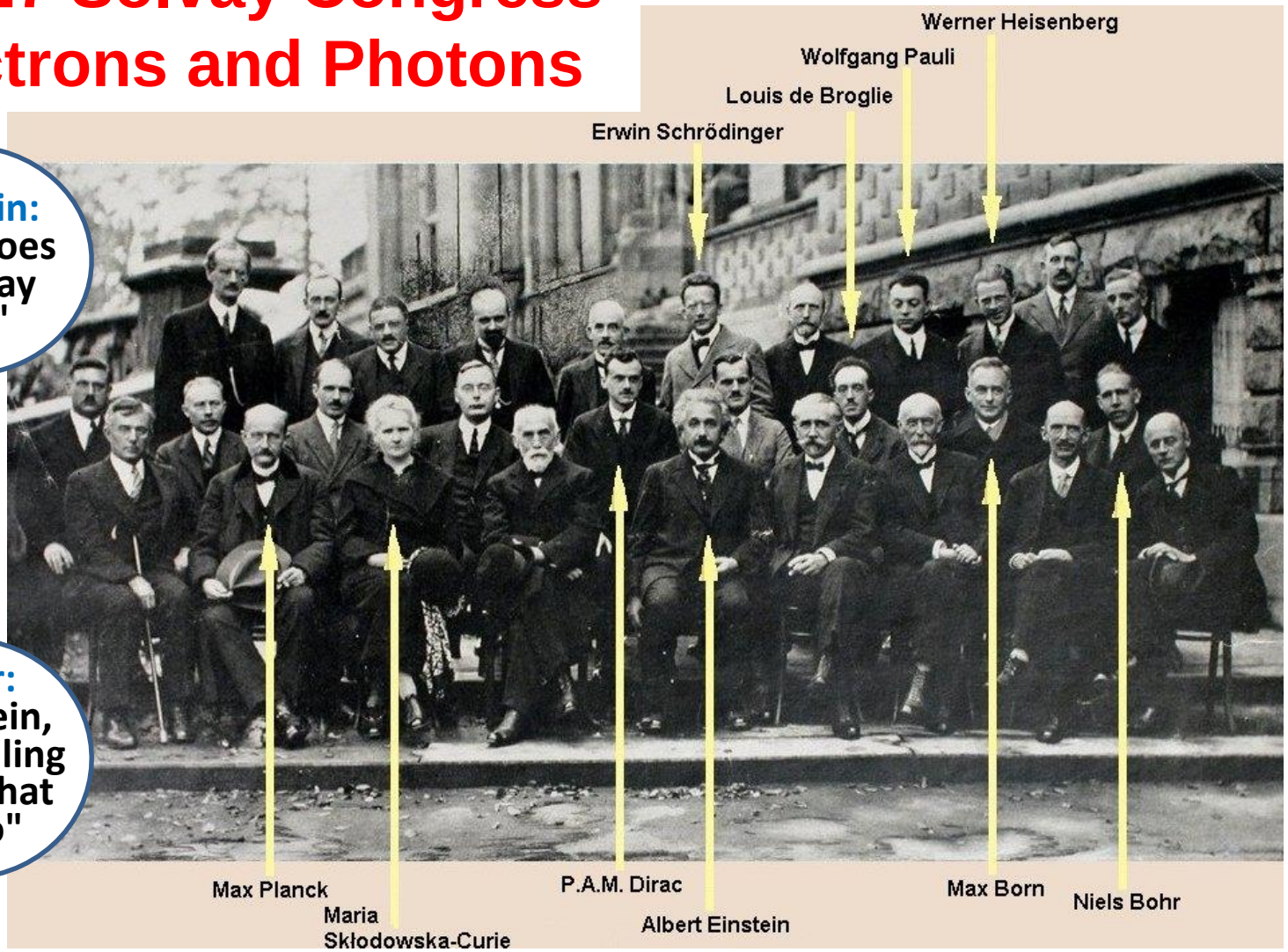


Quantum Theory states that the electrons inside an atom possess both particle- and wave-like properties:

- **There is always an integer number of electrons orbiting the nucleus.**
- **It is impossible to determine the exact location of an electron. Electrons do not have a definite path around the nucleus. The probable location of an electron is based on how much energy it has.**
- **The modern term "atomic orbital" refers to the physical region or space where the electron can be calculated to be present.**
- **Electrons whirl about the nucleus billions of times in one second and can jump between orbitals in a particle-like fashion, losing or gaining energy.**



The 1927 Solvay Congress on Electrons and Photons



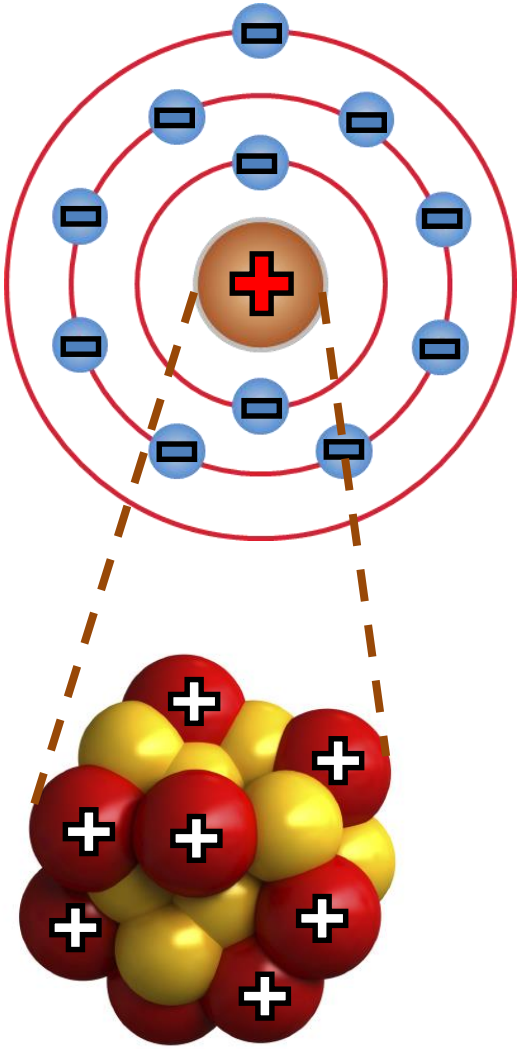
Einstein: "God does not play dice"

Bohr: "Einstein, stop telling God what to do"

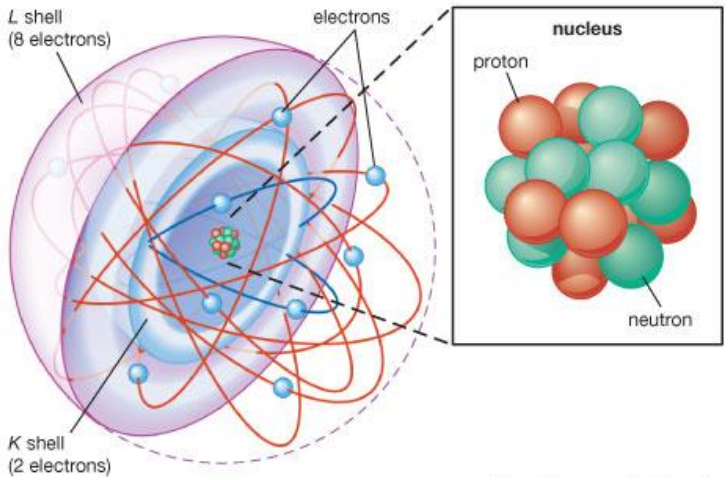
In October 1927, the world's most notable physicists met to discuss the newly formulated quantum theory and subatomic makeup. 17 of the 29 attendees were or later became Nobel Prize winners.

Atomic Structure Summary

- **All atoms have:**
  - a positively charged nucleus
  - and negatively charged electrons moving around within atomic orbitals
- **Atomic nucleus consists of:**
  - positively charged protons
  - and neutrons that have no electric charge



Forces Inside the Atom

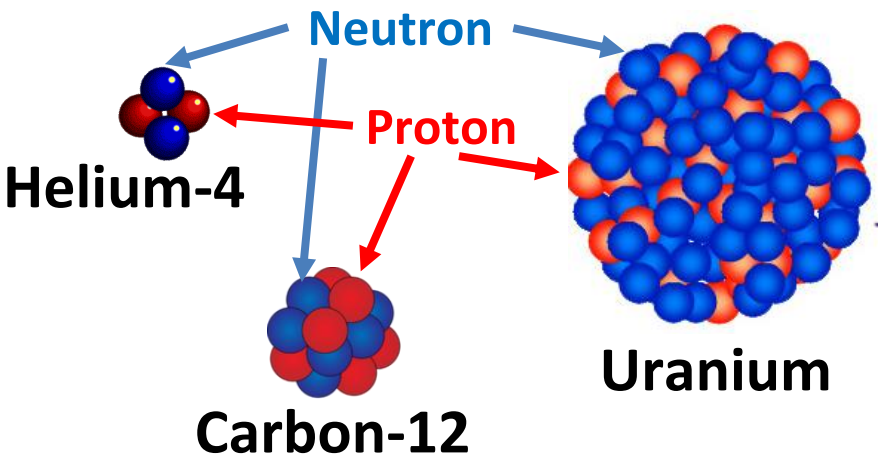


What holds an atom together?

- The electrons are kept in orbit around the nucleus due to an electromagnetic field of attraction between the positive charge of the protons and the negative charge of the electrons.
- The nucleus of protons and neutrons is kept together by the nuclear (strong) force, which *opposes and overcomes the electromagnetic repulsion when particles are very close to each other (~1 fm!).*

Nuclear (binding) energy is the energy associated with the nuclear force:

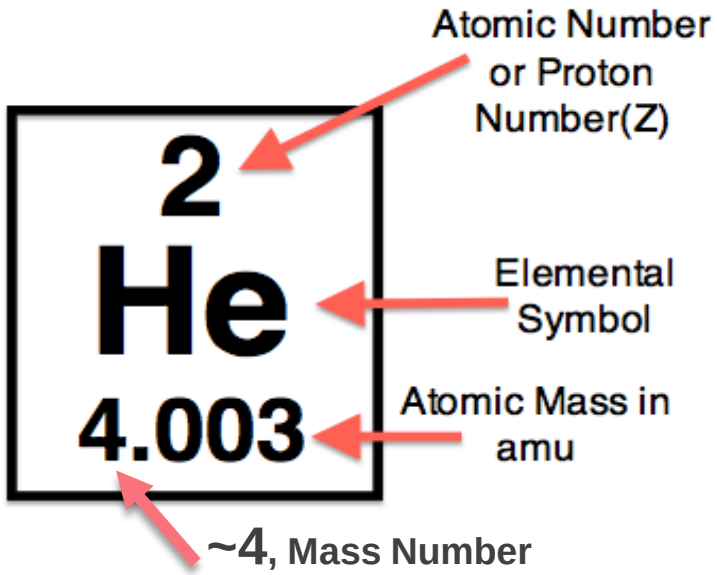
- A stable atom is an atom that has enough binding energy to hold the nucleus together permanently.
- An unstable atom does not have enough binding energy to hold the nucleus together permanently and will lose neutrons and/or protons as it attempts to become stable.



Understanding Elements

The number of protons and neutrons in the nucleus give the atoms their specific characteristics.

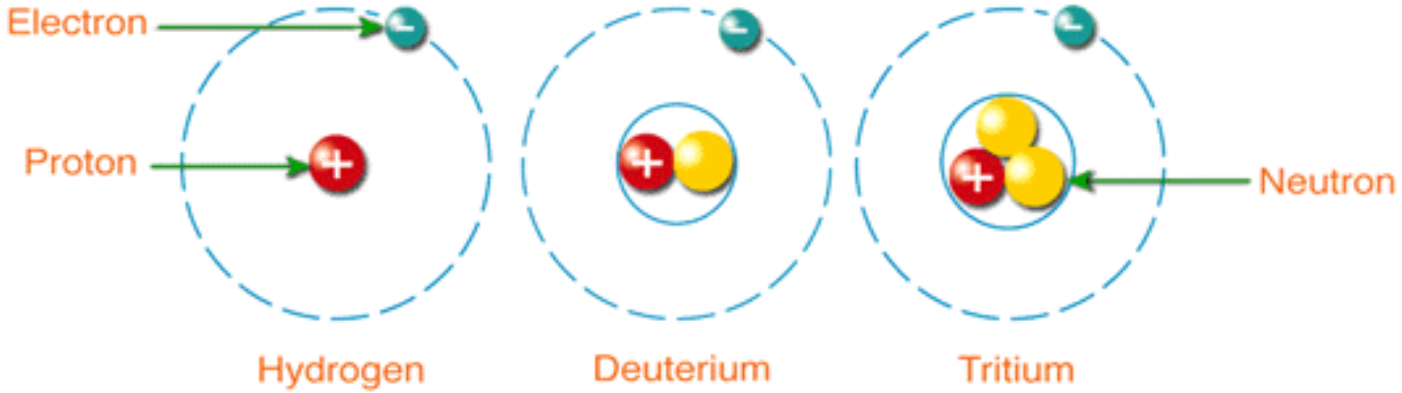
- **All atoms of the same chemical element contain the same number of protons, defined by a unique atomic number of that element.**
- **For example, all helium atoms, and only helium atoms, contain two protons and have an atomic number of 2.**



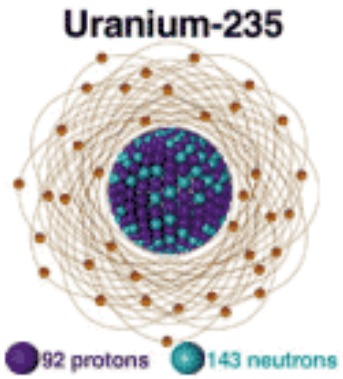
- **Atoms are also characterized by:**
  - **mass number, which is a sum of the number of protons and the number of neutrons in the nucleus (number of *nucleons*)**
  - **atomic mass, "relative isotopic mass" in *unified atomic mass units*, which is roughly (within 1%) equal to the whole mass number (since the mass of a proton and the mass of a neutron are almost the same and the mass of the atom's electrons is negligibly small)**

What is Isotope?

<u>Isotopes</u> are different forms of a given element that have the same number of *protons* in each atom but differ in number of *neutrons*.



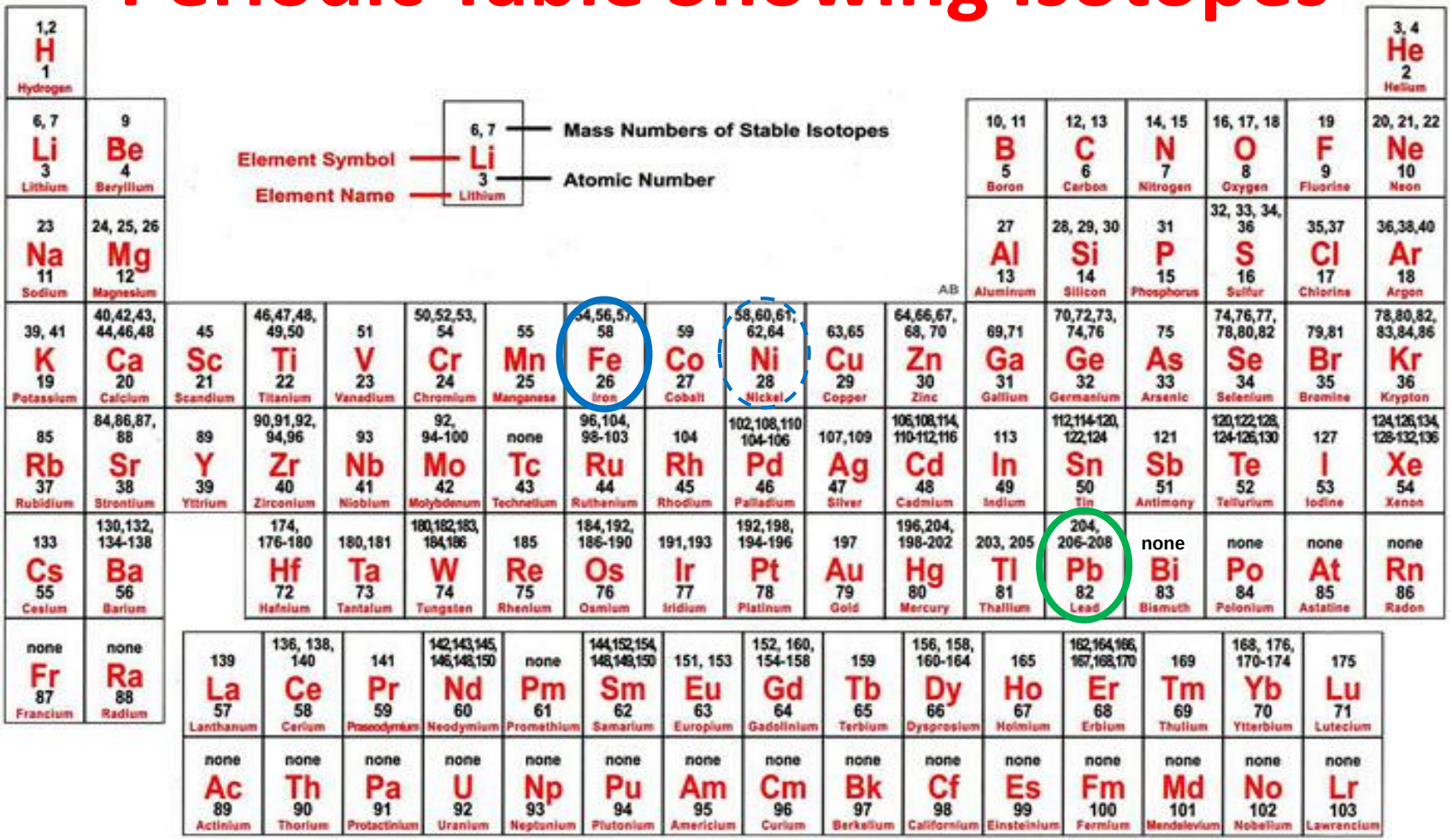
Most elements have more than one isotope.



There are 20 Plutonium isotopes, all of them unstable!

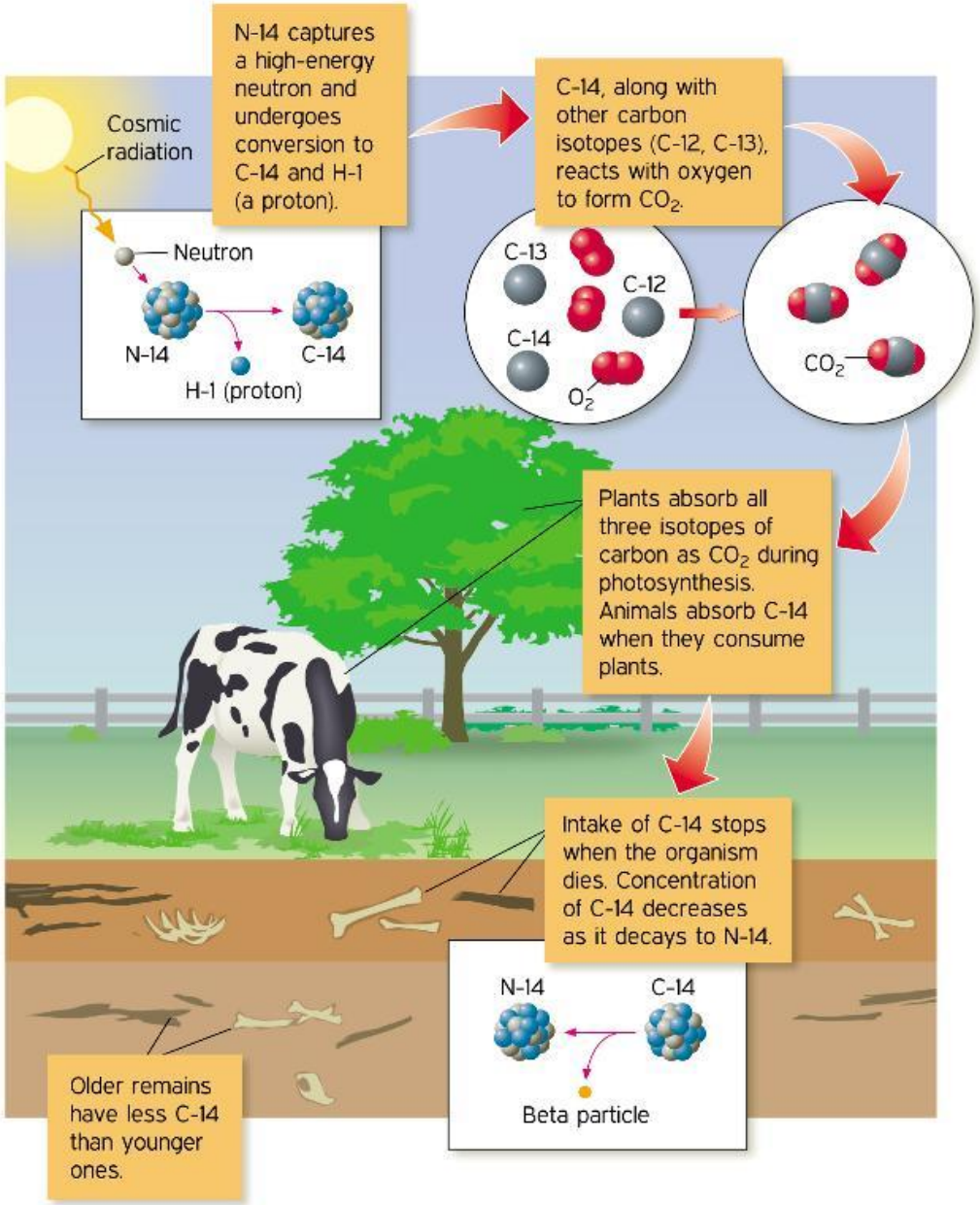
Pu^{228} ⟹ Pu^{247}

Periodic Table Showing Isotopes



- **The nucleus of an iron isotope with mass number 56 is more stable than any other element's nucleus (the farther from 56 an element's mass number is, the more unstable that element's nucleus tends to be).**
- **The heaviest element that still has stable isotopes is Lead.**

Carbon Dating



^{12}C	^{13}C	^{14}C
12.00000	13.00335	14.0
98.89%	1.11%	$t_{1/2}$ = 5715yrs
Stable	Stable	Radioactive Cosmogenic/ anthropogenic

- **A method of determining the age of an object by measuring the radioactive emissions of radiocarbon (C-14), a radioactive isotope of carbon.**
- **Invented by Willard Libby in the late 1940s and soon became a standard tool for archaeologists.**
- **Applicable only to matter which was once living and presumed to be in equilibrium with the atmosphere.**
- **The oldest dates that can be reliably measured by carbon dating are around 50,000 years ago.**