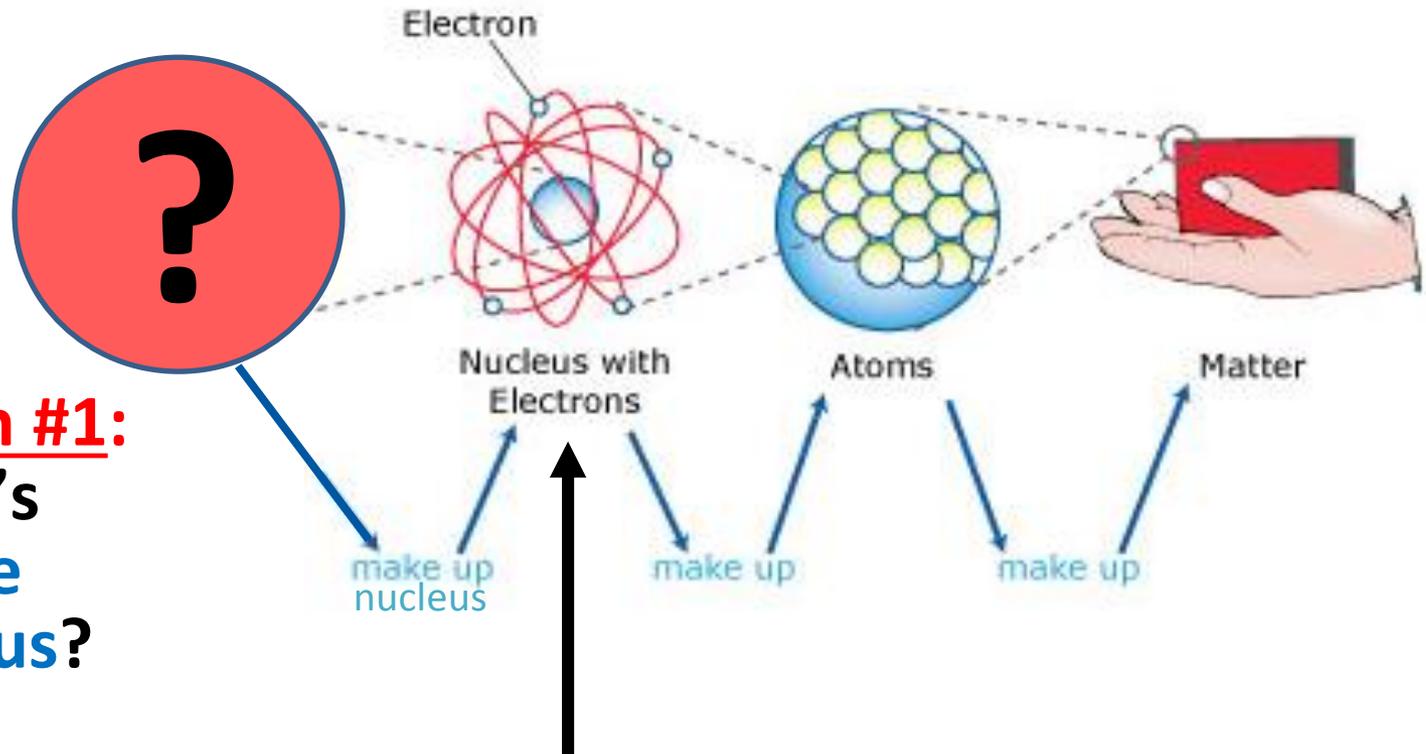


Structure of Matter

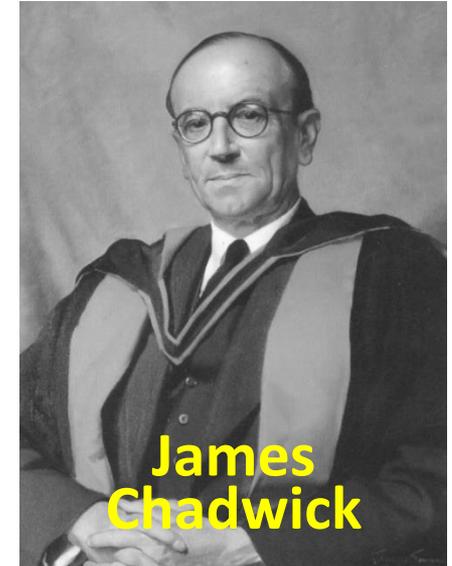


Question #1:
What's
inside
a nucleus?

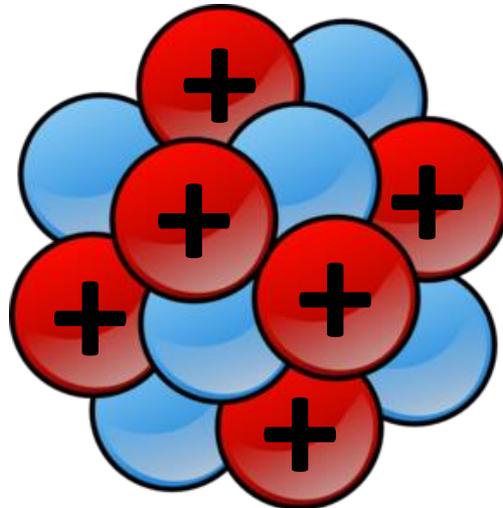
Question #2: Is **planetary model** of the atom *good enough* to explain all experimental observations?

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 $\sim 10^{-10}\text{m}$

Nucleus $\sim 10^{-14}\text{m}$

Proton $\sim 10^{-15}\text{m}$

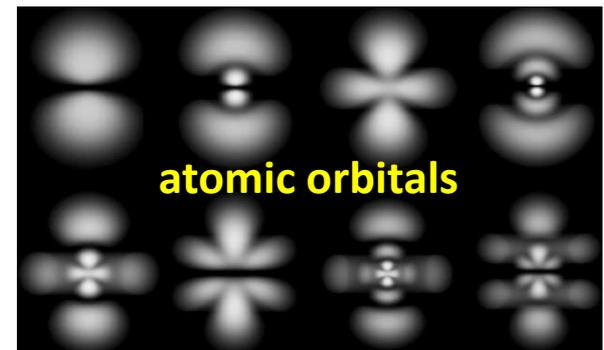
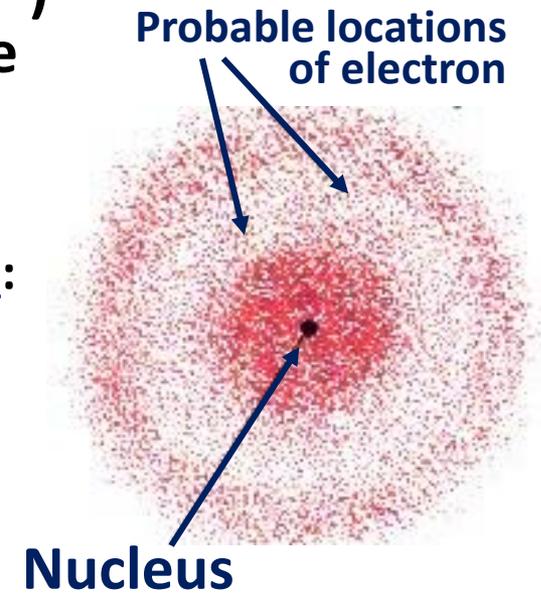
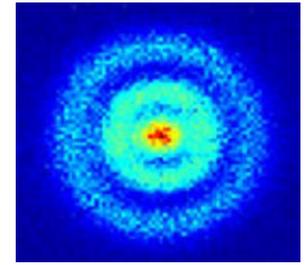
Neutron $\sim 10^{-15}\text{m}$

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:

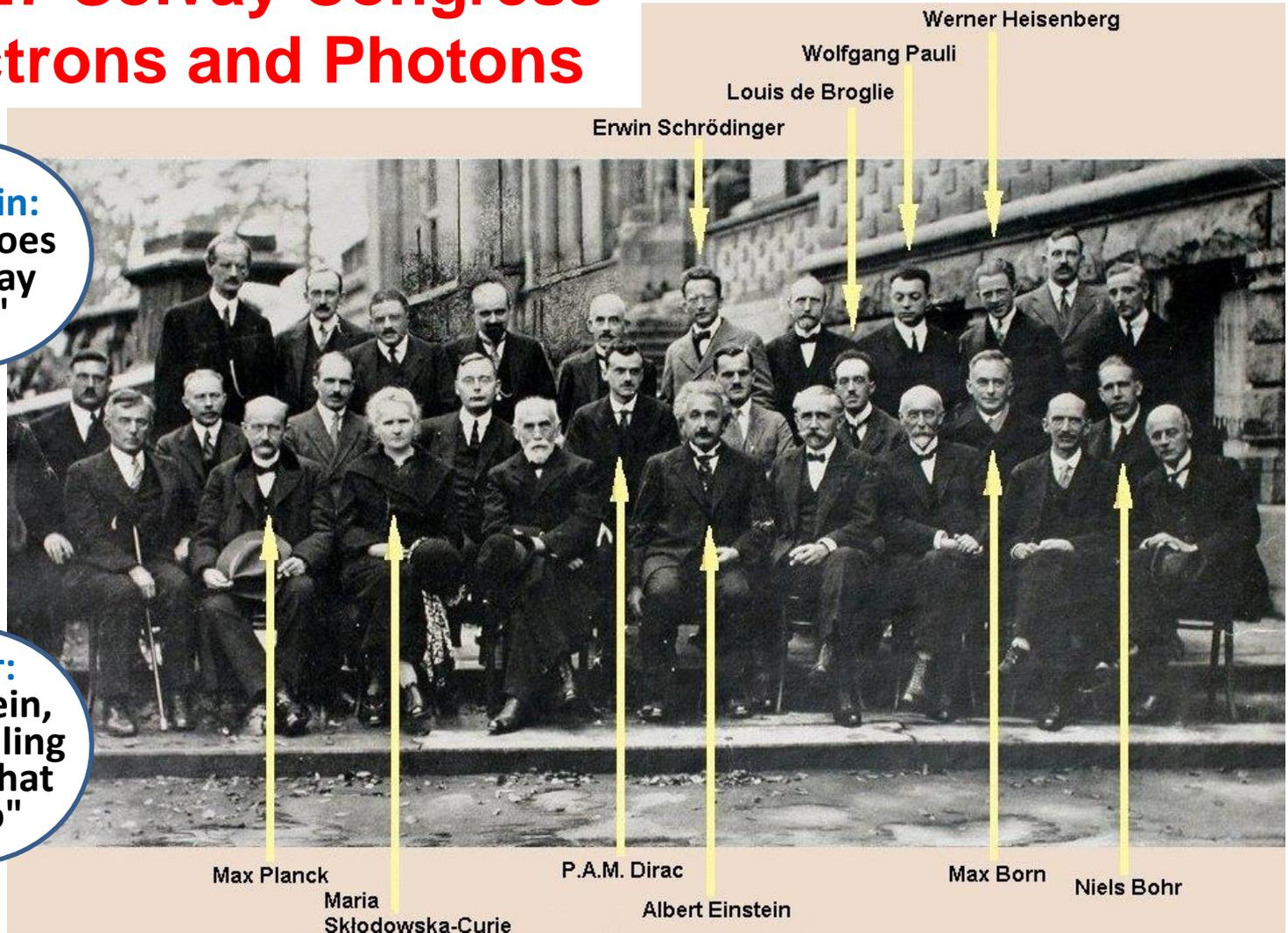
- There is always an **integer number of electrons** orbiting the nucleus.
- It is **impossible to determine the exact location** of an electron. Electrons do not have a definite path around the nucleus. The **probable location of an electron** is based on how much energy it has.
- The modern term “**atomic 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"

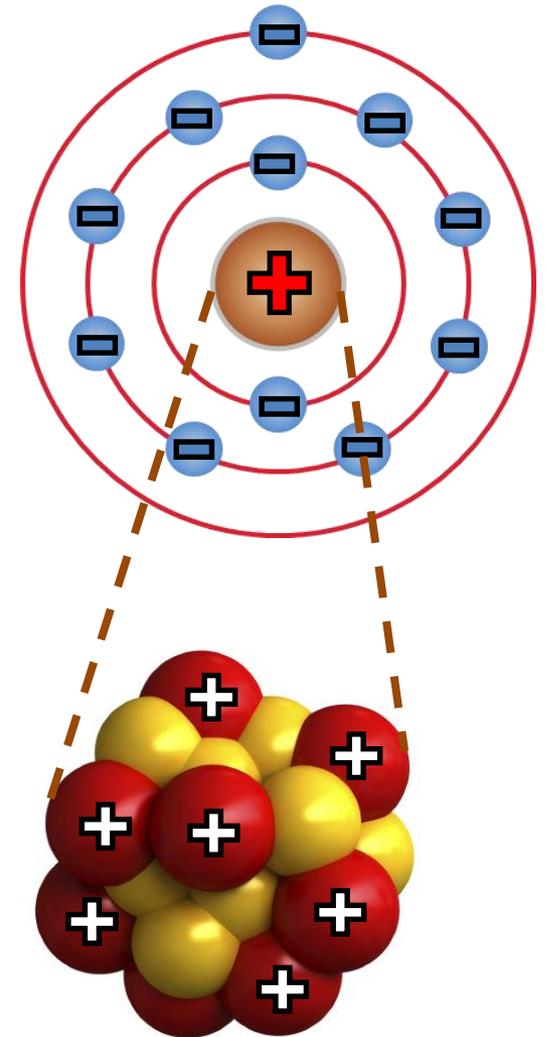
Bohr:
"Einstein, stop telling God what to do"



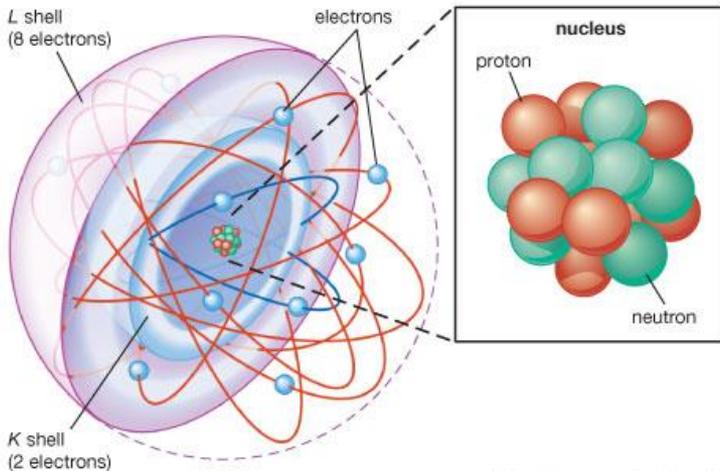
In October 1927, the world's most notable physicists met to discuss the newly formulated quantum theory and subatomic makeup. 17 of the 29 attendees were or later became Nobel Prize winners.

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

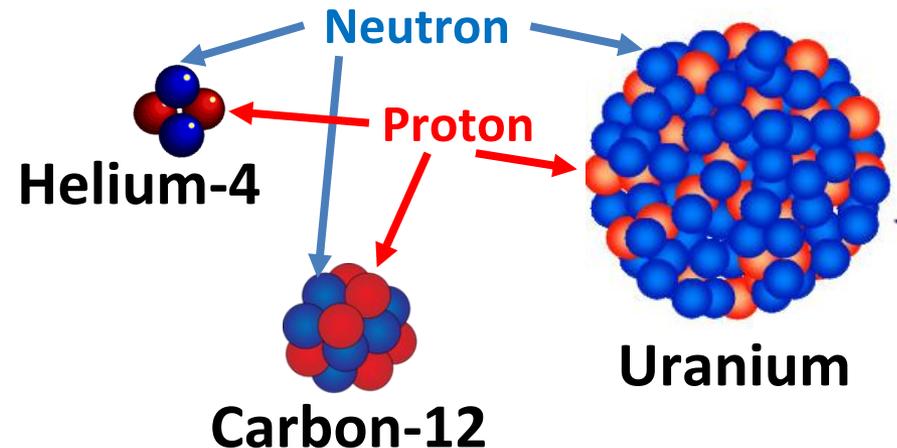


What holds an atom together?

- 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**:

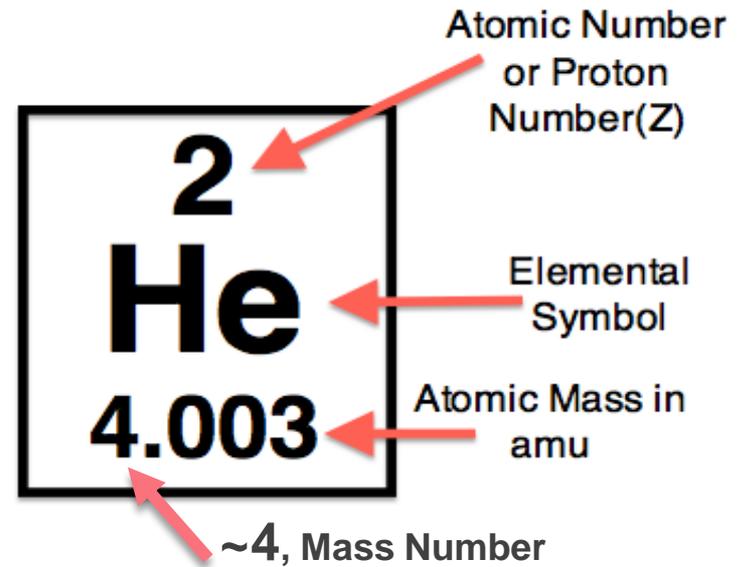
- A stable atom is an atom that has enough binding energy to hold the nucleus together permanently.
- An unstable atom does not have enough binding energy to hold the nucleus together permanently and will lose neutrons and/or protons as it attempts to become stable.



Understanding Elements

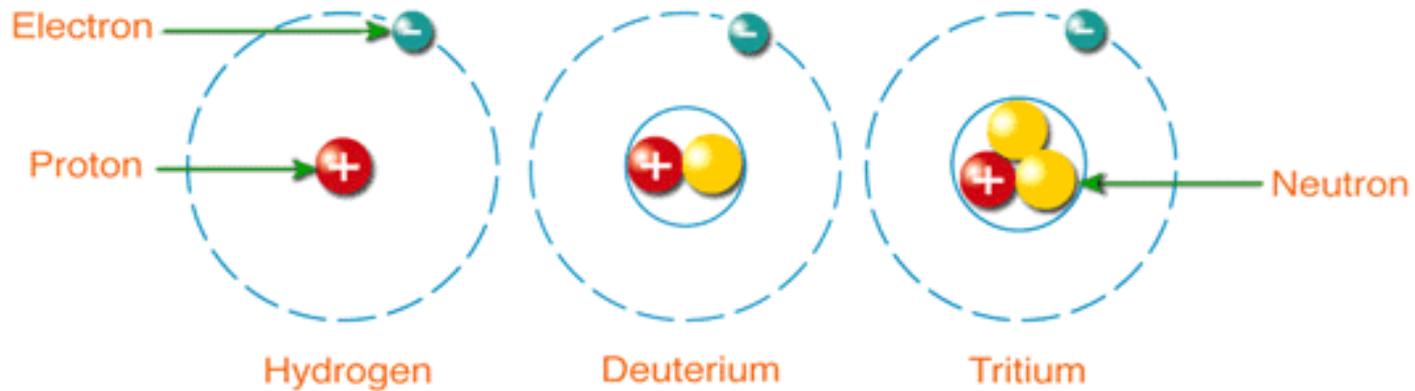
The number of protons and neutrons in the nucleus give the atoms their specific characteristics.

- 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)

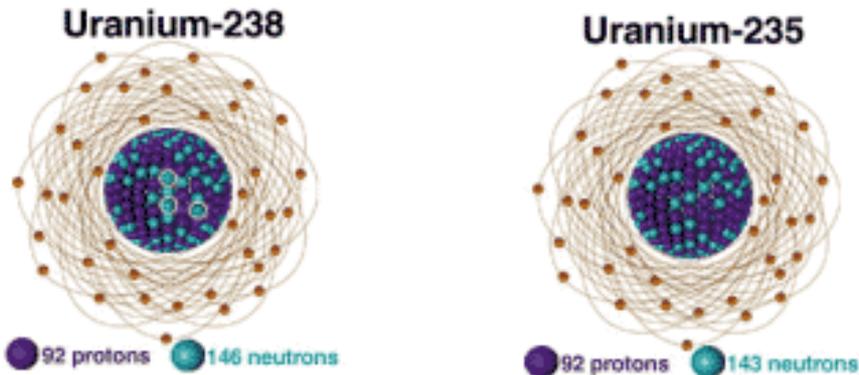


What is Isotope?

Isotopes 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!**

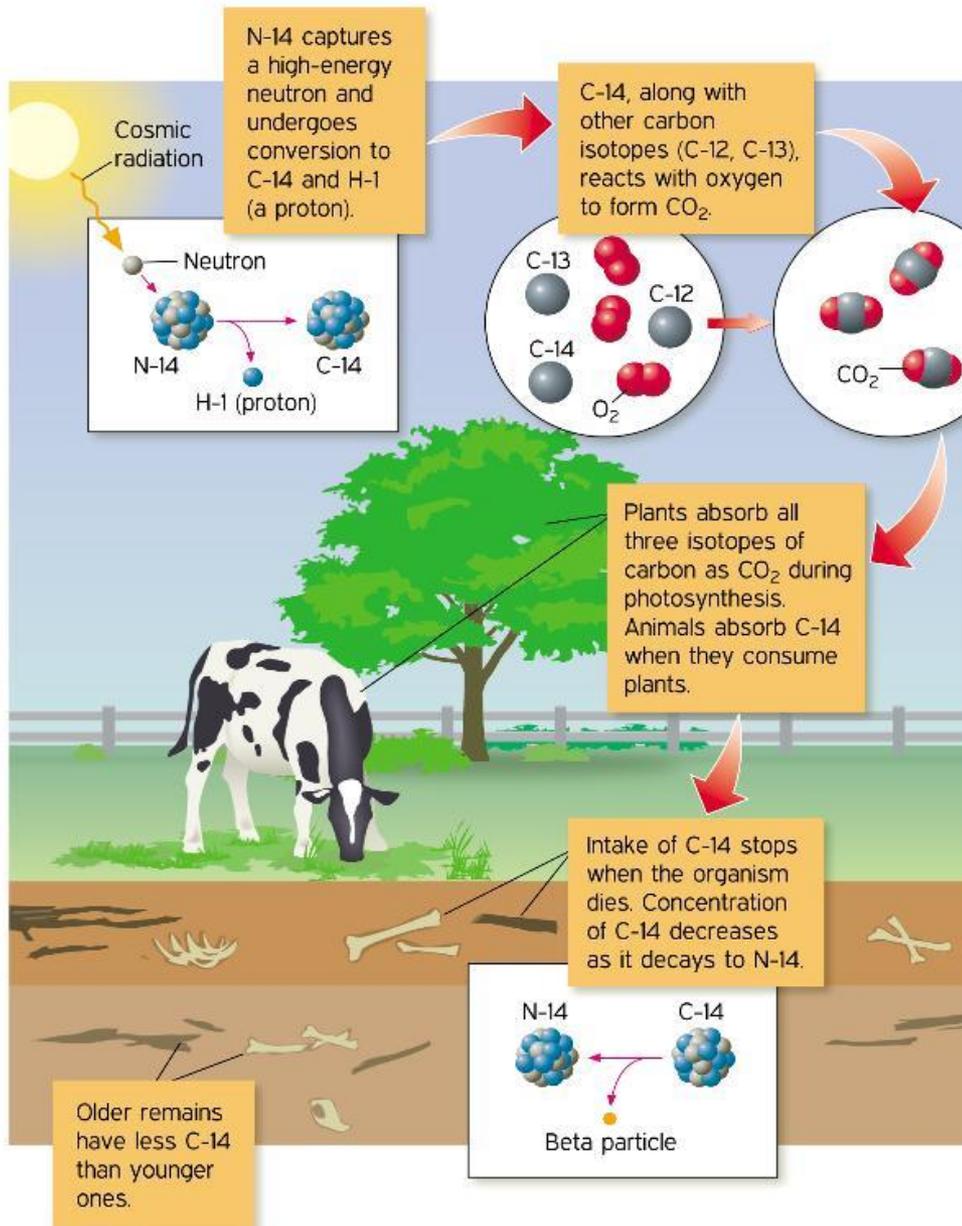


Periodic Table Showing Isotopes

1,2 H 1 Hydrogen																	3, 4 He 2 Helium						
6, 7 Li 3 Lithium	9 Be 4 Beryllium	<div style="display: flex; align-items: center; gap: 10px;"> <div style="border: 1px solid black; padding: 5px;"> 6, 7 Li 3 Lithium </div> <div> Mass Numbers of Stable Isotopes Element Symbol Element Name </div> </div>																10, 11 B 5 Boron	12, 13 C 6 Carbon	14, 15 N 7 Nitrogen	16, 17, 18 O 8 Oxygen	19 F 9 Fluorine	20, 21, 22 Ne 10 Neon
23 Na 11 Sodium	24, 25, 26 Mg 12 Magnesium	<div style="display: flex; align-items: center; gap: 10px;"> <div style="border: 1px solid black; padding: 5px;"> 6, 7 Li 3 Lithium </div> <div> Mass Numbers of Stable Isotopes Element Symbol Element Name </div> </div>																27 Al 13 Aluminum	28, 29, 30 Si 14 Silicon	31 P 15 Phosphorus	32, 33, 34, 36 S 16 Sulfur	35, 37 Cl 17 Chlorine	36, 38, 40 Ar 18 Argon
39, 41 K 19 Potassium	40, 42, 43, 44, 46, 48 Ca 20 Calcium	45 Sc 21 Scandium	46, 47, 48, 49, 50 Ti 22 Titanium	51 V 23 Vanadium	50, 52, 53, 54 Cr 24 Chromium	55 Mn 25 Manganese	54, 56, 57, 58 Fe 26 Iron	59 Co 27 Cobalt	58, 60, 61, 62, 64 Ni 28 Nickel	63, 65 Cu 29 Copper	64, 66, 67, 68, 70 Zn 30 Zinc	69, 71 Ga 31 Gallium	70, 72, 73, 74, 76 Ge 32 Germanium	75 As 33 Arsenic	74, 76, 77, 78, 80, 82 Se 34 Selenium	79, 81 Br 35 Bromine	78, 80, 82, 83, 84, 86 Kr 36 Krypton						
85 Rb 37 Rubidium	84, 86, 87, 88 Sr 38 Strontium	89 Y 39 Yttrium	90, 91, 92, 94, 96 Zr 40 Zirconium	93 Nb 41 Niobium	92, 94-100 Mo 42 Molybdenum	none Tc 43 Technetium	96, 104, 98-103 Ru 44 Ruthenium	104 Rh 45 Rhodium	102, 108, 110, 104-106 Pd 46 Palladium	107, 109 Ag 47 Silver	106, 108, 114, 110-112, 116 Cd 48 Cadmium	113 In 49 Indium	112, 114-120, 122, 124 Sn 50 Tin	121 Sb 51 Antimony	120, 122, 126, 124-126, 130 Te 52 Tellurium	127 I 53 Iodine	124, 126, 134, 128-132, 136 Xe 54 Xenon						
133 Cs 55 Cesium	130, 132, 134-138 Ba 56 Barium		174, 176-180 Hf 72 Hafnium	180, 181 Ta 73 Tantalum	180, 182, 183, 184, 186 W 74 Tungsten	185 Re 75 Rhenium	184, 192, 186-190 Os 76 Osmium	191, 193 Ir 77 Iridium	192, 198, 194-196 Pt 78 Platinum	197 Au 79 Gold	196, 204, 198-202 Hg 80 Mercury	203, 205 Tl 81 Thallium	204, 206-208 Pb 82 Lead	none Bi 83 Bismuth	none Po 84 Polonium	none At 85 Astatine	none Rn 86 Radon						
none Fr 87 Francium	none Ra 88 Radium	139 La 57 Lanthanum	136, 138, 140 Ce 58 Cerium	141 Pr 59 Praseodymium	142, 143, 145, 146, 148, 150 Nd 60 Neodymium	none Pm 61 Promethium	144, 152, 154, 148, 149, 150 Sm 62 Samarium	151, 153 Eu 63 Europium	152, 160, 154-158 Gd 64 Gadolinium	159 Tb 65 Terbium	156, 158, 160-164 Dy 66 Dysprosium	165 Ho 67 Holmium	162, 164, 166, 167, 168, 170 Er 68 Erbium	169 Tm 69 Thulium	168, 176, 170-174 Yb 70 Ytterbium	175 Lu 71 Lutetium							
		none Ac 89 Actinium	none Th 90 Thorium	none Pa 91 Protactinium	none U 92 Uranium	none Np 93 Neptunium	none Pu 94 Plutonium	none Am 95 Americium	none Cm 96 Curium	none Bk 97 Berkelium	none Cf 98 Californium	none Es 99 Einsteinium	none Fm 100 Fermium	none Md 101 Mendelevium	none No 102 Nobelium	none Lr 103 Lawrencium							

- 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.