

Nuclear Reactions

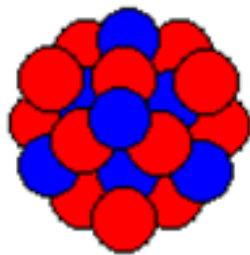
involve change of the atomic nucleus

1. **Radioactive decay** – an unstable nucleus spontaneously emits a small particle of **ionizing radiation** to become a **different isotope** of the same element or a **different element** (the latter process is called *transmutation*).
2. **Nuclear Fusion** – the **joining** of two atomic nuclei to form a larger one.
3. **Nuclear Fission** – the **splitting** of an atomic nucleus into two smaller ones.

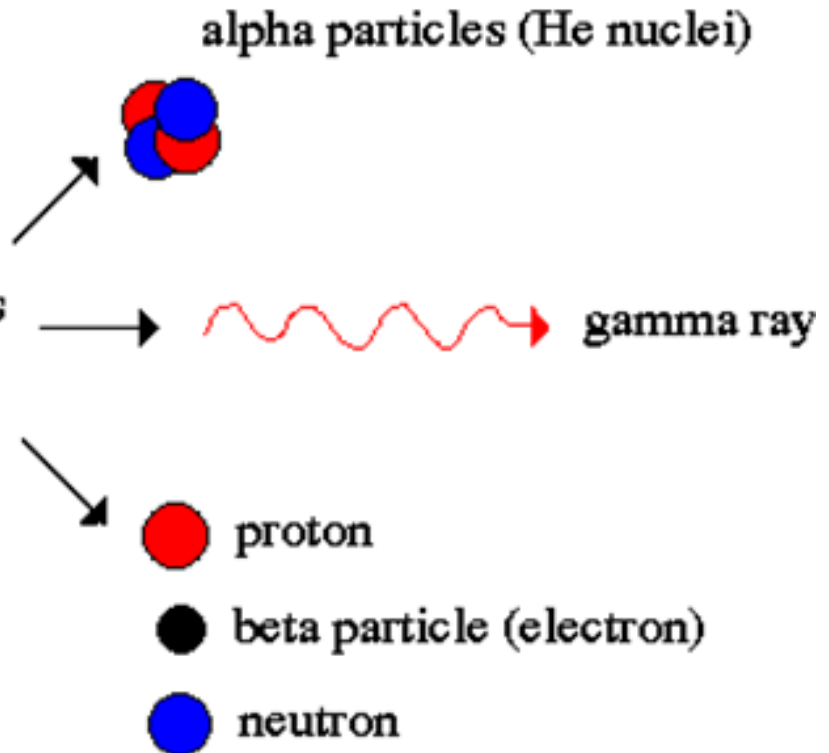
Radioactive Decay

Radioactive decay, also known as radioactivity or nuclear decay, is the process by which a nucleus of an unstable atom loses energy by **emitting ionizing radiation**: ${}^4\text{He}$ (alpha particles), β particles (electrons), γ rays (energetic photons), neutrons.

A heavy nucleus is usually unstable, due to many positive protons pushing apart.



spontaneous
decay



Radioactive decay is a **random** (*stochastic*) process at the level of single atoms.

Ionizing Radiation

can pose a serious health threat to humans: it is capable of changing the basic makeup of atoms and molecules in cells, and more specifically the DNA molecules inside of cells.

Alpha Particle

LARGE PARTICLE, TRAVELS A FEW INCHES
STOPPED BY A SHEET OF PAPER



- interacts strongly with matter
- unable to penetrate the outer layer of dead skin cells
- **capable of causing serious cell damage if an alpha emitting substance is ingested in food or air**

Beta Particle

VERY SMALL PARTICLE, TRAVELS A FEW FEET
STOPPED BY WOOD, PLASTIC OR ALUMINUM



- can penetrate skin a few centimeters
- **main threat is still primarily from internal emission from ingested material**

Neutron

SMALL PARTICLE, TRAVELS A FEW FEET
ENERGY ABSORBED BY WATER AND CONCRETE



- the only type of radiation that is **able to turn other materials radioactive**

Gamma Ray

HIGH ENERGY, TRAVELS LONG DISTANCES
ENERGY ABSORBED BY HEAVY METALS AND CONCRETE



- very high energy electromagnetic radiation
- **cause diffuse damage throughout the body ("radiation sickness")**

Periodic Table Showing Isotopes

Periodic Table Showing Isotopes

1,2 H 1 Hydrogen																	3, 4 He 2 Helium						
6, 7 Li 3 Lithium	9 Be 4 Beryllium																	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																	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, 128, 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							

6, 7

Mass Numbers of Stable Isotopes

Li

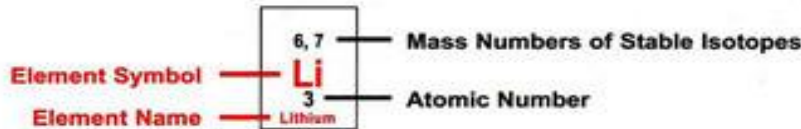
Atomic Number

Element Symbol

Li

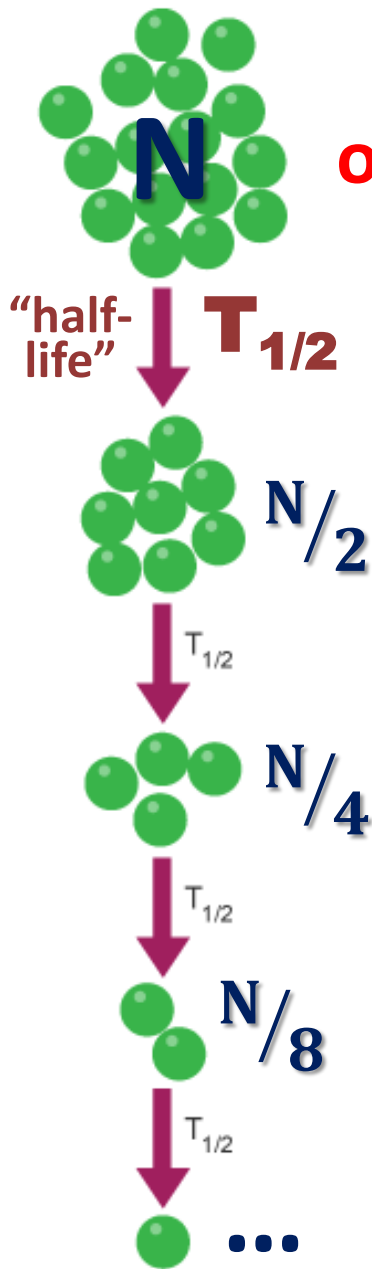
Element Name

Lithium



- The heaviest element that still has stable isotopes is **Lead**.
- Naturally occurring in the Earth's crust, **Potassium-40** and **various isotopes of Uranium, Thorium, Radium, and Radon** are the most commonly found radioactive elements.





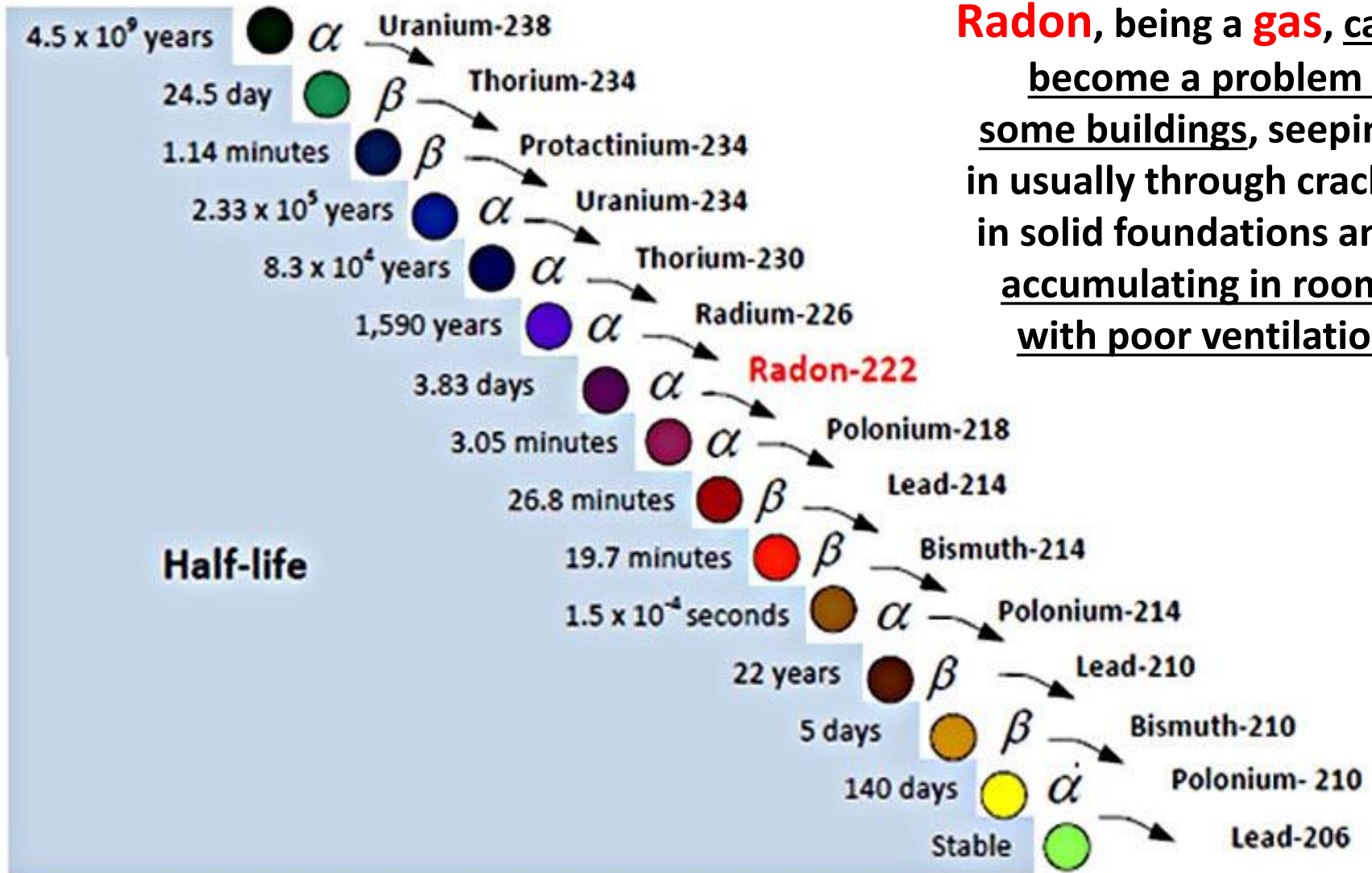
Half-Life of Radioactive Isotope

or how fast do radioactive materials decay?

The decay rate of a radioactive isotope is characterized by its **half-life**, $T_{1/2}$: the *time it takes for one-half of the atoms* of a radioactive material *to disintegrate*.

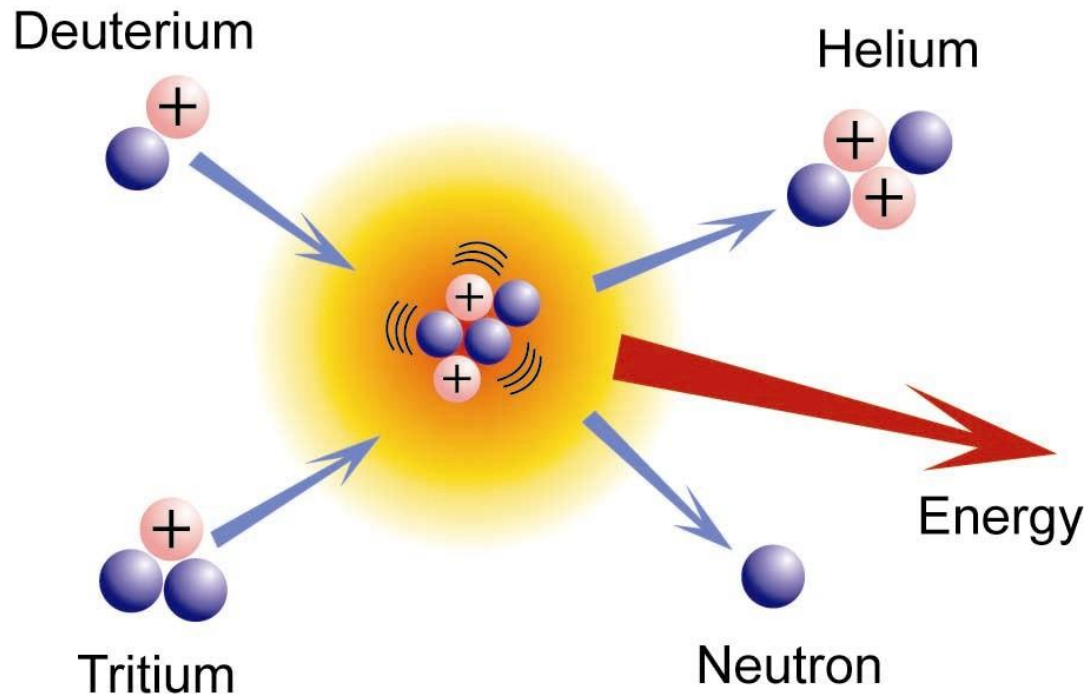
Polonium-215	0.0018 seconds
Bismuth-212	60.5 seconds
Sodium-24	15 hours
Iodine-131	8.07 days
Cobalt-60	5.26 years
Radium-226	1600 years
Uranium-238	4.5 billion years

Uranium-238 Decay Chain



Radon, being a **gas**, can become a problem in some buildings, seeping in usually through cracks in solid foundations and accumulating in rooms with poor ventilation.

Nuclear Fusion



- The fusion of two nuclei with masses lower than iron generally releases energy, while the fusion of nuclei heavier than iron absorbs energy.

Fusion powers active stars!



- Fusion reactions have the **greatest energy density**, that is energy released per unit of mass, **than any known process**.

What is Temperature?

REVIEW



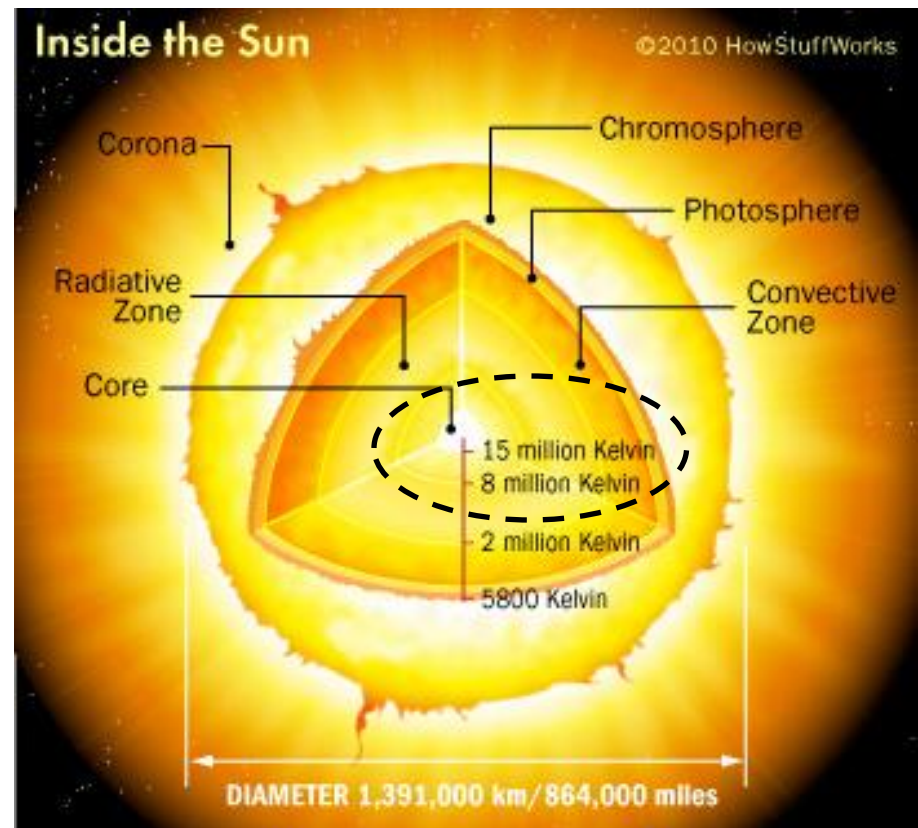
- **Particles of matter are in constant motion** (*vibrating in place in solids, sliding past each other in liquids, flying around freely in gases*), **but they don't all move at the same speed and in the same direction all the time.**
- **Temperature** is a **measure of the average energy associated with random motion of the particles** of a substance.
- The *higher* the temperature of an object, the *faster* on average its particles move.

Flame:
1000-1500°C



Thermonuclear Fusion

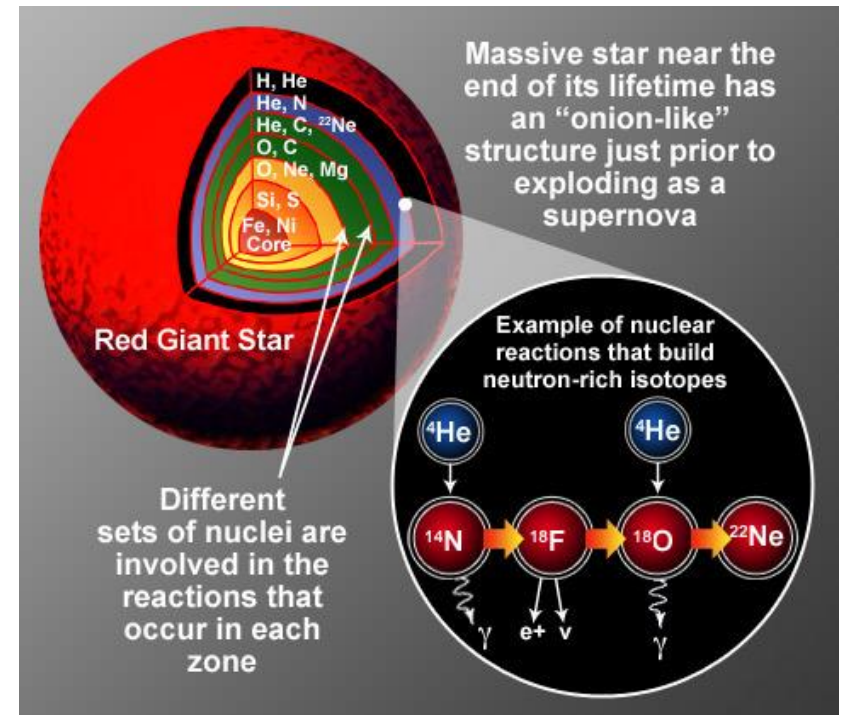
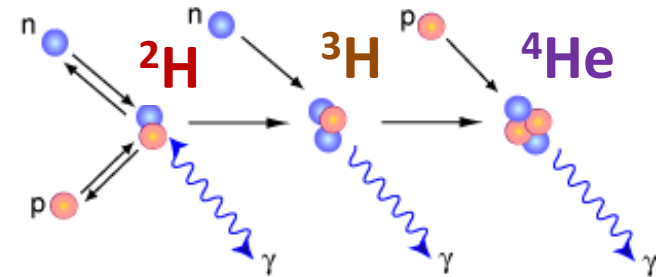
- In order to fuse, **two atomic nuclei must be brought close enough together** (*confinement requirement*) so the electrostatic repulsion can be overcome by the attractive nuclear force which is stronger at close distances.
- If matter is sufficiently **heated** (*plasma state*), **thermonuclear fusion** reaction may occur due to **collisions between the particles of extreme thermal kinetic energies**.
- In nature, extremely high temperature conditions exist in the **cores of active stars**.



Nucleosynthesis

Nucleosynthesis is the natural process that **creates new atomic nuclei** from pre-existing nucleons, primarily protons and neutrons:

- Big Bang nucleosynthesis: the first nuclei, **hydrogen and helium**, were formed about *three minutes* after the Big Bang.
- Stellar nucleosynthesis: with the formation of **stars**, heavier nuclei were created from hydrogen and helium, a process that continues today; the **heaviest element** produced by fusion in a normal star is **iron**.
- Supernova nucleosynthesis: production of elements from **iron to uranium** occurs *within seconds* in a supernova explosion.

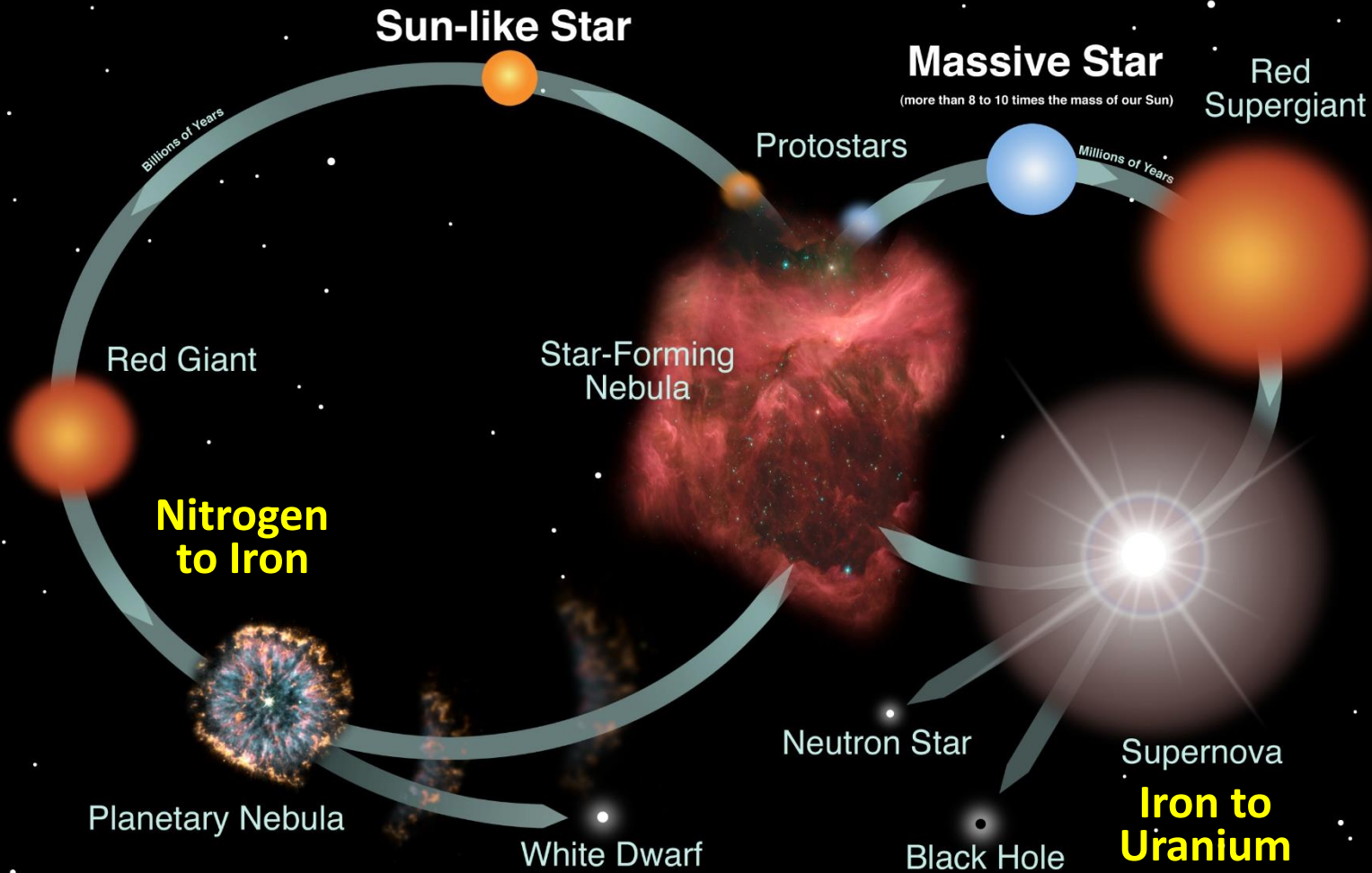


Stellar Recycling



5 minutes after the Big Bang: 75% H and 25% He.

10+ billion years of nucleosynthesis: 98% H and He combined, 2% complex elements.



the lives of stars

Artificial Fusion

Laboratory fusion of hydrogen isotopes was first accomplished by Mark Oliphant in 1932 based on transmutation experiments.

- Nuclear fusion on a large scale in an explosion was first carried out on **November 1, 1952**, in the *Ivy Mike* hydrogen bomb test on an island in the Pacific Ocean.



- International research into developing **controlled self-sustained thermonuclear fusion** (seen as a means of producing large scale cleaner energy) has been ongoing for more than 60 years and recently resulted in several breakthroughs.

Nuclear fusion can fulfill...

...the ancient dream of alchemists ☺



Gold can be made by slamming
isotopes of hydrogen nuclei called
deuterium into platinum:



The **catch** is that gold produced in this manner would be **much more expensive** than gold mined from the Earth...