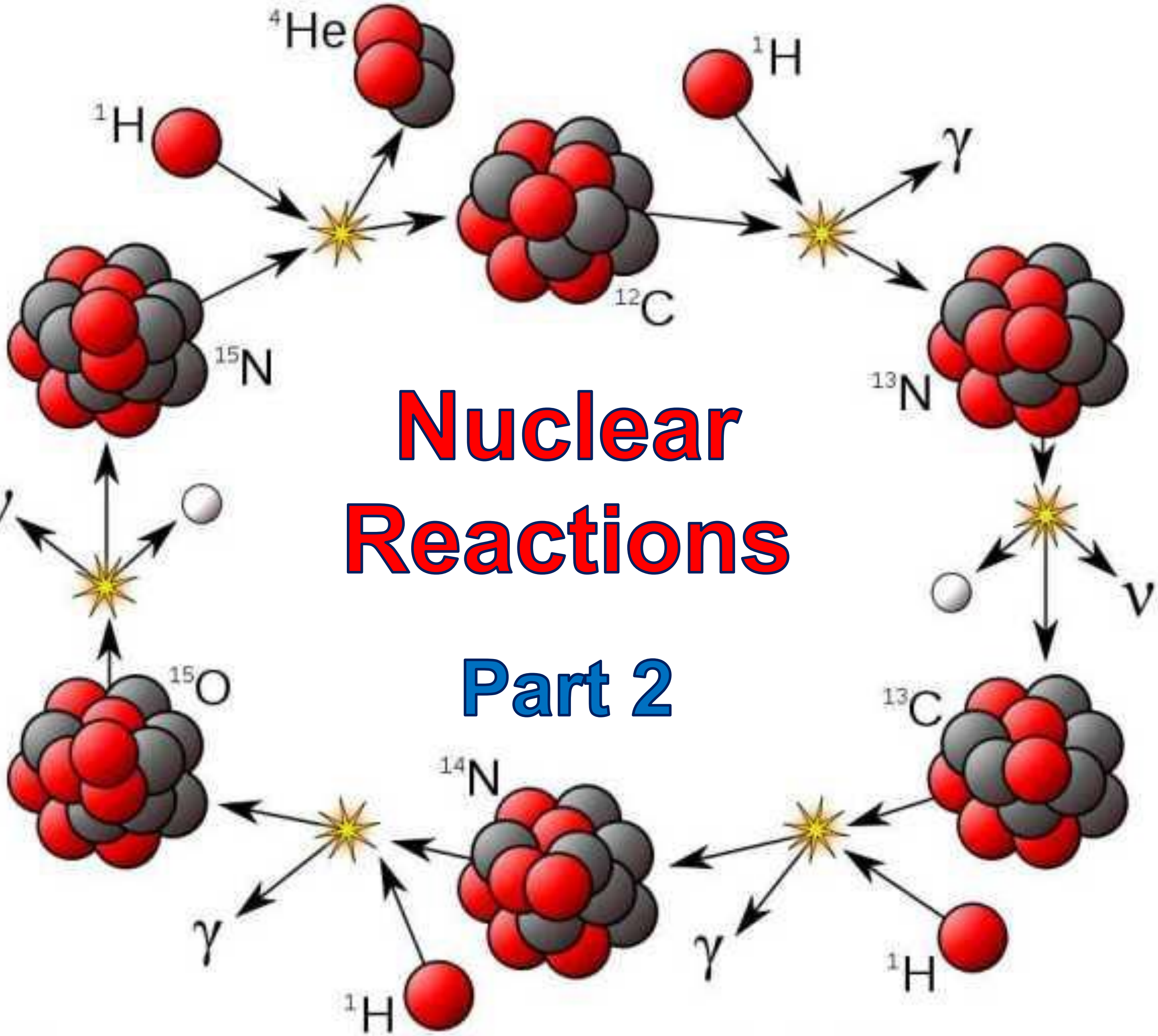
Nuclear Reactions

Part 2



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***).

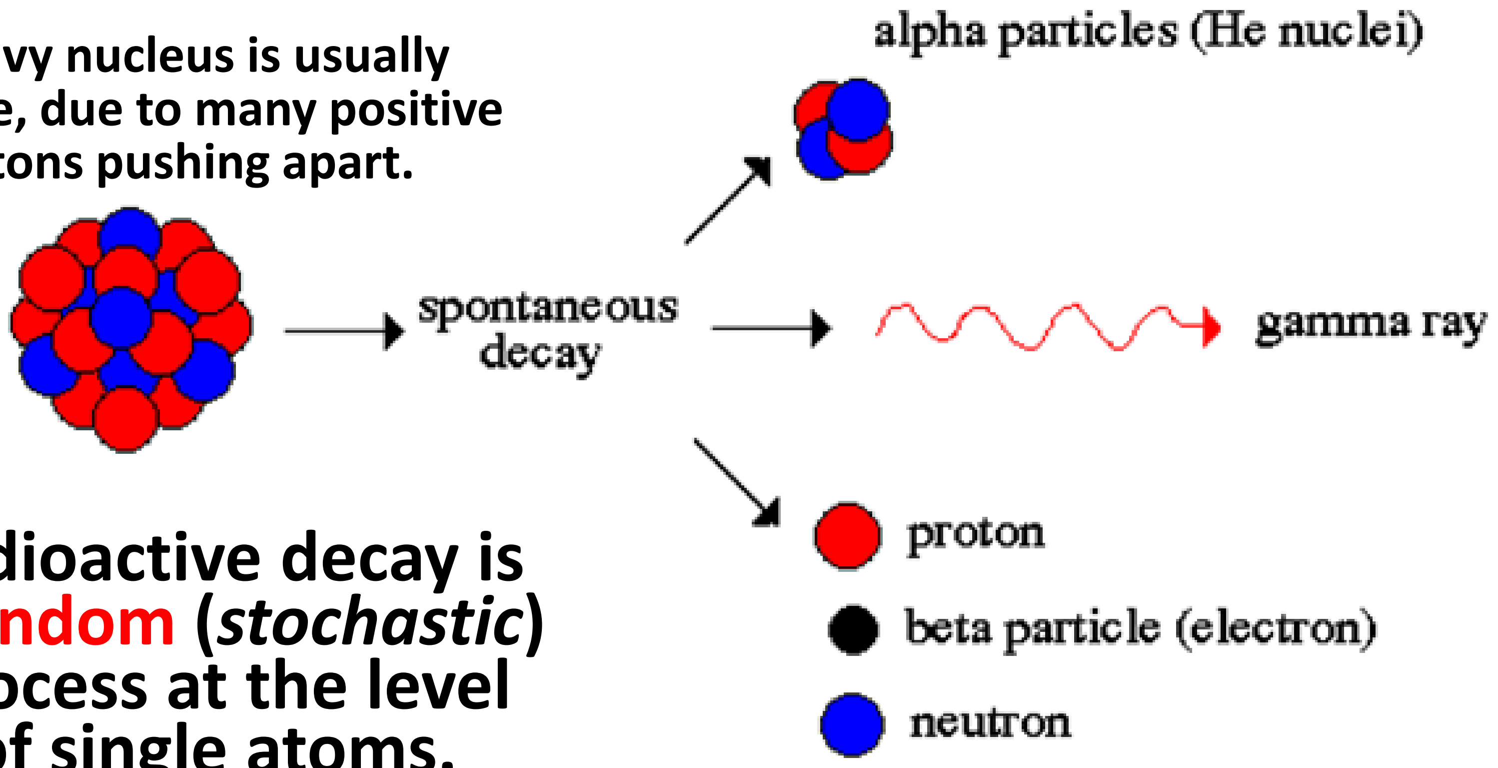
2. **Nuclear Fusion** – the **joining** of two atomic nuclei to form a larger one.

3. **Nuclear Fission** – the **splitting** of an atomic nucleus into two smaller ones.

Radioactive Decay

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

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



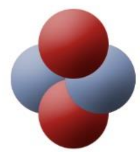
Radioactive decay is a random (*stochastic*) process at the level of single atoms.

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

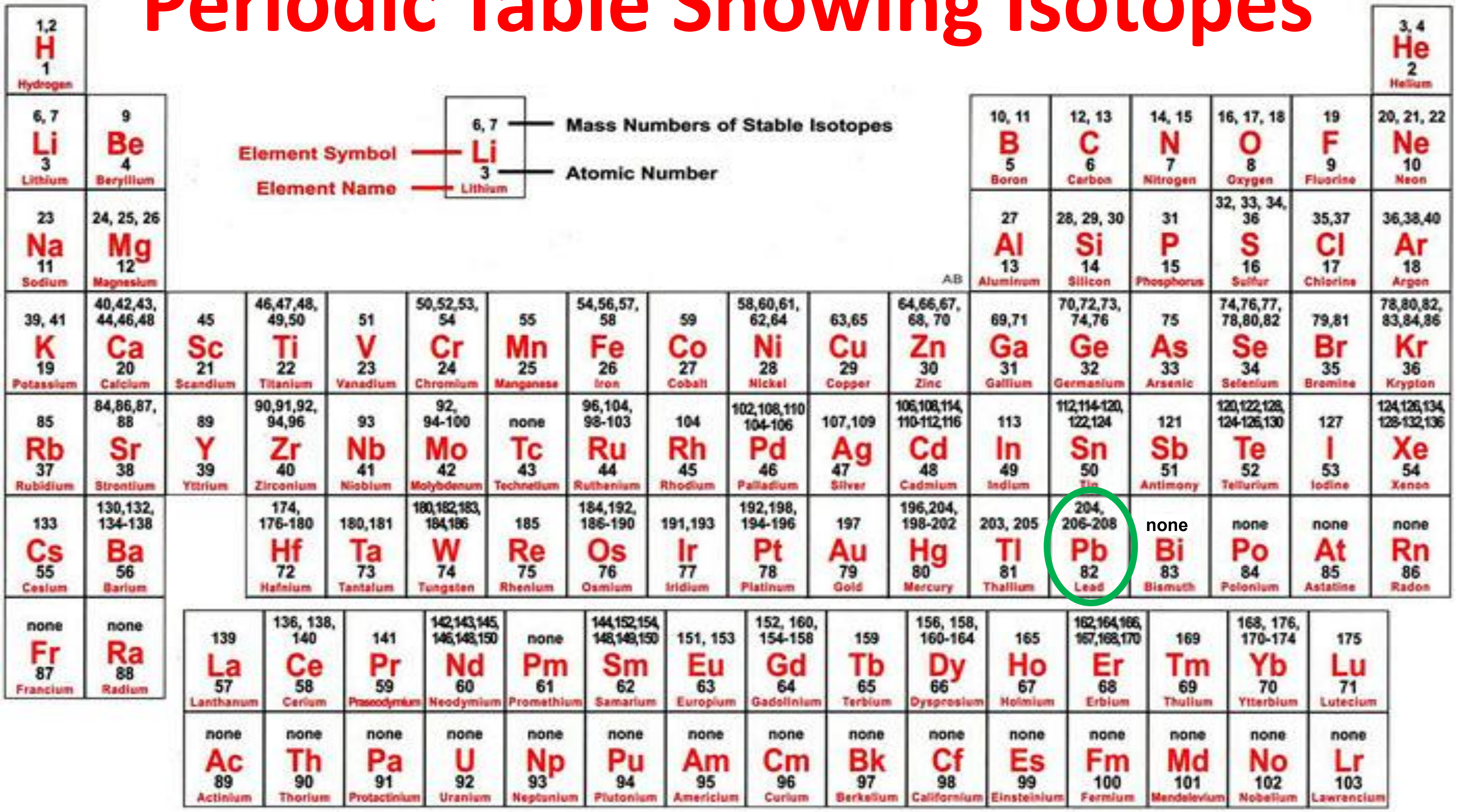
Gamma Ray

HIGH ENERGY, TRAVELS LONG DISTANCES

ENERGY ABSORBED BY HEAVY METALS AND CONCRETE

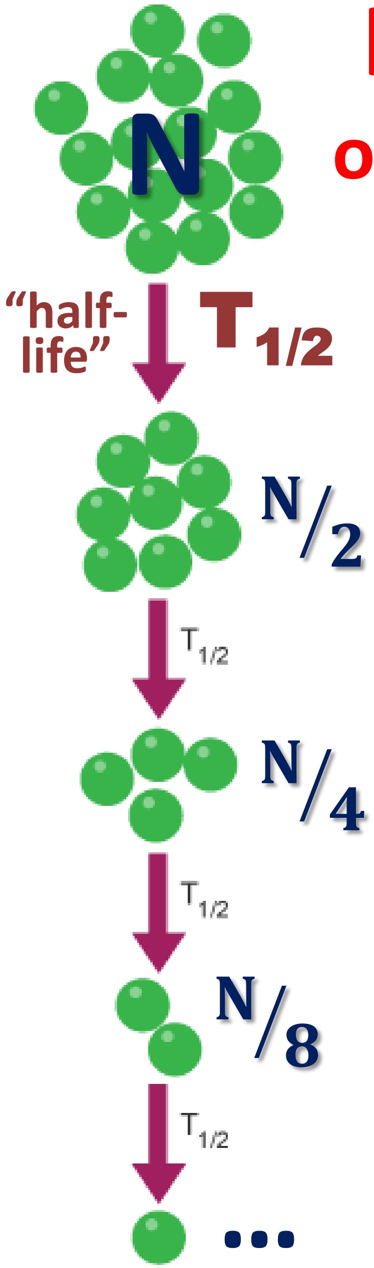
- very high energy electromagnetic radiation
- cause diffuse damage throughout the body (“radiation sickness”)

Periodic Table Showing Isotopes



- 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.

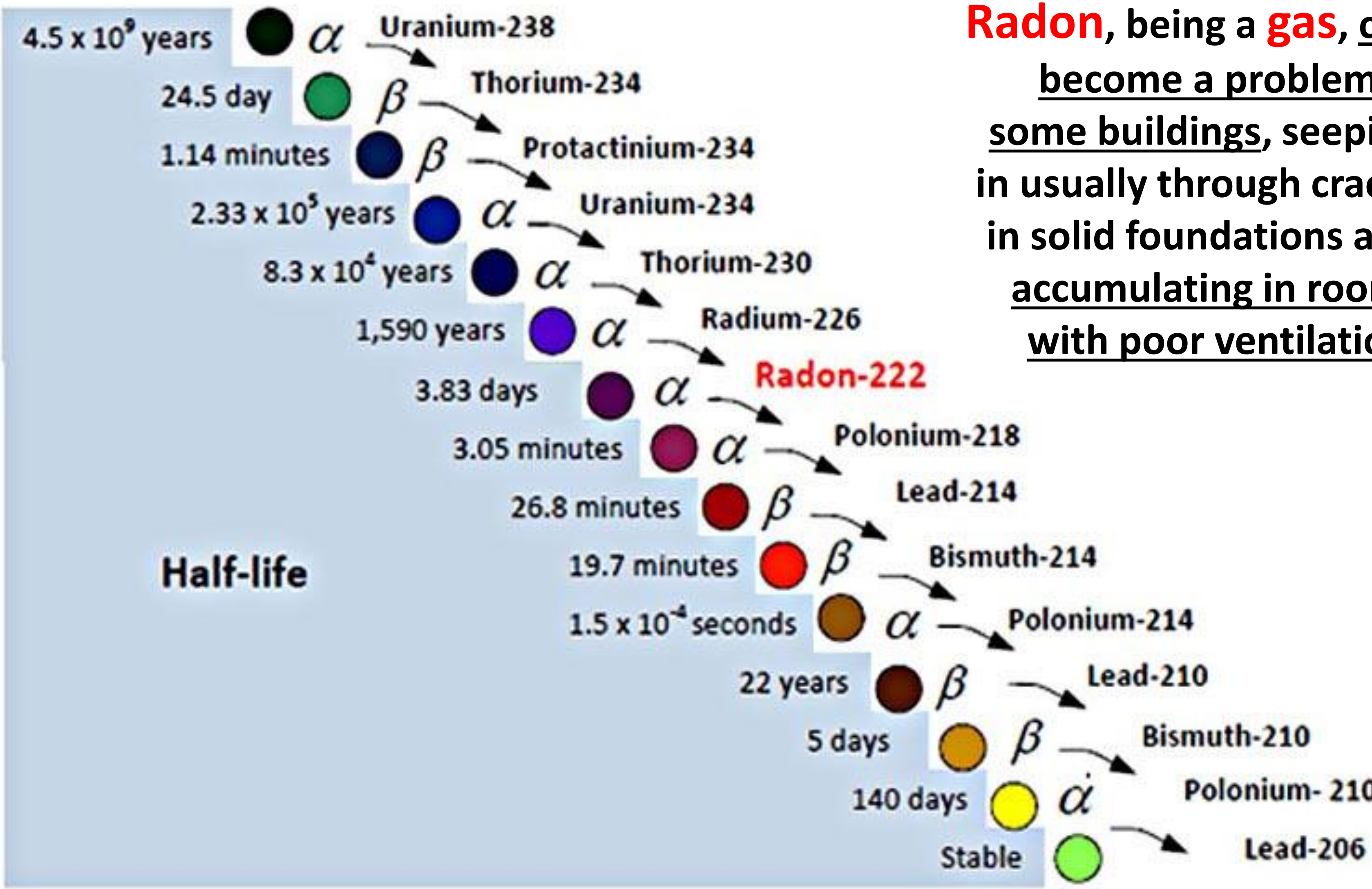
Half-Life of Radioactive Isotope
or how fast do radioactive materials decay?



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*.

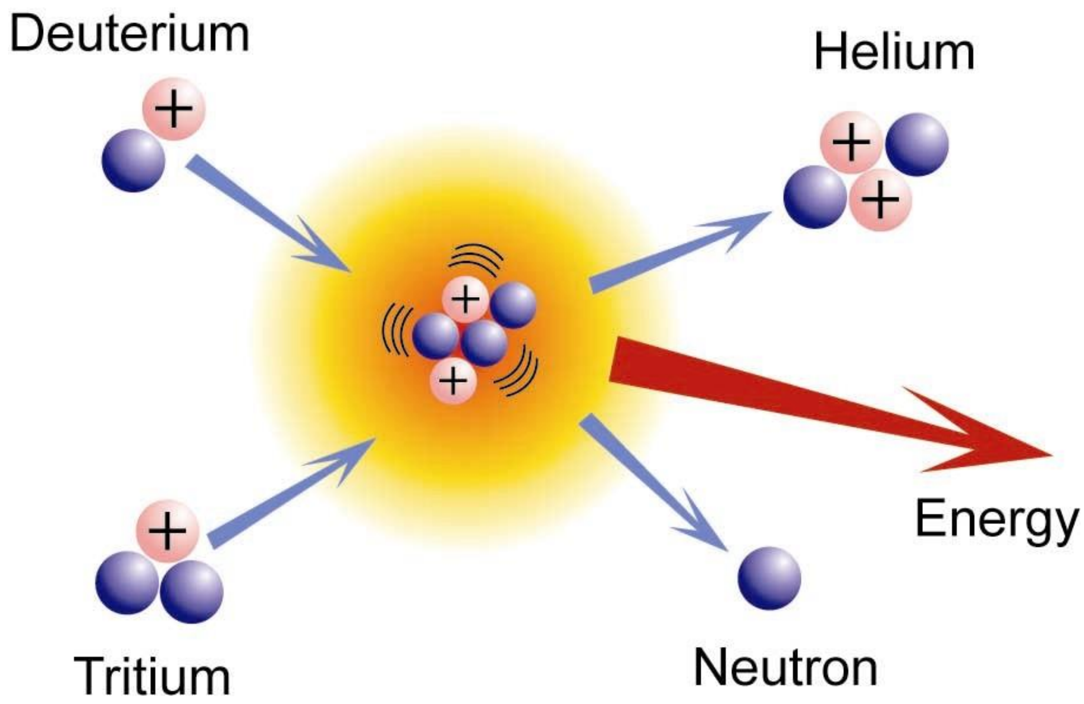
Polonium-215	0.0018 seconds
Bismuth-212	60.5 seconds
Sodium-24	15 hours
Iodine-131	8.07 days
Cobalt-60	5.26 years
Radium-226	1600 years
Uranium-238	4.5 billion years

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 <u>masses lower than iron</u> generally <u>releases energy</u>, while the fusion of nuclei <u>heavier than iron absorbs energy</u>.**

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.**

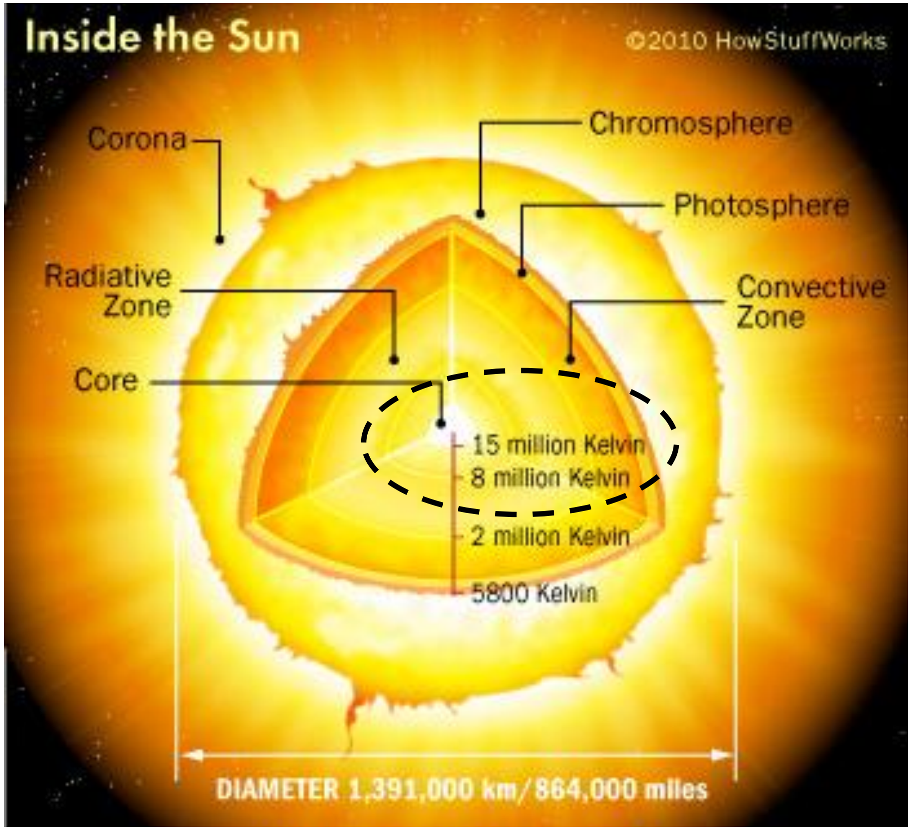
Flame:
1000-1500°C

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.

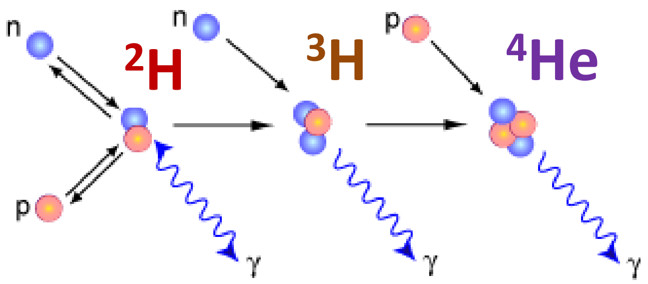
- If matter is sufficiently **heated** (*plasma state*), **thermonuclear fusion** reaction may occur due to **collisions between the particles of extreme thermal kinetic energies**.

- In nature, extremely high temperature conditions exist in the **cores of active stars**.

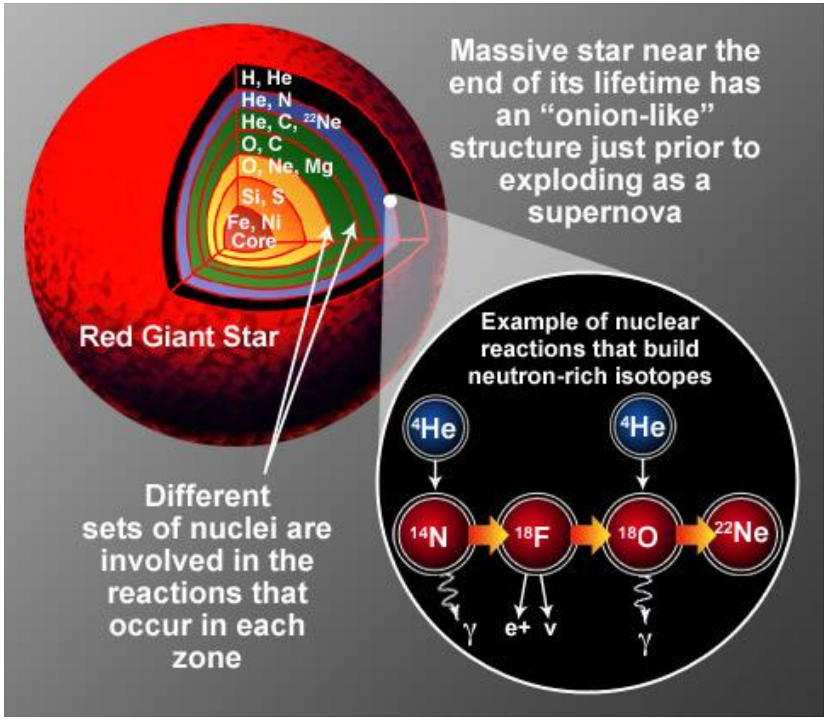


Nucleosynthesis

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



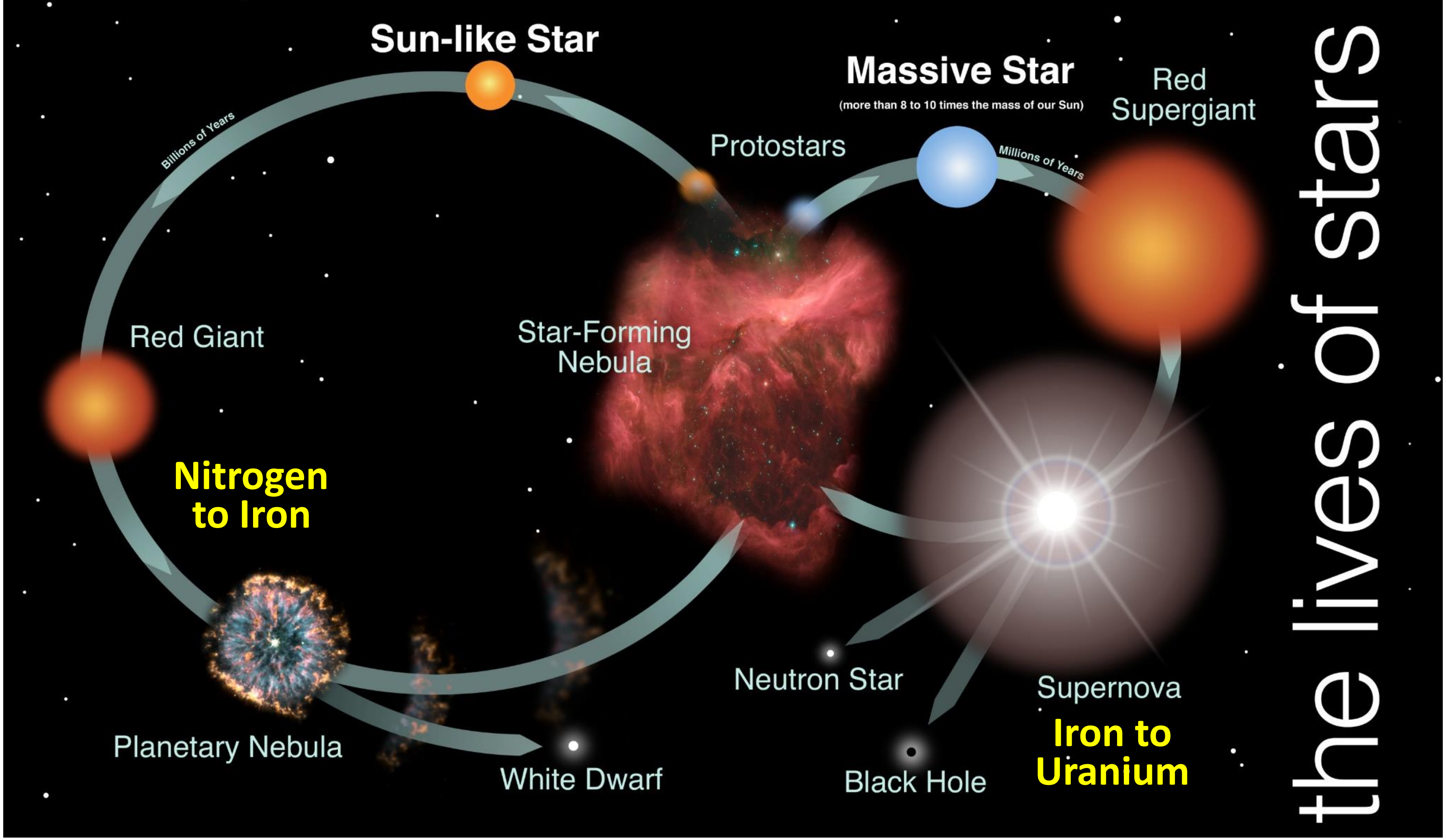
- **Big Bang nucleosynthesis**: the first nuclei, hydrogen and helium, were formed about *three minutes* after the Big Bang.
- **Stellar nucleosynthesis**: with the formation of stars, heavier nuclei were created from hydrogen and helium, a process that continues today; the heaviest element produced 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.



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:

$$H^{2} + Pt^{196} \rightarrow Au^{197} + \text{neutron}$$

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