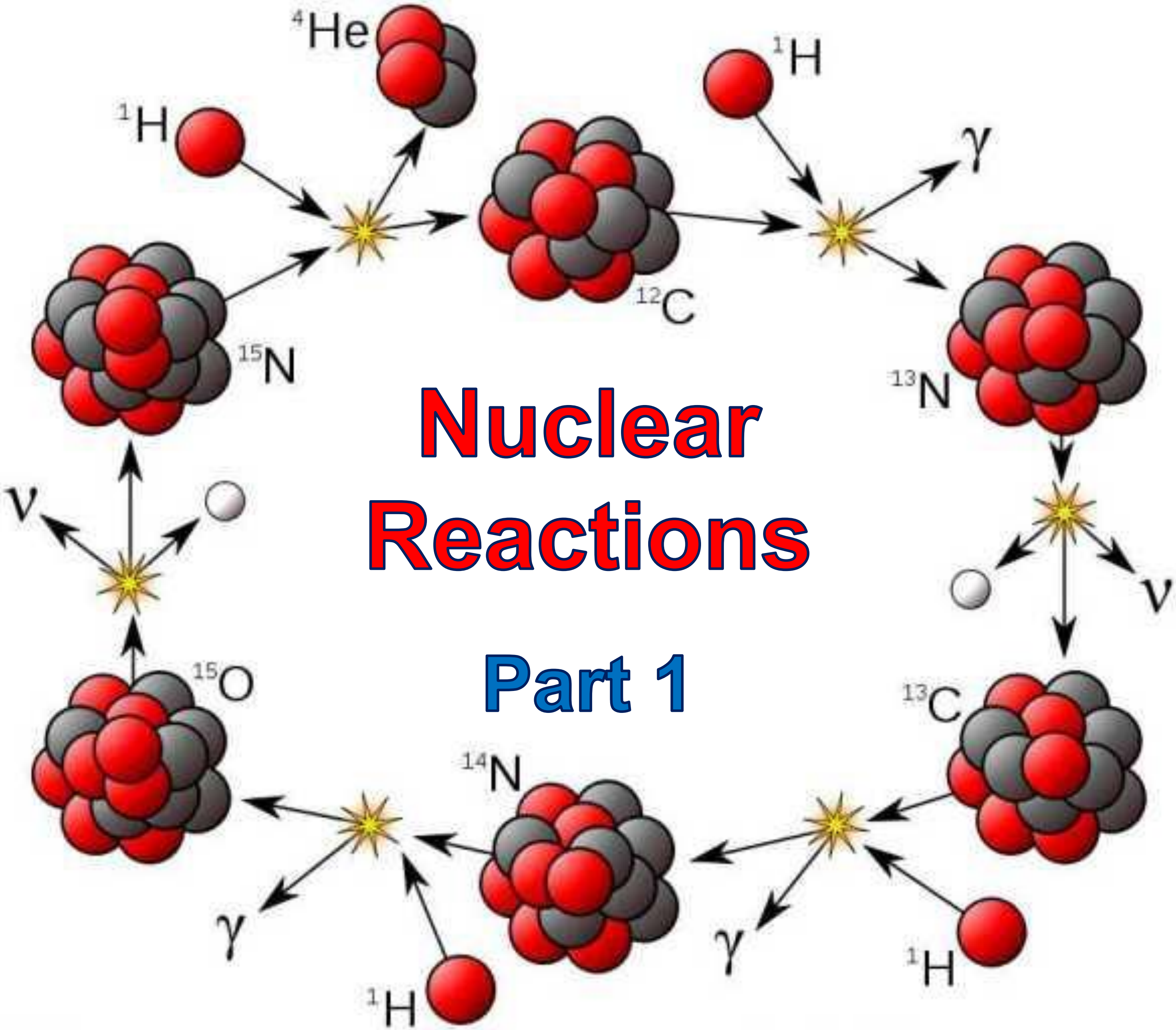
Nuclear Reactions

Part 1



Three Types of Nuclear Reactions

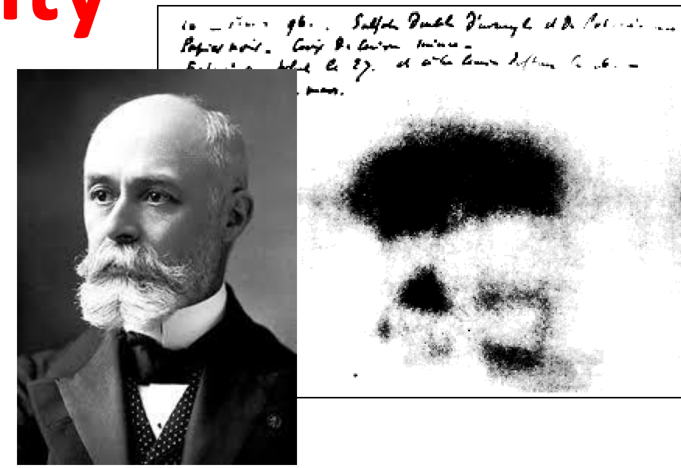
1. **Radioactive decay** – an unstable nucleus spontaneously emits a small particle of radiation to become a **different isotope** of the same element or a **different element** (such process is called ***transmutation***).

Our today's focus

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

3. **Nuclear Fission** – the **splitting** of an atom into two smaller atoms.

Discovery of Radioactivity



- **Henri Becquerel, 1896:**

  - radioactivity was first discovered in uranium salts during his work on phosphorescence.

- **Marie Sklodowska-Curie and Pierre Curie, 1898:**

  - conducted a systematic study to determine which other elements and compounds emitted “mysterious radiation” that they called “radioactivity”,

  - isolated a new radioactive element, ***polonium*** (named in honor of Marie's home country),

  - four years later, discovered an even more intensely radioactive substance, which they called ***radium***.

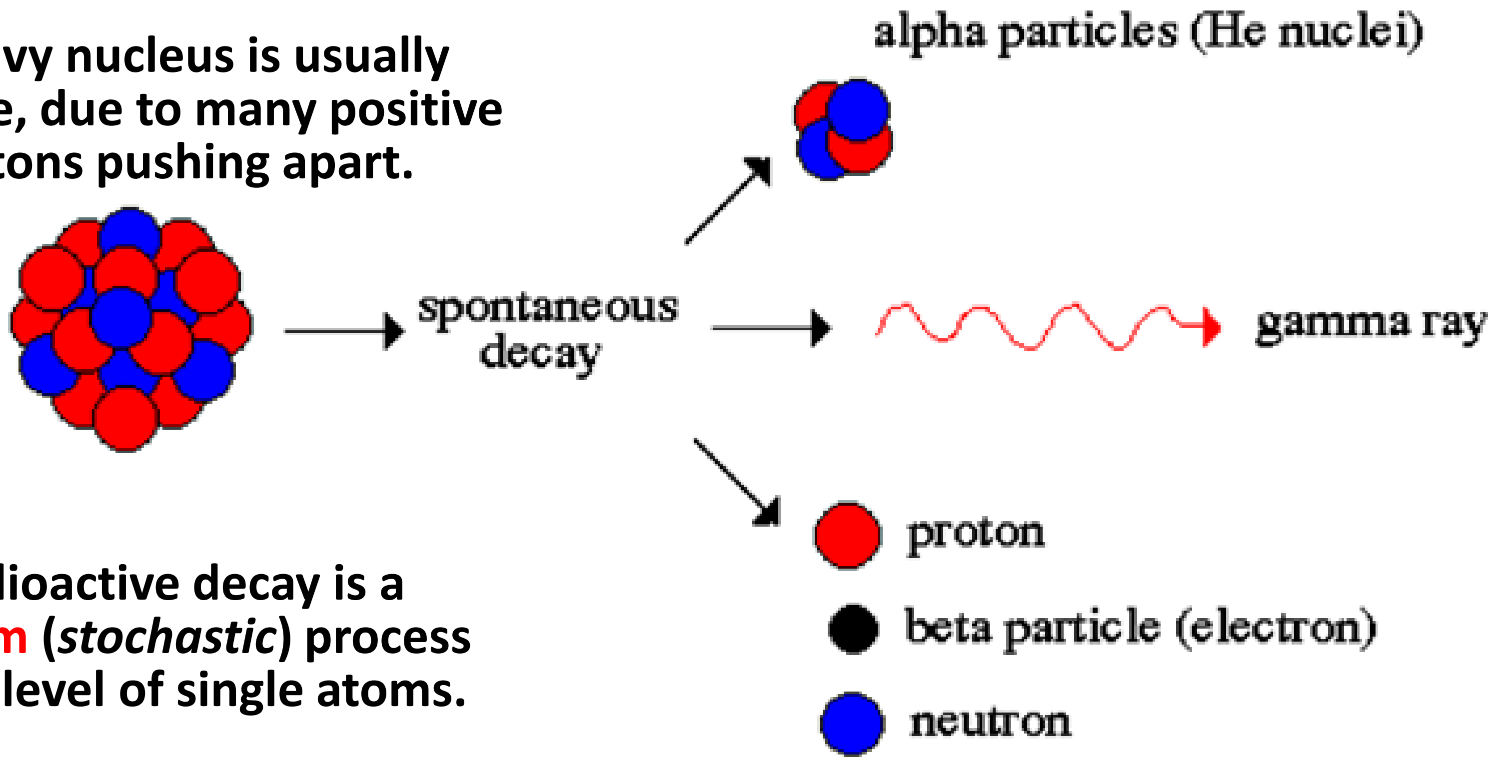
- **Ernest Rutherford and Frederick Soddy, 1899-1903:**

  - discovered three different types of radiation "rays" with very different powers of penetration, introduced the term “half-life”, and proposed that atoms were not conserved in radioactive emissions.

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.

Half-Life of Radioactive Isotope

The decay rate of a radioactive isotope is characterized by its half-life: the *time it takes for one-half of the atoms* of a radioactive material *to disintegrate*.

Radioisotope	Half-life
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

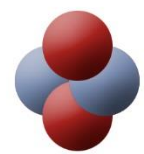
Ionizing Radiation

<u>Ionizing radiation</u> 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

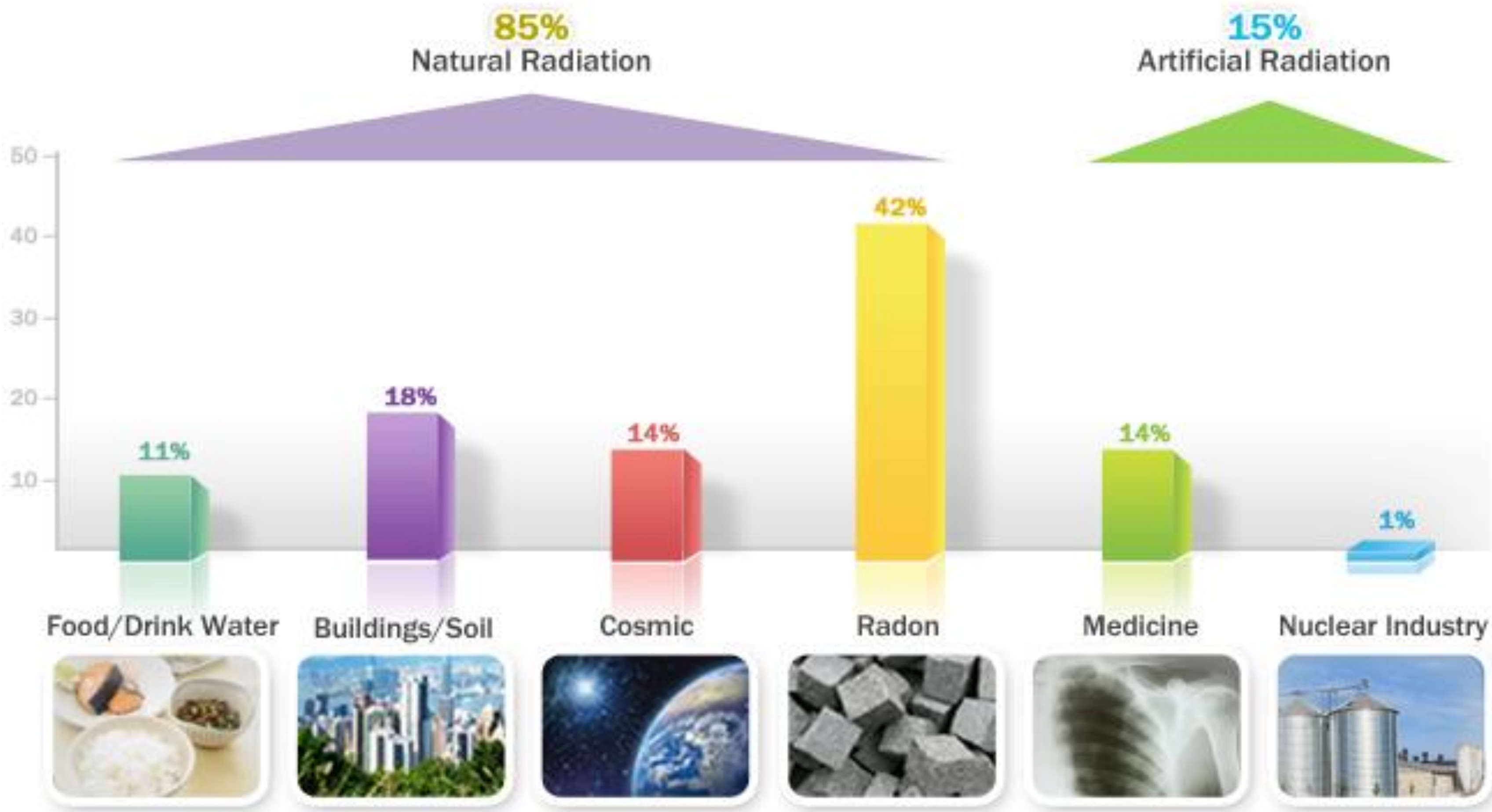
HIGH ENERGY, TRAVELS LONG DISTANCES

ENERGY ABSORBED BY HEAVY METALS AND CONCRETE

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

Sources of Background Radiation

Radioactive material is <u>fairly common</u> in nature and our daily life, and <u>generally pretty harmless</u> in that state.



Naturally Occurring Sources of Radiation

Food:

- Bananas, being naturally very high in potassium, consequently have a higher than usual amount of potassium-40, a radioactive isotope.
- The food with the highest concentration of radioactive elements, in this case radium, is the Brazil nut.

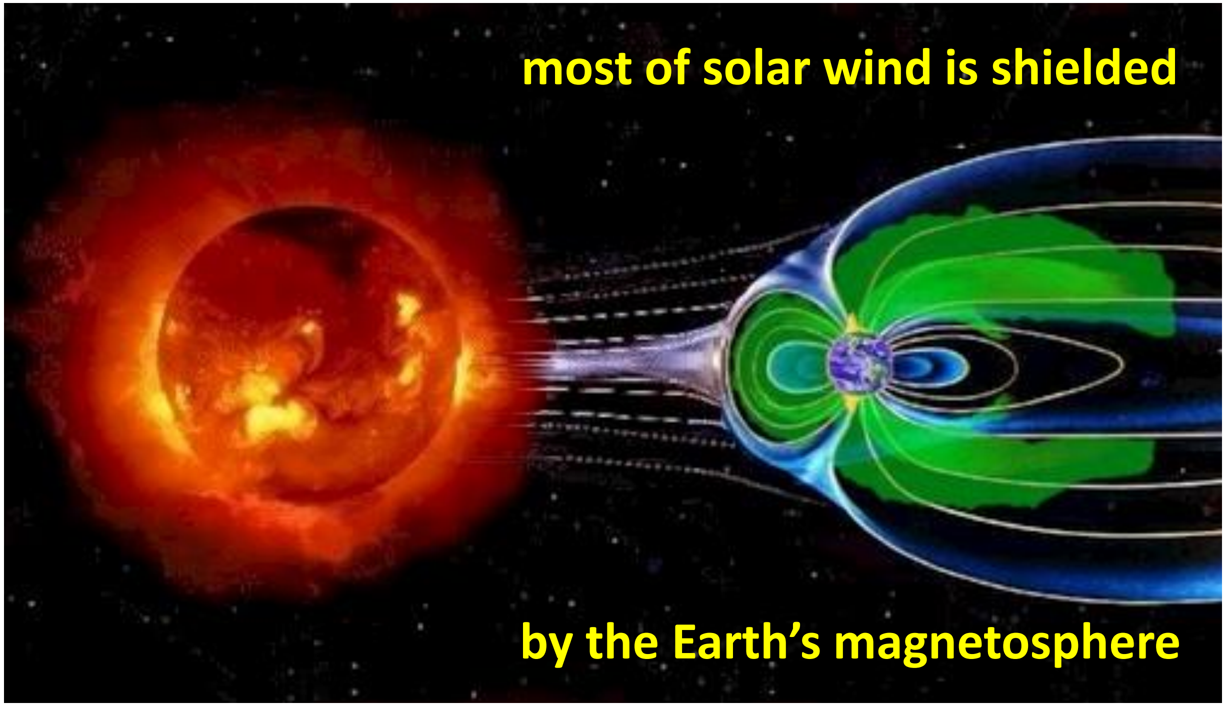
Minerals and materials buried in the earth:

- Most common are potassium-40, uranium-238, and thorium-232 (all with fairly long half-lives).
- Additionally, there are small quantities of shorter-lived materials (greater activity), such as radium-226 and radon-222 (both come as decay products of uranium deposits in the bedrock).
- Radon, being a gas, can become a problem in some houses and other buildings, seeping in usually through cracks in solid foundations, and accumulating in rooms with poor ventilation.

Naturally Occurring Sources of Radiation

The Sun:

- Powered by a <u>continuous nuclear reaction</u>, main sequence stars give off quite a bit of radiation of every sort!



Cosmic radiation:

- Makes up <u>about 14%</u> of the total annual background radiation a person is exposed to over the course of a year.
- The <u>exposure rate is slightly increased</u> by living at <u>higher altitudes</u>, and even more so by <u>air travel</u> (flight crews on long-distance, high-altitude flights tend to accumulate about 30% more annual radiation exposure than the average person!).

Background Radiation Exposure

- A certain percentage of atoms inside a human body are radioactive: most common are Carbon-14, since life is carbon-based, and Potassium-40, since Potassium forms an important part of DNA molecules; about 15 million atoms of Potassium-40 (producing beta particles and some gamma rays) and about 7,000 atoms of natural uranium (releasing alpha particles) disintegrate inside each individual every hour.
- From the sky, about 100,000 neutrons from cosmic rays pass through an average person every hour.
- Radiation inhaled with the air: about 30,000 atoms (radon, polonium, bismuth, and lead) decay each hour in our lungs giving off alpha or beta particles and gamma rays.
- Radiation coming from the soil/buildings: more than 200 million gamma rays pass through the average person each hour.
- Total typical exposure for an average person is ~2.4 mSv (millisieverts) per year; lowest level dose linked to increased cancer risk is 100 mSv; doses higher than 1 Sv can be lethal.