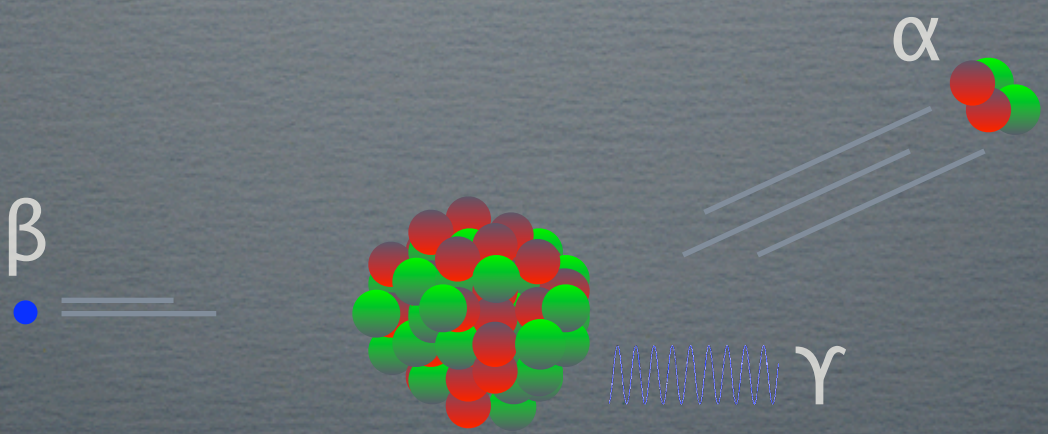
Nuclear Physics



Douglas Gilliland
Sarasota High School

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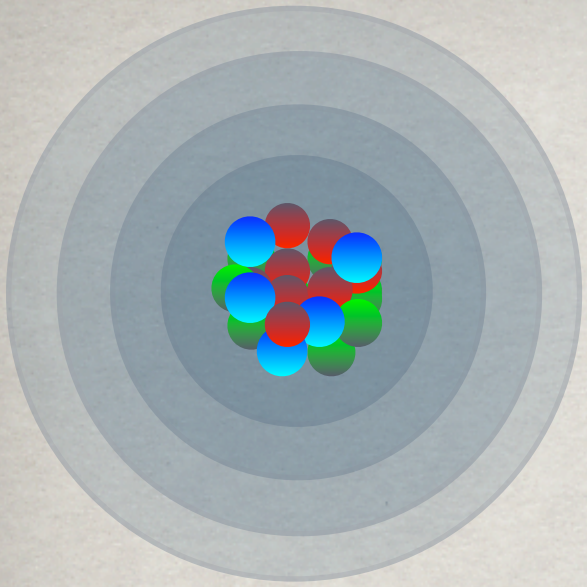


Review: The Atom

- The atom is composed of a nucleus containing protons and neutrons, and electrons outside the nucleus in energy levels.

+

- Protons possess a positive charge and have a mass of 1 AMU.

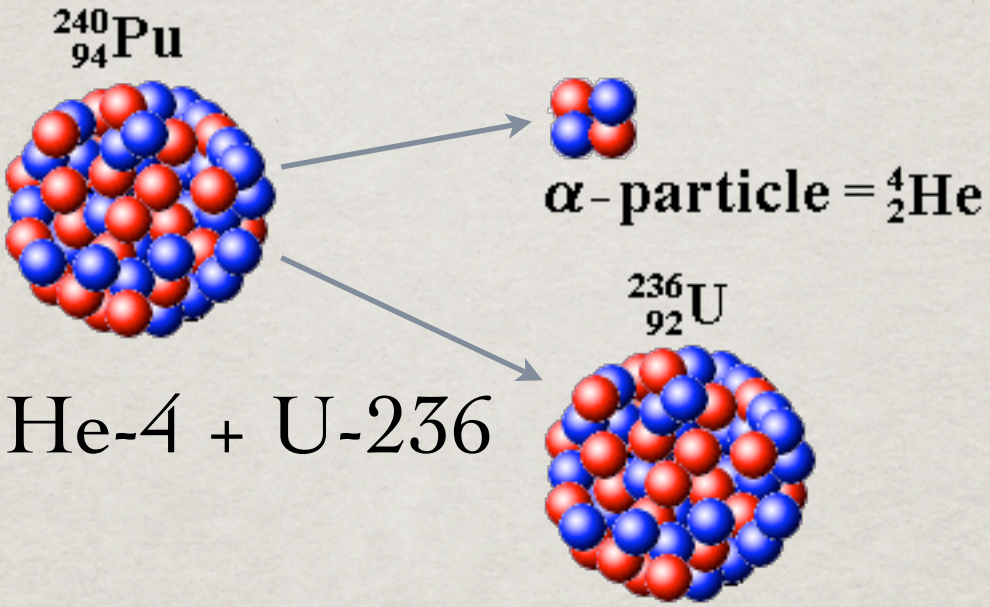
0

- Neutrons possess a no charge and have a mass of 1 AMU.

-

- Electrons possess a negative charge and have a mass of O AMU.

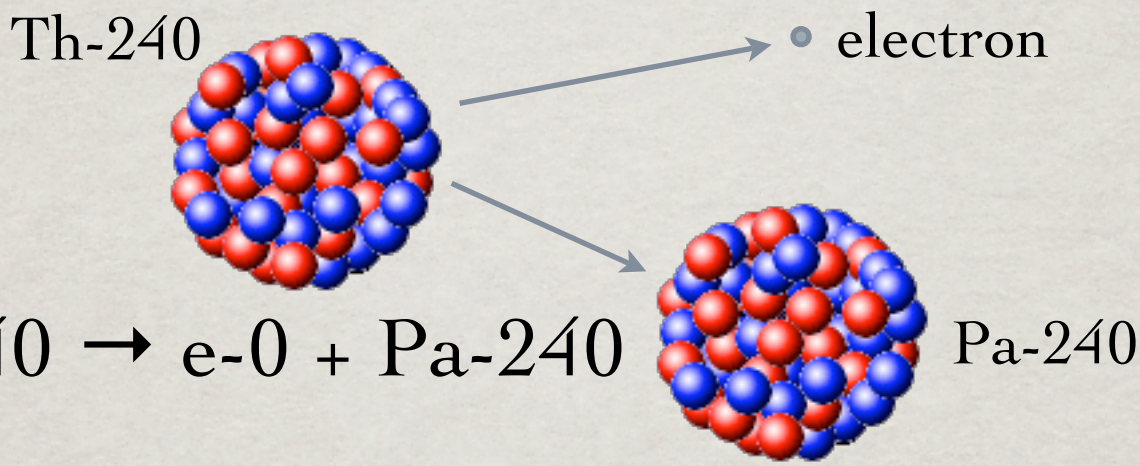
Alpha Radiation



Pu-240 → He-4 + U-236

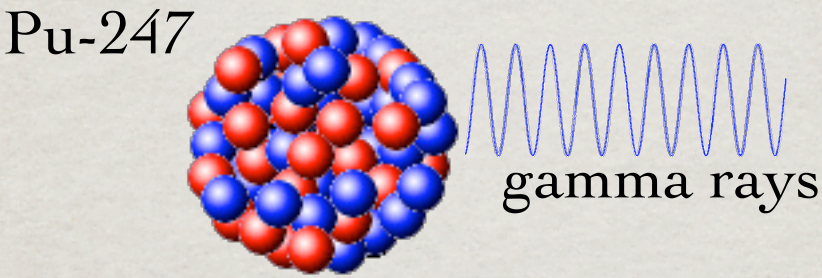
- Occurs when the nucleus emits two protons and two neutrons (a Helium nucleus).
- The atomic mass of the original isotope decreases by 4, atomic number decreases by 2.
- Symbol is α.

Beta Radiaion



- Occurs when a neutron breaks into a proton (which remains in the nucleus) and an electron which is emitted.
- The atomic mass of the original isotope remains the same, atomic number increases by 1.
- Symbol is β.

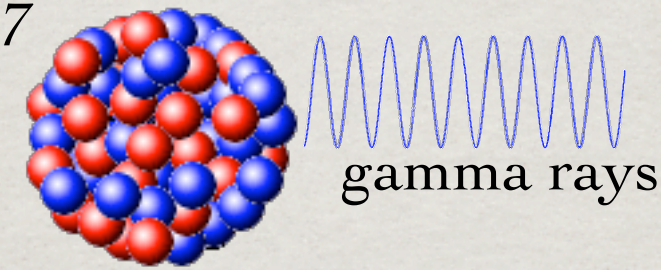
Gamma Radiation



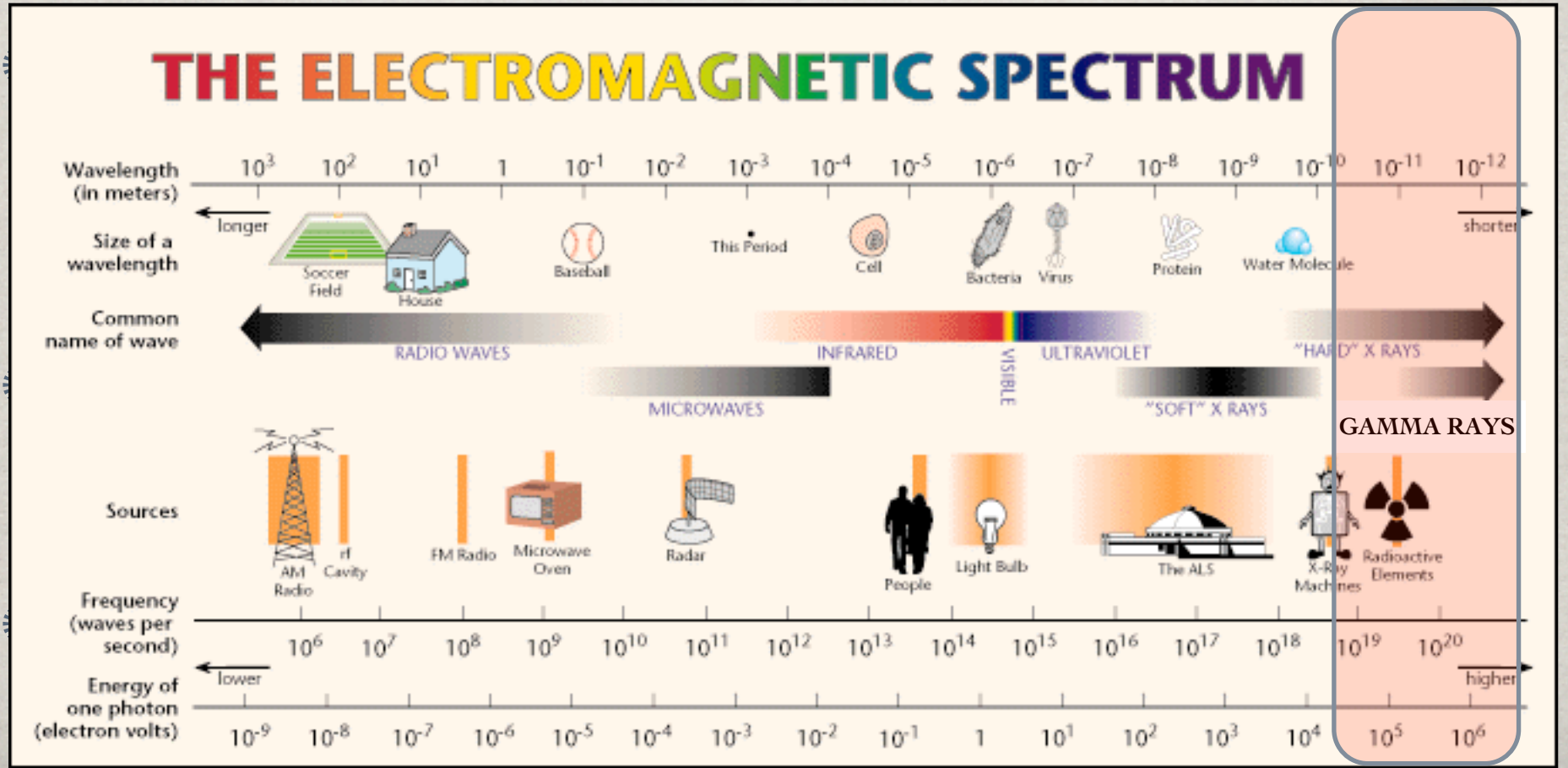
- Energy in the form of high energy electromagnetic waves are emitted from the nucleus.
- The atomic mass and atomic number remain unchanged.
- Symbol is γ. Has more energy than either alpha or beta radiation.

Gamma Radiation

Pu-247



gamma rays



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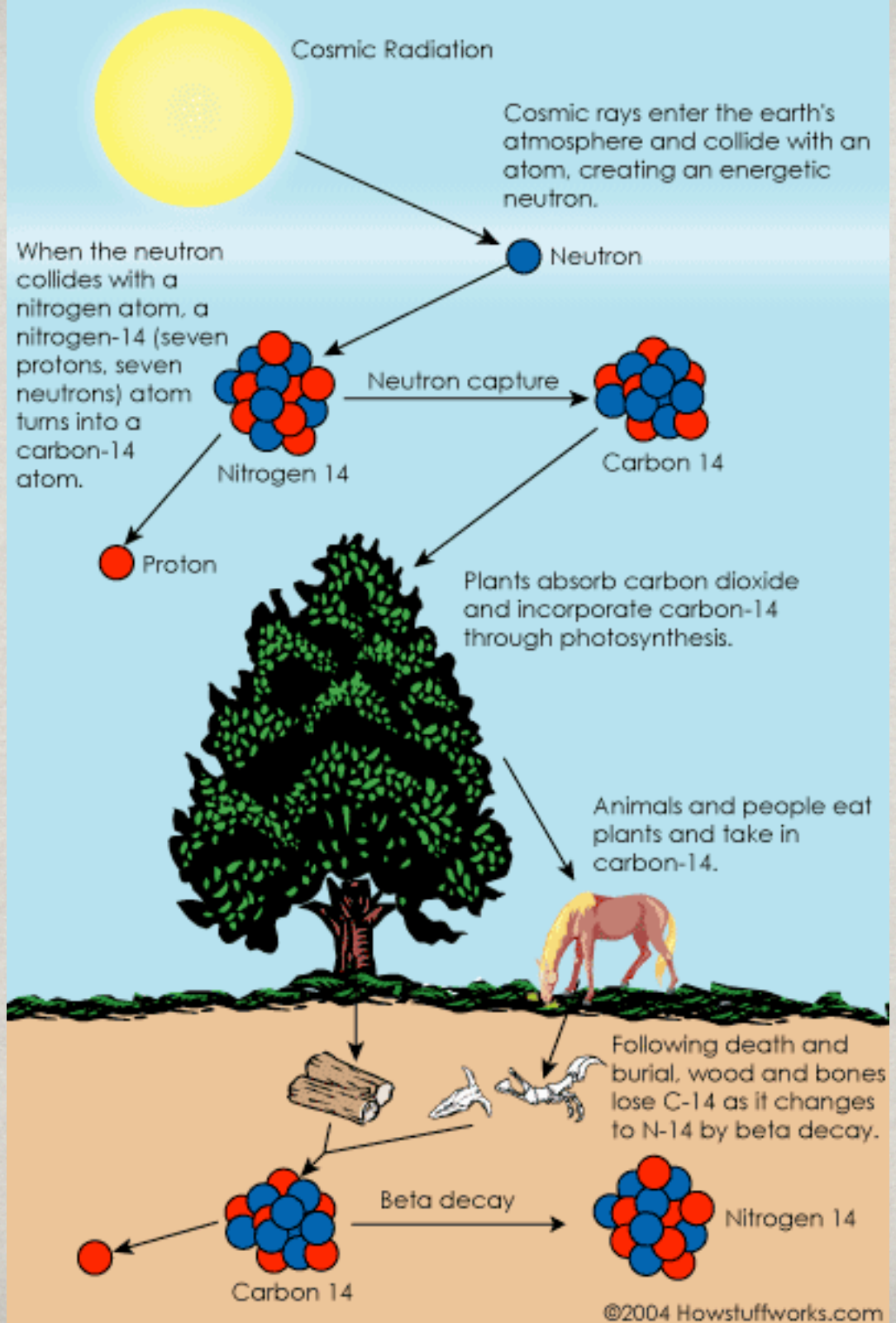
Half-Life

- All radioactive isotopes decay at different rates - some very fast and some very slow.
- Unlike a chemical reaction, the decay rate is not effected by temperature, pressure, surface area... it remains constant.
- The amount of time it takes for half the mass of a radioactive sample to decay is called the half-life.
- Each radioactive element has it's own half-life.


Cosmic Radiation
Cosmic rays enter the earth's atmosphere and collide with an atom, creating an energetic neutron.
Neutron
When the neutron collides with a nitrogen atom, a nitrogen-14 (seven protons, seven neutrons) atom turns into a carbon-14 atom.
Neutron capture
Nitrogen 14
Carbon 14
Proton
Plants absorb carbon dioxide and incorporate carbon-14 through photosynthesis.
Animals and people eat plants and take in carbon-14.
Following death and burial, wood and bones lose C-14 as it changes to N-14 by beta decay.
Beta decay
Nitrogen 14
Carbon 14
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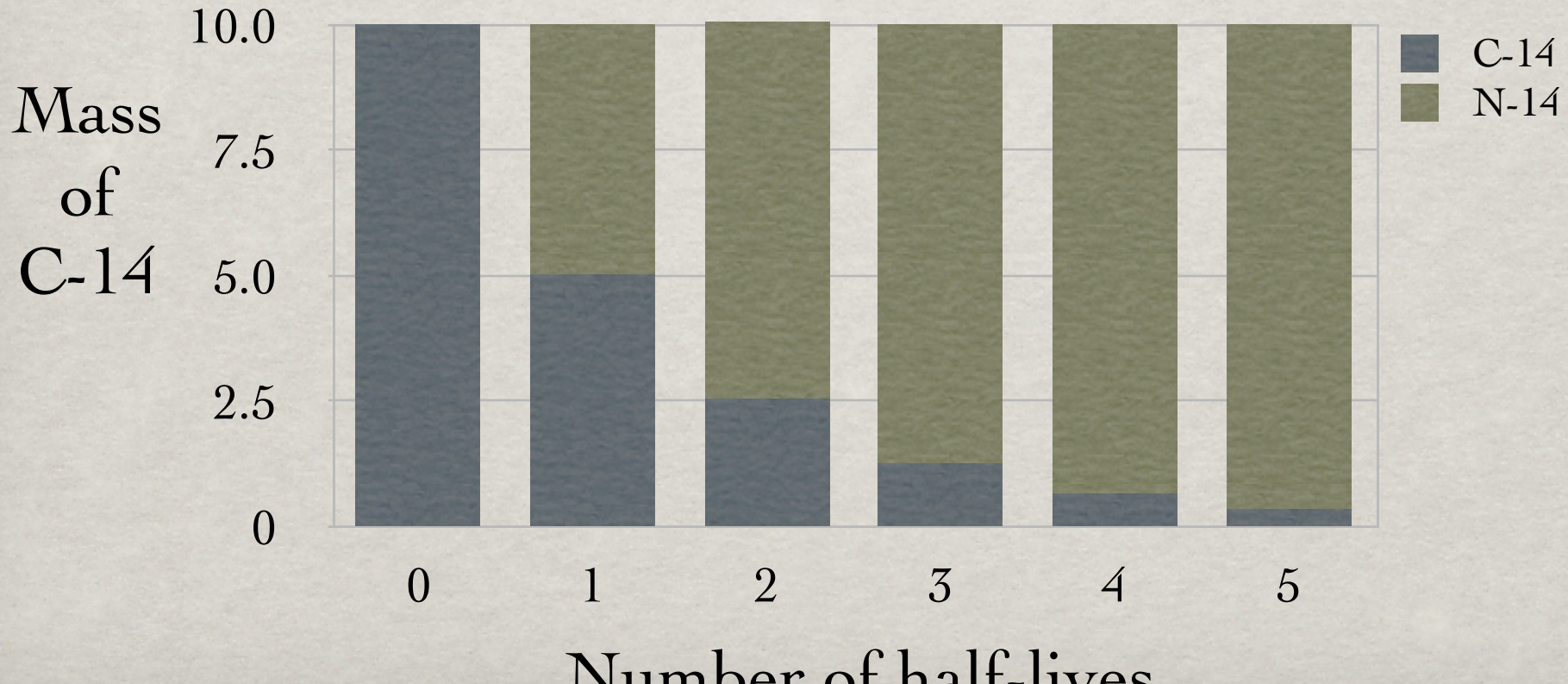
C-14 Half-Life

Carbon-14 is a radioactive isotope that goes through beta decay to become a stable isotope, Nitrogen-14.
The half-life of C-14 is 5,730 years.

$$^{14}_{6}C \rightarrow ^{0}_{-1}e + ^{14}_{7}N$$



Carbon-14 Dating

A scientist wishes to determine the age of a skeleton. She takes a sample of a bone and calculates that when the person was alive, the bone sample contained 9.80 grams of C-14.

She grinds up the sample, burns it and captures the CO2 produced and finds that it contains only 0.613 grams of C-14.

How old is the bone?

Step 1: Calculate how many half-lives it went through.

half-lives	0	1	2	3	4
mass	$\frac{9.80\text{ g.}}{2}$	$= \frac{4.90\text{ g.}}{2}$	$= \frac{2.45\text{ g.}}{2}$	$= \frac{1.225\text{ g}}{2}$	$= 0.613\text{ g}$

Step 2: Multiply the number of half-lives times C-14's half-life.

4 Half-lives x 5,730 years/ Half-life = 22,900 years

note: C-14 dating is only reliable to 60,000 years.

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Nuclear Energy: Fission & Fusion

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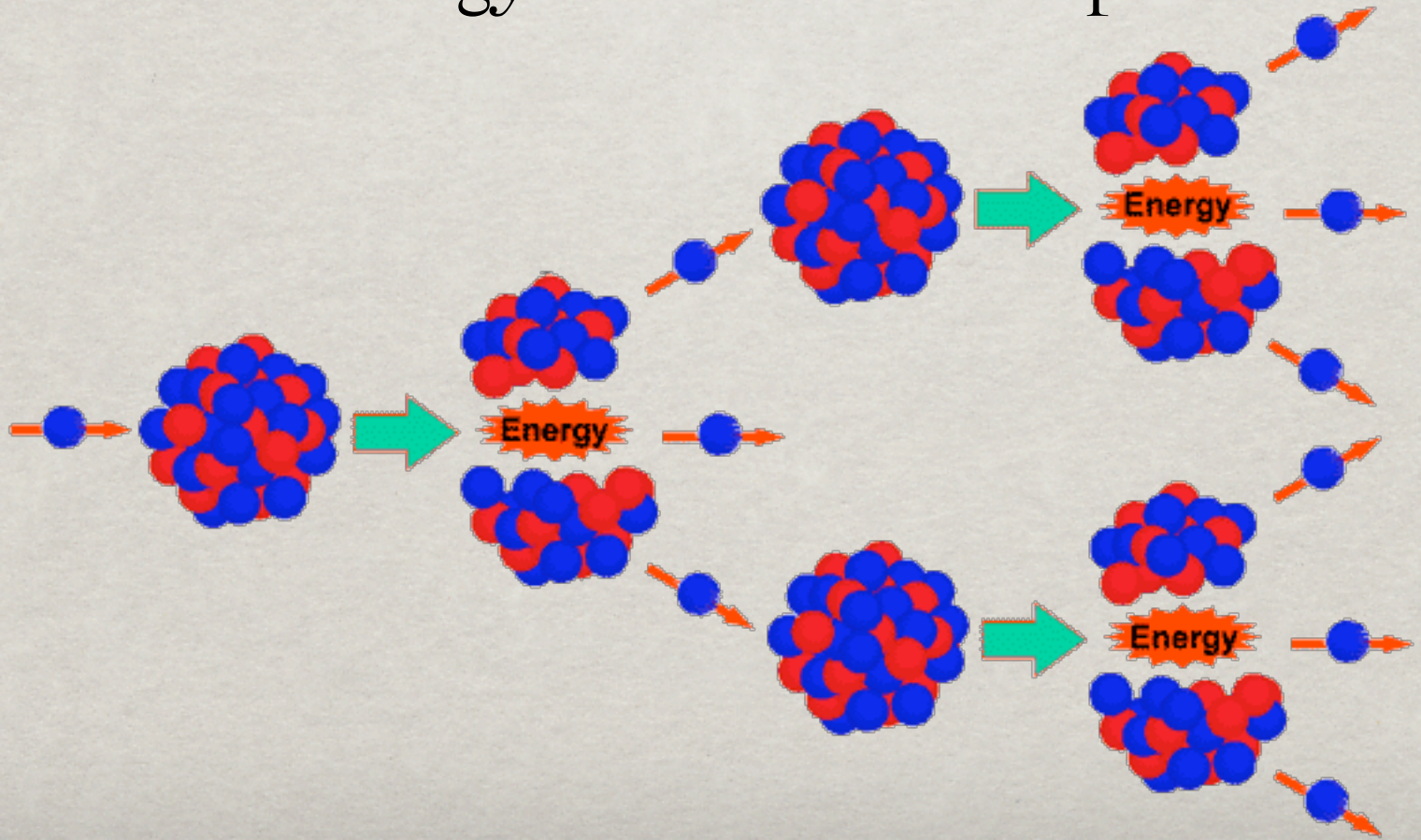
Fission

Splitting a Uranium Atom

Fission: Splitting a Nucleus

A high energy neutron strikes a large nucleus (U-235).
The nucleus splits into two smaller nuclei and 3 neutrons.
The splitting of the large nucleus produces heat energy.
The 3 neutrons split 3 U-235 nuclei, producing 9 neutrons and 3x more heat energy. The 9 neutrons split 9 U-235 nuclei...



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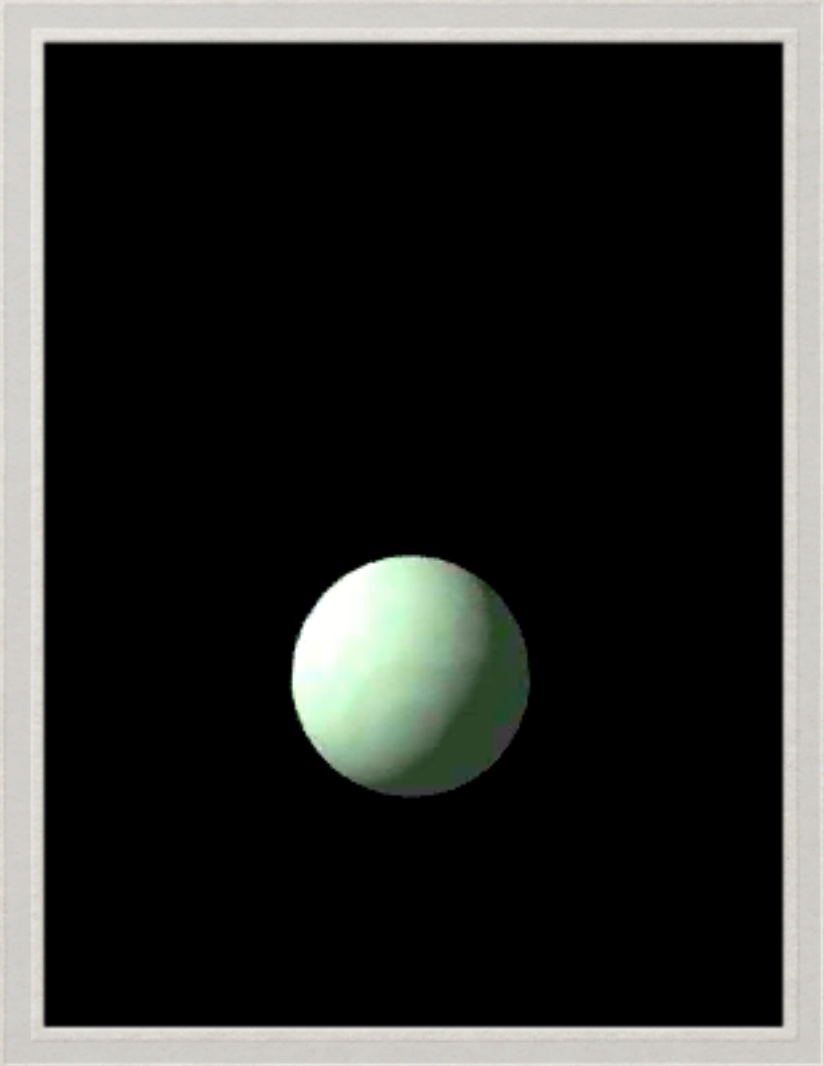
Fission of U-235

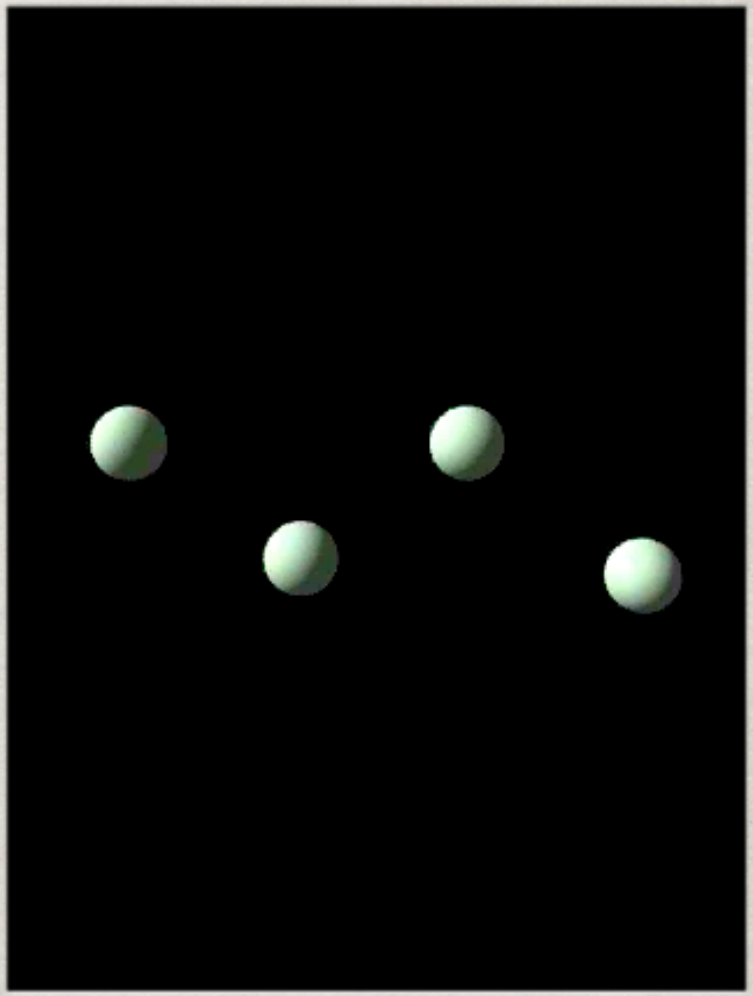
- A fission reaction produces two smaller radioactive nuclei that are nuclear waste products.



Fission of U-235

- A fission reaction produces two smaller radioactive nuclei that are nuclear waste products.

- The chain reaction cannot produce an explosion unless 2 lbs or more of U-235 is present. This is called the "critical mass".



Nuclear Fission Chain Reaction

The splitting of one U-235 atom results in the release of a small amount of energy and 3 neutrons. Those 3 neutrons split 3 U-235 atoms, producing 3x the energy and 9 neutrons. How many U-235 atoms would split in 10 fissions?

Answer: 88,573 U-235 fission reactions.

Number of fissions	0	1	2	3	4	5	6	7	8	9	10
Number of atoms splitting	1	3	9	27	81	243	729	2187	6561	19683	59049

Apply this idea to striking 1 match, which causes 3 matches to strike... Think of the heat produced by 88,573 matches!

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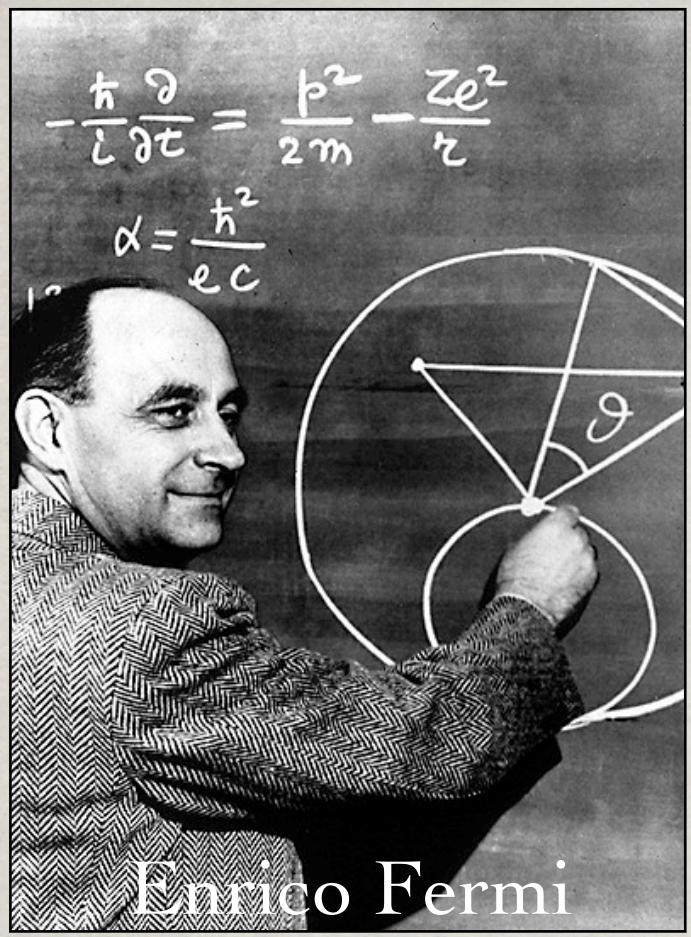
Enrico Fermi



In 1938 the Italian scientist Enrico Fermi immigrated to the United States to escape the fascist dictator Mussolini.

On December 2, 1942 he and a group of nuclear scientists created the first controlled nuclear fission reaction under the Univ. of Chicago stadium.

This discovery lead to the Manhattan Project - Americas program to develop the atomic bomb.

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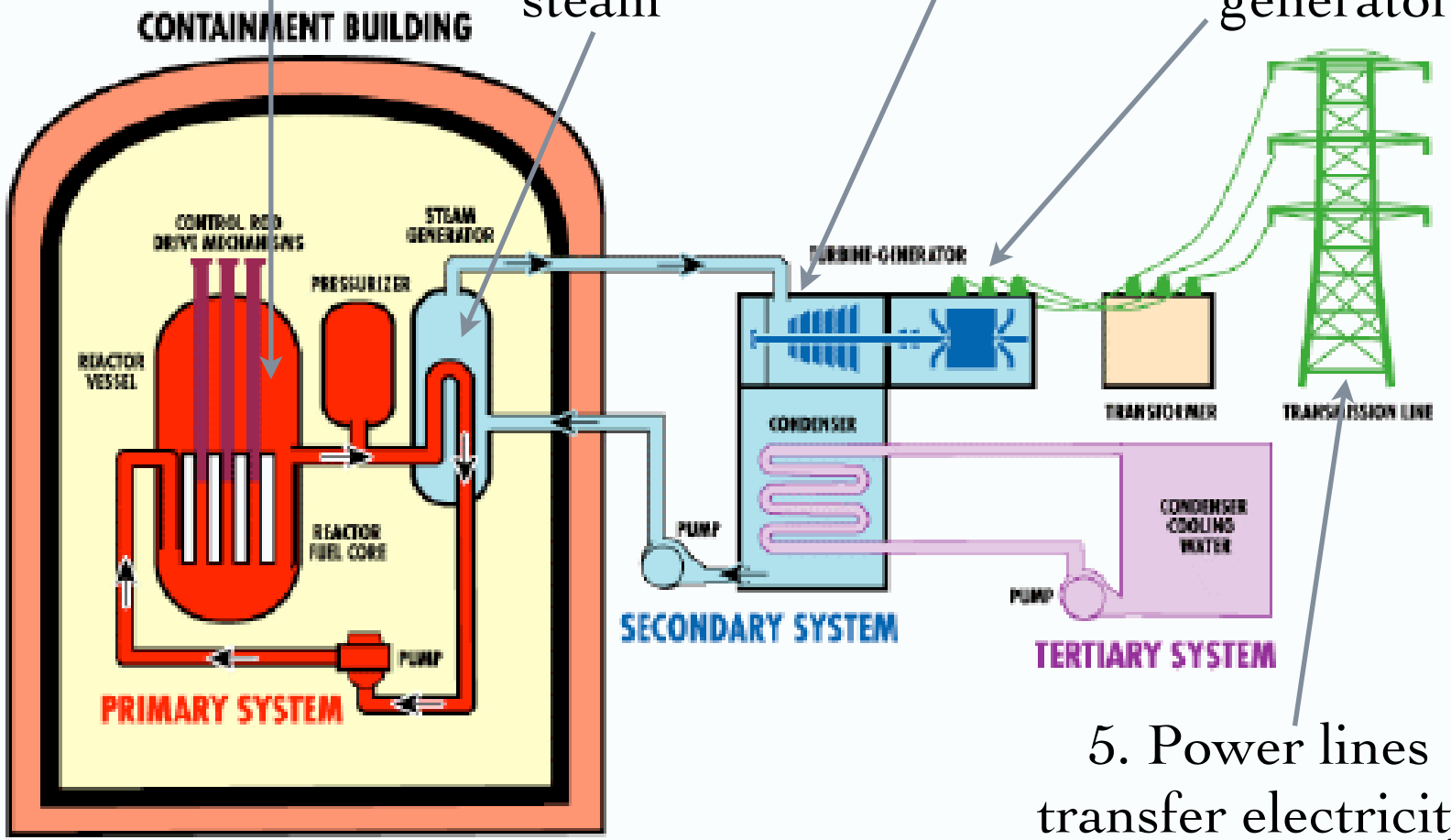
Nuclear Power Plant

1. Nuclear fission makes heat
2. Heat water to make steam
3. Steam turns turbine
4. Turbine turns generator



5. Power lines transfer electricity to cities

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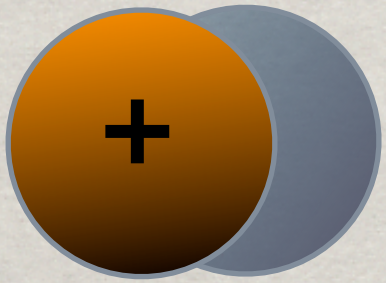
Fusion

Combining Two Hydrogen Nuclei

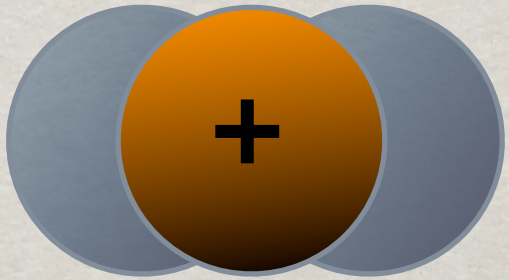
FUSION:
Combining 2 Nuclei

Two isotopes of hydrogen, H-2 (deuterium) and H-3 (tritium), heated to millions of degrees and traveling at extremely high velocities, collide and fuse to make He-4 and a neutron. When the fusion occurs heat energy is released.

$$H\text{-}2 + H\text{-}3 \rightarrow He\text{-}4 + n\text{-}1$$



H-2
deuterium



H-3
tritium

Fusion: Combining 2 Nuclei

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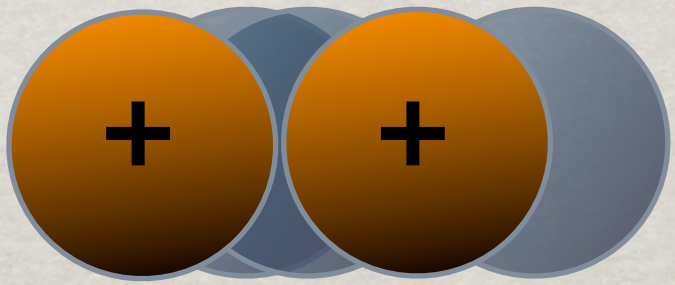

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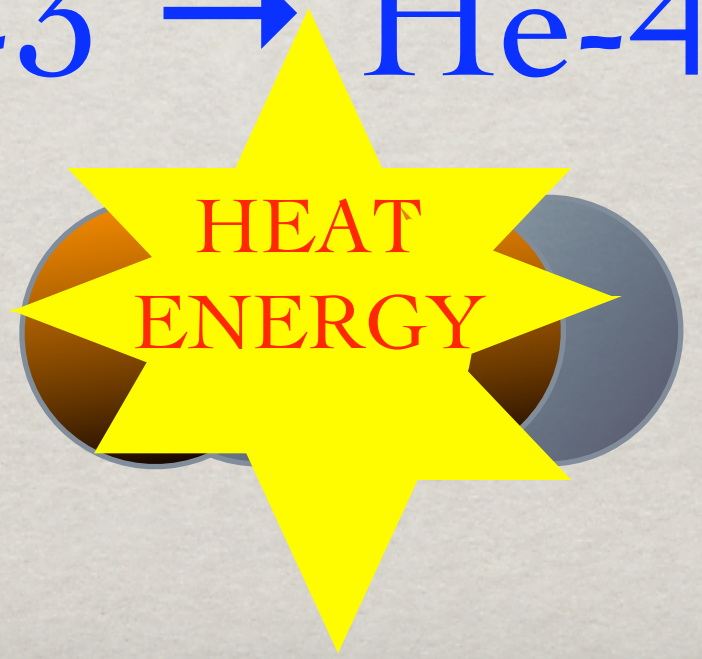

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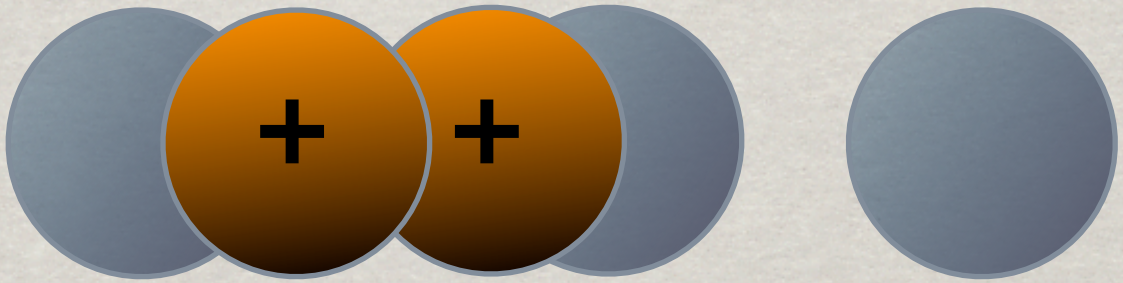

He-4
Helium

Neutron

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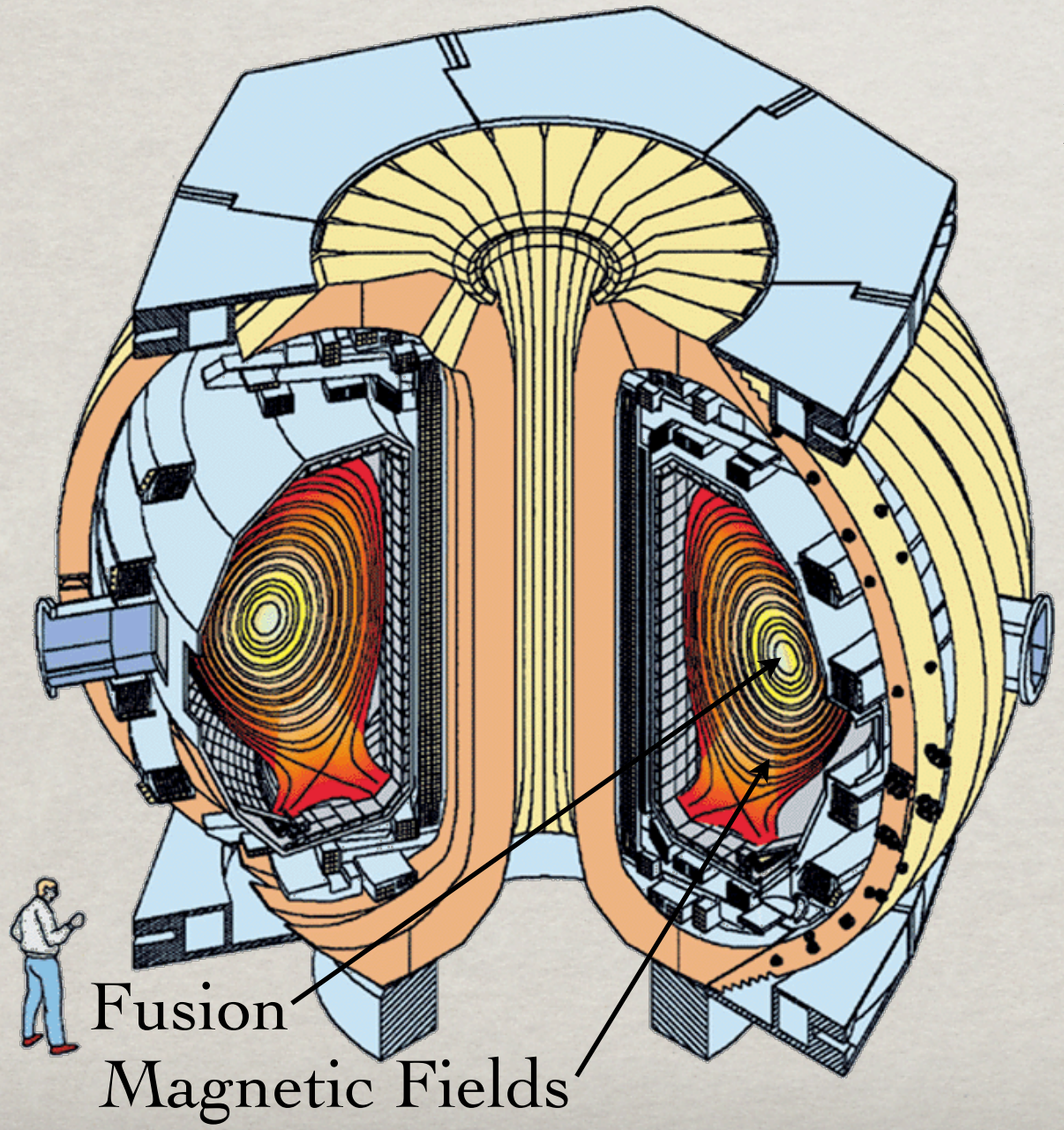
The Sun & Stars produce energy through fusion.

All our energy, except for fission, can be traced back to fusion, the energy of the sun.

Food → Animals & Plants → Photosynthesis → Sun
Petroleum → Organic matter → Photosynthesis → Sun
Wind → Heating of the Earth's surface → Sun
Hydroelectric → Rain → Heating of the Earth's surface → Sun
Solar energy → Sun
Almost 100% of the Earth's energy comes from the Sun!

Tokamak Fusion Reactor



This experimental fusion reactor, located at Princeton University, uses magnetic fields to contain the fusion reaction.

The Tokamak reactor has produced a temperature of 510,000,000 °C, more than 30x hotter than the center of the Sun and the highest temperature ever recorded in a laboratory.

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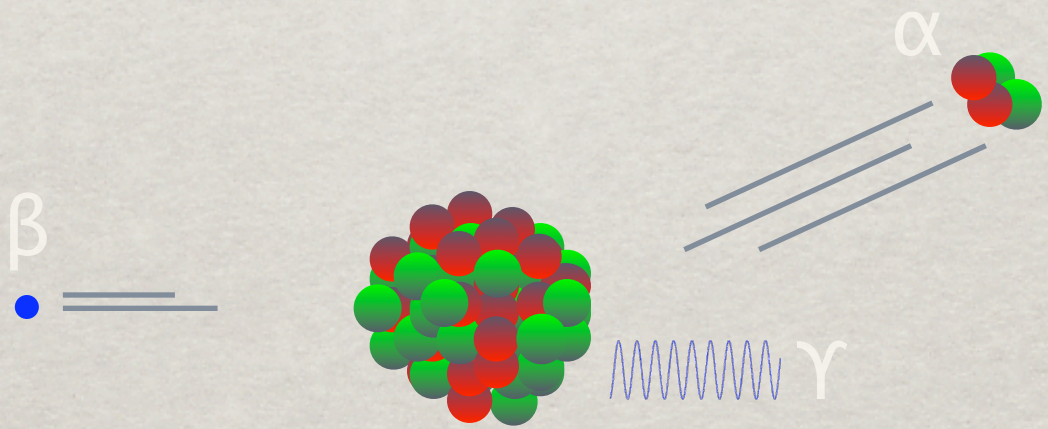
Nuclear Medicine



Using the power of the nucleus to heal.

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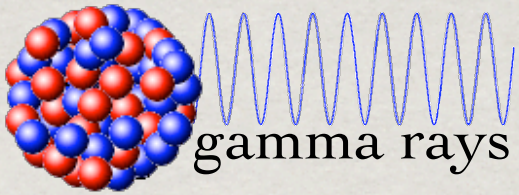
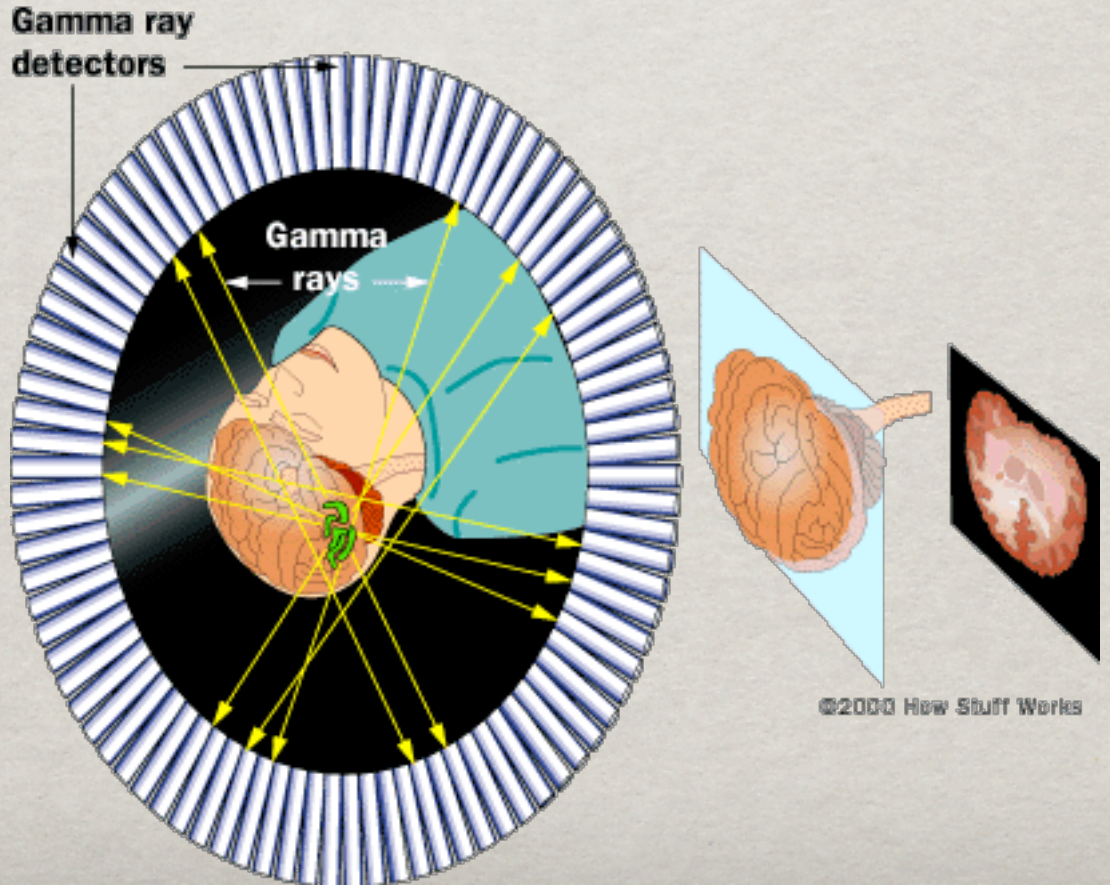
Radiation Treatment



- Uses Gamma radiation produced by radioistopes (like Co-60) to kill cancer cells.
- Gamma rays are especially effective in killing fast growing cancer cells.
- Hair cells, stomach and intestine lining cells, skin cells and blood cells are strongly affected by radiation. This is the reason why individuals going through radiation treatment often feel nauseous, tired and lose their hair.

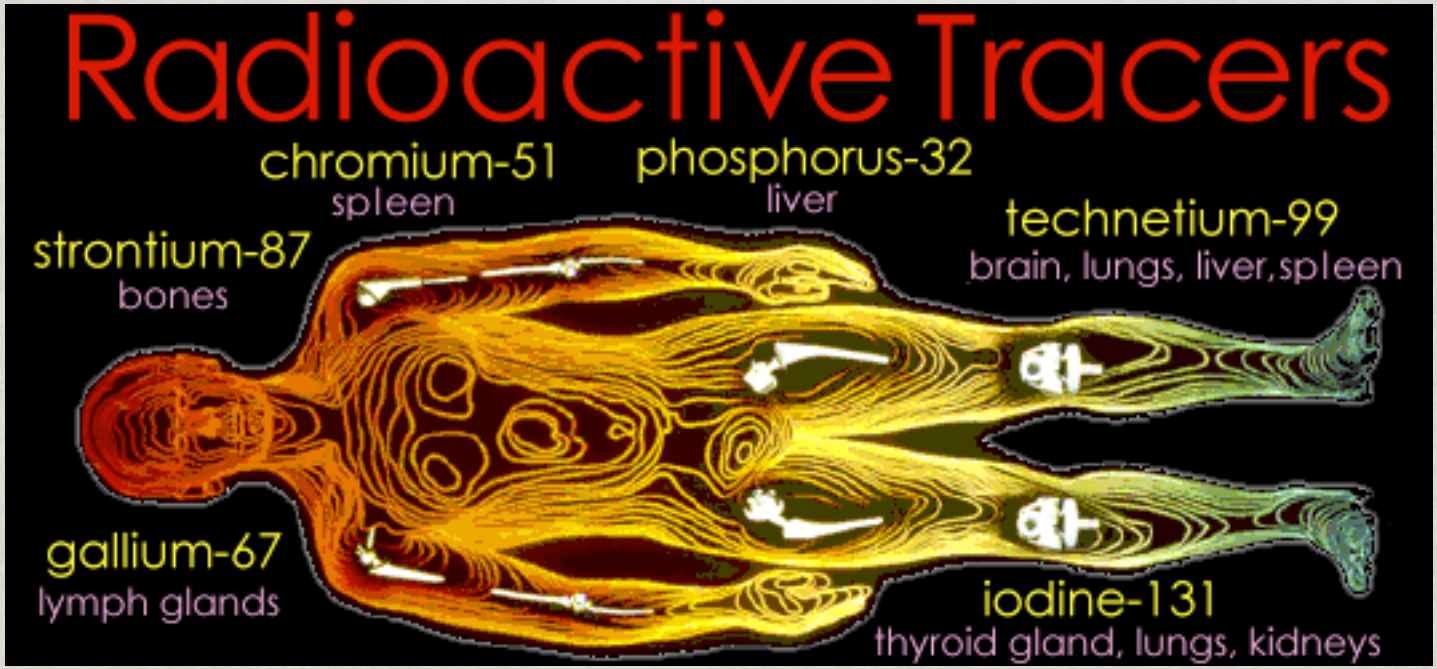
Positron Emission Tomography (PET)

Patients are injected with a radioisotope which produces gamma radiation. The PET machine uses these gamma rays to produce a 3-D image of the body.



Radioactive Tracers

Tracers are radioactive isotopes whose pathway can be followed as they travel through animals, plants or other matter.



Example: The thyroid gland in your neck controls human growth & metabolism. It also absorbs iodine in your blood. To see if the thyroid is working, doctors inject small amounts of radioactive I-131 into a patient's blood and measure how much accumulates in their thyroid with a Geiger counter like device.

Nuclear Physics Index