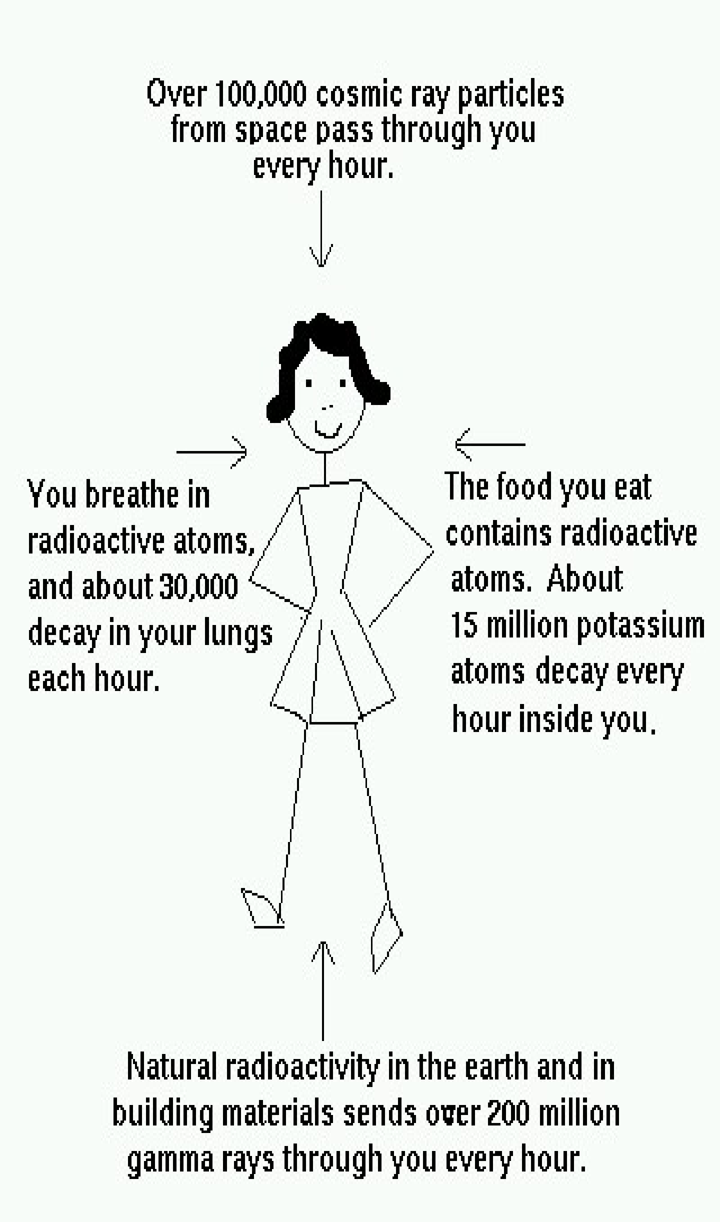
Nuclear Chemistry

Nuclear Reactions

- **Occur when nuclei emit particles and/or rays.**
- **Atoms are often converted into atoms of another element.**
- **May involve protons, neutrons, and electrons.**
- **Associated with large energy changes.**
- **Reaction rate is not normally affected by temperature, pressure, or catalysts.**

The Basics of Radiation

- Radioactive materials have an unstable nucleus that release one or more particles or energy
- Nuclear radiation refers to the released energy and matter.
- A large part of the radiation you are exposed to comes from background radiation (from the sun – solar and the earth – terrestrial.
- Radiation is going through you all the time.



Discovery of Radioactivity

- In 1895 Wilhelm Roentgen found that invisible rays were emitted when electrons bombarded the surface of certain materials.
- The emitted rays were discovered because they caused photographic plates to darken.
- Roentgen named these invisible high-energy emissions X rays.

The first X-ray is of Roentgen wife hand

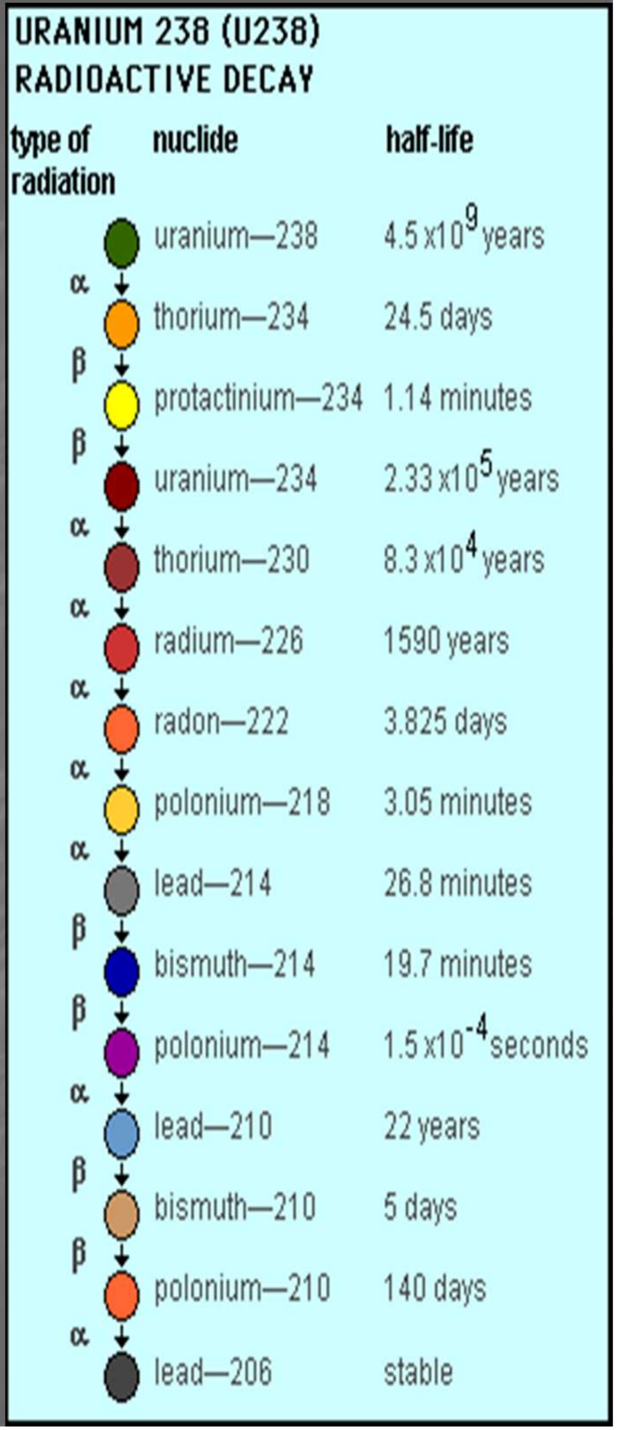
in 2004 the International Union of Pure and Applied Chemistry named element 111, roentgenium, a radioactive element with multiple unstable isotopes

Discovery of Radioactivity

- **Marie Curie and her husband Pierre isolated the components of emitting the rays.**
  - **Named the process by which materials give off such rays = radioactivity**
    - **the rays and particles emitted by a radioactive source are called radiation.**
- **In 1889, the Curies identified 2 new elements**
  - **polonium and radium, and the basis of their radioactivity.**

A review of Isotopes

- **Isotopes are atoms of the same element that have different numbers of neutrons.**
  - **Radioisotopes- Isotopes of atoms with unstable nuclei**
    - **emit radiation to attain more stable atomic configurations in a process called radioactive decay.**
- **During radioactive decay, unstable atoms lose energy by emitting one of several types of radiation.**



The Three Most Common Types of Radiation

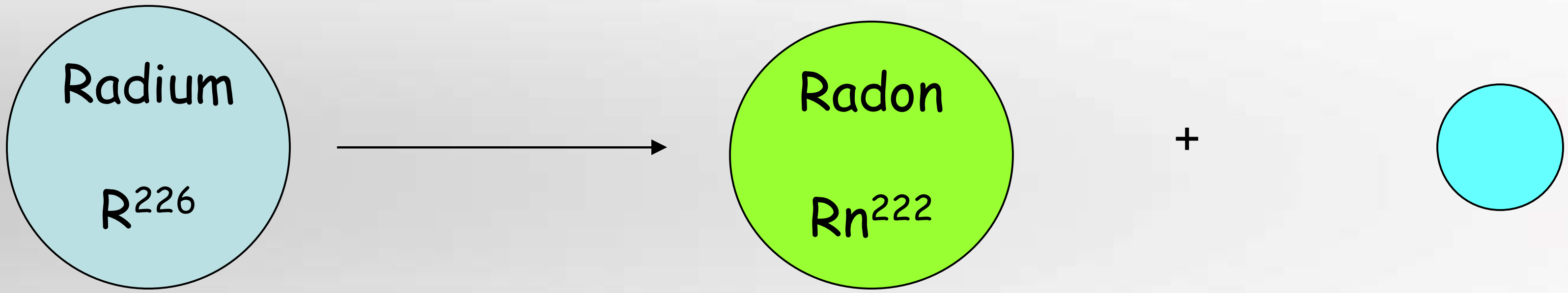
- **Alpha (α)**
- **Beta (β)**
- **Gamma (γ)**
- Neutron Emission

1. Alpha (α)

- **Symbol:** $^{4}_{2}He$
- **Carry a 2+ charge**
- **Are deflected toward the negatively charged plate**
- **They are NOT very penetrating- single sheet of paper stops alpha particles. Do not travel far because of the size and can barely pass through a piece of paper.**
- **Has the same composition as a helium nucleus- two protons and two neutrons. Which is why it has the symbol above.**
- **Loss of an Alpha particle by a nucleus results in the formation of a new nucleus, lighter than the original by four mass units.**

$$^{238}_{92}U \rightarrow \ ^{234}_{90}Th + \ ^{4}_{2}He^{2+},$$

Alpha Particles:



88 protons
138 neutrons

86 protons
136 neutrons

2 protons
2 neutrons

The **alpha-particle** (α) is a **Helium nucleus**.

It's the same as the element Helium, with the electrons stripped off !

2. Beta (β)

- Symbol: $^{0}_{-1}\beta$

- carry a 1- charge and are deflected toward the positively charged plate

- Very fast moving electron that has been emitted from a neutron of an unstable nucleus.
- Travels faster and has more energy than alpha particles. Can travel through 3 mm of aluminum or 10 mm of wood.

- Example: Beta decay process is the decay of iodine- 131 into xenon- 131 by beta-particle emission

$$^{131}_{53}I \longrightarrow \, ^{0}_{-1}\beta + \, ^{131}_{54}Xe$$

- Have greater penetrating power than alpha particles
  - A thin metal foil is required to stop beta particles.

Beta Particles:

Carbon C^{14} → Nitrogen N^{14} + e^-

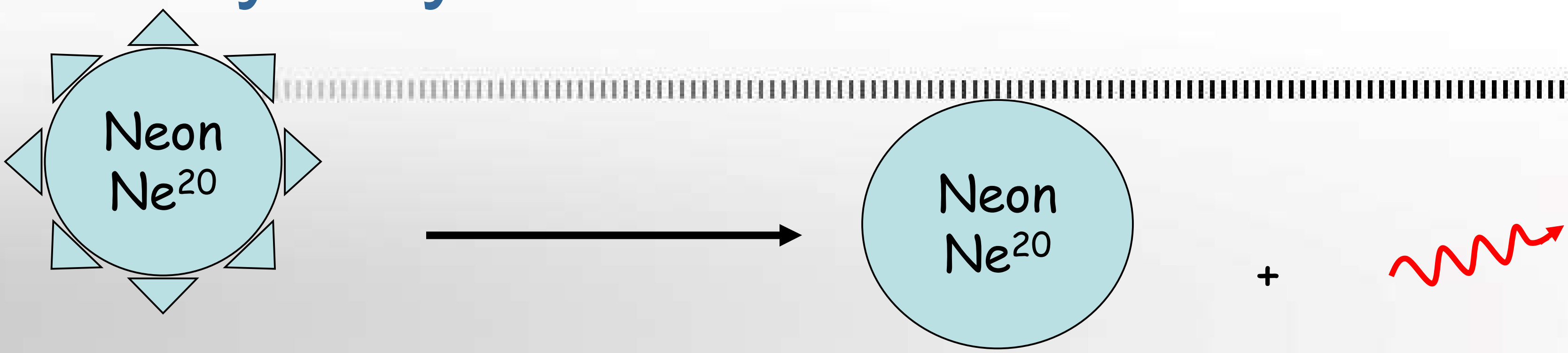
Carbon C^{14}	Nitrogen N^{14}	electron (beta-particle)
6 protons	7 protons	
8 neutrons	7 neutrons	

During this decay, one neutron changes to a proton
And an electron is released.
This causes Carbon 14 to decay to Nitrogen 14.

3. Gamma (γ)

- **Symbol:** $^{0}_{0}\gamma$
- **Are high-energy electromagnetic radiation.**
- **Rays almost always accompany alpha and beta radiation as they account for most of the energy loss that occurs as a nucleus decays.**
- **Extremely penetrating and can be very damaging to living tissue. Gamma Rays have very high energy and can travel through 60 cm of aluminum and 7 cm of lead.**
- **Only partially blocked by lead and concrete.**
- **Gamma rays are also used for diagnostic purposes in nuclear medicine.**

Gammy Rays



10 protons
10 neutrons
(in excited state)

10 protons
10 neutrons
(lowest energy state)

gamma

A *gamma* is a high energy *light particle.*

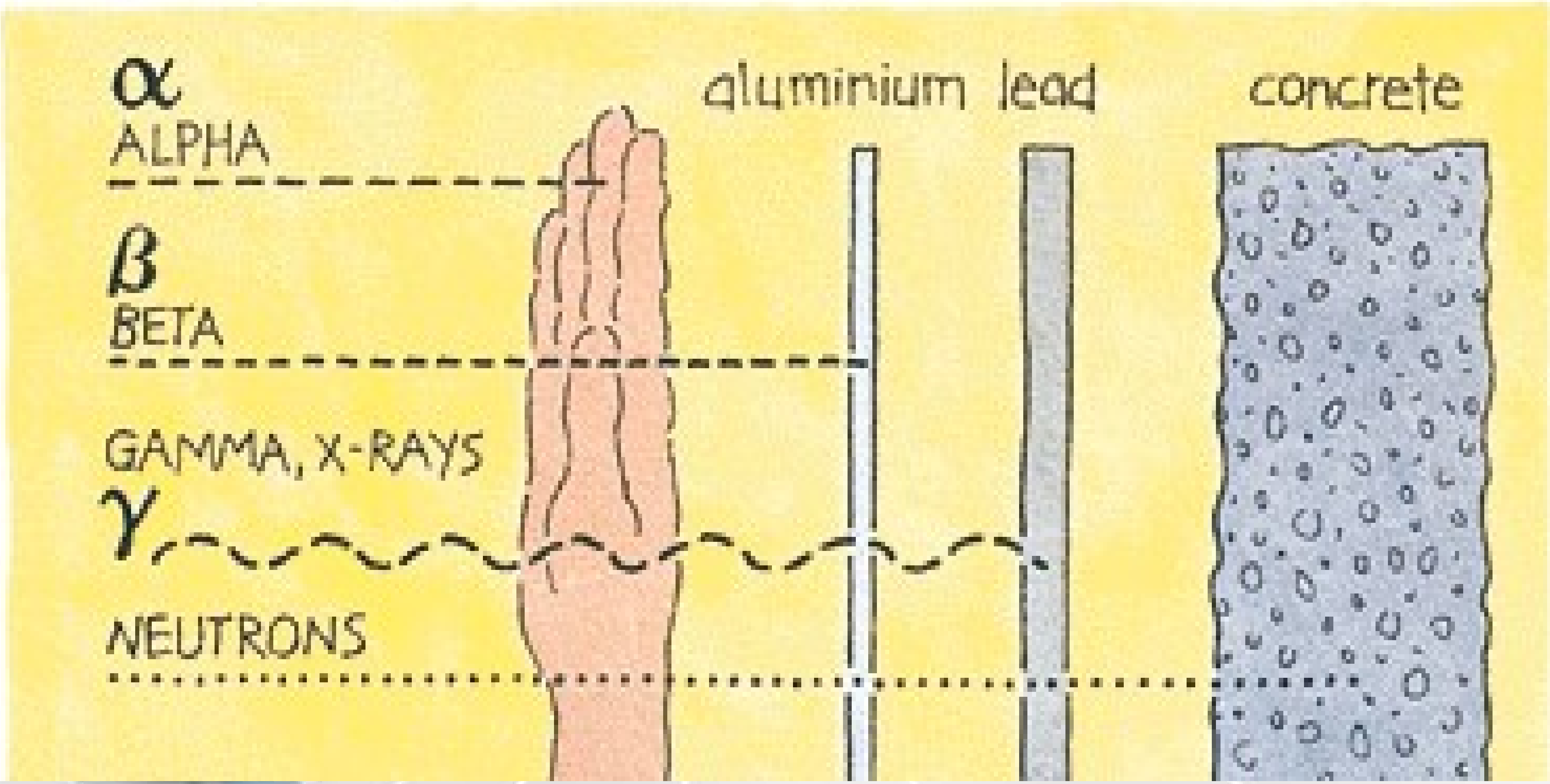
It is NOT visible by your naked eye because it is not in the visible part of the EM spectrum.

Gamma Rays can cause much more damage to living things Than alpha and beta particles.

4. Neutron Emission

- – The release of a neutron from a nucleus. There is no charge which allows them to travel much farther. (can travel through a 15 cm block of lead). The process occurs during nuclear fission.

Types of Radiation



Applications

- Medicine
  - Chemotherapy
  - Power pacemakers
  - Diagnostic tracers
- Agriculture
  - Irradiate food
  - Pesticide
- Energy
  - Fission
  - Fusion

Importance to Us: Half-Life

- Each radioactive isotope has a different decay rate. Measuring half-life can be useful when dating materials.

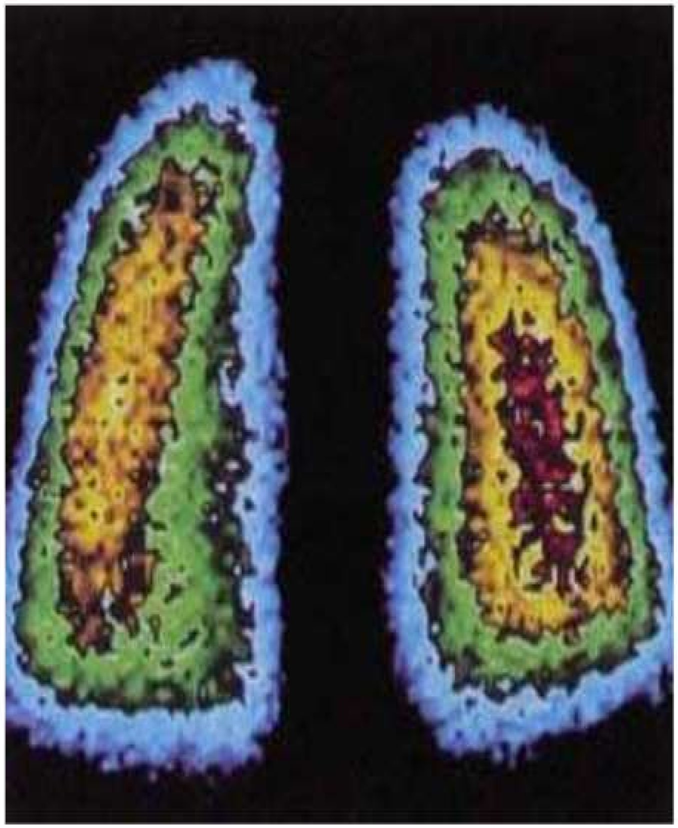
For example: Potassium-40 decays to Argon-40, so the ratio of Potassium-40 to argon-40 is smaller for older rocks than it is for younger rocks.

- Scientists use Carbon-14 to date more recent materials like remains of an animal or parts of ancient clothing.

(Half-Life. This term refers to the amount of time it takes for half of the radioactive substance to decay)

Importance to Us: Producing Energy

Fission and Fusion



Courtesy CNRI/Phototake

Images of human lungs obtained from a γ-ray scan.

Courtesy Kelley Culpepper/Transparencies, Inc.

A cancer patient receiving radiation therapy.

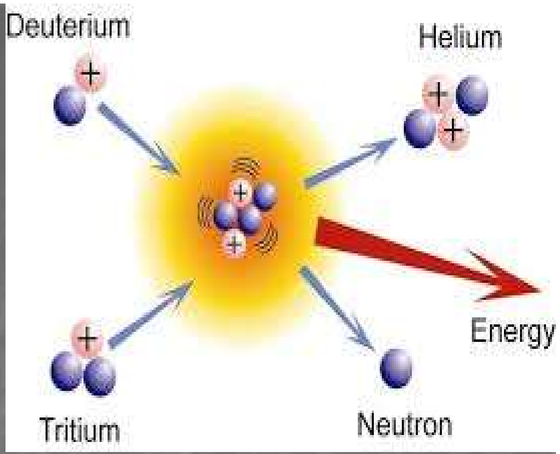
Chemistry In Action: Food Irradiation

Dosage	Effect
Up to 100 kilorad	Inhibits sprouting of potatoes, onions, garlics. Inactivates trichinae in pork. Kills or prevents insects from reproducing in grains, fruits, and vegetables.
100 – 1000 kilorads	Delays spoilage of meat poultry and fish. Reduces salmonella. Extends shelf life of some fruit.
1000 to 10,000 kilorads	Sterilizes meat, poultry and fish. Kills insects and microorganisms in spices and seasoning.

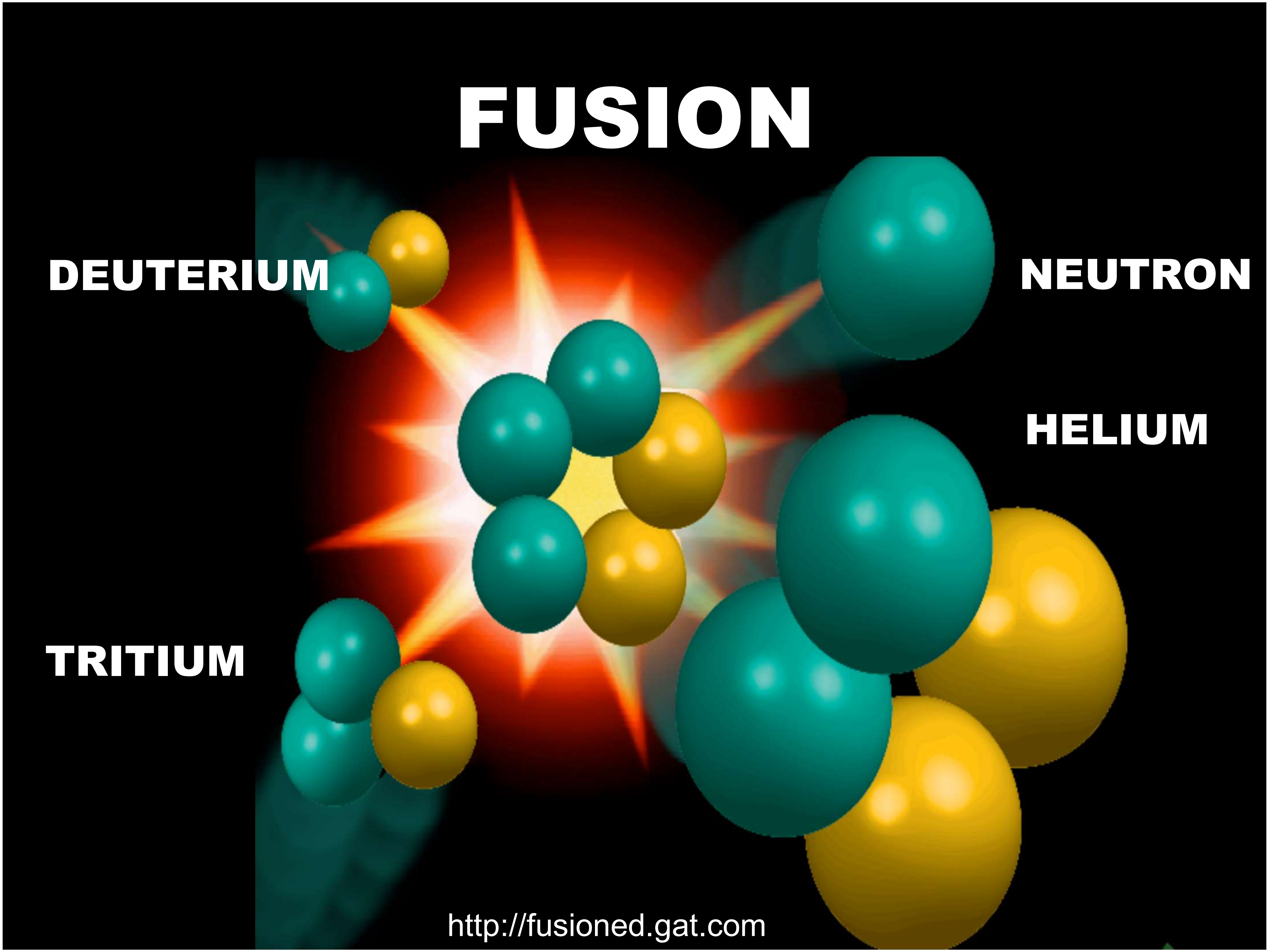
More facts

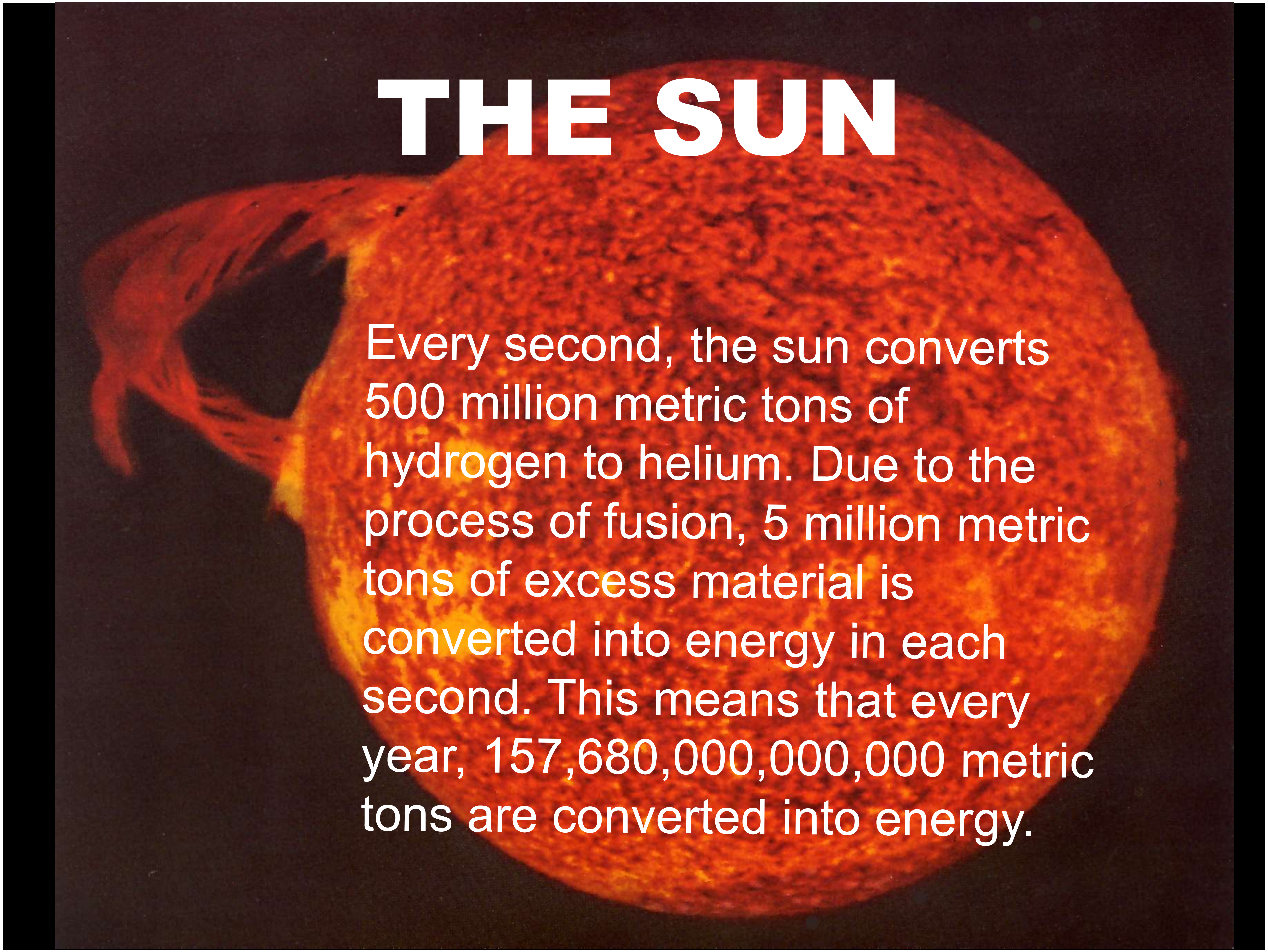
- 20 rem ⇒ decreased white blood cell count after instantaneous exposure
- 100-400 rem ⇒ vomiting, diarrhea, lesions, cancer-risk increase
- 500-1000 ⇒ death w/in 2 months
- 1000-2000 ⇒ death w/in 2 weeks
- Above 2000 ⇒ death w/in hours

Nuclear Fusion



- Nuclear fusion is the process by which multiple nuclei join together to form a heavier nucleus.
- It is accompanied by the release or absorption of energy depending on the masses of the nuclei involved..


FUSION
DEUTERIUM
NEUTRON
HELIUM
TRITIUM
http://fusioned.gat.com


THE SUN
Every second, the sun converts 500 million metric tons of hydrogen to helium. Due to the process of fusion, 5 million metric tons of excess material is converted into energy in each second. This means that every year, 157,680,000,000,000 metric tons are converted into energy.

Learning Check

What process creates energy in the Sun?

Fusion of hydrogen into helium in the Sun's core generates the Sun's energy.

How long ago did fusion generate the energy we now receive as sunlight?

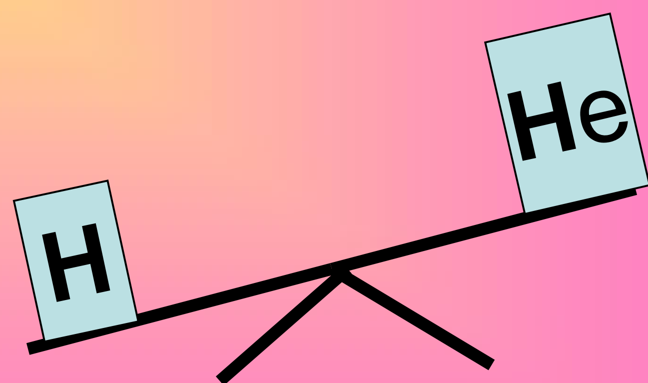
Fusion created the energy we receive today about a million years ago. This is the time it takes for photons and then convection to transport energy through the solar interior to the photosphere. Once sunlight emerges from the photosphere, it takes only about 8 minutes to reach Earth.

Nuclear Fusion

- Iron and nickel nuclei have the largest binding energies per nucleon of all nuclei and therefore are the most stable.
- The fusion of two nuclei lighter than iron or nickel generally releases energy.
- The fusion of nuclei heavier than them absorbs energy.

Fusion Changes Mass to Energy
$E=mc^2$

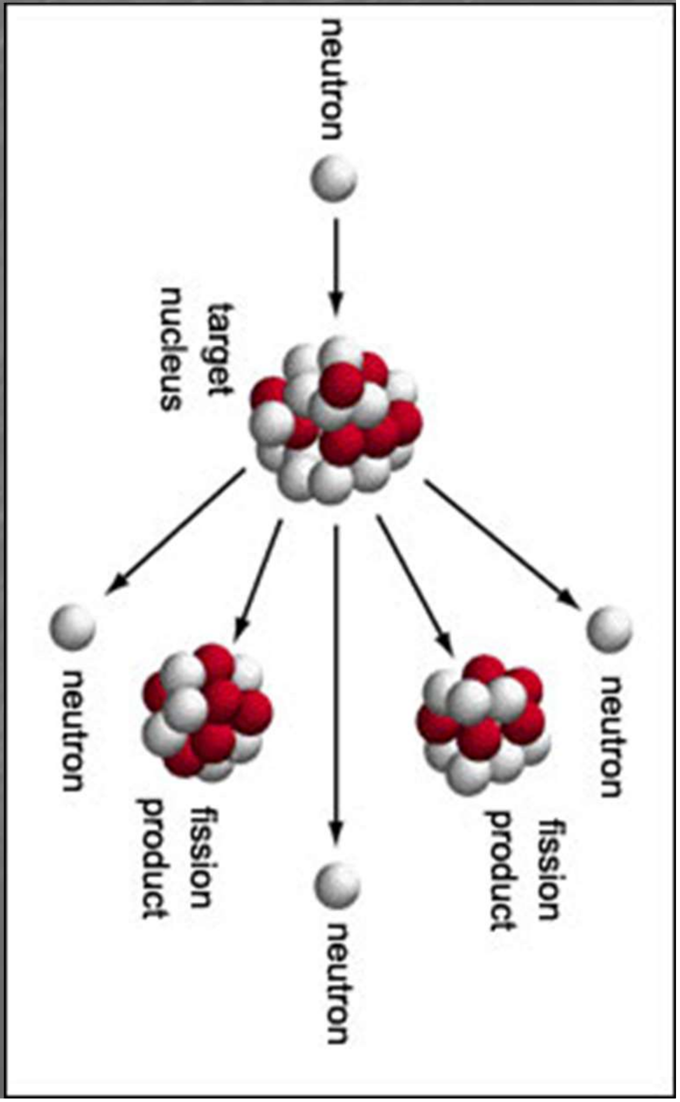
.993 kg Helium



1kg Hydrogen

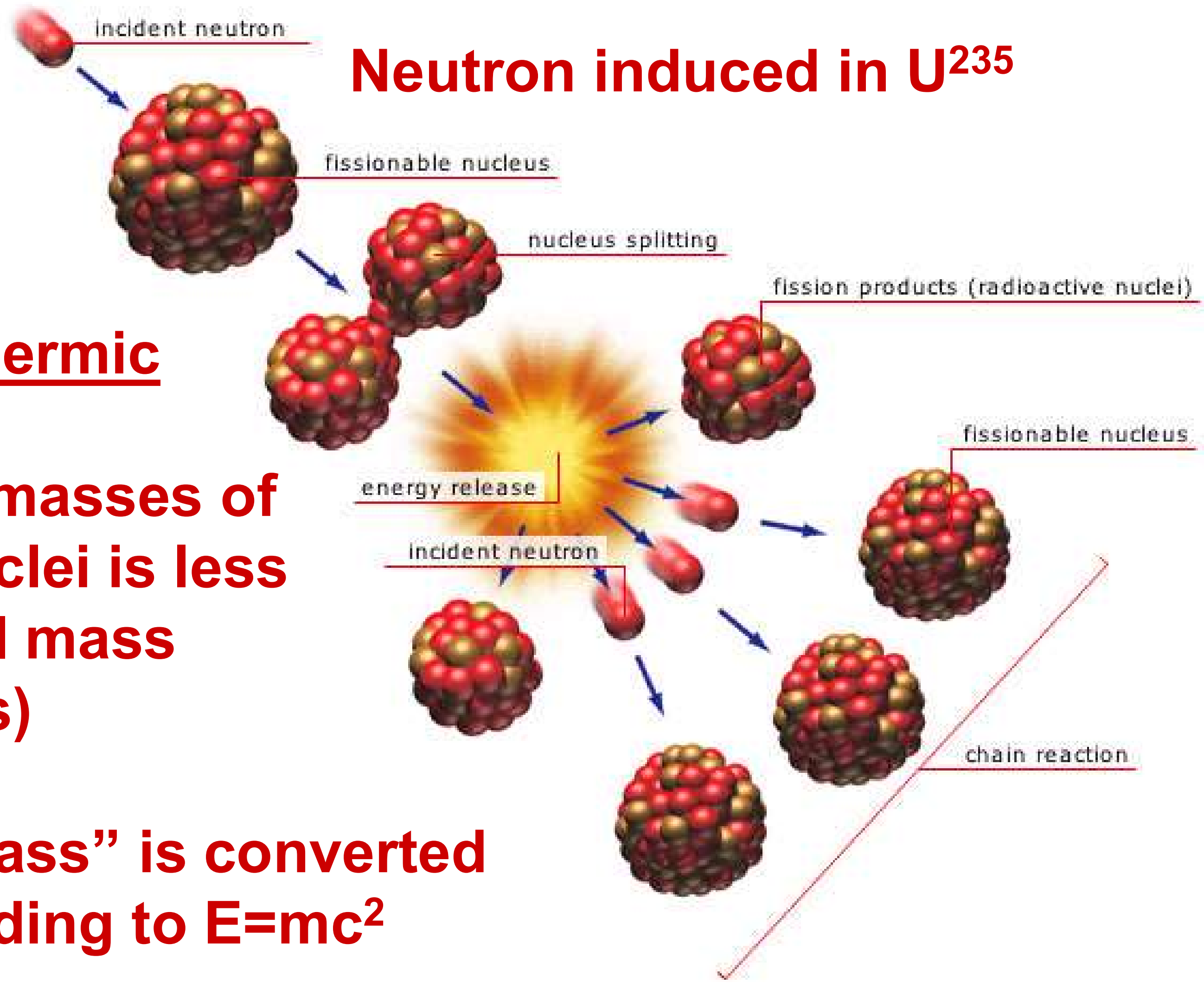
NUCLEAR FISSION

A reaction in which an atomic nucleus of a radioactive element splits by bombardment from an external source, with simultaneous release of large amounts of energy, used for electric power generation



Nuclear Fission

Neutron induced in U^{235}



<u>Fission is Exothermic</u>

The sum of the masses of the resulting nuclei is less than the original mass (about 0.1% less)

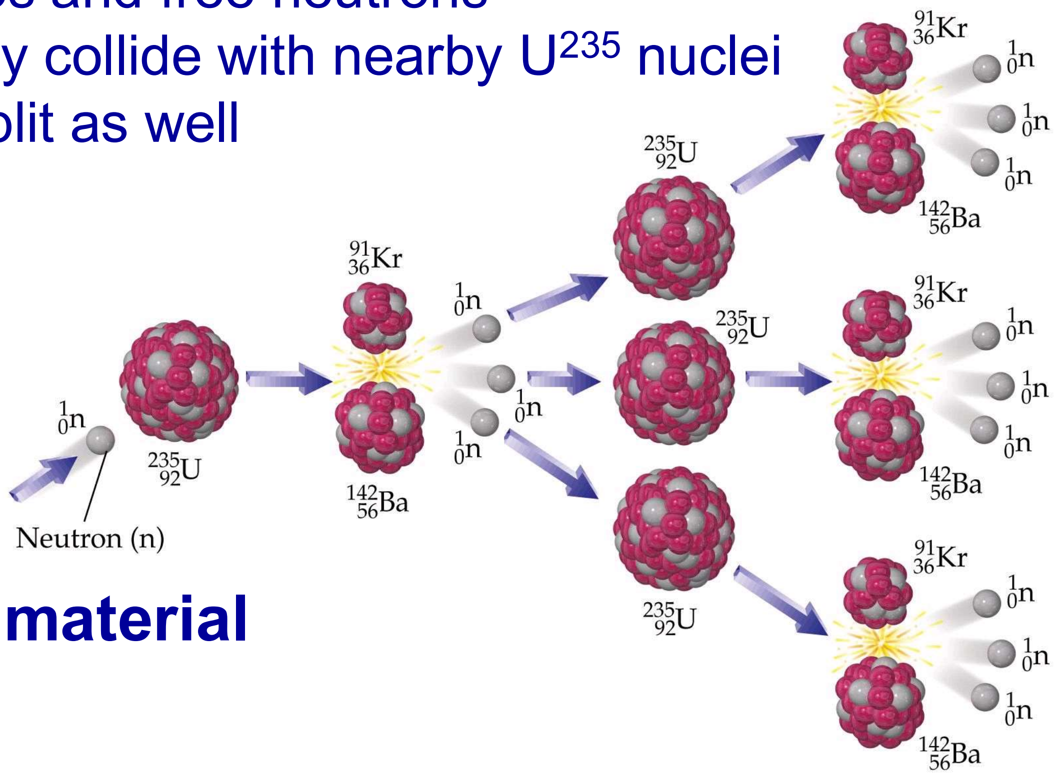
The "missing mass" is converted to energy according to $E=mc^2$

Neutrons may:

1 - Cause another fission by colliding with a U^{235} nucleus

- Creates two smaller nuclides and free neutrons
- The free neutrons potentially collide with nearby U^{235} nuclei
- May cause the nuclide to split as well

Each split (fission) is accompanied by a large quantity of **E-N-E-R-G-Y**

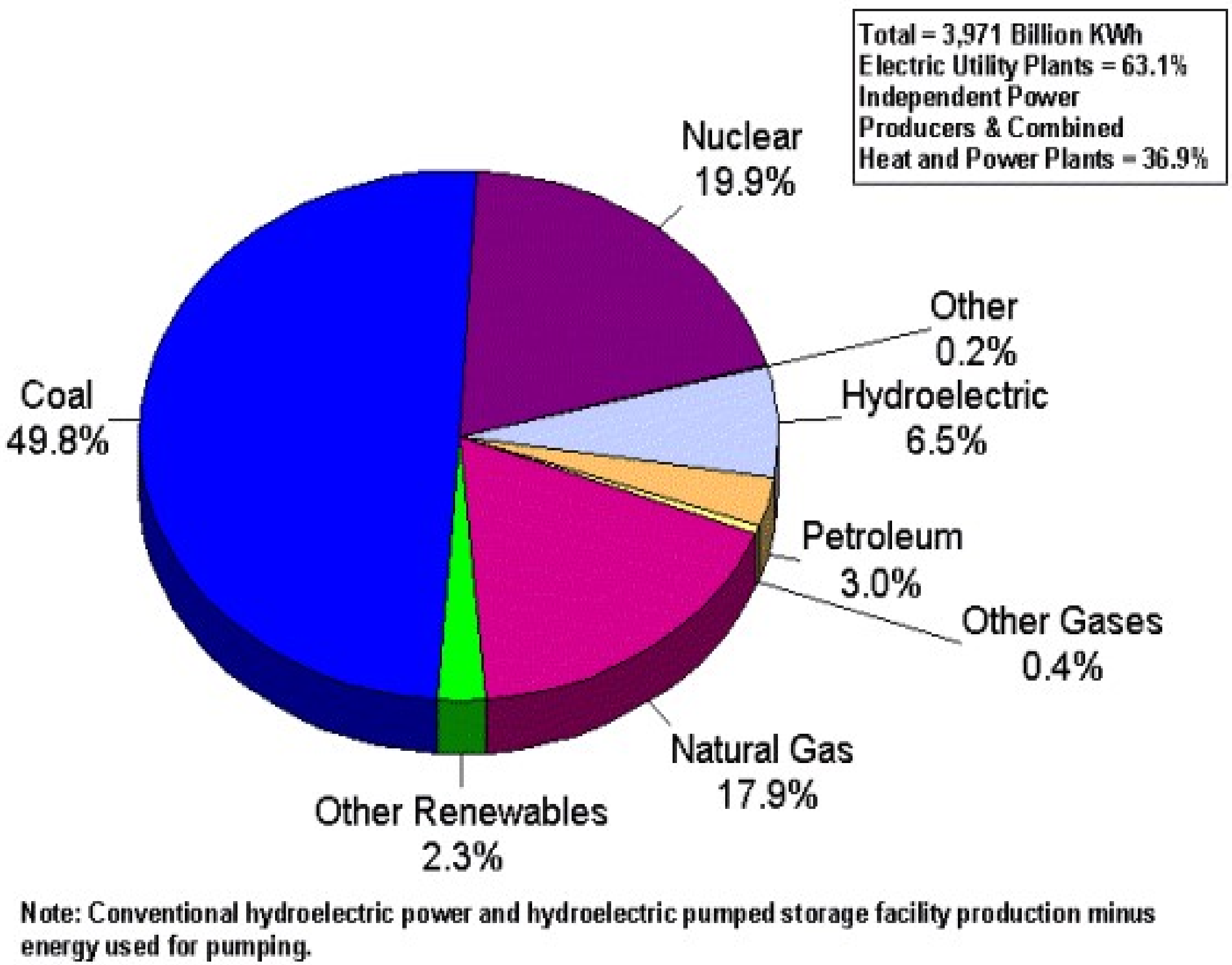


2 - Be absorbed in other material

3 - Lost in the system

If sufficient neutrons are present, we may achieve a **chain reaction**

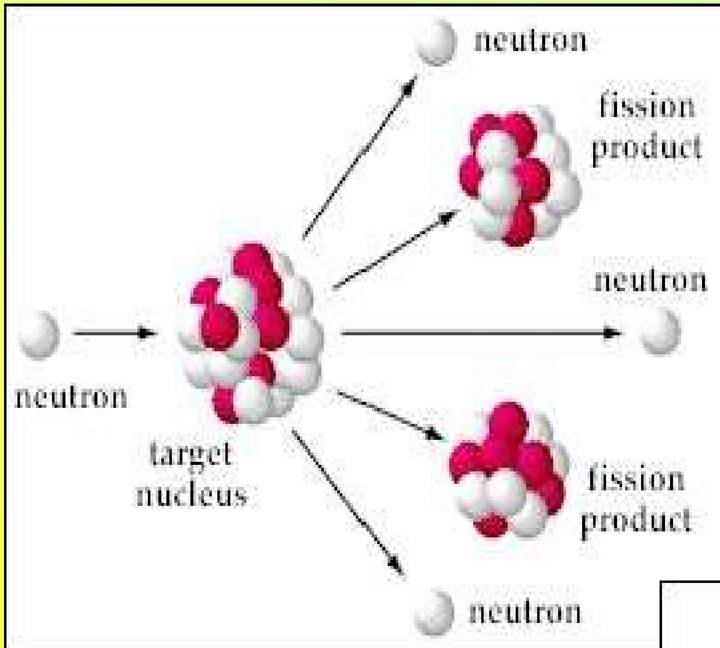
U.S. Electrical Power Production by Source



Source: EIA

(2004)

Review

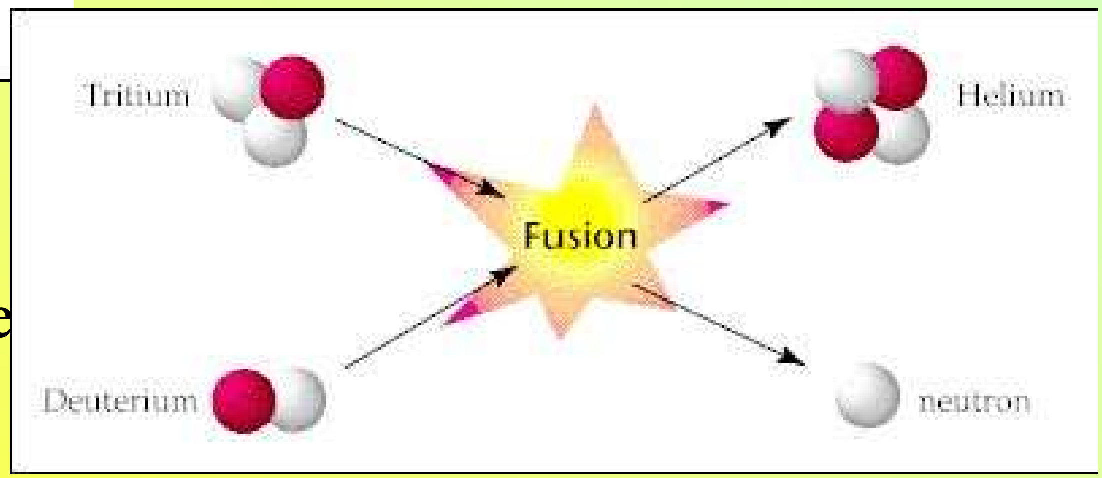


Nuclear fission:

A large nucleus splits into several small nuclei when impacted by a neutron, and energy is released in this process

Nuclear fusion:

Several small nuclei fuse together and release energy.



Nuclear Fission vs Nuclear Fusion

Nuclear Fission	Nuclear Fusion
A heavy nucleus breaks up to form two lighter nuclei.	Two nuclei combine to form a heavy nucleus.
It involves a chain reaction.	Chain reaction is not involved.
The heavy nucleus is bombarded with neutrons.	Light nuclei are heated to an extremely high temperature.
We have proper mechanisms to control fission reaction for generating electricity.	Proper mechanisms to control fusion reaction are yet to be developed.
Disposal of nuclear waste is a great environmental problem.	Disposal of nuclear waste is not involved.
Raw material is not easily available and is costly.	Raw material is comparatively cheap and easily available.