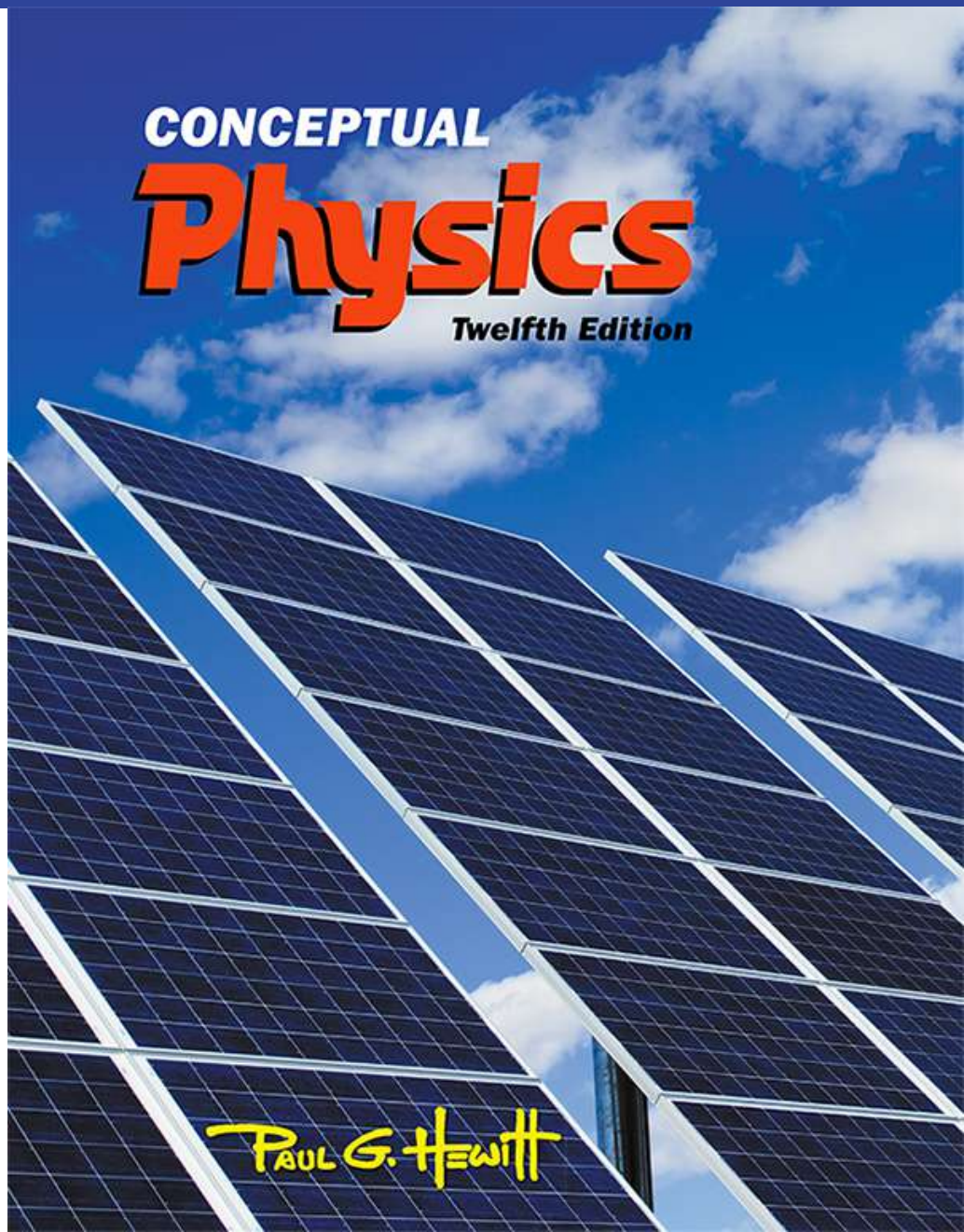
Lecture Outline

Chapter 33: The Atomic Nucleus and Radioactivity



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This lecture will help you understand:

- X-Rays and Radioactivity
- Alpha, Beta and Gamma Rays
- Environmental Radiation
- The Atomic Nucleus and the Strong Force
- Radioactive Half-Life
- Radiation Detectors
- Transmutation of Elements
- Radiometric Dating

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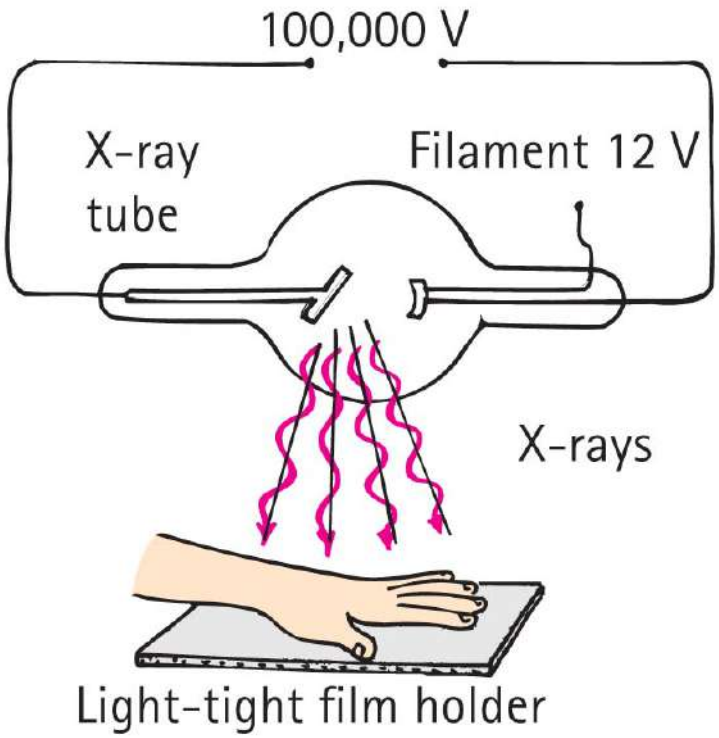
X-Rays and Radioactivity

- Roentgen discovered X-rays produced by a beam of electrons striking the glass surface of a gas-discharge tube.
- He found that X-rays could pass through solid materials, could ionize the air, showed no refraction in glass, and were undeflected by magnetic fields.



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X-Rays and Radioactivity, Continued

- X-rays are high-frequency electromagnetic waves, usually emitted by the de-excitation of the innermost orbital electrons of atoms.
- An energetic beam of electrons striking a solid surface excites the innermost electrons and produces higher-frequency photons of X-radiation.

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X-Rays and Radioactivity, Continued-1

- X-ray photons have high energy and can penetrate many layers of atoms before being absorbed or scattered.
- X-rays do this when they pass through your soft tissue to produce an image of the bones inside your body.

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X-Rays and Radioactivity, Continued-2

- Radioactivity
  - Radioactivity is the process of nuclear decay (radioactive decay).
  - Nothing new in the environment; it's been going on since time zero.
  - It warms Earth's interior, is in the air we breathe, and is present in all rocks (some in trace amounts).
  - It is natural.

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X-Rays and Radioactivity
CHECK YOUR NEIGHBOR

The radioactive decay of nature's elements occurs in the

A. soil we walk on.
B. air we breathe.
C. interior of Earth.
D. All of the above.

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X-Rays and Radioactivity
CHECK YOUR ANSWER

The radioactive decay of nature's elements occurs in the

D. All of the above.

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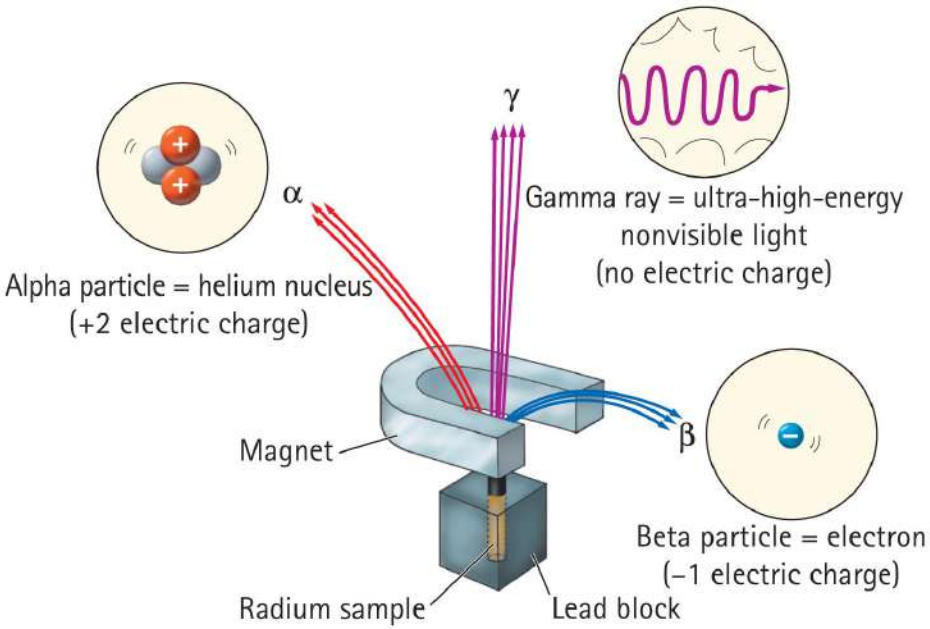
Alpha, Beta, and Gamma Rays

- Radioactive elements emit three distinct types of radiation:
  - α —alpha: positively charged (helium nuclei)
  - β —beta: negatively charged (electrons)
  - γ —gamma (electromagnetic radiation)



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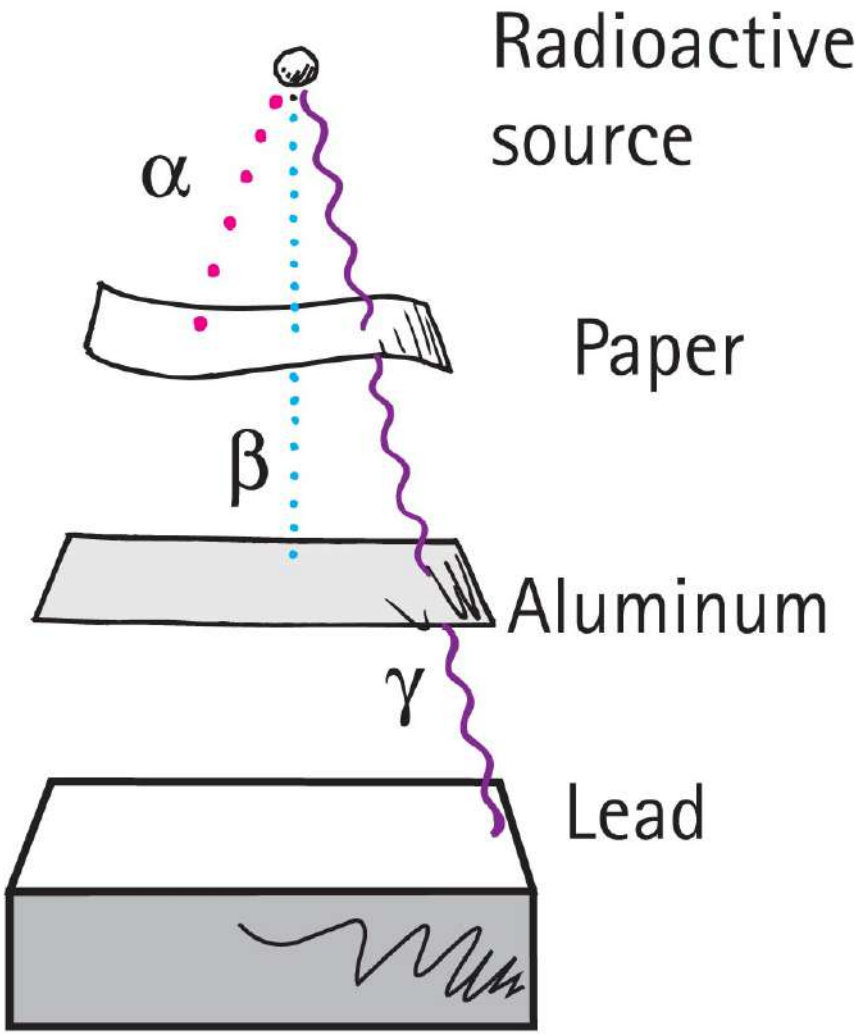
Alpha, Beta, and Gamma Rays, Continued

- Relative penetrations



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Alpha, Beta, and Gamma Rays
CHECK YOUR NEIGHBOR

The origins of radioactivity go back to

A. military activities in the mid-20th century.
B. the Industrial Revolution two centuries ago.
C. the beginning of human error.
D. before humans emerged on Earth.

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Alpha, Beta, and Gamma Rays
CHECK YOUR ANSWER

The origins of radioactivity go back to

D. before humans emerged on Earth.

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Alpha, Beta, and Gamma Rays
CHECK YOUR NEIGHBOR, Continued

Any atom that emits an alpha particle or beta particle

A. becomes an atom of a different element, always.
B. may become an atom of a different element.
C. becomes a different isotope of the same element.
D. increases its mass.

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Alpha, Beta, and Gamma Rays
CHECK YOUR ANSWER, Continued

Any atom that emits an alpha particle or beta particle

A. becomes an atom of a different element, always.

Explanation:

Contrary to the failures of alchemists of old to change elements from one to another, this was going on all around them—unnoticed.

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Alpha, Beta, and Gamma Rays, Continued-1

- Food irradiation kills microbes.
  - Doesn't make the food radioactive.
  - There is no diarrhea with astronauts in space (their food is first irradiated).

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Alpha, Beta, and Gamma Rays
CHECK YOUR NEIGHBOR, Continued-1

Which of these is the nucleus of the helium atom?

A. Alpha
B. Beta
C. Gamma
D. All are different forms of helium.

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Alpha, Beta, and Gamma Rays
CHECK YOUR ANSWER, Continued-1

Which of these is the nucleus of the helium atom?

A. Alpha

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Alpha, Beta, and Gamma Rays
CHECK YOUR NEIGHBOR, Continued-2

Which of these is actually a high-speed electron?

A. Alpha
B. Beta
C. Gamma
D. All are high speed.

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Alpha, Beta, and Gamma Rays
CHECK YOUR ANSWER, Continued-2

Which of these is actually a high-speed electron?

B. Beta

Explanation:

Choice D may be true, but doesn't directly answer the question.

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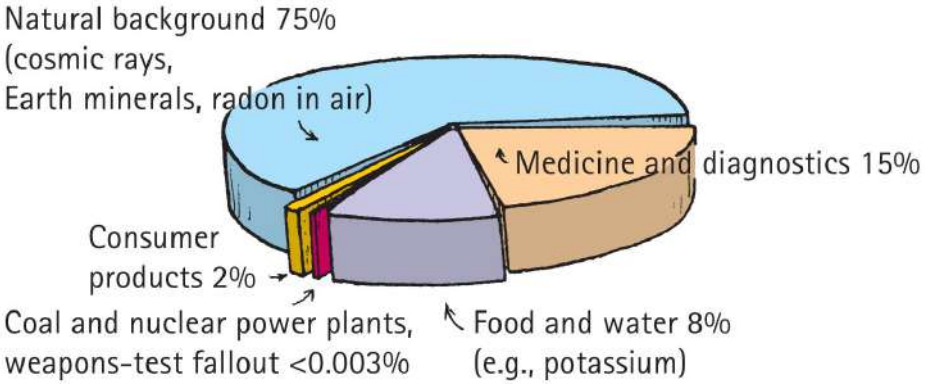
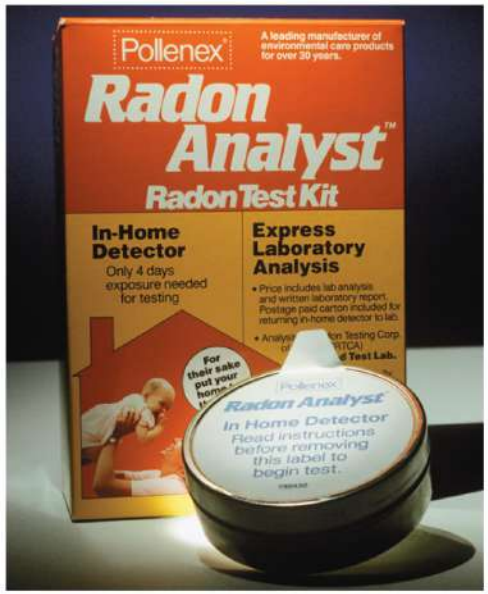
Environmental Radiation

- Radon, a common environmental hazard





  - Most radiation from natural background
  - About 1/5 from nonnatural sources

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Environmental Radiation, Continued

- Units of radiation

Particle	Radiation	Dosage	Factor		Health effect
alpha	1 rad	x	10	=	10 rems
beta	10 rad	x	1	=	10 rems

- Doses of radiation
  - Lethal doses of radiation begin at 500 rems.

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Environmental Radiation, Continued-1

Source received annually	Typical dose (mrem)
Natural origin	
Cosmic radiation	33
Ground	33
Air (Radon-222)	198
Human tissues (K-40; Ra-226)	35

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Environmental Radiation, Continued-2

Doses of radiation	Typical dose (mrem)
Human origin	
Medical procedures	
Diagnostic X-rays	40
Nuclear diagnostics	15
TV tubes, other consumer products	11
Weapons-test fallout	1
Commercial fossil-fuel power plants	<1
Commercial nuclear power plants	<<1

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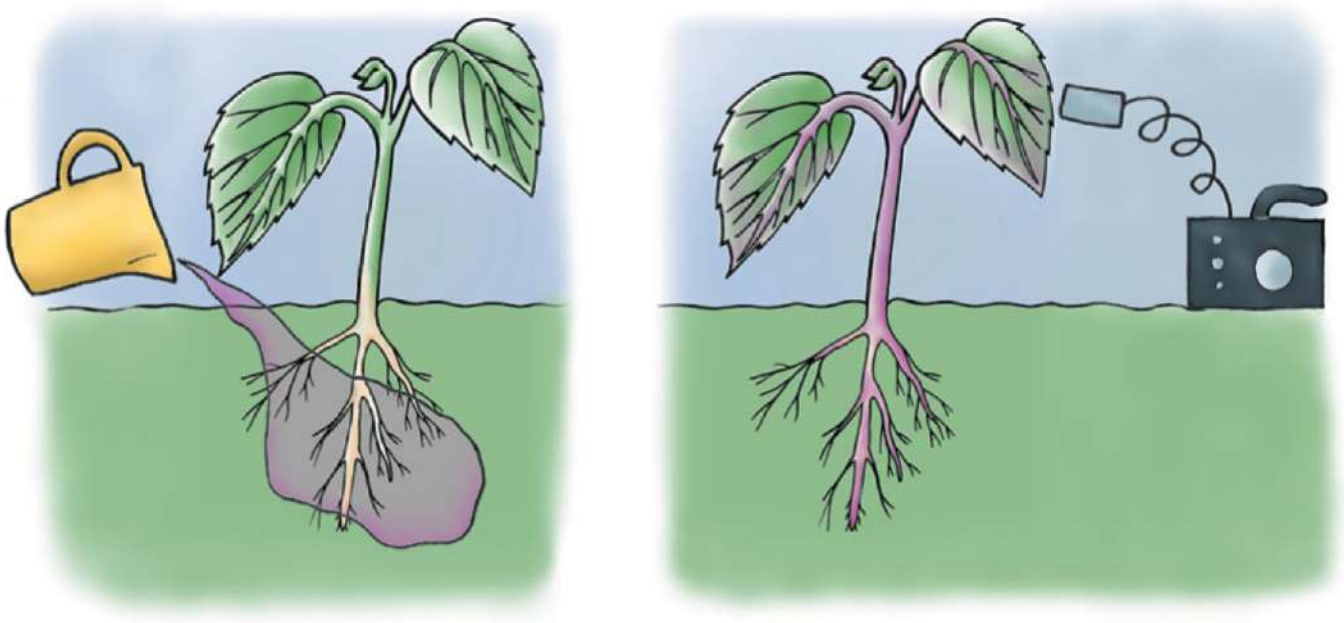
Environmental Radiation, Continued-3

- Radioactive tracers
  - Radioactive isotopes used to trace such pathways are called *tracers*.



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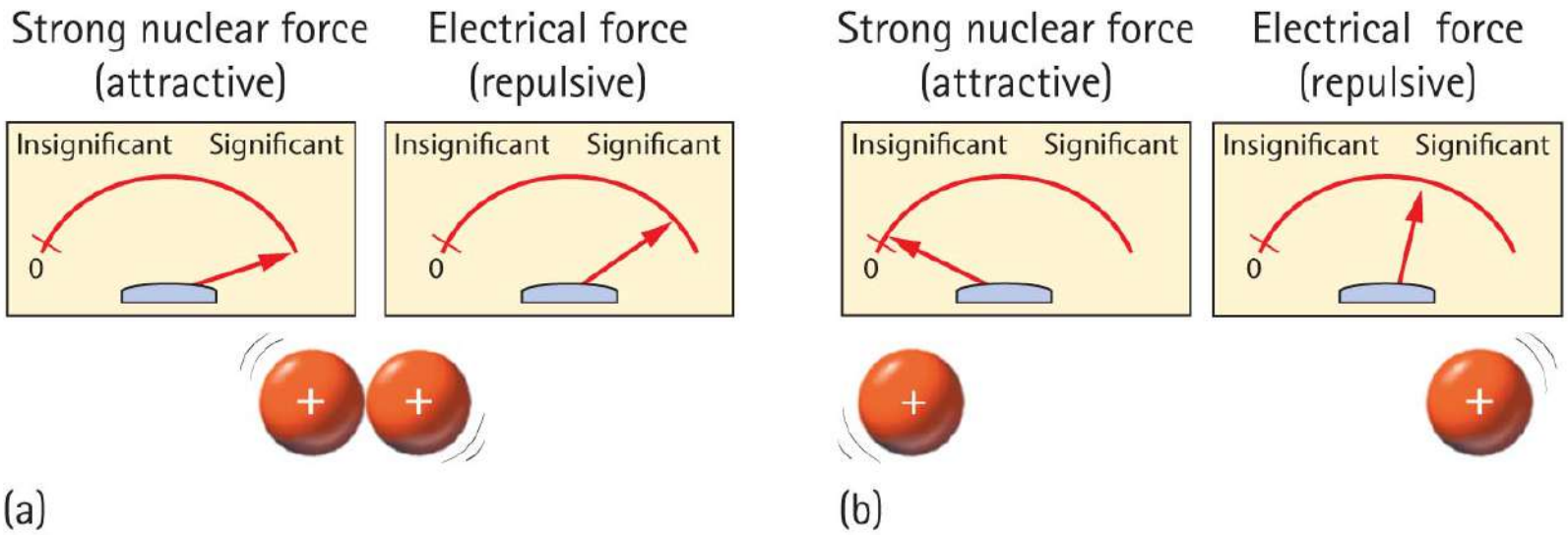
The Atomic Nucleus and the Strong Force

- The strong force holds nucleons together.



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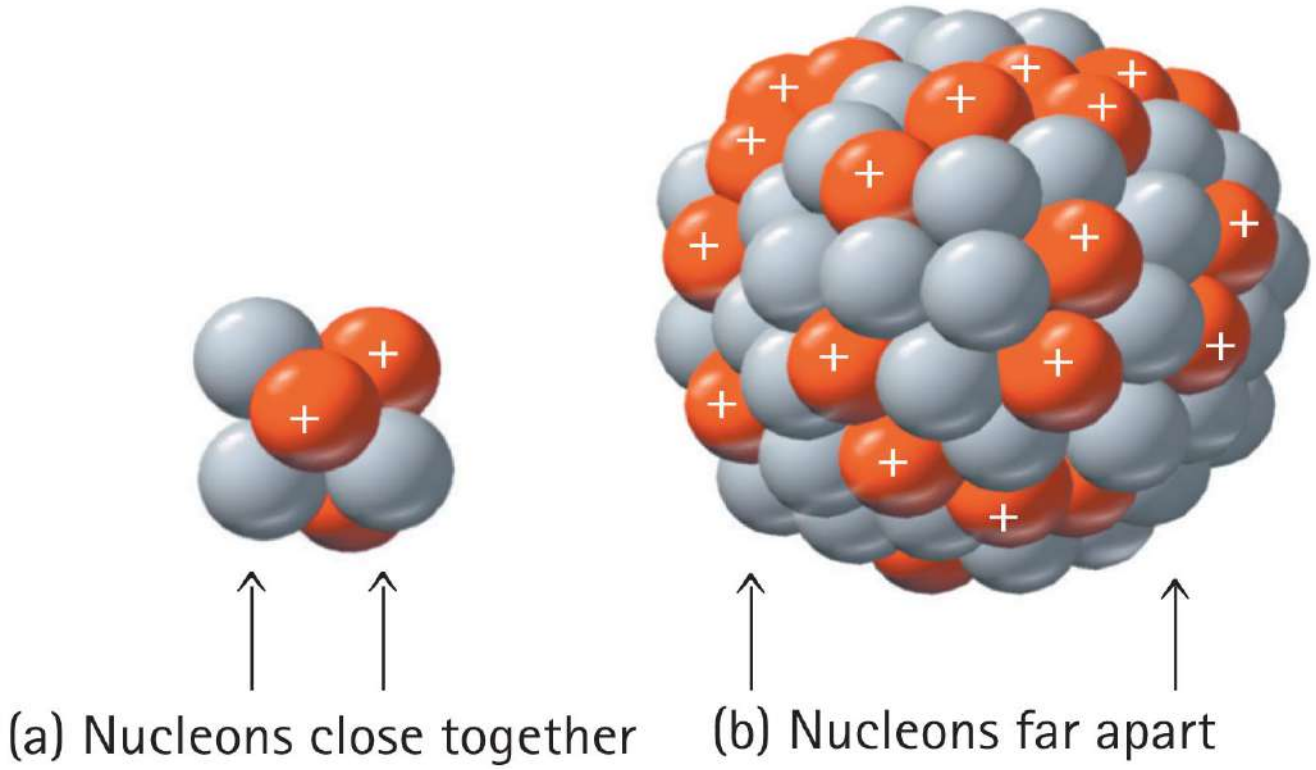
The Atomic Nucleus and the Strong Force, Continued

- The strong force is more effective with smaller nuclei.



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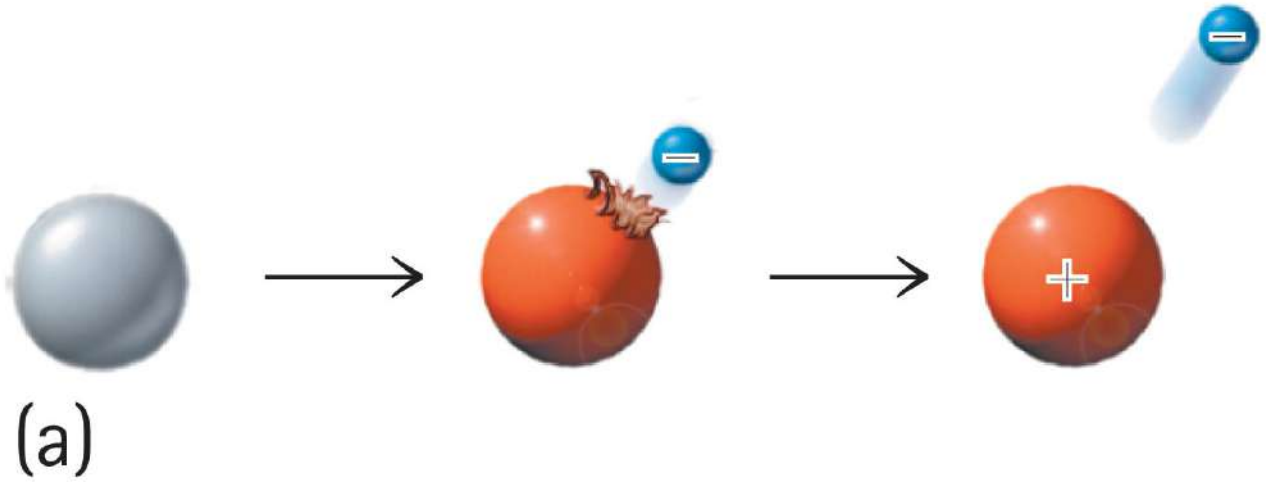
The Atomic Nucleus and the Strong Force, Continued-1

- A lone neutron is radioactive and spontaneously transforms to a proton and an electron.



(a)

  - A neutron needs protons around to keep this from happening.

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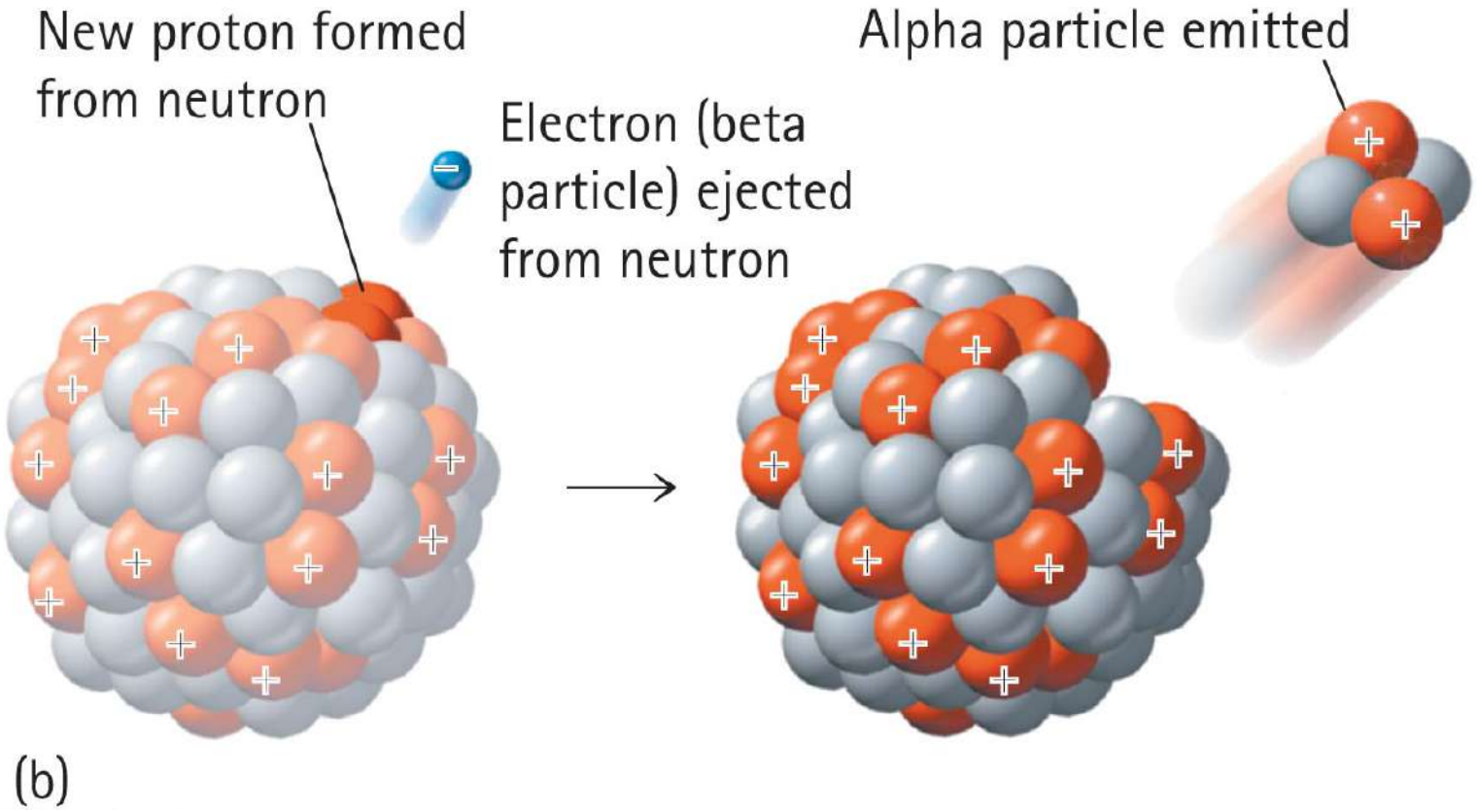
The Atomic Nucleus and the Strong Force, Continued-2

- Alpha emission



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The Atomic Nucleus and the Strong Force
CHECK YOUR NEIGHBOR

The strong force is a force in the

A. atom that holds electrons in orbit.
B. nucleus that holds nucleons together.
C. Both A and B.
D. Neither A nor B.

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The Atomic Nucleus and the Strong Force
CHECK YOUR ANSWER

The strong force is a force in the

B. nucleus that holds nucleons together.

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The Atomic Nucleus and the Strong Force CHECK YOUR NEIGHBOR, Continued

In the nucleus of an atom, the strong force is a relatively

A. short-range force.
B. long-range force.
C. unstable force.
D. neutralizing force.

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The Atomic Nucleus and the Strong Force CHECK YOUR ANSWER, Continued

In the nucleus of an atom, the strong force is a relatively

A. short-range force.

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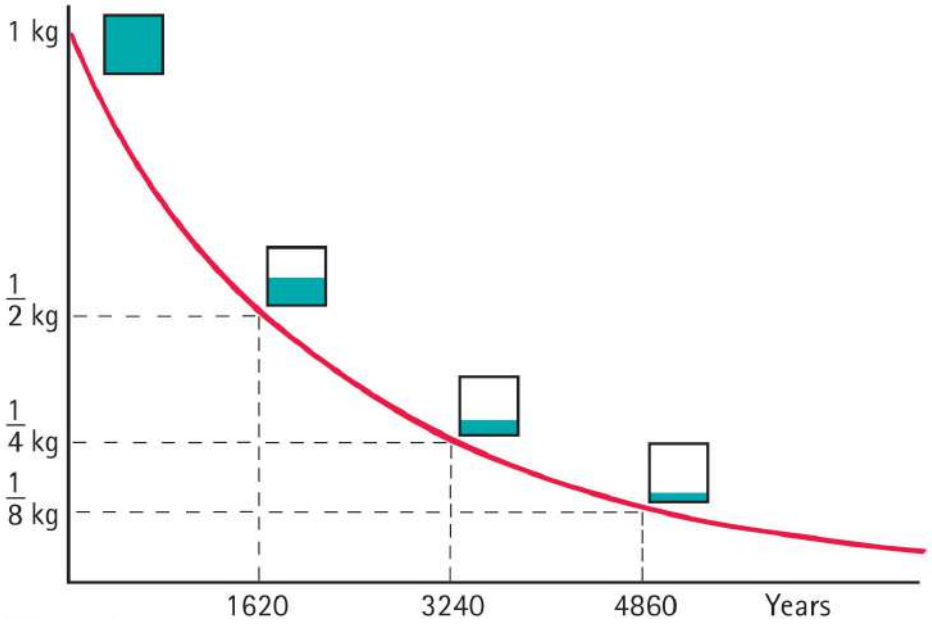
Radioactive Half-Life

- The rate of decay for a radioactive isotope is measured in terms of a characteristic time, the half-life, the time for half of an original quantity of an element to decay.



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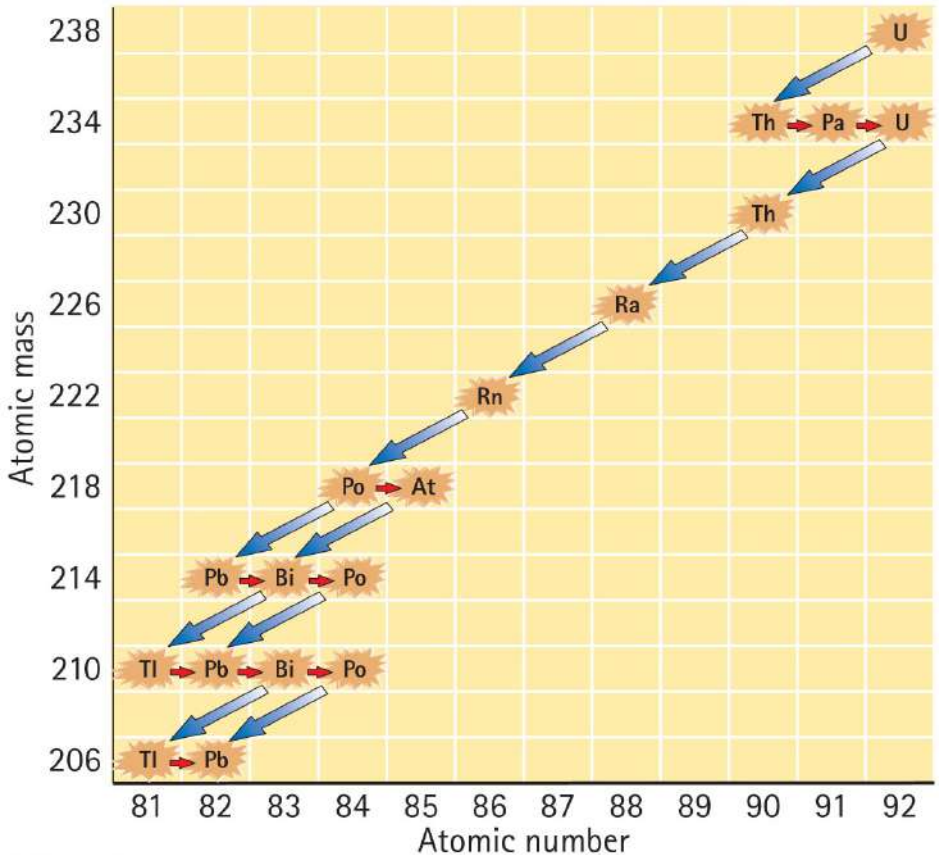
Radioactive Half-Life, Continued

- Uranium-238 to lead-206 through a series of alpha and beta decays. In 4.5 billion years, half the uranium presently in Earth will be lead.



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Radioactive Half-Life
CHECK YOUR NEIGHBOR

A certain isotope has a half-life of 10 years. This means the amount of that isotope remaining at the end of 10 years will be

A. zero.
B. one-quarter.
C. half.
D. the same.

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Radioactive Half-Life
CHECK YOUR ANSWER

A certain isotope has a half-life of 10 years. This means the amount of that isotope remaining at the end of 10 years will be

C. half.

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Radioactive Half-Life
A challenge…

Suppose the number of neutrons in a reactor that is starting up doubles each minute, reaching 1 billion neutrons in 10 minutes. When did the number of neutrons reach half a billion?

A. 1 minute
B. 2 minutes
C. 5 minutes
D. 9 minutes

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Radioactive Half-Life
CHECK YOUR ANSWER, Continued

Suppose the number of neutrons in a reactor that is starting up doubles each minute, reaching 1 billion neutrons in 10 minutes. When did the number of neutrons reach half a billion?

D. 9 minutes

Explanation:

This question would be appropriate with Appendix E, Exponential Growth and Doubling Time. Can you see that working backward, each minute has half the number of neutrons?

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Radiation Detectors

- Geiger counter detects incoming radiation by a short pulse of current triggered when radiation ionizes a gas in the tube.
- Scintillation counter indicates incoming radiation by flashes of light produced when charged particles or gamma rays pass through the counter.

(a)

(b)

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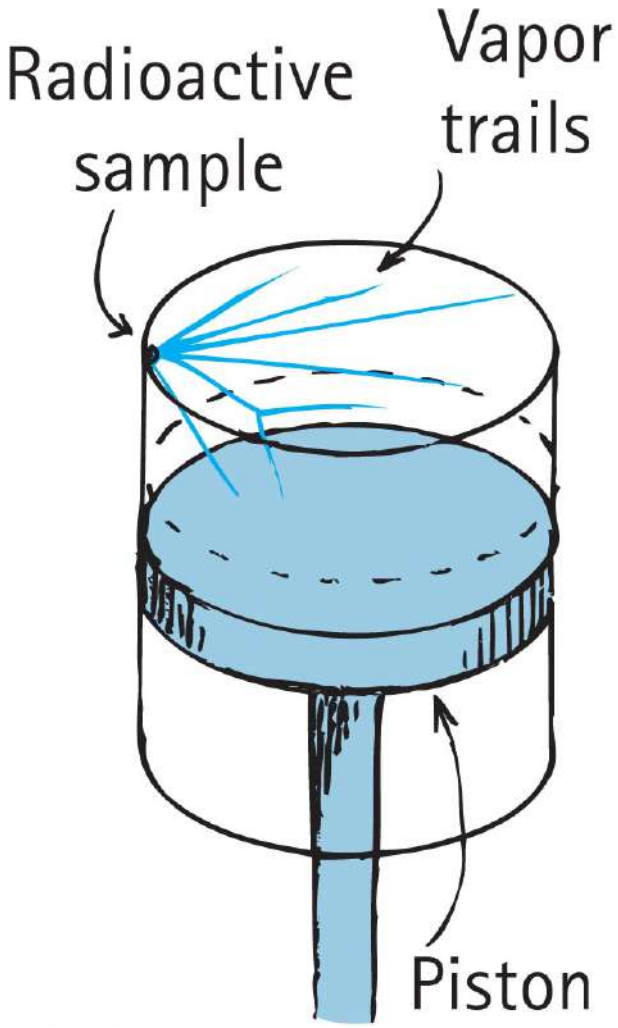
Radiation Detectors, Continued

- Cloud chamber:
  - Charged particles moving through supersaturated vapor leave trails.
  - When the chamber is in a strong electric or magnetic field, bending of the tracks provides information about the charge, mass, and momentum of the particles.



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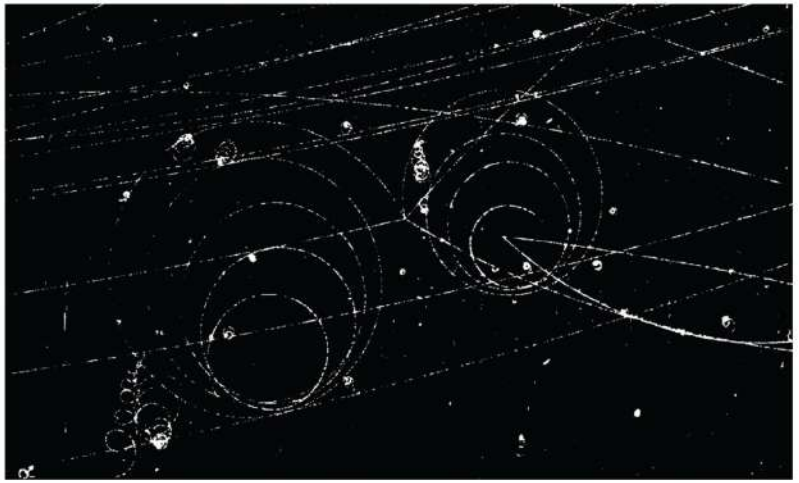
Radiation Detectors, Continued-1

- Bubble chamber:
  - Liquid hydrogen is heated under pressure in a glass and stainless steel chamber to a point just short of boiling.
  - If the pressure in the chamber is suddenly released at the moment an ion-producing particle enters, a thin trail of bubbles is left along the particle's path.



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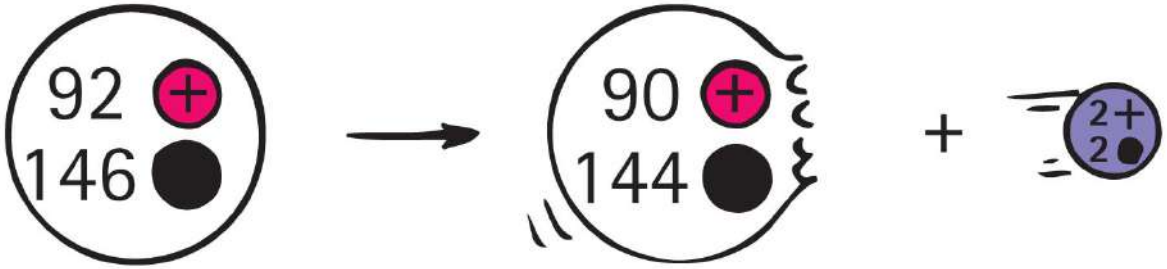
Transmutation of the Elements

- With alpha or beta particle, a different element is formed. This is transmutation, which occurs in natural events and is also initiated artificially in the laboratory.



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

- Uranium naturally transmutes to thorium when an alpha particle is emitted.

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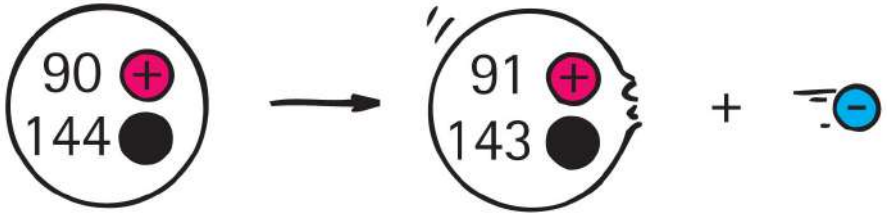
Transmutation of the Elements, Continued

- Natural transmutation



$$^{234}_{90}\mathrm{Th} \rightarrow {}^{234}_{91}\mathrm{Pa} + {}^{0}_{-1}e$$

  - Thorium naturally transmutes to protactinium when a beta particle is emitted.
  - An electron is $^{0}_{-1}e$.
    - Superscript 0 indicates electron's mass is insignificant compared with nucleons.
    - Subscript -1 is the electric charge of the electron.

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Transmutation of the Elements
CHECK YOUR NEIGHBOR

When an element ejects an alpha particle and a beta particle, the atomic number of the resulting element

A. reduces by 2.
B. reduces by 4.
C. increases by 2.
D. increases by 4.

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Transmutation of the Elements
CHECK YOUR ANSWER

When an element ejects an alpha particle and a beta particle, the atomic number of the resulting element

A. reduces by 2.

Explanation:

An alpha particle (a helium nucleus) has atomic number 2. Ejection of an alpha particle means a loss of 2 protons, so the atomic number of the element is lowered by 2.

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Transmutation of the Elements
CHECK YOUR NEIGHBOR, Continued

When an element ejects an alpha particle and a beta particle, the atomic number of that element

A. reduces by 1.
B. increases by 1.
C. reduces by 2.
D. increases by 2.

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Transmutation of the Elements
CHECK YOUR ANSWER, Continued

When an element ejects an alpha particle and a beta particle, the atomic number of that element

A. reduces by 1.

Explanation:

Alpha emission reduces atomic number by 2, and beta emission increases atomic number by 1, so net result is -1.

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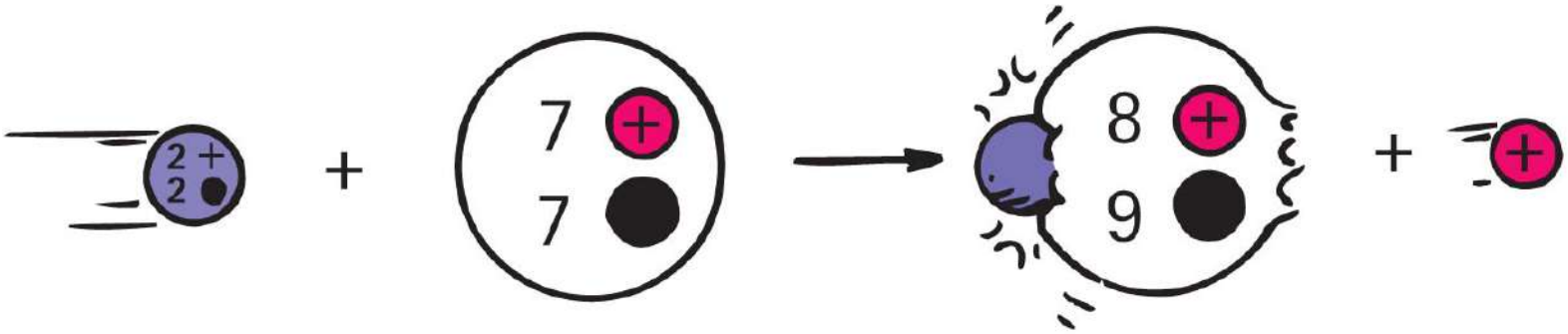
Transmutation of the Element

- Artificial transmutation



$$^{4}_{2}\mathrm{He} + {}^{14}_{7}\mathrm{N} \rightarrow {}^{17}_{8}\mathrm{O} + {}^{1}_{1}\mathrm{H}$$

  - An alpha particle fired at and impacting on a nitrogen atom, which transmutes to oxygen and hydrogen

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Transmutation of the Elements
CHECK YOUR NEIGHBOR, Continued-1

Atoms can transmute into completely different atoms in

A. nature.
B. laboratories.
C. Both A and B.
D. Neither A nor B.

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Transmutation of the Elements
CHECK YOUR ANSWER, Continued-1

Atoms can transmute into completely different atoms in

C. Both A and B.

Explanation:

Atomic transmutation occurs in nature, in laboratories, and as far as we know, throughout the cosmos.

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Transmutation of the Elements
CHECK YOUR NEIGHBOR, Continued-2

An element emits 1 beta particle, and its product then emits 1 alpha particle. The atomic number of the resulting element is changed by

A. 0.
B. -1.
C. -2.
D. None of the above.

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Transmutation of the Elements
CHECK YOUR ANSWER, Continued-2

An element emits 1 beta particle, and its product then emits 1 alpha particle. The atomic number of the resulting element is changed by

B. –1.

Explanation:

Beta emission increases atomic number by 1, then alpha emission decreases atomic number by 2, so the net change is –1.

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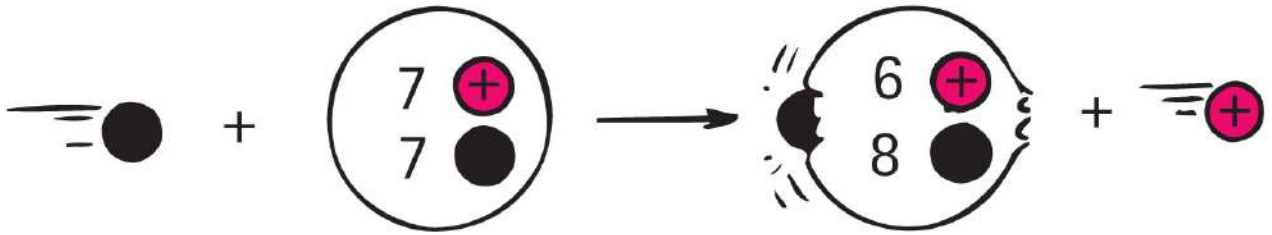
Radiometric Dating

- Earth's atmosphere is continuously bombarded by cosmic rays, which causes many atoms in the upper atmosphere to transmute. These transmutations result in many protons.
- A nitrogen that captures a neutron and becomes an isotope of carbon by emitting a proton:



$$^{1}_{0}n + {}^{14}_{7}\mathrm{N} \rightarrow {}^{14}_{6}\mathrm{C} + {}^{1}_{1}\mathrm{H}$$

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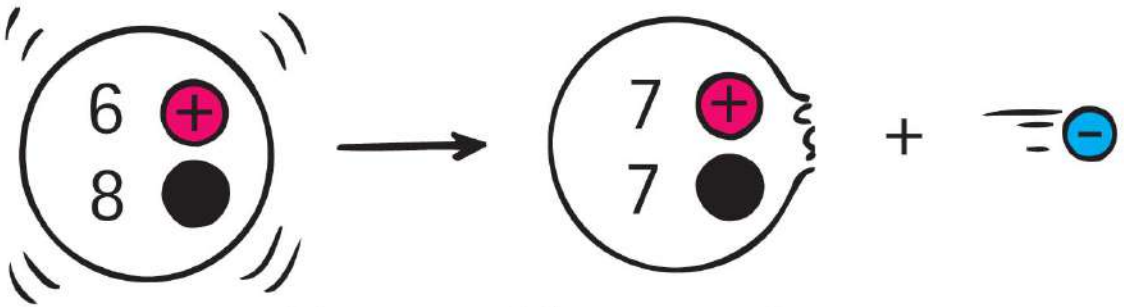
Radiometric Dating, Continued

- Carbon-14 is a beta emitter and decays back to nitrogen.



- Because living plants take in carbon dioxide, any C-14 lost by decay is immediately replenished with fresh C-14 from the atmosphere.
- Dead plants continue emitting C-14 without replenishment.

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Radiometric Dating, Continued-1

- Relative amounts of C-12 to C-14 enable dating of organic materials.

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Radiometric Dating
CHECK YOUR NEIGHBOR

The half-life of carbon-14 is about 5730 years, which means that the present amount in your bones will reduce to zero

A. when you die.
B. in about 5730 years.
C. in about twice 5730 years.
D. None of the above.

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Radiometric Dating
CHECK YOUR ANSWER

The half-life of carbon-14 is about 5730 years, which means that the present amount in your bones will reduce to zero

D. None of the above.

Explanation:

In theory, the amount never reaches zero. In eons to come, trace amounts of the carbon-14 in your bones, even if completely dissolved, will still exist.

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