Preview

- Lesson Starter
- Objectives
- Mass Defect and Nuclear Stability
- Nucleons and Nuclear Stability
- Nuclear Reactions

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Lesson Starter

- Nuclear reactions result in much larger energy changes than chemical reactions do.
- There is approximately 1 g of deuterium in 30 L of sea water.
- The fusion of the deuterium contained in 30 L of sea water would produce as much energy as the combustion of about 9 000 L of gasoline would.

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Objectives

- **Explain** what a nuclide is, and describe the different ways nuclides can be represented.
- **Define** and relate the terms mass defect and nuclear binding energy.
- **Explain** the relationship between number of nucleons and stability of nuclei.
- **Explain** why nuclear reactions occur, and know how to balance a nuclear equation.

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- Protons and neutrons are called **nucleons.**
- An atom is referred to as a **nuclide.**
- An atom is identified by the number of protons and neutrons in its nucleus.
  - example: radium-228

$$\begin{array}{ll} \textit{atomic number} \longrightarrow & 228 \\ \textit{mass number} \longrightarrow & 88 \end{array}\ \text{Ra}$$

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Mass Defect and Nuclear Stability

- The difference between the mass of an atom and the sum of the masses of its protons, neutrons, and electrons is called the **mass defect.**

- The measured mass of $^{4}_{2}\text{He}$, 4.002 602 amu, is 0.030 377 amu *less* than the combined mass, 4.032 979 amu.

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Mass Defect and Nuclear Stability, *continued*

Nuclear Binding Energy

- According to Albert Einstein's equation $E = mc^2$, mass can be converted to energy, and energy to mass.

- The is the **nuclear binding energy,** the energy released when a nucleus is formed from nucleons.

- The nuclear binding energy is a measure of the stability of a nucleus.

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Nuclear Binding Energy

Click below to watch the Visual Concept.

Visual Concept

Mass Defect and Nuclear Stability, *continued*

Nuclear Binding Energy, *continued*

- The mass units of the mass defect can be converted to energy units by using Einstein’s equation.

1. Convert 0.030 377 amu to kilograms

$$0.030\ 377\ \text{amu} \times \frac{1.6605 \times 10^{-27}\ \text{kg}}{1\ \text{amu}} = 5.0441 \times 10^{-29}\ \text{kg}$$

2. Calculate the energy equivalent.

$$E=mc^2$$

$$E = (5.0441 \times 10^{-29}\ \text{kg})(3.00 \times 10^{8}\ \text{m/s})^2$$

$$= 4.54 \times 10^{-12}\ \text{kg} \bullet \text{m}^2/\text{s}^2 = 4.54 \times 10^{-12}\ \text{J}$$

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Mass Defect and Nuclear Stability, *continued*

Binding Energy per Nucleon

- The *binding energy per nucleon* is the binding energy of the nucleus divided by the number of nucleons it contains

- Elements with intermediate atomic masses have the greatest binding energies per nucleon and are therefore the most stable.

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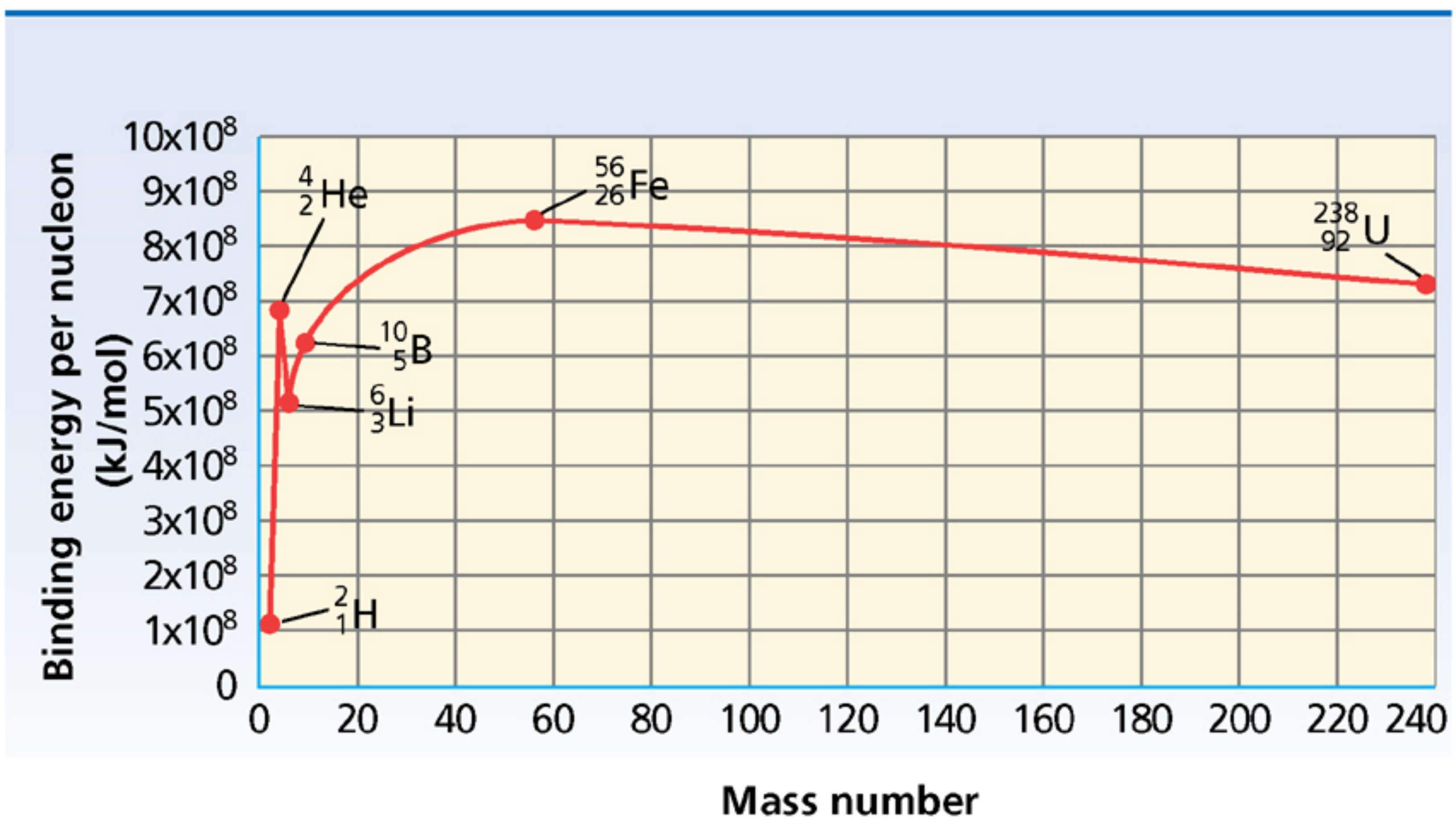
Binding Energy Per Nucleon



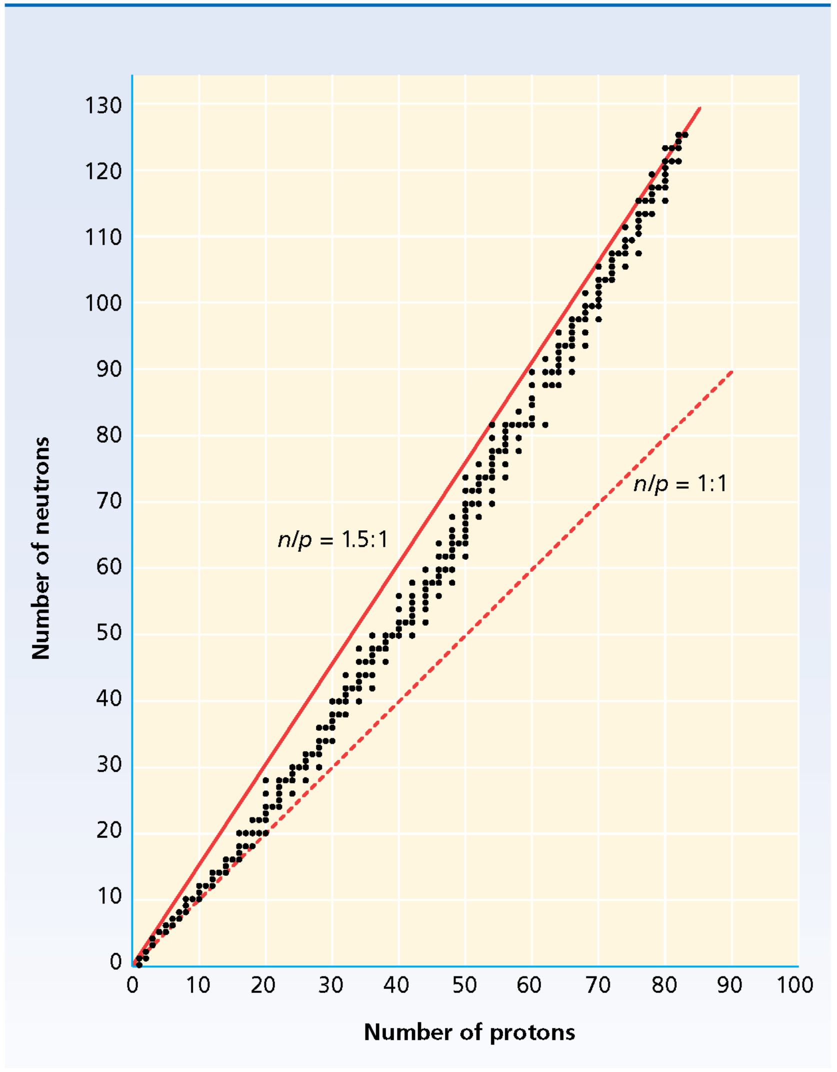
Nucleons and Nuclear Stability

- The stable nuclei cluster over a range of neutron-proton ratios is referred to as the *band of stability.*

- Among atoms having low atomic numbers, the most stable nuclei are those with a neutron-proton ratio of approximately 1:1.
  - example: ${}^{4}_{2}\mathrm{He}$

- As the atomic number increases, the stable neutron-proton ratio increases to about 1.5:1.
  - example: ${}^{206}_{82}\mathrm{Pb}$

Band of Stability



Nucleons and Nuclear Stability, *continued*

- The band of stability can be explained by the relationship between the nuclear force and the electrostatic forces between protons.
- Stable nuclei tend to have even numbers of nucleons.
- According to the **nuclear shell model,** nucleons exist in different energy levels, or shells, in the nucleus.
- The numbers of nucleons that represent completed nuclear energy levels—2, 8, 20, 28, 50, 82, and 126—are called **magic numbers.**

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Nuclear Reactions

- Unstable nuclei undergo spontaneous changes that change their number of protons and neutrons.

- A **nuclear reaction** is a reaction that affects the nucleus of an atom.

$$ {}^{9}_{4}\text{Be} + {}^{4}_{2}\text{He} \rightarrow {}^{12}_{6}\text{C} + {}^{1}_{0}n $$

- A **transmutation** is a change in the identity of a nucleus as a result of a change in the number of its protons.

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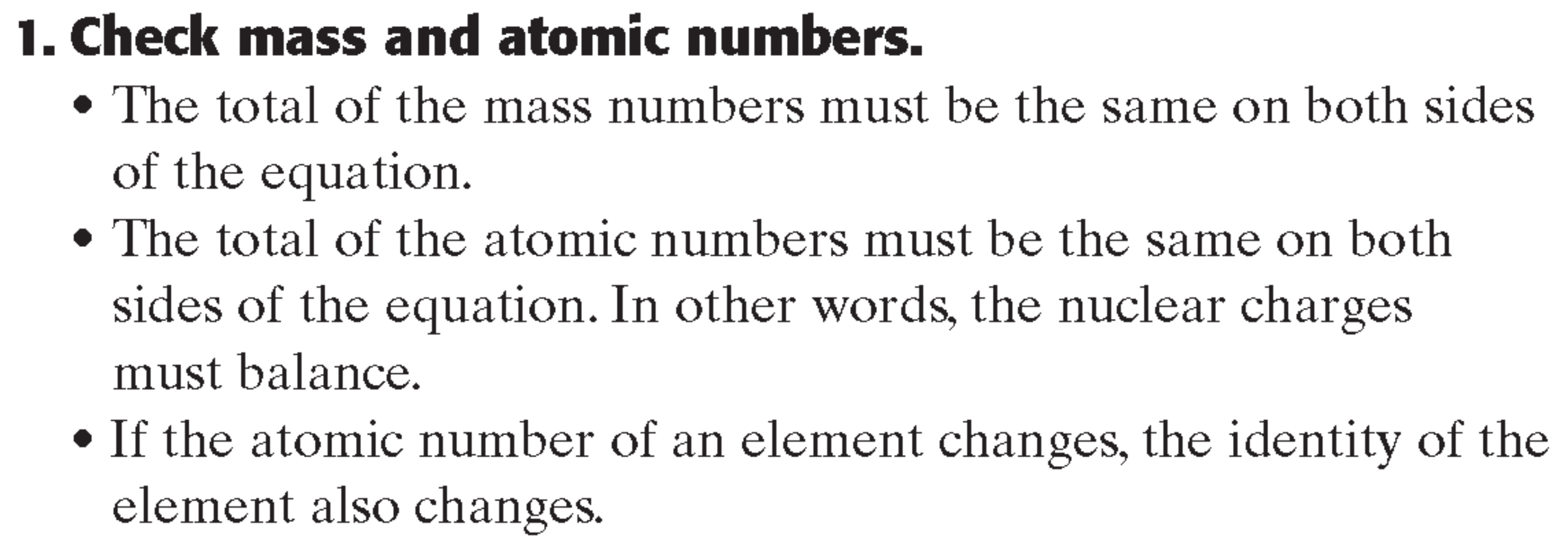
Nuclear Reaction

Click below to watch the Visual Concept.

Visual Concept

Balancing Nuclear Equations



1. Check mass and atomic numbers.

- The total of the mass numbers must be the same on both sides of the equation.
- The total of the atomic numbers must be the same on both sides of the equation. In other words, the nuclear charges must balance.
- If the atomic number of an element changes, the identity of the element also changes.

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Balancing Nuclear Equations

2. Determine how nuclear reactions change mass and atomic numbers.

- If a beta particle, ${}^{0}_{-1}e$, is released, the mass number does not change but the atomic number increases by one.
- If a positron, ${}^{0}_{+1}e$ is released, the mass number does not change but the atomic number decreases by one.
- If a neutron, ${}^{1}_{0}n$, is released, the mass number decreases by one and the atomic number does not change.
- Electron capture does not change the mass number but decreases the atomic number by one.
- Emission of an alpha particle, ${}^{4}_{2}\mathrm{He}$, decreases the mass number by four and decreases the atomic number by two.
- When a positron and an electron collide, energy in the form of gamma rays is generated.

Nuclear Reactions, *continued*

Sample Problem A

Identify the product that balances the following nuclear reaction: $^{212}_{84}\text{Po} \rightarrow {}^{4}_{2}\text{He} + \underline{\quad ? \quad}$

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Nuclear Reactions, *continued*

Sample Problem A Solution

1. The total mass number and atomic number must be equal on both sides of the equation.

$$^{212}_{84}\text{Po} \rightarrow \, ^{4}_{2}\text{He} + \underline{\quad ? \quad}$$

mass number: 212 − 4 = 208 **atomic number: 84 − 2 = 82**

2. The nuclide has a mass number of 208 and an atomic number of 82, $^{208}_{82}\text{Pb}$.

3. The balanced nuclear equation is

$$\boxed{^{212}_{84}\text{Po} \rightarrow \, ^{4}_{2}\text{He} + \, ^{208}_{82}Pb}$$

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Preview

- Lesson Starter
- Objectives
- Types of Radioactive Decay
- Half-Life
- Decay Series
- Artificial Transmutations

Lesson Starter

- Propose different ways for an unstable nucleus to get into the band of stability.

- An unstable nucleus can undergo
  - alpha emission
  - beta emission
  - positron emission
  - and electron capture

Objectives

- **Define** and relate the terms radioactive decay and nuclear radiation.
- **Describe** the different types of radioactive decay and their effects on the nucleus.
- **Define** the term half-life, and explain how it relates to the stability of a nucleus.

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Objectives, *continued*

- **Define** and relate the terms decay series, parent nuclide, and daughter nuclide.
- **Explain** how artificial radioactive nuclides are made, and discuss their significance.

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- **Radioactive decay** is the spontaneous disintegration of a nucleus into a slightly lighter nucleus, accompanied by emission of particles, electromagnetic radiation, or both.
- **Nuclear radiation** is particles or electromagnetic radiation emitted from the nucleus during radioactive decay.
- An unstable nucleus that undergoes radioactive decay is a **radioactive nuclide.**
- All of the nuclides beyond atomic number 83 are unstable and thus radioactive.

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Types of Radioactive Decay

- A nuclide’s type and rate of decay depend on the nucleon content and energy level of the nucleus.

Alpha Emission

- An **alpha particle** (α) is two protons and two neutrons bound together and is emitted from the nucleus during some kinds of radioactive decay.
- ${}^{4}_{2}\mathrm{He}$
- Alpha emission is restricted almost entirely to very heavy nuclei.

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Types of Radioactive Decay, *continued*

Beta Emission

- A **beta particle** *(β)* is an electron emitted from the nucleus during some kinds of radioactive decay.
- To decrease the number of neutrons, a neutron can be converted into a proton and an electron.

$$^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}\beta$$

- The atomic number increases by one and the mass number stays the same.

End Of Slide

Types of Radioactive Decay, *continued*

Positron Emission

- A **positron** is a particle that has the same mass as an electron, but has a positive charge, and is emitted from the nucleus during some kinds of radioactive decay.

- To decrease the number of protons, a proton can be converted into a neutron by emitting a positron.

$$ {}^{1}_{1}p \rightarrow {}^{1}_{0}n + {}^{0}_{+1}\beta $$

- The atomic number decreases by one and the mass number stays the same.

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Types of Radioactive Decay, *continued*

Electron Capture

- In **electron capture,** an inner orbital electron is captured by the nucleus of its own atom.
- To increase the number of neutrons, an inner orbital electron combines with a proton to form a neutron.

$$ {}^{0}_{-1}e + {}^{1}_{1}p \rightarrow {}^{1}_{0}n $$

- The atomic number decreases by one and the mass number stays the same.

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Electron Capture

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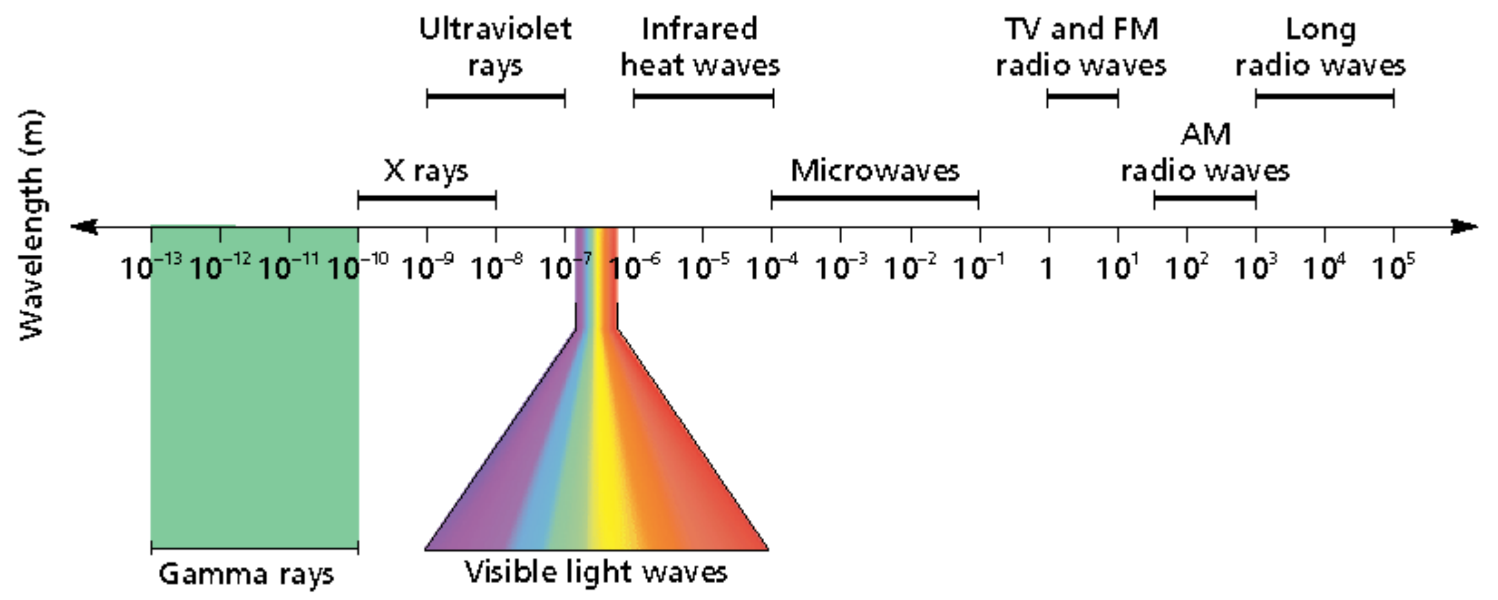
Visual Concept

Types of Radioactive Decay, *continued*

Gamma Emission



- **Gamma rays** (γ) are high-energy electromagnetic waves emitted from a nucleus as it changes from an excited state to a ground energy state.

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Comparing Alpha, Beta and Gamma Particles

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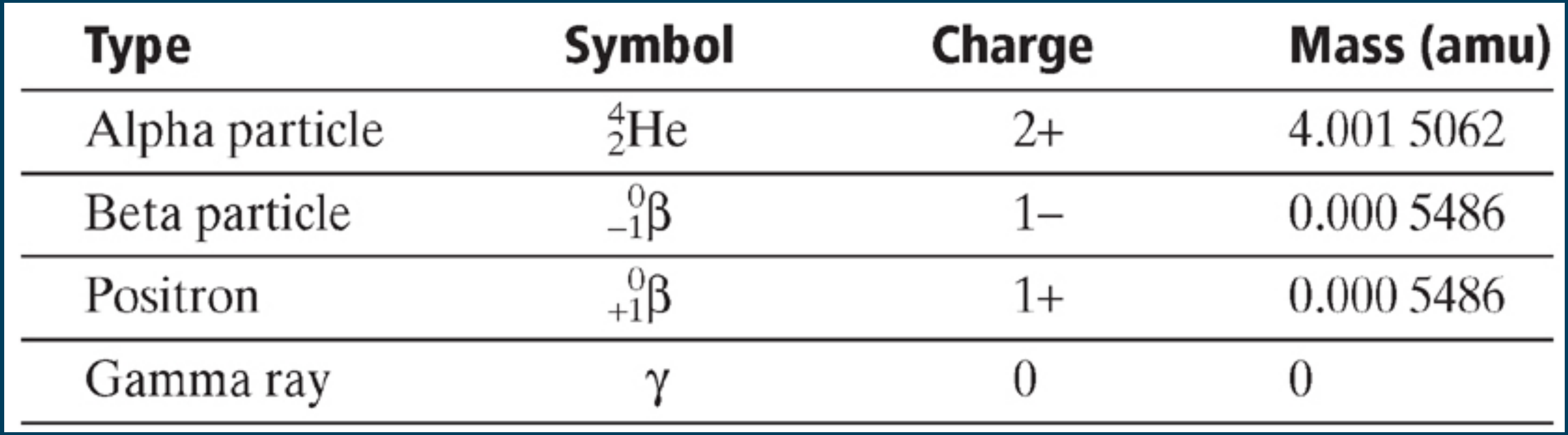
Visual Concept

Radioactive Nuclide Emissions



Type	Symbol	Charge	Mass (amu)
Alpha particle	$^{4}_{2}\mathrm{He}$	2+	4.001 5062
Beta particle	$^{0}_{-1}\beta$	1−	0.000 5486
Positron	$^{0}_{+1}\beta$	1+	0.000 5486
Gamma ray	γ	0	0

Half-Life

- **Half-life,** $t_{1/2}$, is the time required for half the atoms of a radioactive nuclide to decay.

- Each radioactive nuclide has its own half-life.

- More-stable nuclides decay slowly and have longer half-lives.

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Half-Life

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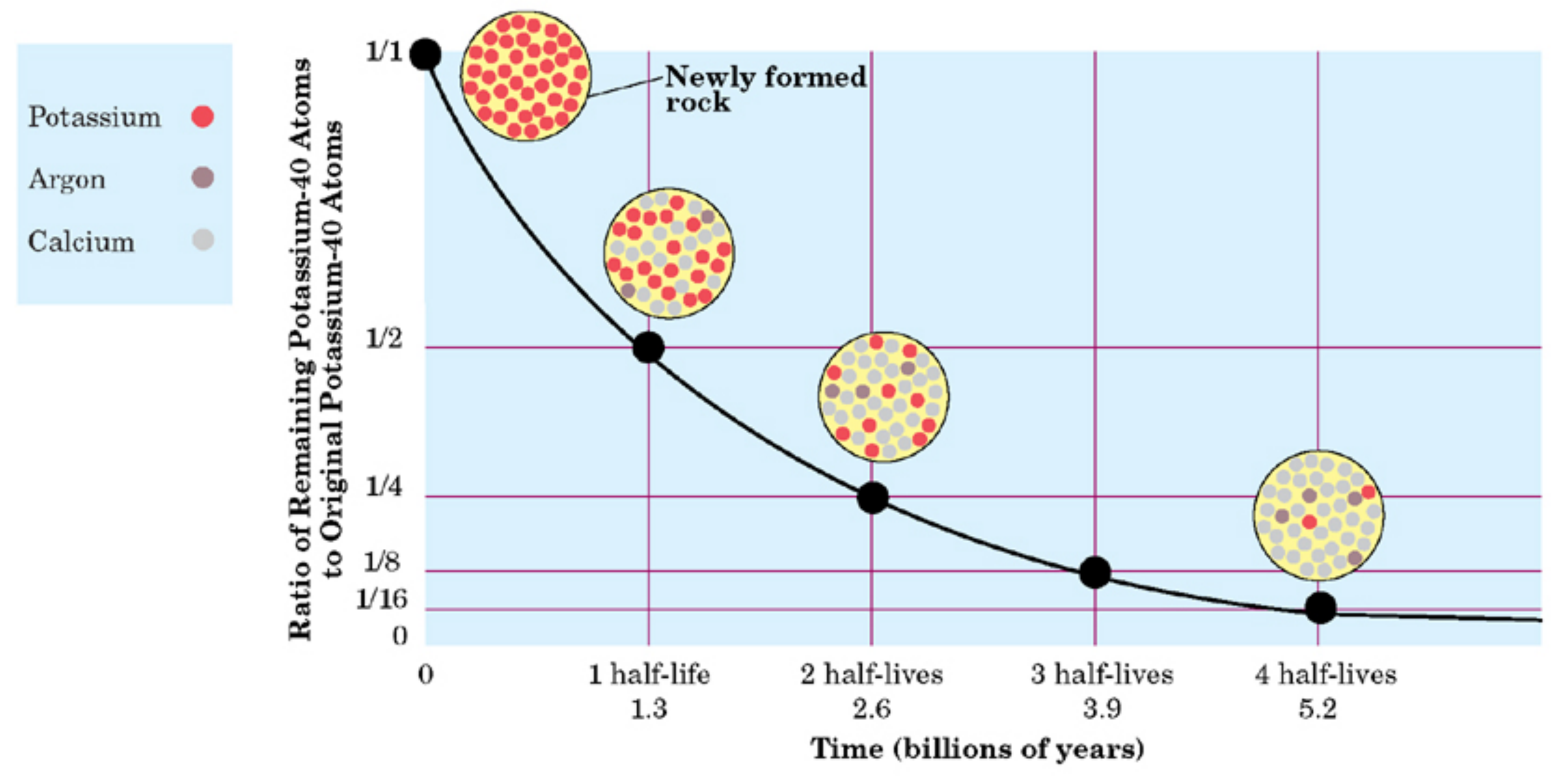
Visual Concept

Potassium-40 Half-Life



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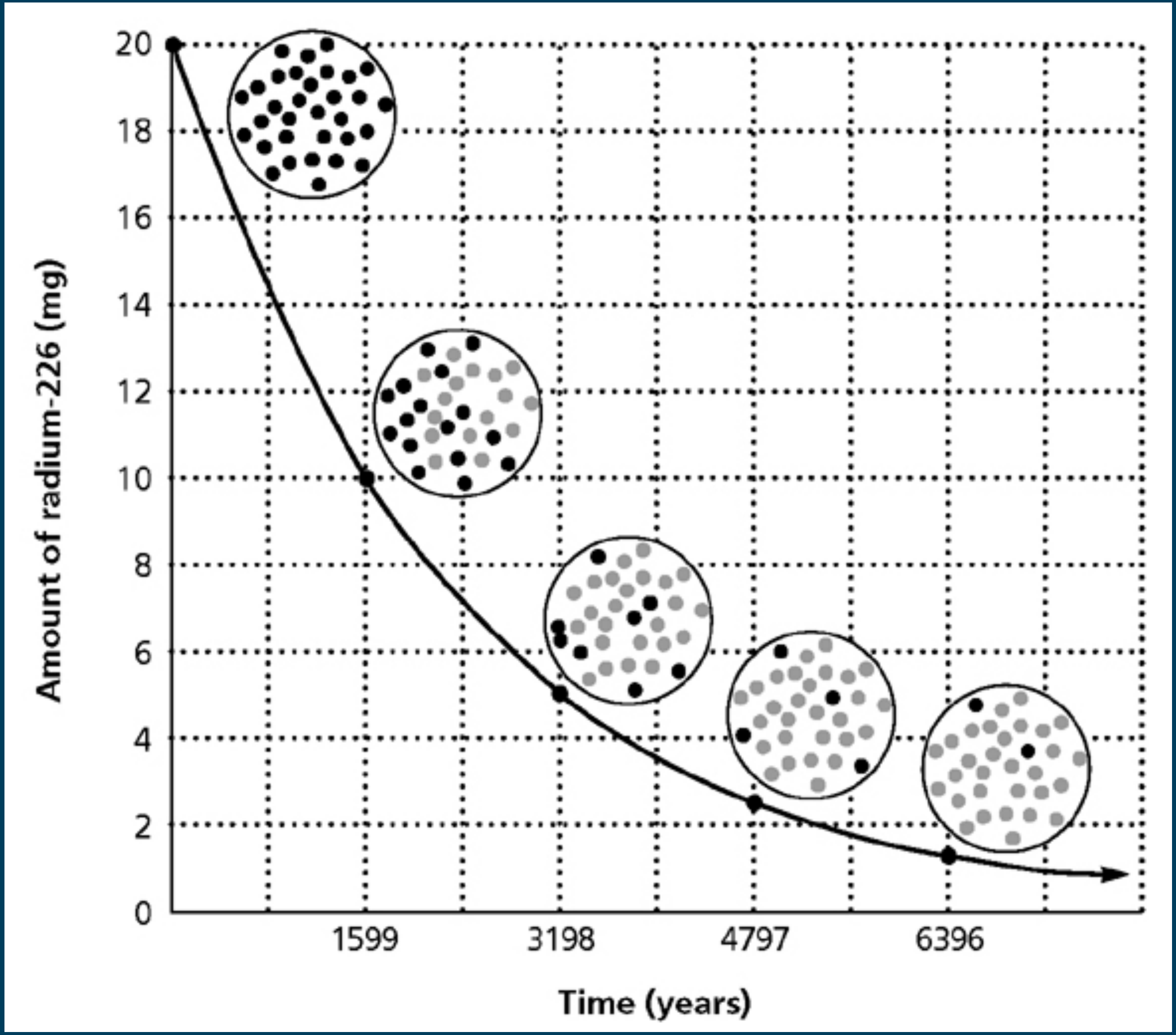
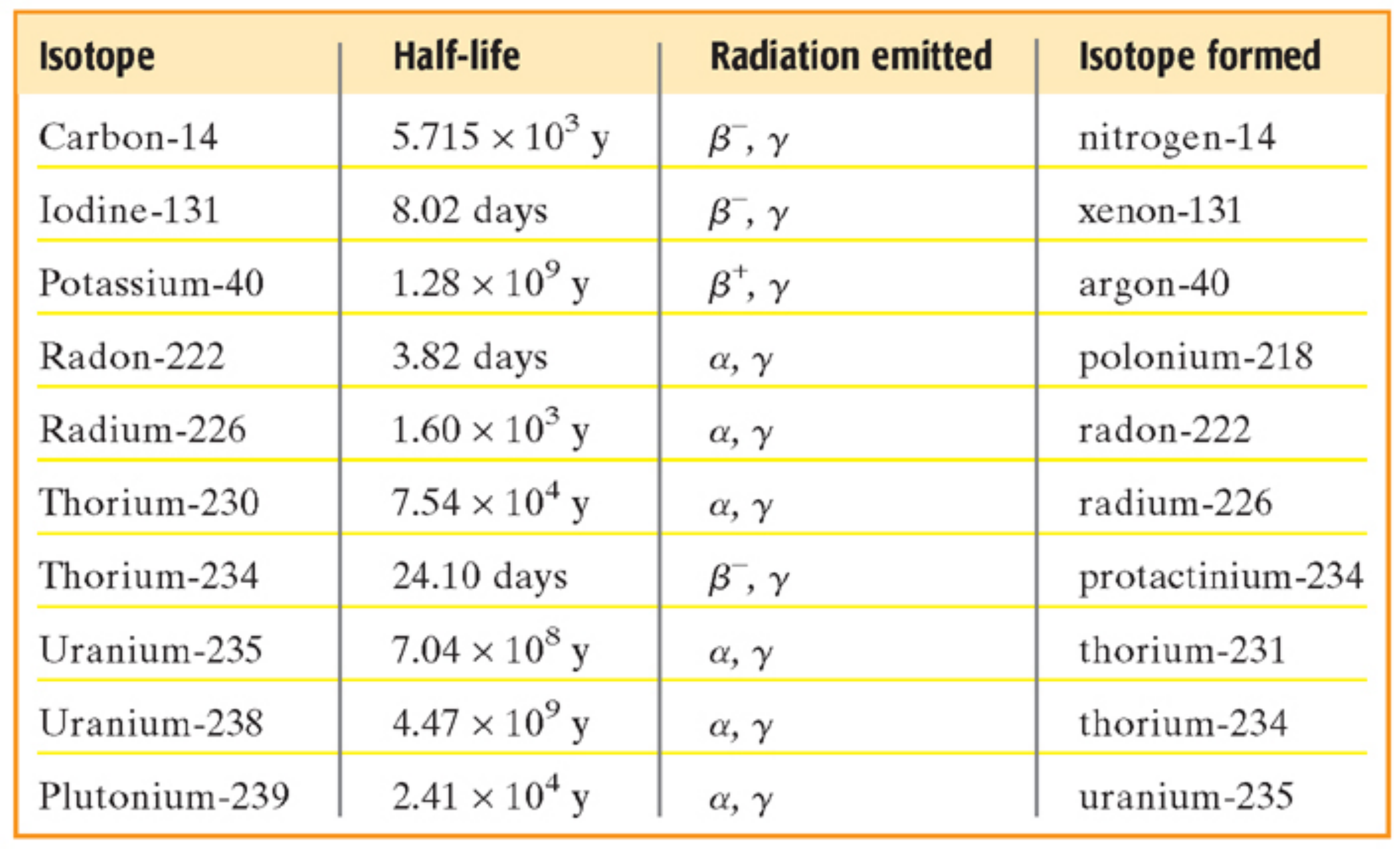
Rate of Decay



Half-Lives of Some Radioactive Isotopes



Isotope	Half-life	Radiation emitted	Isotope formed
Carbon-14	5.715×10^3 y	β^-, γ	nitrogen-14
Iodine-131	8.02 days	β^-, γ	xenon-131
Potassium-40	1.28×10^9 y	β^+, γ	argon-40
Radon-222	3.82 days	α, γ	polonium-218
Radium-226	1.60×10^3 y	α, γ	radon-222
Thorium-230	7.54×10^4 y	α, γ	radium-226
Thorium-234	24.10 days	β^-, γ	protactinium-234
Uranium-235	7.04×10^8 y	α, γ	thorium-231
Uranium-238	4.47×10^9 y	α, γ	thorium-234
Plutonium-239	2.41×10^4 y	α, γ	uranium-235

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Half-Life, *continued*

Sample Problem B

Phosphorus-32 has a half-life of 14.3 days. How many milligrams of phosphorus-32 remain after 57.2 days if you start with 4.0 mg of the isotope?

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Half-Life, *continued*

Sample Problem B Solution

Given: original mass of phosphorus-32 = 4.0 mg
half-life of phosphorus-32 = 14.3 days
time elapsed = 57.2 days

Unknown: mass of phosphorus-32 remaining after 57.2 days

Solution:

$$\text{number of half-lives} = \text{time elapsed (days)} \times \frac{\text{1 half-life}}{\text{14.3 days}}$$

$$\text{amount of phosphorus-32 remaining} =$$

$$\text{original amount of phosphorus-32} \times \frac{1}{2} \text{for each half-life}$$

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Half-Life, *continued*

Sample Problem B Solution, *continued*

$$\text{number of half-lives} = 52.7 \text{ days} \times \frac{1 \text{ half-life}}{14.3 \text{ days}} = 4 \text{ half-lives}$$

$$\text{amount of phosphorus-32 remaining} =$$

$$4.0 \text{ mg} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = \boxed{0.25 \text{ mg}}$$

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Decay Series

- A **decay series** is a series of radioactive nuclides produced by successive radioactive decay until a stable nuclide is reached.

- The heaviest nuclide of each decay series is called the **parent nuclide.**

- The nuclides produced by the decay of the parent nuclides are called **daughter nuclides.**

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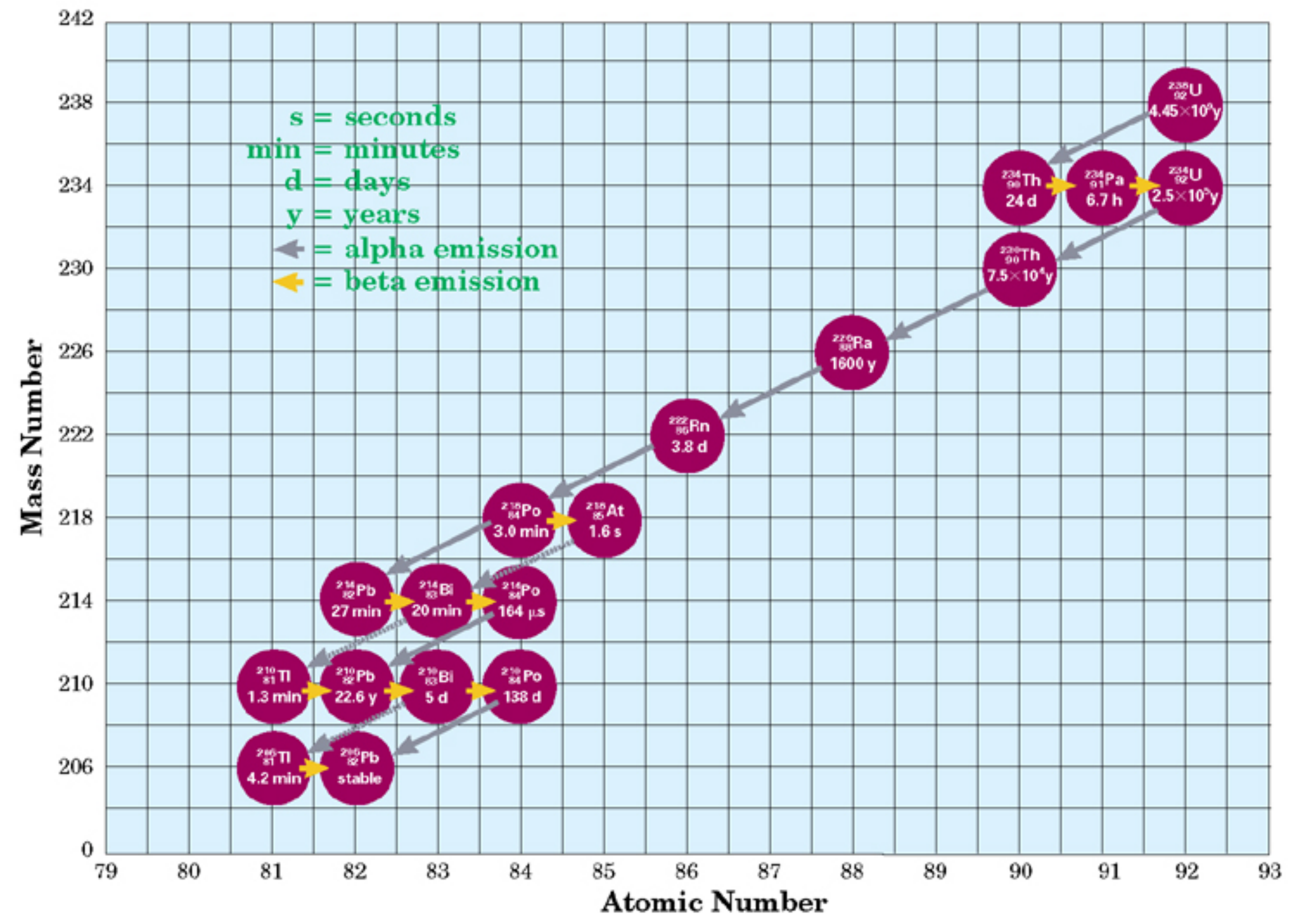
Uranium-238 Decay



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Decay Series

Click below to watch the Visual Concept.

Visual Concept

Parent and Daughter Nuclides

Click below to watch the Visual Concept.

Visual Concept

Rules for Nuclear Decay

Click below to watch the Visual Concept.

Visual Concept

Artificial Transmutations

- *Artificial radioactive nuclides* are radioactive nuclides not found naturally on Earth.
- They are made by **artificial transmutations,** bombardment of nuclei with charged and uncharged particles.
- **Transuranium elements** are elements with more than 92 protons in their nuclei.
    - Artificial transmutations are used to produce the transuranium elements.

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Preview

- Objectives
- Radiation Exposure
- Radiation Detection
- Applications of Nuclear Radiation
- Nuclear Waste

Objectives

- **Compare** the penetrating ability and shielding requirements of alpha particles, beta particles, and gamma rays.
- **Define** the terms roentgen and rem, and distinguish between them.
- **Describe** three devices used in radiation detection.
- **Discuss** applications of radioactive nuclides.

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Alpha, Beta, and Gamma Radiation

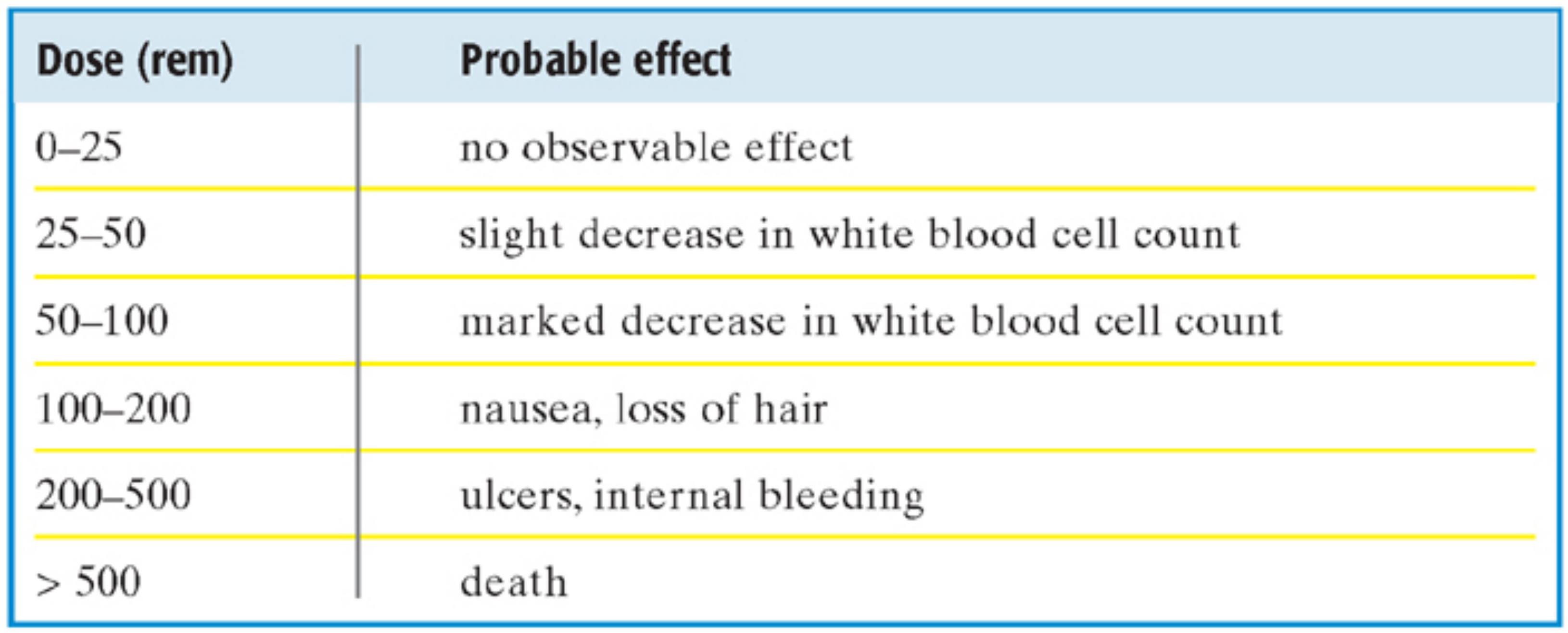
Click below to watch the Visual Concept.

Visual Concept

Radiation Exposure

- Nuclear radiation can transfer the energy from nuclear decay to the electrons of atoms or molecules and cause ionization.
- The **roentgen (R)** is a unit used to measure nuclear radiation exposure; it is equal to the amount of gamma and X ray radiation that produces 2×10^9 ion pairs when it passes through 1 cm^3 of dry air.
- A **rem** is a unit used to measure the dose of any type of ionizing radiation that factors in the effect that the radiation has on human tissue.

Effect of Whole-Body Exposure to a Single Dose of Radiation



Dose (rem)	Probable effect
0–25	no observable effect
25–50	slight decrease in white blood cell count
50–100	marked decrease in white blood cell count
100–200	nausea, loss of hair
200–500	ulcers, internal bleeding
> 500	death

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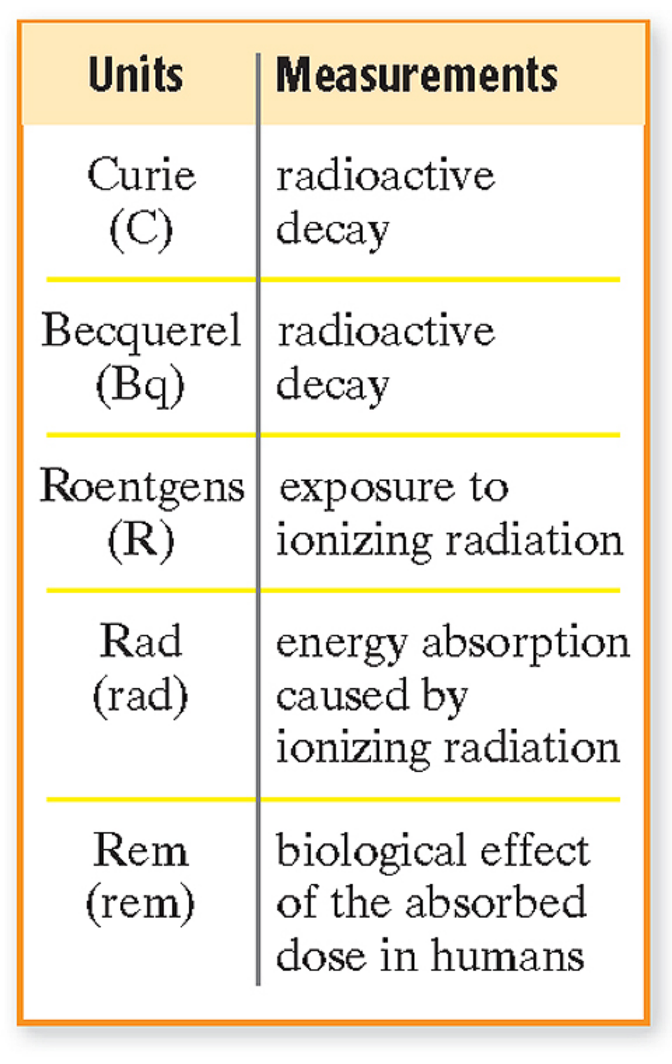
Radiation Detection

- **Film badges** use exposure of film to measure the approximate radiation exposure of people working with radiation.
- **Geiger-Müller counters** are instruments that detect radiation by counting electric pulses carried by gas ionized by radiation.
- **Scintillation counters** are instruments that convert scintillating light to an electric signal for detecting radiation.
  - Substances that *scintillate* absorb ionizing radiation and emit visible light.

Units Used in Measurements of Radioactivity



Units	Measurements
Curie (C)	radioactive decay
Becquerel (Bq)	radioactive decay
Roentgens (R)	exposure to ionizing radiation
Rad (rad)	energy absorption caused by ionizing radiation
Rem (rem)	biological effect of the absorbed dose in humans

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Applications of Nuclear Radiation

Radioactive Dating

- **Radioactive dating** is the process by which the approximate age of an object is determined based on the amount of certain radioactive nuclides present.
  - Age is estimated by measuring either the accumulation of a daughter nuclide or the disappearance of the parent nuclide.
  - Carbon-14 is used to estimate the age of organic material up to about 50 000 years old.

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Radiometric Dating

Click below to watch the Visual Concept.

Visual Concept

Applications of Nuclear Radiation, *continued*

Radioactive Nuclides in Medicine

- In medicine, radioactive nuclides are used to destroy certain types of cancer cells.
  - cobalt-60
- **Radioactive tracers** are radioactive atoms that are incorporated into substances so that movement of the substances can be followed by radiation detectors.
  - Radioactive tracers can be used to diagnose diseases.

End Of Slide

Radioactive Tracer

Click below to watch the Visual Concept.

Visual Concept

Applications of Nuclear Radiation, *continued*

Radioactive Nuclides in Agriculture

- Radioactive tracers in fertilizers are used to determine the effectiveness of the fertilizer.

- Nuclear radiation is also used to prolong the shelf life of food.

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Nuclear Waste

Nuclear Fission and Nuclear Fusion

- Fission is the primary process powering nuclear reactors.
- The products of the fission include the nuclei as well as the nucleons formed from the fragments' radioactive decay.
- Both fission and fusion produce **nuclear waste.**
- Fission produces more waste than fusion.

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Nuclear Waste, *continued*

Containment of Nuclear Waste

- Nuclear waste needs to be contained so that living organisms can be shielded from radioactivity.
- There are two main types of containment: on-site storage and off-site disposal.

Storage of Nuclear Waste

- The most common form of nuclear waste is spent fuel rods from nuclear power plants.
- Fuel rods can be contained temporarily above the ground in water pools or in dry casks.

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Nuclear Waste, *continued*

Disposal of Nuclear Waste

- Disposal of nuclear waste is done with the intention of never retrieving the materials.
- There are 77 disposal sites around the United States.
- A new site called Yucca Mountain is being developed for the permanent disposal of much of the nuclear waste.

Preview

- Lesson Starter
- Objectives
- Nuclear Fission
- Nuclear Fusion

Lesson Starter

- For the elements lighter than iron, fusion of two smaller elements into a larger element emits energy.
- For elements larger than iron, fission of a larger element into two smaller elements emits energy.
- Compare the relative energy changes in a physical change, a chemical reaction, and a nuclear reaction.

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Objectives

- **Define** nuclear fission, chain reaction, and nuclear fusion, and distinguish between them.
- **Explain** how a fission reaction is used to generate power.
- **Discuss** the possible benefits and the current difficulty of controlling fusion reactions.

End Of Slide

Nuclear Fission

- In **nuclear fission,** a very heavy nucleus splits into more-stable nuclei of intermediate mass.
- Enormous amounts of energy are released.
- Nuclear fission can occur spontaneously or when nuclei are bombarded by particles.

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Nuclear Fission, *continued*

Nuclear Chain Reaction

- A **chain reaction** is a reaction in which the material that starts the reaction is also one of the products and can start another reaction.
- The minimum amount of nuclide that provides the number of neutrons needed to sustain a chain reaction is called the **critical mass.**
- **Nuclear reactors** use controlled-fission chain reactions to produce energy and radioactive nuclides.

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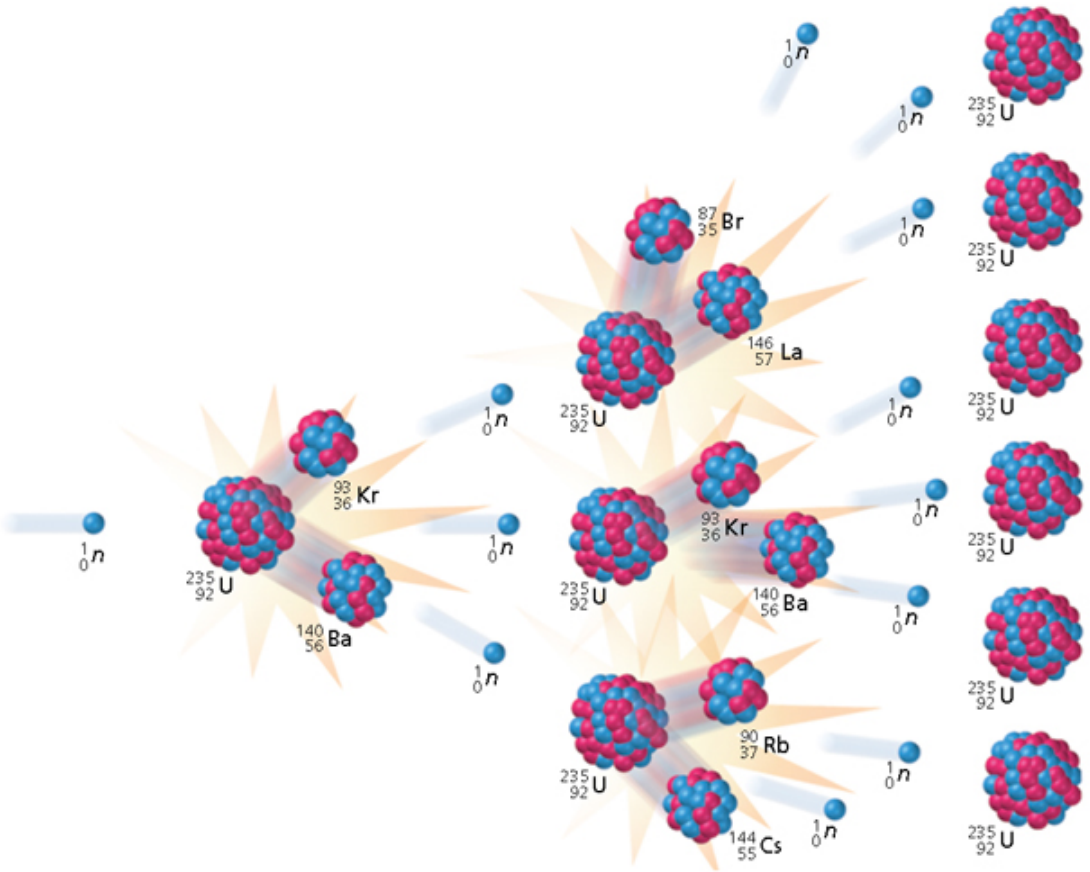
Nuclear Chain Reaction



Fission induction of uranium-235 by bombardment with neutrons can lead to a chain reaction when a critical mass of uranium-235 is present.

Nuclear Chain Reaction

Click below to watch the Visual Concept.

Visual Concept

Critical Mass

Click below to watch the Visual Concept.

Visual Concept

Nuclear Fission, *continued*

Nuclear Power Plants

- **Nuclear power plants** use energy as heat from nuclear reactors to produce electrical energy.
- They have five main components: shielding, fuel, control rods, moderator, and coolant.

1. **Shielding** is radiation-absorbing material that is used to decrease exposure to radiation, especially gamma rays, from nuclear reactors.
2. Uranium-235 is typically used as the fissile fuel.

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Nuclear Fission, *continued*

Nuclear Power Plants, *continued*

- The five main components of nuclear power plants, *continued*

3. The coolant absorbs the energy as heat that is produced
4. **Control rods** are neutron-absorbing rods that help control the reaction by limiting the number of free neutrons
5. A **moderator** is used to slow down the fast neutrons produced by fission.

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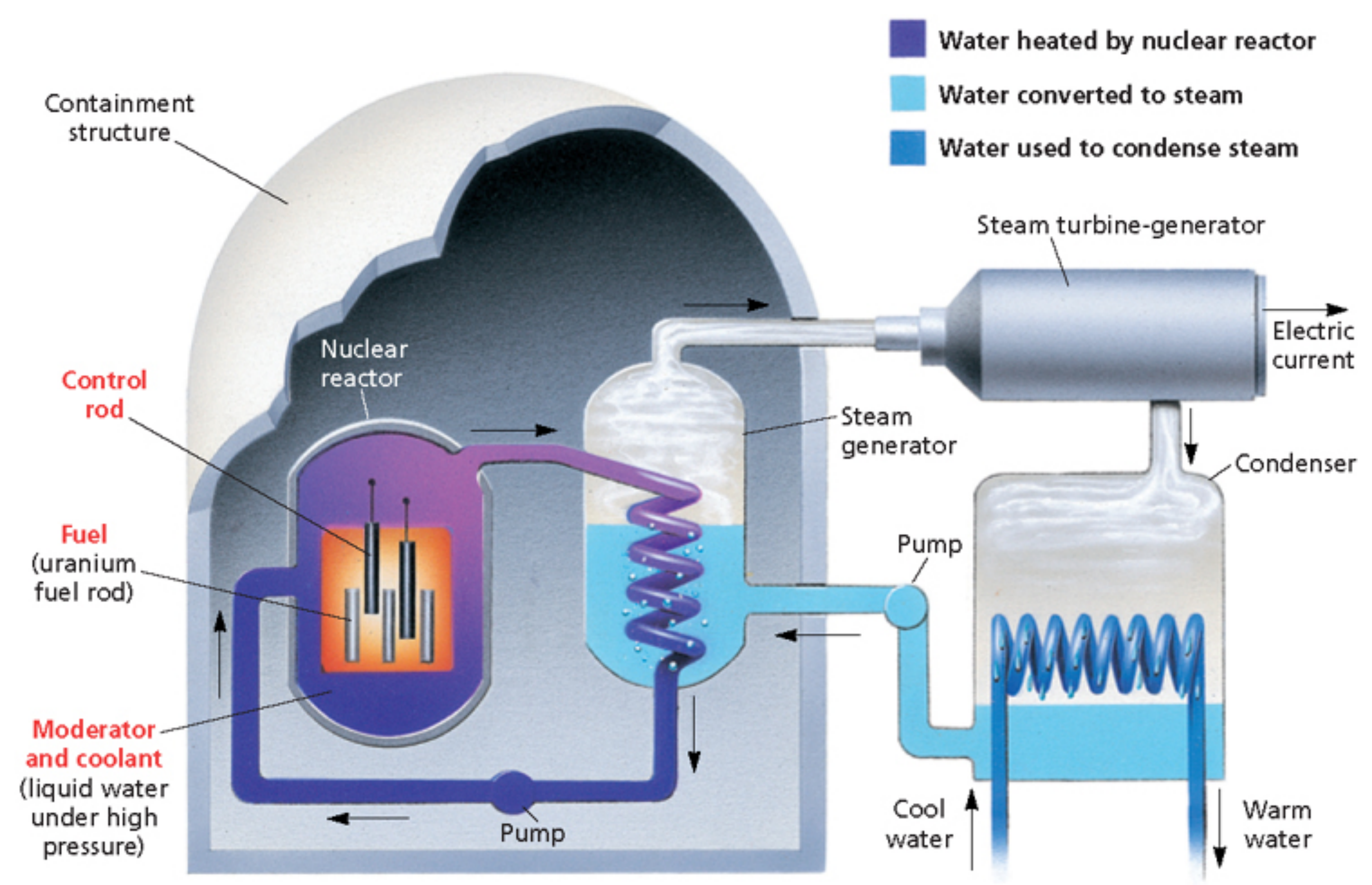
Nuclear Power Plant Model



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Nuclear Fusion

- In **nuclear fusion,** low-mass nuclei combine to form a heavier, more stable nucleus.
- Nuclear fusion releases even more energy per gram of fuel than nuclear fission.
- If fusion reactions can be controlled, they could be used for energy generation.

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Nuclear Fusion

Click below to watch the Visual Concept.

Visual Concept

End of Chapter 21 Show