Radioactivity-1

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Lecture 8

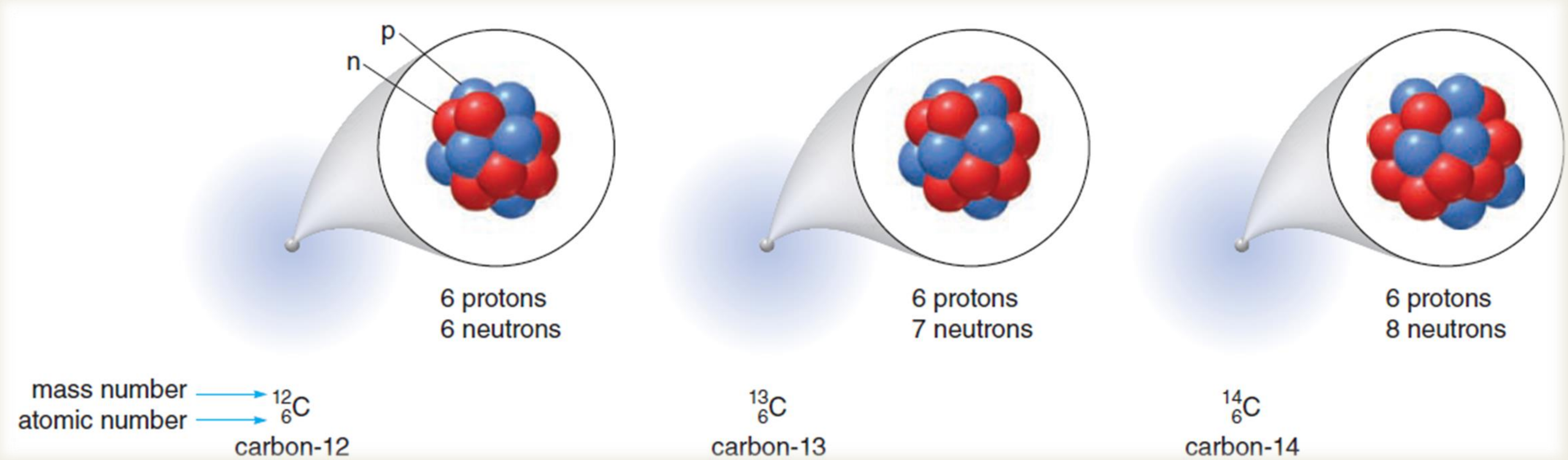
Lecture Goals

➢ In this chapter you will learn how to:

- ❶ Describe the different types of radiation emitted by a radioactive nucleus
- ❷ Write equations for nuclear reactions
- ❸ Define half-life
- ❹ Recognize the units used for measuring radioactivity
- ❺ Give examples of common radioisotopes used in medical diagnosis and treatment
- ❻ Describe the features of medical imaging techniques that do not use radioactivity

1. Isotopes

- The nucleus of an atom is composed of protons and neutrons.
- ***The atomic number (Z)*** = the number of protons in the nucleus.
- ***The mass number (A)*** = the number of protons and neutrons in the nucleus.
- ***Isotopes*** are atoms of the same element having a different number of neutrons.
- As a result, isotopes have the same atomic number (Z) but different mass numbers (A).



Many isotopes are stable, but a larger number are not.

A *radioactive isotope,* called a *radioisotope,* is unstable and spontaneously emits energy to form a more stable nucleus.

Radioactivity is the nuclear radiation emitted by a radioactive isotope

PROBLEM

Iodine-123 and iodine-131 are radioactive isotopes used for the diagnosis or treatment of thyroid disease. Complete the following table for both isotopes.

	Atomic Number	Mass Number	Number of Protons	Number of Neutrons	Isotope Symbol
Iodine-123					
Iodine-131					

Analysis

- The atomic number = the number of protons.
- The mass number = the number of protons + the number of neutrons.
- Isotopes are written with the mass number to the upper left of the element symbol and the atomic number to the lower left.

Solution

	Atomic Number	Mass Number	Number of Protons	Number of Neutrons	Isotope Symbol
Iodine-123	53	123	53	123 – 53 = 70	${}^{123}_{53}I$
Iodine-131	53	131	53	131 – 53 = 78	${}^{131}_{53}I$

Home Work

PROBLEM 9.1

Complete the following table for two isotopes of cobalt. Cobalt-60 is commonly used in cancer therapy.

	Atomic Number	Mass Number	Number of Protons	Number of Neutrons	Isotope Symbol
Cobalt-59					
Cobalt-60					

PROBLEM 9.2

Each of the following radioisotopes is used in medicine. For each isotope give its: [1] atomic number; [2] mass number; [3] number of protons; [4] number of neutrons.

a. $^{85}_{38}Sr$ used in bone scans

b. $^{67}_{31}Ga$ used in abdominal scans

c. selenium-75 used in pancreas scans

2. Types of Radiation

- Different forms of radiation are emitted when a radioactive nucleus is converted to a more stable nucleus, including **alpha particles, beta particles, positrons,** and **gamma radiation.**

A. An alpha particle is a high-energy particle that contains two protons and two neutrons.

alpha particle: α or $^{4}_{2}He$

An alpha particle, symbolized by the Greek letter alpha (**α**) or the element symbol for helium, has a +2 charge and a mass number of 4.

B. *A beta particle* is a high-energy electron. beta particle: β or $^{0}_{-1}e$

An electron has a –1 charge and a negligible mass compared to a proton. A beta particle, symbolized by the Greek letter beta (**β**), is also drawn with the symbol for an electron, **e**, with a mass number of 0.

C. ***Positron*** is called an antiparticle of a **β** particle, since their charges are different but their masses are the same.   Symbol: $^{0}_{+1}e$ or β^{+}

Thus, a positron has a negligible mass like a β particle, but is opposite in charge, +1. A positron, symbolized as β+, is also drawn with the symbol for an electron, e, with a mass number of 0.

D. ***Gamma rays*** are high-energy radiation released from a radioactive nucleus.

Gamma rays, symbolized by the Greek letter gamma (**γ**), are a form of energy and thus they have no mass or charge. gamma ray: γ

Table Types of Radiation

Type of Radiation	Symbol	Charge	Mass
Alpha particle	α or $^{4}_{2}He$	+2	4
Beta particle	β or $^{0}_{-1}e$	–1	0
Positron	β^{+} or $^{0}_{+1}e$	+1	0
Gamma ray	γ	0	0

3.The Effects of Radioactivity

- Radioactivity cannot be **seen, smelled, tasted, heard, or felt**, and yet it can have powerful effects Because it is high in energy, ***nuclear radiation penetrates the surface of an object or living organism where it can damage or kill cells***. The cells that are most sensitive to radiation are those that undergo **rapid cell division**, such as those in bone marrow, reproductive organs, skin, and the intestinal tract. Since cancer cells also rapidly divide, they are also particularly sensitive to radiation.
- Alpha (α) particles, β particles, and γ rays differ in the extent to which they can penetrate a surface. Alpha particles are the heaviest of the radioactive particles, and as a result they move the slowest and penetrate the least.
- Gamma rays travel the fastest and readily penetrate body tissue.
- That **γ** rays kill cells is used to an advantage in the food industry. To decrease the incidence of harmful bacteria in foods, certain fruits and vegetables are irradiated with **γ** rays that kill any bacteria contained in them.

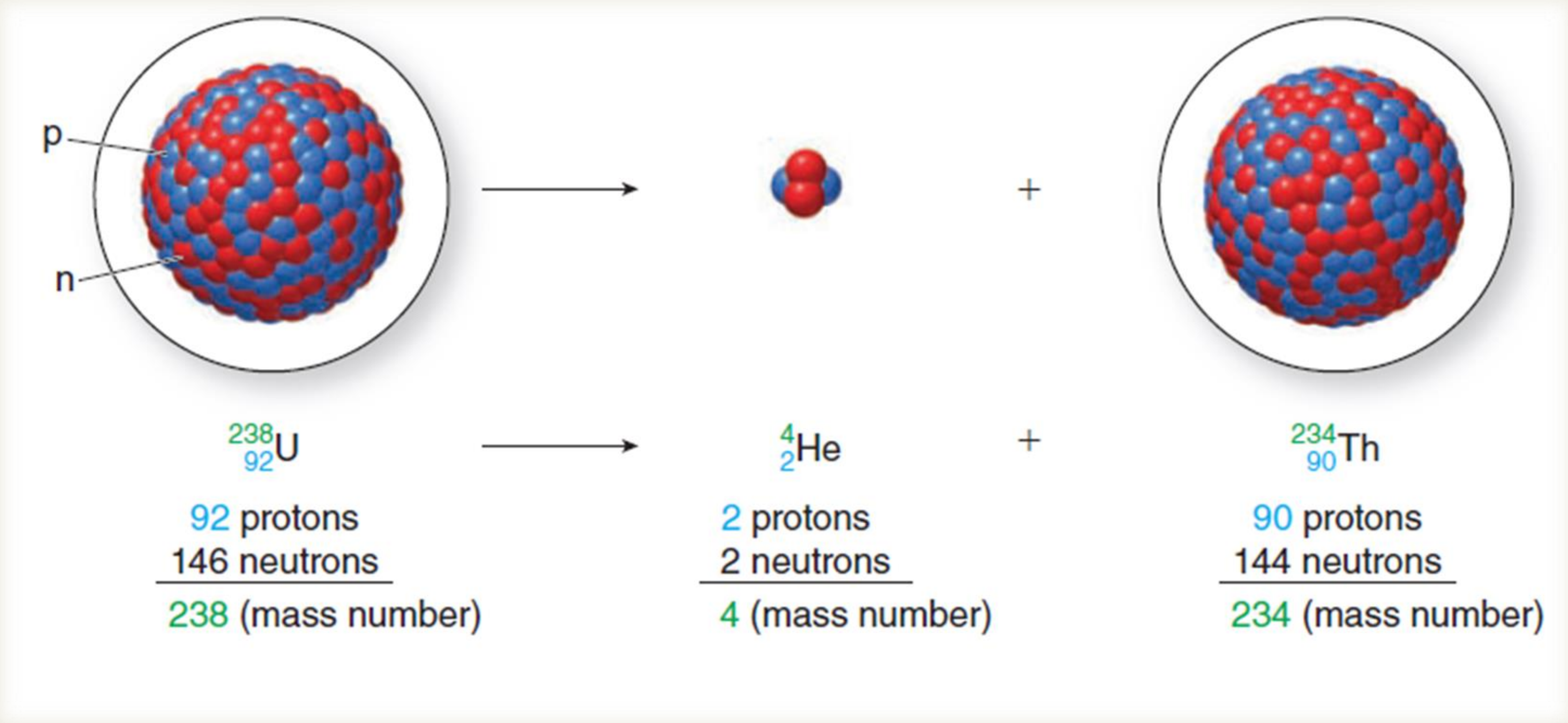
4. Nuclear Reactions

- ***Radioactive decay*** is the process by which an unstable radioactive nucleus emits radiation, forming a nucleus of new composition.
- A nuclear equation can be written for this process, which contains the original nucleus, the new nucleus, and the radiation emitted. Unlike a chemical equation that balances atoms, in a nuclear equation the mass numbers and the atomic numbers of the nuclei must be balanced.

- The sum of the mass numbers (A) must be equal on both sides of a nuclear equation.
- The sum of the atomic numbers (Z) must be equal on both sides of a nuclear equation.

4.1.Alpha Emission

- Alpha emission is the decay of a nucleus by emitting an **α** particle. For example, uranium-238 decays to thorium-234 by loss of an α particle.



Since an α particle has two protons, **the new nucleus has *two fewer protons* than the original nucleus.** Because it has a *different* number of protons, the new nucleus represents a *different* element.

How To Balance an Equation for a Nuclear Reaction

Example Write a balanced nuclear equation showing how americium-241, a radioactive element used in smoke detectors, decays to form an **α** particle.

Step [1] Write an incomplete equation with the original nucleus on the left and the particle emitted on the right.

- Include the mass number and atomic number (from the periodic table) in the equation.

$$^{241}_{95}\text{Am} \longrightarrow {}^{4}_{2}\text{He} + ?$$

Step [2] Calculate the mass number and atomic number of the newly formed nucleus on the right.

- Mass number: Subtract the mass of an α particle (4) to obtain the mass of the new nucleus; 241 – 4 = 237.
- Atomic number: Subtract the two protons of an α particle to obtain the atomic number of the new nucleus; 95 – 2 = 93.

Step [3] Use the atomic number to identify the new nucleus and complete the equation.

- From the periodic table, the element with an atomic number of 93 is neptunium, Np.
- Write the mass number and the atomic number with the element symbol to complete the equation.

$$241 = 4 + 237$$
$$95 = 2 + 93$$

$$^{241}_{95}\text{Am} \longrightarrow {}^{4}_{2}\text{He} + {}^{237}_{93}\text{Np}$$

PROBLEM

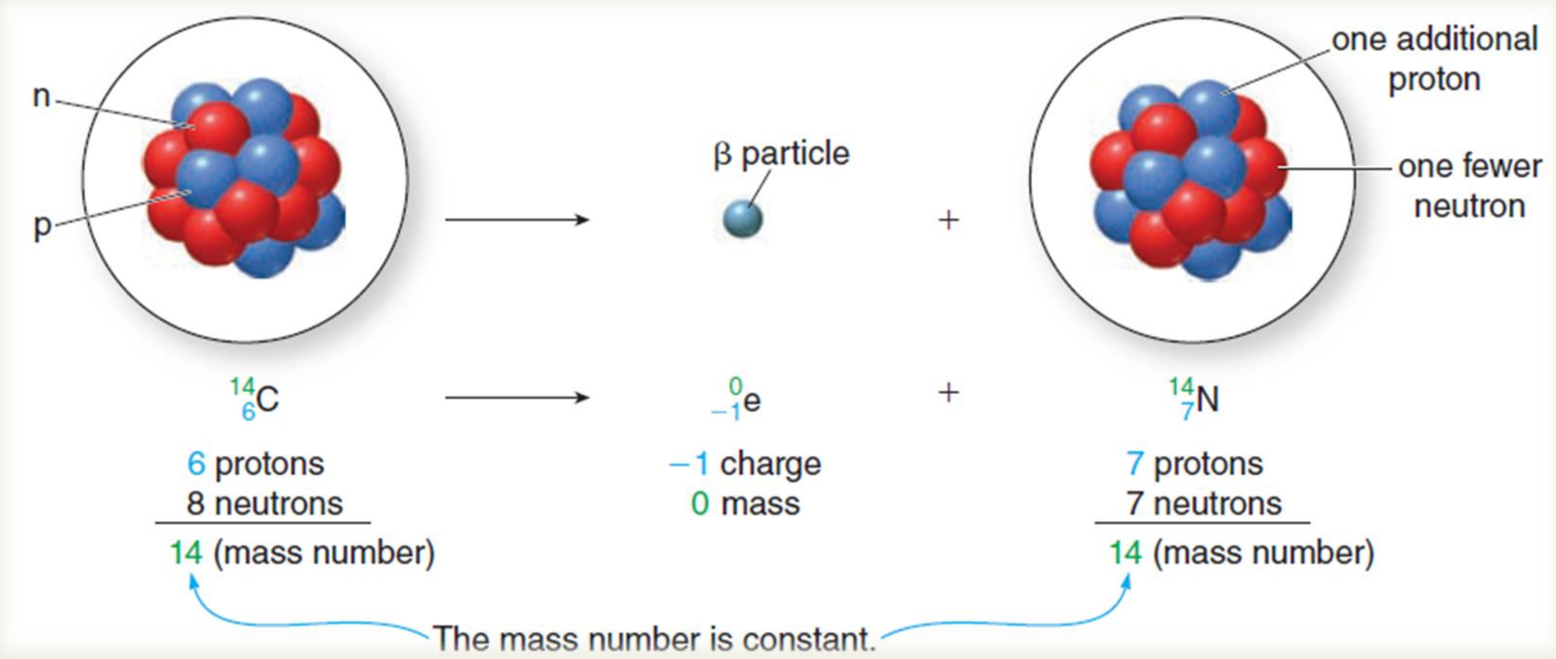
Radon, a radioactive gas formed in the soil, can cause lung cancers when inhaled in high concentrations for a long period of time. Write a balanced nuclear equation for the decay of radon-222, which emits an α particle.

HEALTH NOTE

Americium-241 is a radioactive element contained in smoke detectors. The decay of α particles creates an electric current that is interrupted when smoke enters the detector, sounding an alarm.

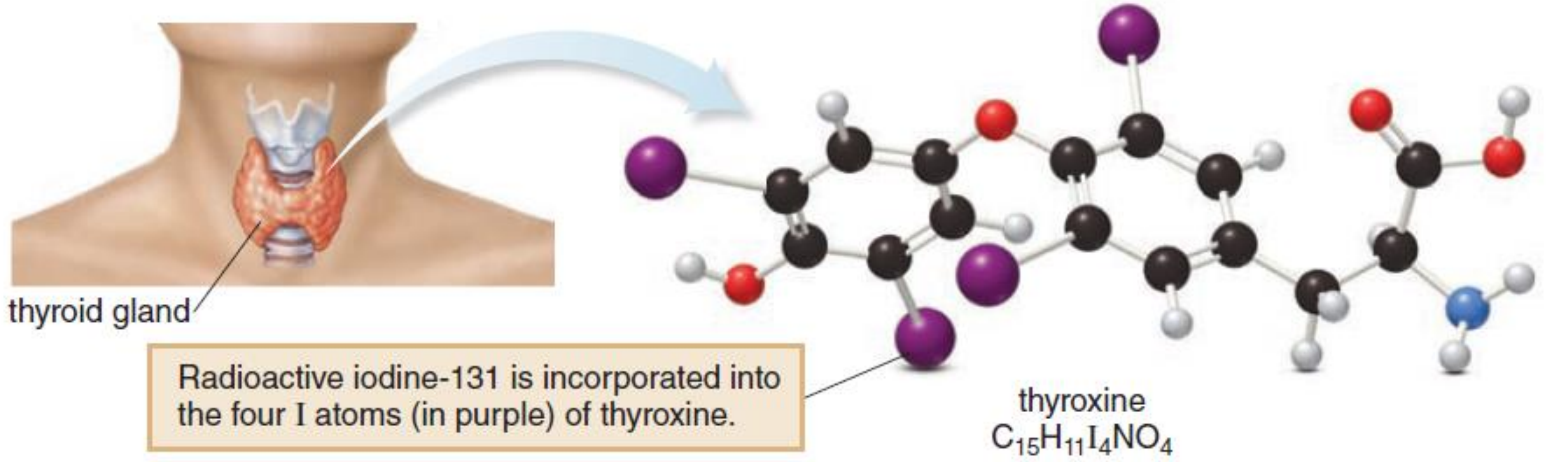
4.2.Beta Emission

- Beta emission is the decay of a nucleus by emitting a **β** particle. For example, carbon-14 decays to nitrogen-14 by loss of a β particle. The decay of carbon-14 is used to date archaeological specimens.



In β emission, one neutron of the original nucleus decays to a β particle and a proton. As a result, ***the new nucleus has one more proton and one fewer neutron than the original nucleus.***

- Radioactive elements that emit β radiation are widely used in medicine. Iodine-131, a radioactive element that emits β radiation, is used to treat hyperthyroidism, a condition resulting from an overactive thyroid gland (Figure 9.1). Moreover, since β radiation is composed of high-energy electrons that penetrate tissue in a small, localized region, radioactive elements situated in close contact with tumor cells kill them. Although both healthy and diseased cells are destroyed by this internal radiation therapy, rapidly dividing tumor cells are more sensitive to its effects and therefore their growth and replication are affected the most.



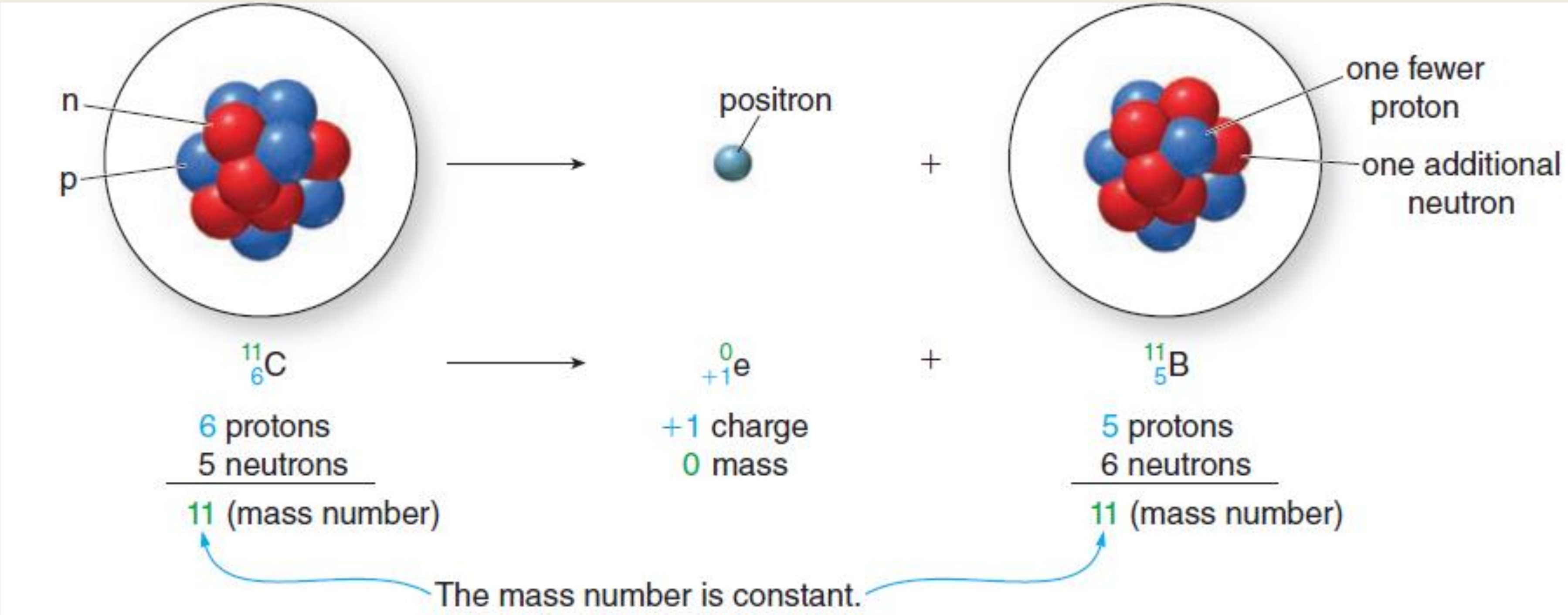
Iodine-131 is incorporated into the thyroid hormone thyroxine. Beta radiation emitted by the radioactive isotope destroys nearby thyroid cells, thus decreasing the activity of the thyroid gland and bringing the disease under control.

PROBLEM

Write a balanced nuclear equation for the β emission of phosphorus-32, a radioisotope used to treat leukemia and other blood disorders.

4.3. Positron Emission

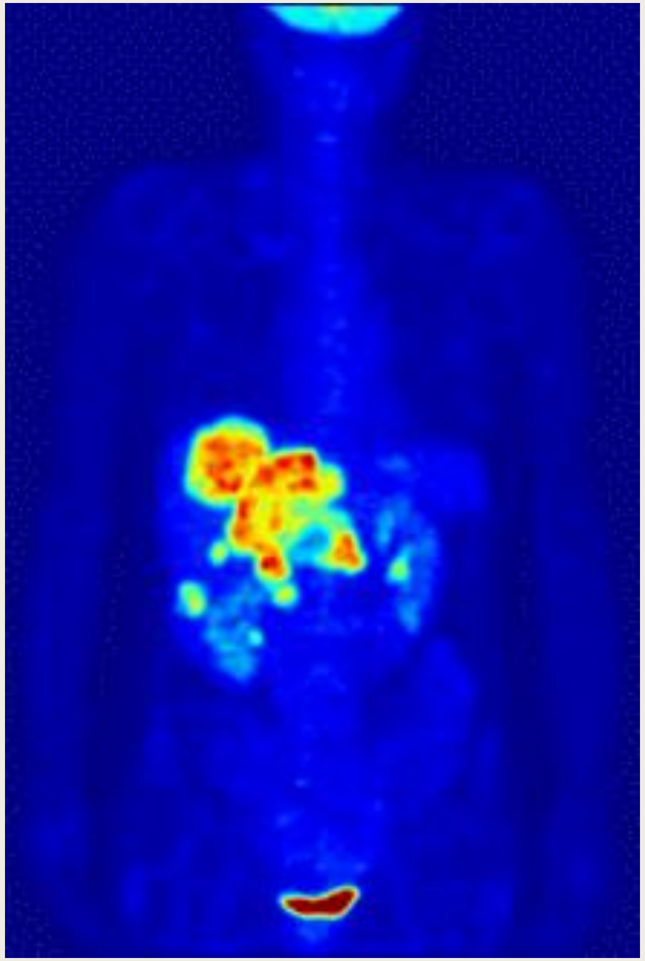
- Positron emission is the decay of a nucleus by emitting a positron (**β^+**). For example, carbon-11, an artificial radioactive isotope of carbon, decays to boron-11 by loss of a β^+ particle. Positron emitters are used in a relatively new diagnostic technique, positron emission tomography (PET)



In positron emission, one proton of the original nucleus decays to a β+ particle and a neutron. ***As a result, the new nucleus has one fewer proton and one more neutron than the original nucleus.***

PROBLEM

Write a balanced nuclear equation for the positron emission of Fluorine-18, a radioisotope used for imaging in PET scans.

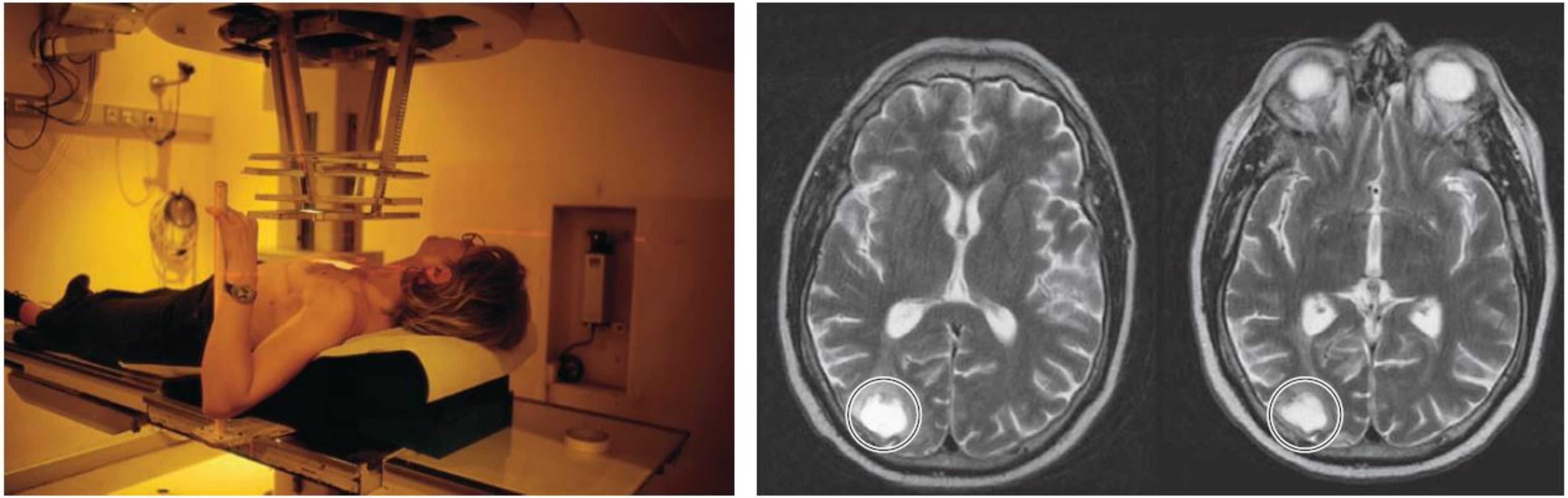


4.4. Gamma Emission

- Gamma emission is the decay of a nucleus by emitting **γ** radiation. Since γ rays are simply a form of energy, their emission causes no change in the atomic number or mass number of a radioactive nucleus. Gamma emission sometimes occurs alone. For example, one form of technetium-99, written as technetium-99m, is an energetic form of the technetium nucleus that decays with emission of γ rays to technetium-99, a more stable but still radioactive element.
- **Technetium-99m is a widely used radioisotope in medical imaging**. Because it emits high-energy **γ** rays but decays in a short period of time, it is used to image the brain, thyroid, lungs, liver, skeleton, and many other organs.

4.4. Gamma Emission

a. b. c.



a. Gamma radiation from the decay of cobalt-60 is used to treat a variety of tumors, especially those that cannot be surgically removed.

b. A tumor (bright area in circle) before radiation treatment

c. A tumor (bright area in circle) that has decreased in size after six months of radiation treatment

End