Radioactivity

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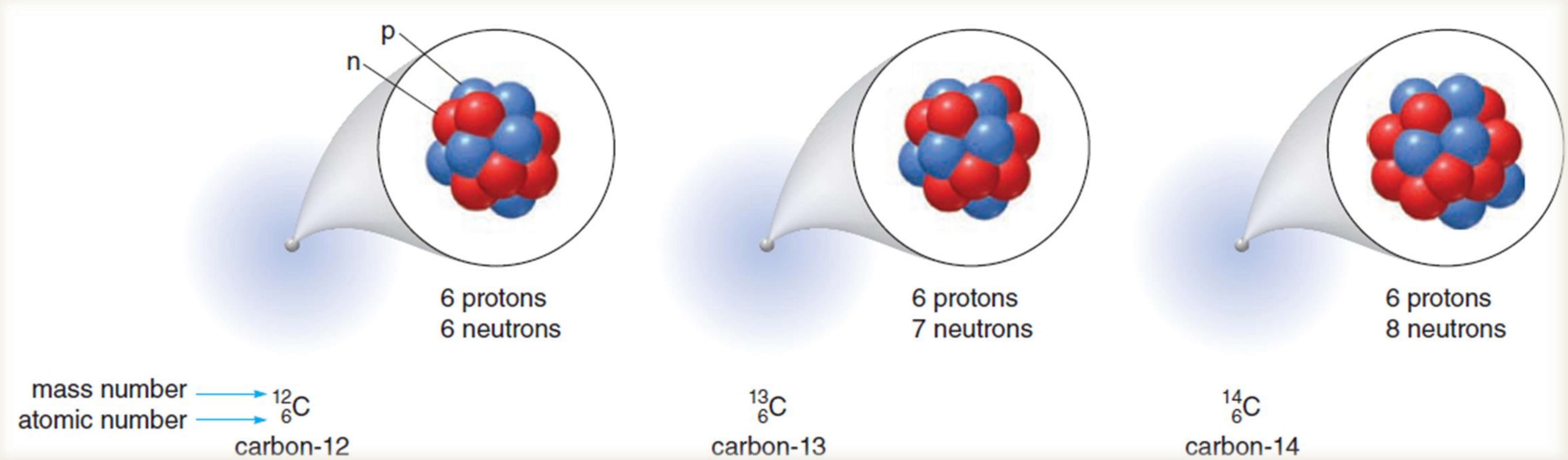
Lecture 5

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	${}^{123}_{53}\mathrm{I}$
Iodine-131	53	131	53	131 – 53 = 78	${}^{131}_{53}\mathrm{I}$

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.

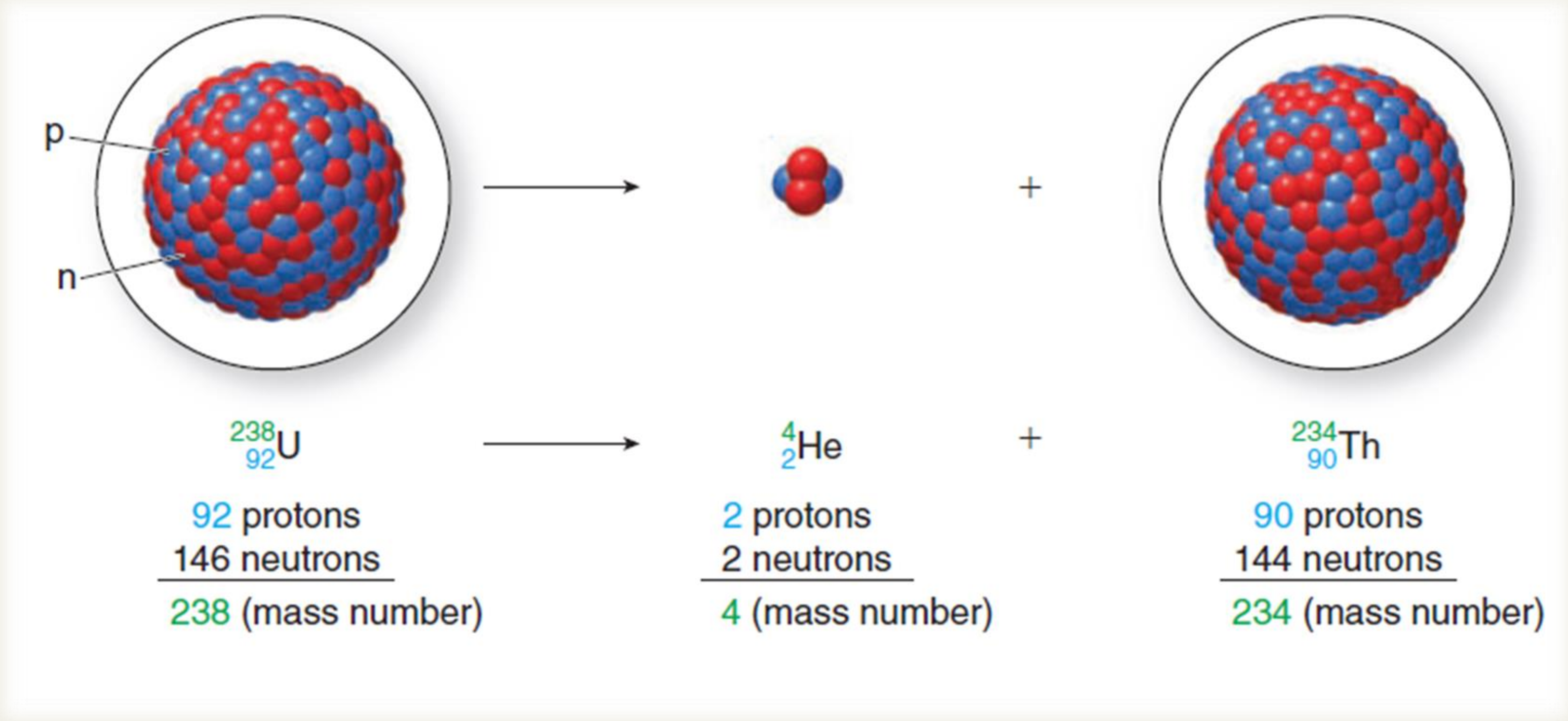
4. Nuclear Reactions

- ***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

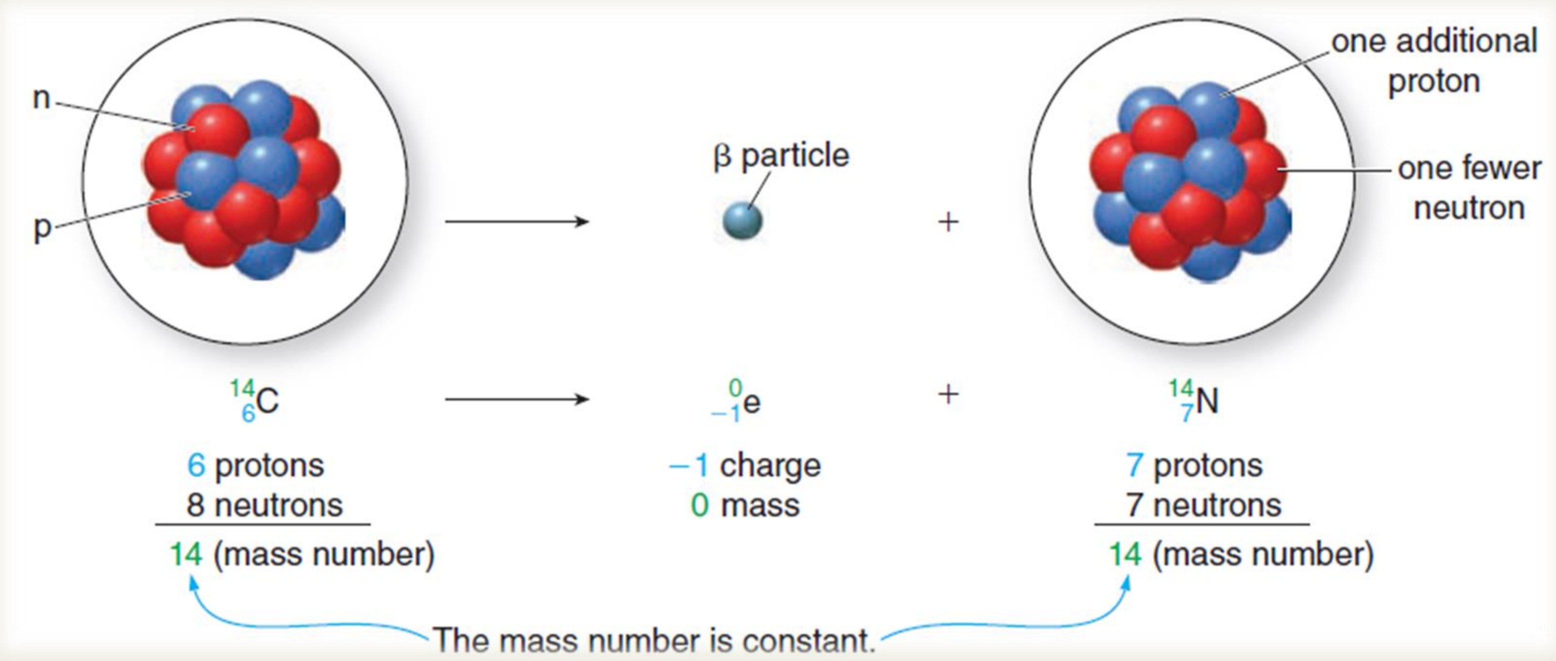
Radon, a radioactive gas formed in the soil, can cause lung cancers when inhaled in high concentrations for a long period of time. Write a balanced nuclear equation for the decay of radon-222, which emits an α particle.

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.

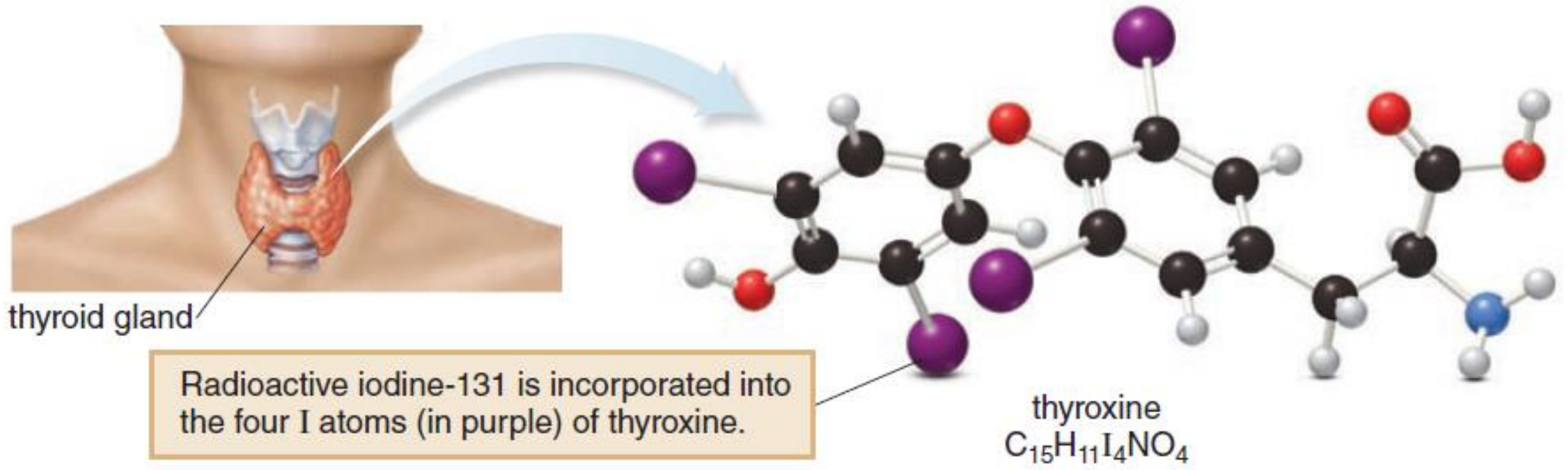
4.2.Beta Emission

- 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.



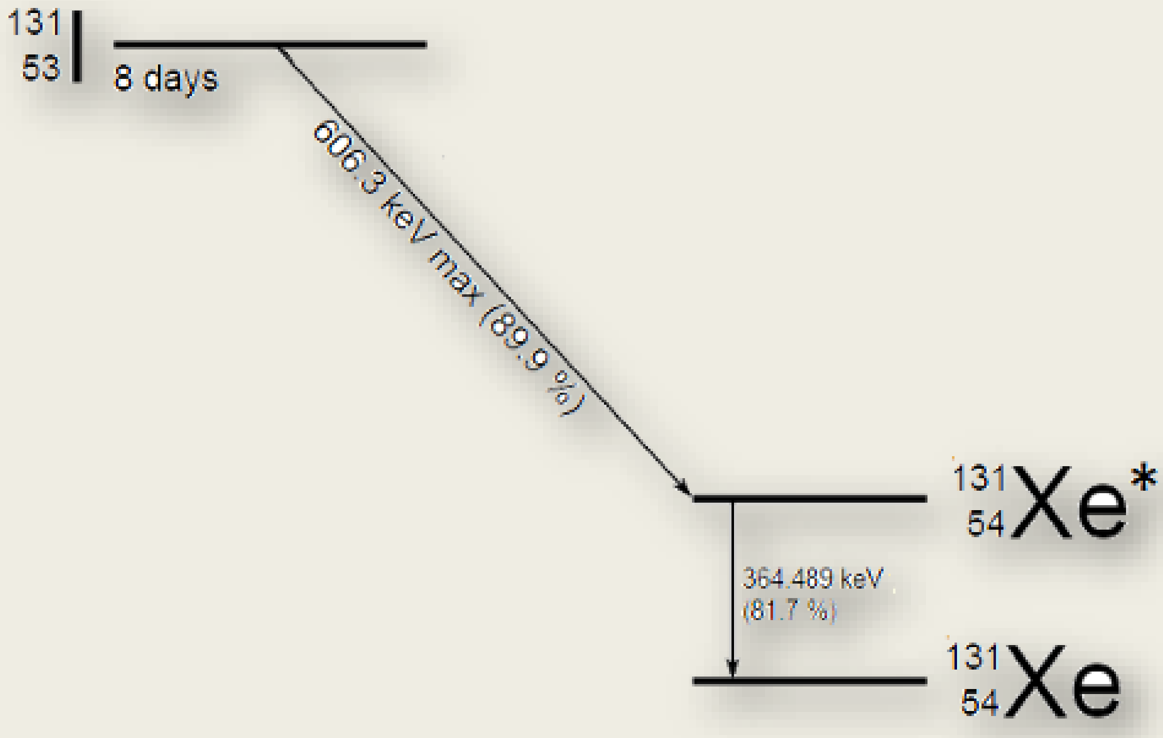
In β emission, one neutron of the original nucleus decays to a β particle and a proton. As a result, ***the new nucleus has one more proton and one fewer neutron than the original nucleus.***

- 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.

- Iodine-131 is readily absorbed by the follicular cells of the thyroid gland via the sodium/iodine symporter. As the atoms of iodine-131 accumulate in the thyroid, they eventually undergo a two-step radioactive decay process that releases high energy electrons and electromagnetic radiation in the form of gamma rays. These highly energetic electrons can penetrate and damage surrounding tissue within 2 mm from the source of emission. Roughly 90 percent of iodine-131 atoms decay into xenon-131

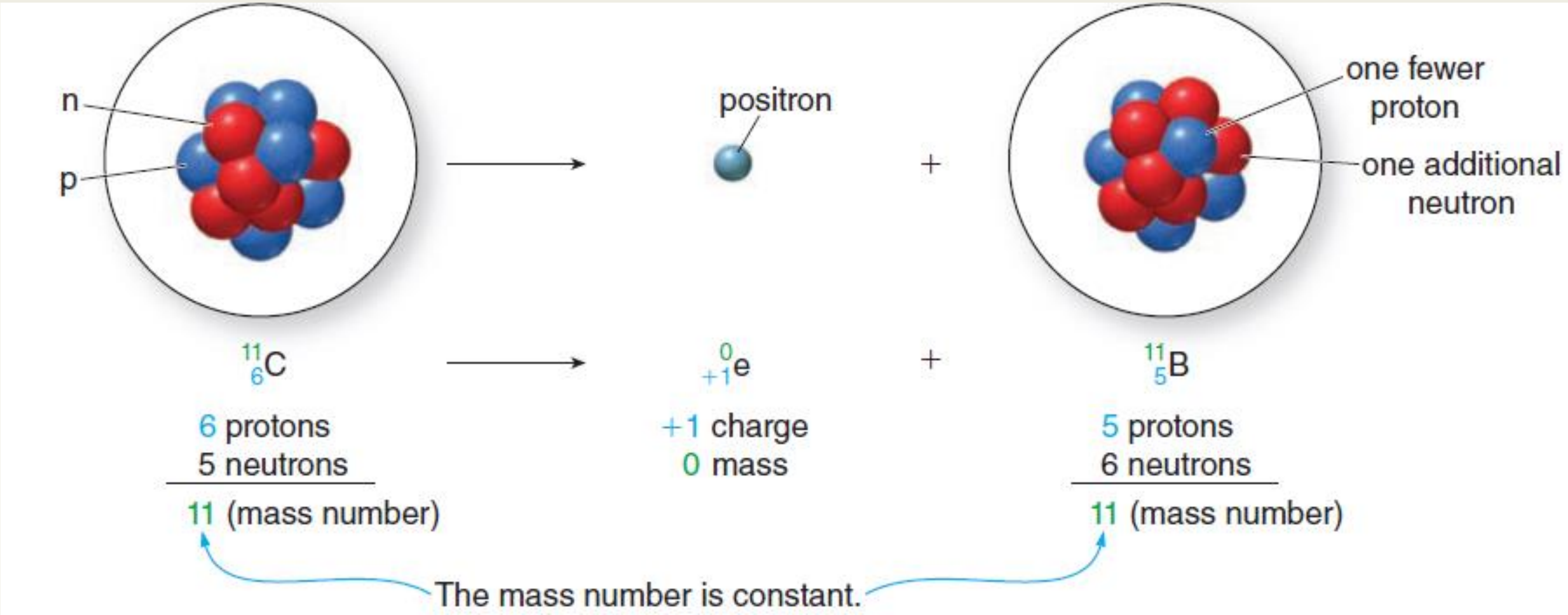


PROBLEM

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

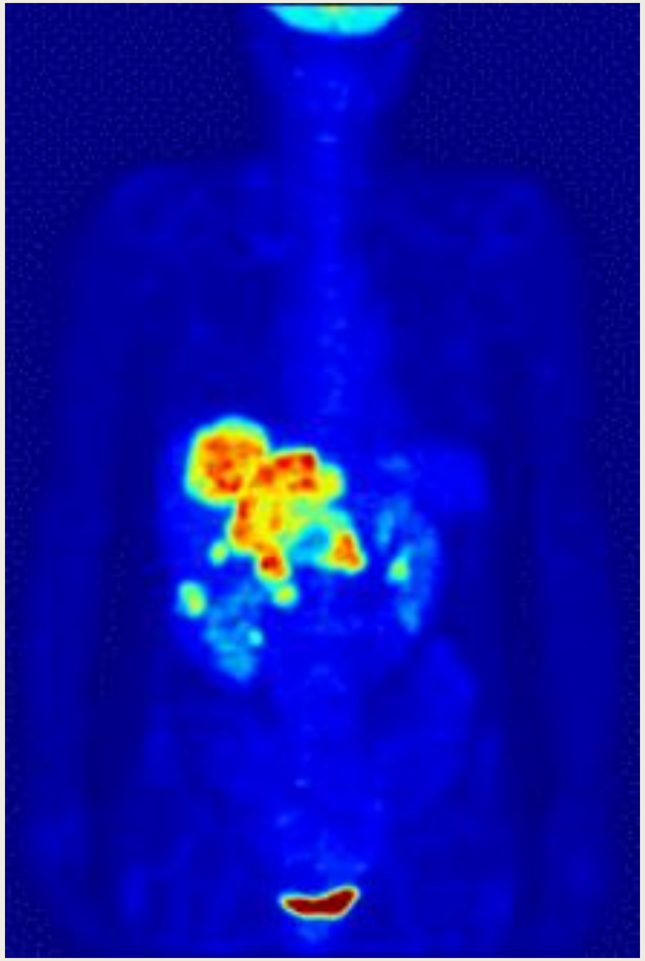
- Positron emission is the decay of a nucleus by emitting a positron (**β^+**). For example, carbon-11, an artificial radioactive isotope of carbon, decays to boron-11 by loss of a β^+ particle. Positron emitters are used in a relatively new diagnostic technique, positron emission tomography (PET)



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

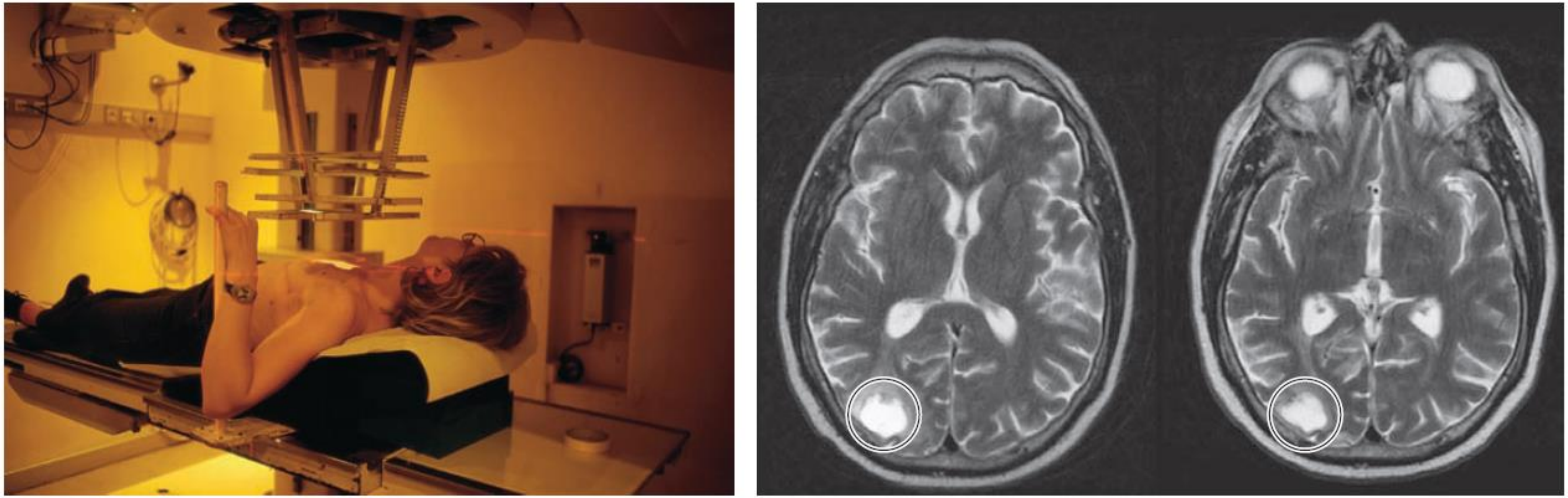
Write a balanced nuclear equation for the positron emission of Fluorine-18, a radioisotope used for imaging in PET scans.



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



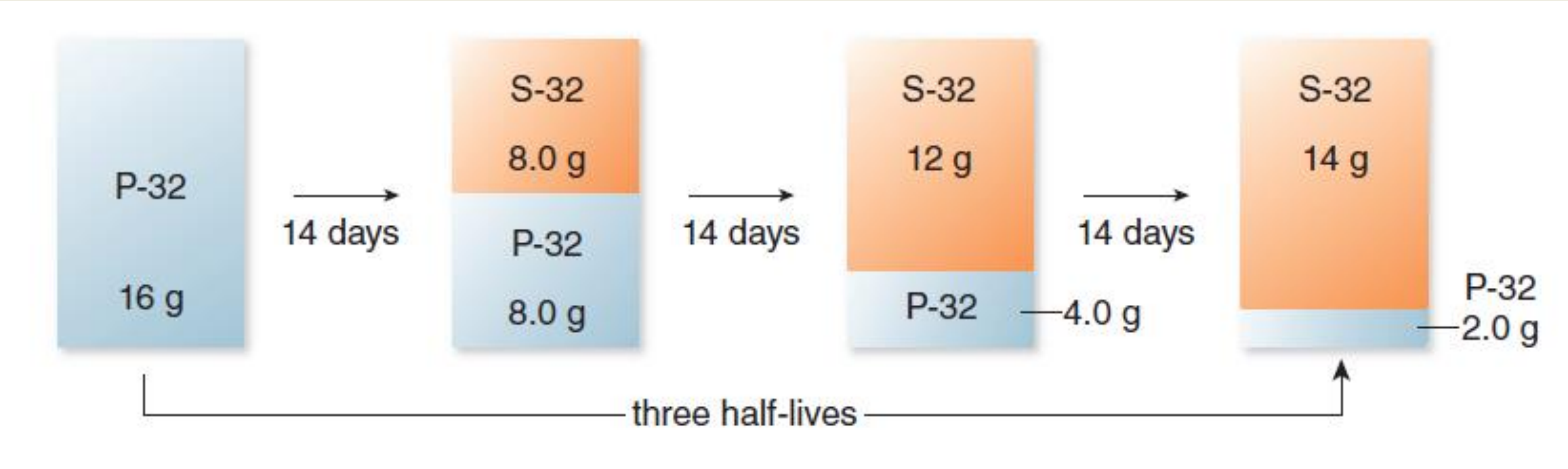
a. Gamma radiation from the decay of cobalt-60 is used to treat a variety of tumors, especially those that cannot be surgically removed.

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

5. Half-Life

- How fast do radioactive isotopes decay? It depends on the isotope.
- The half-life ($t_{1/2}$) **of a radioactive isotope is the time it takes for one-half of the sample to decay.**
- Suppose we have a sample that contains 16 g of phosphorus-32, a radioactive isotope that decays to sulfur-32 by β emission. Phosphorus-32 has a half-life of approximately 14 days. Thus, after 14 days, the sample contains only half the amount of P-32—8.0 g. After another 14 days (a total of two half-lives), the 8.0 g of P-32 is again halved to 4.0 g. After another14 days (a total of three half-lives), the 4.0 g of P-32 is halved to 2.0 g, and so on. Every 14 days, half of the P-32 decays.



Many naturally occurring isotopes have long half-lives. Examples include carbon-14 (5,730 years) and uranium-235 (7.0×10^8 years). Radioisotopes that are used for diagnosis and imaging in medicine have short half-lives so they do not linger in the body. Examples include technetium-99m (6.0 hours) and iodine-131 (8.0 days). **The half-life of a radioactive isotope is a property of a given isotope and is independent of the amount of sample, temperature, and pressure.**

Sodium-24 is a radioisotope used for examining circulation.

A. Write a balanced nuclear equation for the β decay of sodium-24.
B. If $t_{1/2}$ for Na-24 is 15 h, how much of an 84-mg sample remains after 2.5 days?
C. If the radioactivity of a 5.0-mL vial of sodium-24 is 10.0 mCi, what volume must be administered to give a 6.5-mCi dose?

6. Detecting and Measuring Radioactivity

- We all receive a miniscule daily dose of radiation from cosmic rays and radioactive substances in the soil. Additional radiation exposure comes from television sets, dental X-rays, and other man-made sources.
- **How can radiation be detected and measured when it can’t be directly observed by any of the senses?**
- A Geiger counter is a small portable device used for measuring radioactivity. It consists of a tube filled with argon gas that is ionized when it comes into contact with nuclear radiation. This in turn generates an electric current that produces a clicking sound on a meter. Geiger counters are used to locate a radiation source or a site that has become contaminated by radioactivity.

6. Detecting and Measuring Radioactivity

- The amount of radioactivity in a sample is measured by the number of nuclei that decay per unit time-disintegrations per second. **The most common unit is the curie (Ci)**, and smaller units derived from it, the millicurie (mCi) and the microcurie (μCi). One curie equals 3.7×10^{10} disintegrations/second, which corresponds to the decay rate of 1 g of the element radium.

- The becquerel (Bq), an SI unit, is also used to measure radioactivity; 1 Bq = 1 disintegration/second. Since each nuclear decay corresponds to one becquerel, 1 Ci = 3.7×10^{10} Bq.

Table 9.3 Units Used to Measure Radioactivity

1 Ci	=	3.7×10^{10} disintegrations/s
1 Ci	=	3.7×10^{10} Bq
1 Ci	=	1,000 mCi
1 Ci	=	1,000,000 μCi

PROBLEM

A patient must be given a 4.5-mCi dose of iodine-131, which is available as a solution that contains 3.5 mCi/mL. What volume of solution must be administered?

The curie is named for Polish chemist Marie Skłodowska Curie who discovered the radioactive elements polonium and radium, and received Nobel Prizes for both Chemistry and Physics in the early twentieth century.

7. Medical Uses of Radioisotopes

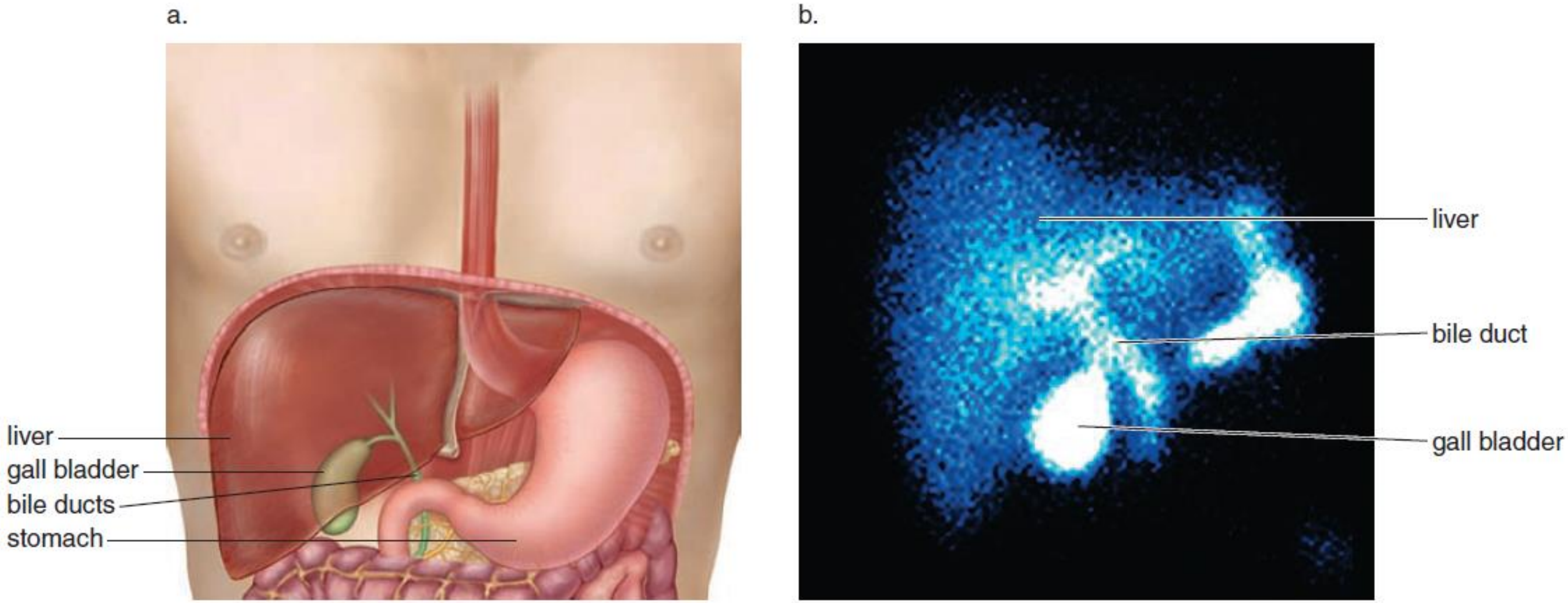
- Radioactive isotopes are used for both diagnostic and therapeutic procedures in medicine.

7.1. Radioisotopes Used in Diagnosis

- Radioisotopes are routinely used to determine if an organ is functioning properly or to detect the presence of a tumor. The isotope is ingested or injected and the radiation it emits can be used to produce a scan.
- The radioactive atom is bonded to a larger molecule that targets a specific organ. An organ that has increased or decreased uptake of the radioactive element can indicate disease, the presence of a tumor, or other conditions.

- A HIDA scan (hepatobiliary iminodiacetic acid scan) uses a technetium-99m-labeled molecule to evaluate the functioning of the gall bladder and bile ducts After injection, the technetium-99m travels through the bloodstream and into the liver, gall bladder, and bile ducts, where, in a healthy individual, the organs are all clearly visible on a scan. When the gall bladder is inflamed or the bile ducts are obstructed by gallstones, uptake of the radioisotope does not occur and these organs are not visualized because they do not contain the radioisotope.
- Red blood cells tagged with technetium-99m are used to identify the site of internal bleeding in an individual.
- Bone scans performed with technetium-99m can show the location of metastatic cancer, so that specific sites can be targeted for radiation therapy.

Figure 9.4 HIDA Scan Using Technetium-99m

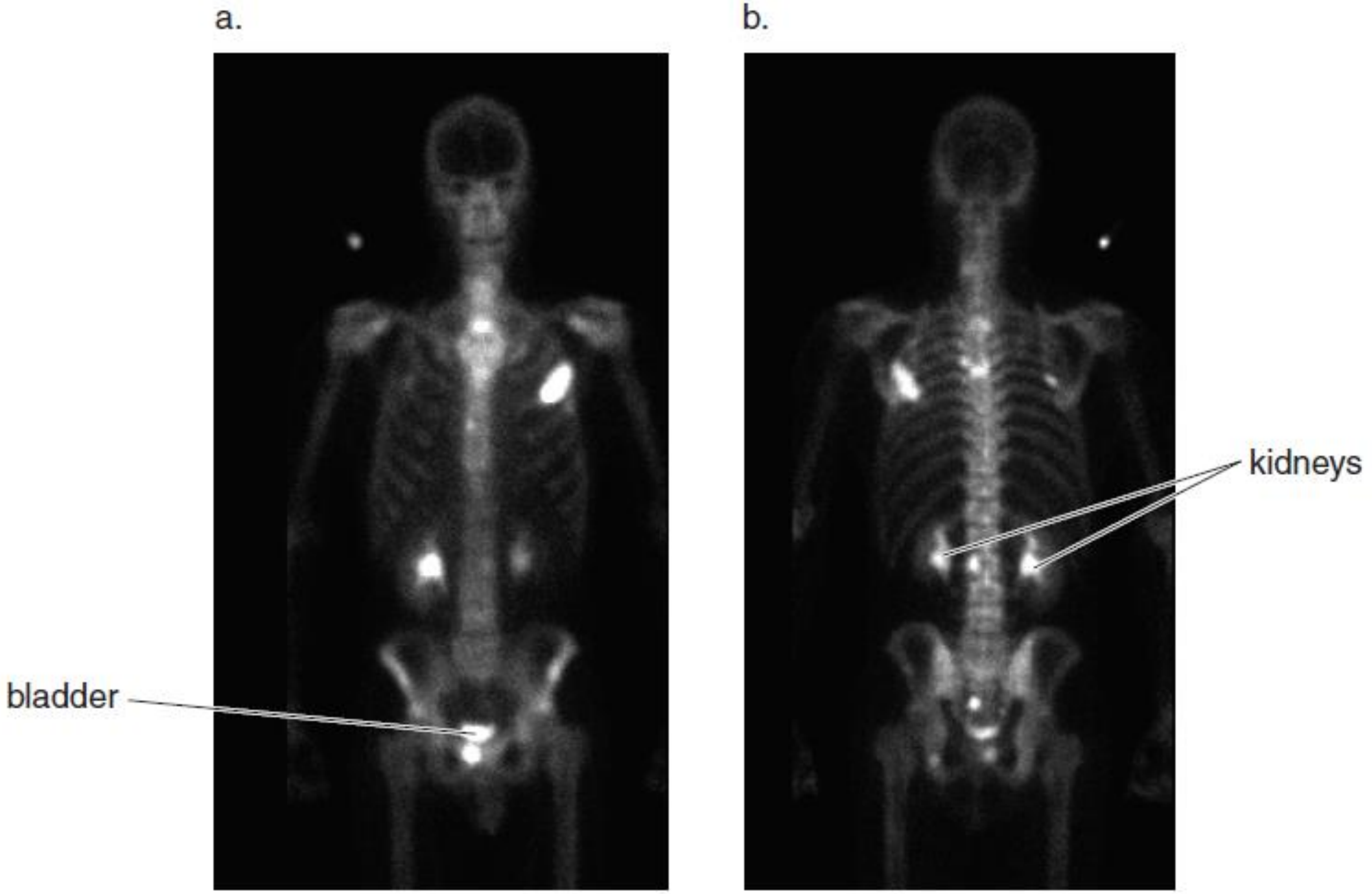


a. Schematic showing the location of the liver, gall bladder, and bile ducts

b. A scan using technetium-99m showing bright areas for the liver, gall bladder, and bile ducts, indicating normal function

Figure 9.5

Bone Scan Using Technetium-99m



The bone scan of a patient whose lung cancer has spread to other organs. The anterior view [from the front in (a)] shows the spread of disease to the ribs, while the posterior view [from the back in (b)] shows spread of disease to the ribs and spine. The bright areas in the mid-torso and lower pelvis are due to a collection of radioisotope in the kidneys and bladder, before it is eliminated in the urine.

7.2. Radioisotopes Used in Treatment

- The high-energy radiation emitted by radioisotopes can be used to kill rapidly dividing tumor cells. Two techniques are used. Sometimes the radiation source is external to the body.
- For example, a beam of radiation produced by decaying cobalt-60 can be focused at a tumor. Such a radiation source must have a much longer half-life—5.3 years in this case—than radioisotopes that are ingested for diagnostic purposes. **With this method some destruction of healthy tissue often occurs, and a patient may experience some signs of radiation sickness, including vomiting, fatigue, and hair loss.**

8. Medical Imaging Without Radioactivity

- **X-rays, CT scans**, and **MRIs** are also techniques that provide an image of an organ or extremity that is used for diagnosis of a medical condition. Unlike PET scans and other procedures discussed thus far, however, these procedures are not based on nuclear reactions and they do not utilize radioactivity. In each technique, an energy source is directed towards a specific region in the body, and a scan is produced that is analyzed by a trained medical professional.

End