Chapter 4

Basic Physics for Radiography

Learning Objectives

At the conclusion of this chapter, you will be able to:

- Define matter and list its three forms
- Name the fundamental particles of the atom and list characteristics of each
- Draw or describe a conceptual model of atomic structure
- List and describe five forms of energy
- Draw a sine wave and measure its amplitude and its wavelength
- Relate the wavelength of a sine wave to its velocity and frequency
- Compare and contrast the characteristics of x-rays with the characteristics of visible light
- Explain the relationships between potential difference, current, and resistance in an electric circuit and state the units used to measure each
- State the frequency of alternating current in the United States and Canada using the correct units
- Describe the process of electromagnetic induction
- Draw simple diagrams of a step-up transformer and a step-down transformer

Key Terms

ampere (A)
atom
atomic number
binding energy
chemical compound
circuit
conductor
current
electromagnetic energy
electromagnetic induction
electron
element
frequency
ion
ionization
K-shell
kilovolt peak (kVp)
mass
matter
milliampere (mA)
molecules
neutron
nucleus
photon
potential difference
proton
rectification
resistance (R)
sine wave
transformer
volt (V)
wavelength

Limited operators do not require an extensive background in physics, but some basic principles of physical science are essential to an understanding of x-rays and their use. This chapter covers the basic concepts of **matter**, energy, and electricity and relates these principles to radiography. It also discusses the nature of radiation.

If your educational background includes coursework in physics or chemistry, this chapter will provide a comprehensive review of the pertinent material. If you are unfamiliar with these subjects, it will be important for you to master them so that you can relate well to the material that follows.

Everything of a physical nature in the universe can be classified as either matter or energy. Both matter and energy can exist in several forms.

MATTER

Matter is defined as anything that occupies space and has shape or form. The three basic forms of matter are solids, liquids, and gases. The quantity of matter that makes up any physical object is called its **mass**. Although the scientific definitions differ somewhat, mass is essentially the same thing we think of as "weight." An object may change in form, but its mass is unchangeable. For example, a 20 lb bucket of water may freeze into a 20 lb bucket of ice or it may evaporate, resulting in 20 lb of water vapor. The form changes, but the mass remains the same.

Laws of Conservation

Matter can be neither created nor destroyed, but it can change form.
Energy can be neither created nor destroyed, but it can change form.

Atoms

All matter is composed of "building blocks" called **atoms**. Scientists have determined that atoms may be made up of nearly 100 different subatomic particles, but only three basic particles concern us here. The fundamental particles that compose atoms are **neutrons, protons**, and **electrons**. All neutrons are identical, as are all protons and all electrons. It is the number and arrangement of these particles in the atom that account for the differences in matter.

The neutrons and protons together form the **nucleus** of the atom, its center. The electrons circle the nucleus in orbits called *shells*. A useful model for visualizing atomic structure is that of the solar system, with the nucleus as the sun and the electrons as planets in orbit around the sun (Fig. 4.1). This model was first described by Niels Bohr in 1913 and is referred to as *Bohr's atom*.

Atomic particles differ from one another with respect to electric charge. Neutrons are electrically neutral (0); that is, they have no electric charge. Protons have a positive charge (+). Electrons have a negative charge (−); that is, their charge is equal to, but opposite, the charge of a proton. A particle's charge is important because it results in a magnetic effect. Opposite charges attract one another, seeking a neutral state, and like charges repel one another. Neutral particles neither attract nor repel and are not attracted or repelled by charged particles. Table 4.1 contains a summary of the characteristics of the fundamental atomic particles.

In its "normal" or neutral state, an atom has an equal number of protons and electrons, so the electric charges are balanced and the atom as a whole has no charge. The electrons are arranged in their orbits, with a specific number of electrons allotted to each shell. The shells are lettered alphabetically, beginning with the letter K nearest the nucleus (Fig. 4.2). From the nucleus outward, each additional shell is greater in size and can accommodate a larger number of electrons than the previous shell. Table 4.2 lists atomic shells with their letter symbols and the maximum number of electrons in each. Different types of atoms will have different numbers of electrons in their shells up to the maximum shown. From a radiography standpoint, the most important shell is the **K-shell**. The removal of electrons in this shell is one way in which x-rays are created.

Each of the electrons around the nucleus is in continuous motion. The distance that the shell is from the nucleus determines the energy level of the electron. The electrons

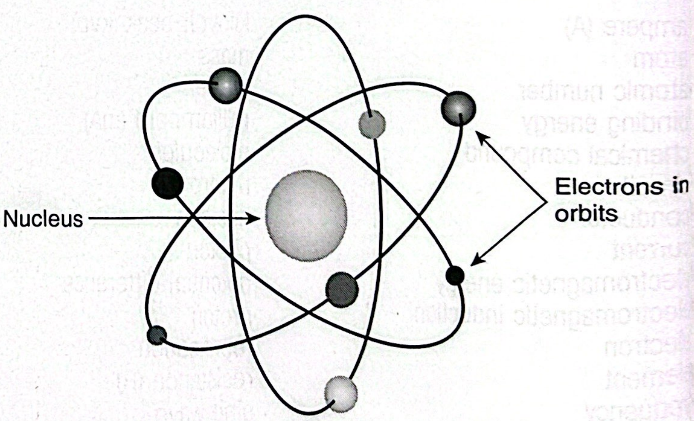


Fig. 4.1 Bohr's concept of the atom.

TABLE 4.1
Fundamental Atomic Particles

Particle	Location	Mass Number	Charge
Proton	Nucleus	1	+1
Neutron	Nucleus	1	0
Electron	Orbital shells		−1

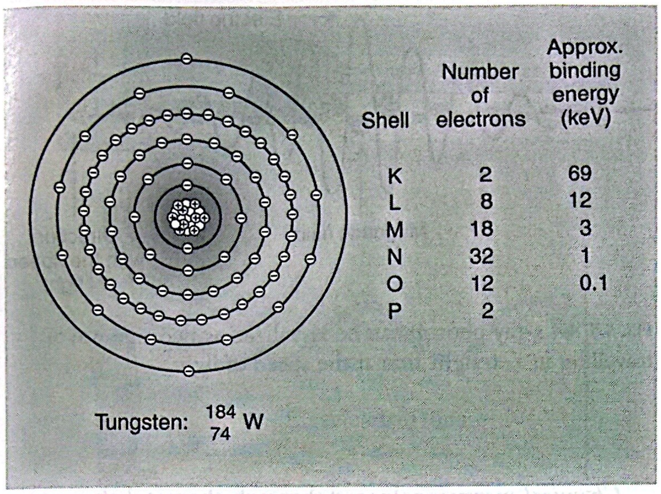


Fig. 4.2 Atomic configuration for tungsten. Note shell number and number of electrons in each shell. Binding energy is higher for shells closer to the nucleus.

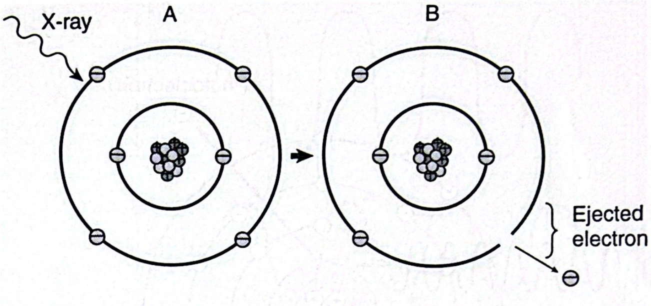


Fig. 4.3 Atom of carbon, which makes up 18% of human tissue. During an x-ray, many carbon atoms will be ionized. (A) X-ray entering the neutral atom. (B) An outer shell electron is ejected, leaving more protons than electrons. This atom is positively charged and ionized. The x-ray is scattered to another atom or outside the body.

TABLE 4.2
Electron Shells

Shell Number	Shell Symbol	Maximum Number of Electrons
1	K	2
2	L	8
3	M	18
4	N	32
5	O	50
6	P	72
7	Q	98

are held in place by a **binding energy**, with electrons nearest the nucleus attached with greater binding energy than those in outer shells. The binding energy of each shell varies for different atoms; larger atoms have greater binding energy than smaller ones.

Elements

The essential characteristic of an atom that determines its type is the number of protons in the nucleus. An **element** is a substance made up of only one type of atom; that is, all atoms of an element have the same **atomic number**. Scientists have identified 118 different elements; many of these are rare, and some of them are human made. Each element has a name and a chemical symbol consisting of one or two letters, and three common elements we may be familiar with are calcium (Ca), iodine (I), and lead (Pb). Each element also has an atomic number that represents the number of protons in the nucleus. The atomic numbers for the three elements described are 20, 53, and 82, respectively. The greater the atomic number, the greater is the element's mass and density. In radiology, a lead bullet inside a body would be easier to see on an x-ray than a calcium stone because of lead's greater atomic number and density. The mass number of the element is the combined total of the protons and neutrons in the nucleus. One of the most important elements used in the production of x-rays is tungsten, which is the element inside the x-ray tube where the x-rays are created (discussed in Chapter 5). Tungsten (see Fig. 4.2) is represented by the symbol W and its atomic number is 74. Its mass number is 184, indicating that the nucleus contains 74 protons and 110 neutrons. The number of neutrons is determined by subtracting the atomic number from the mass number.

Two or more atoms may combine chemically to form **molecules**. This combination occurs with the sharing of one or more outer shell electrons between atoms. A substance that consists of only one type of molecule is called a **chemical compound**. Water is an example of a chemical compound. Its chemical symbol is H_2O, indicating that it is made up of two atoms of hydrogen and one atom of oxygen. Substances that contain more than one type of molecule are called *mixtures*.

Ionization

When a neutral atom gains or loses an electron, it is called an **ion** and the atom is said to be ionized. This process, which is called **ionization**, produces an atom with an electric charge. If an electron is added to a neutral atom, electrons will outnumber the protons and the atom will have a negative charge. If an electron is removed, there will be more protons than electrons, so the atom will have a positive charge. Because the outer orbital electrons are not tightly bound to the nucleus, the application of a small amount of energy can remove an outer orbital electron from the atom (Fig. 4.3).

A familiar example of ionization is the "bad hair day" that occurs when the weather is cold and dry. The friction of a hairbrush removes electrons from atoms in the hair. In very dry air, the electrons cannot readily return to their

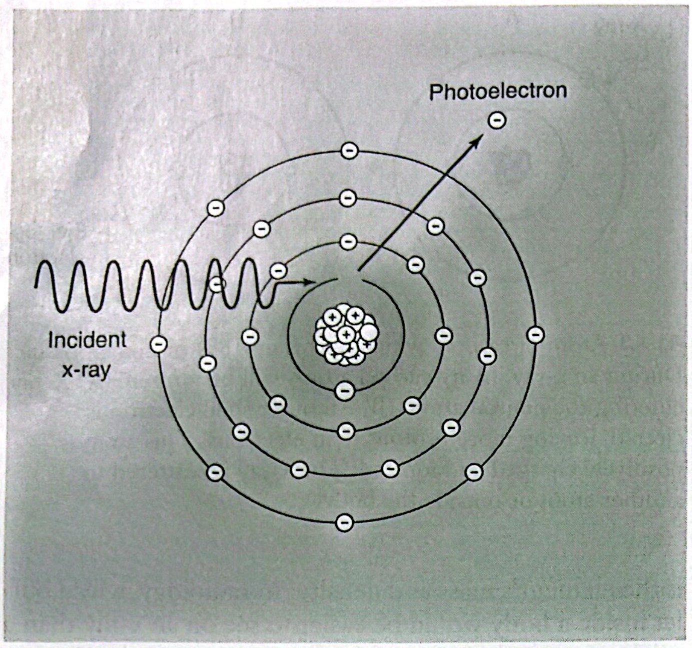


Fig. 4.4 X-ray entering an atom in the human body and interacting with an inner shell electron (K-shell) and causing ionization. The x-ray becomes totally absorbed. The K-shell electron is ejected from the atom.

orbits, and each hair is left with a positive charge. Because like charges repel each other, the hairs are repelled from one another and will not lie smoothly together.

The term ionization is very important in the field of radiology. X-rays cause ionization in the atoms of the human body (Fig. 4.4), a fact that explains many of the negative effects of radiation discussed later in the text.

ENERGY

Energy is defined as the ability to do work. It occurs in several forms and can be changed from one form to another. Some familiar forms of energy include heat, light, and electricity. Scientists have categorized energy in various ways. One method classifies energy into the following types: mechanical, chemical, thermal, nuclear, electric, and electromagnetic.

Mechanical energy can be further classified as either kinetic energy or potential energy. Kinetic energy is energy of motion, the ability of a moving object to do work. For example, a bowling ball in motion has energy to knock down the pins. Potential energy can be thought of as "stored" energy. When a bowling ball has been lifted, the work required to raise it is "stored" in the ball because of its position. When the ball is released, its potential energy is also released and is converted into kinetic energy. In a later chapter you will learn that the x-ray tube has a very high potential energy before the exposure is made.

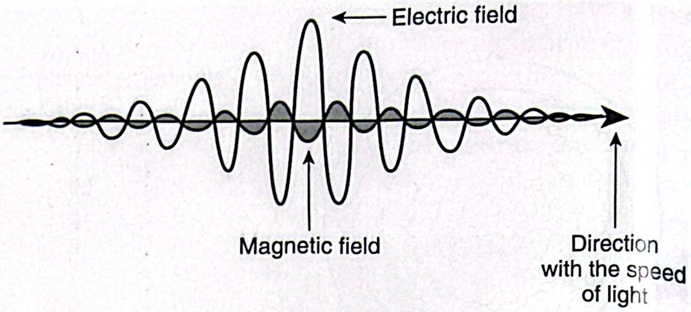


Fig. 4.5 An x-ray photon can be visualized as two sine waves travelling in a straight line at the speed of light.

Chemical energy is released through chemical changes in atoms or molecules. An example of chemical energy is fire. A gasoline engine converts the chemical energy of gasoline into mechanical energy. Chemical energy from the food we eat produces the energy required for muscle movement and many other vital processes.

Thermal energy is commonly called *heat* and is the result of atomic motion. As temperature rises, electrons move faster in their orbits and the orbits expand, which causes the electrons to move farther from the nucleus. This phenomenon explains why matter expands in size when heated and contracts when cooled. In a later chapter you will learn that the majority of energy created in the x-ray tube is converted to heat.

Nuclear energy is the energy released by radionuclides. This is the energy used to produce electricity in a nuclear power plant or the explosion of a nuclear bomb.

Electric energy, or electricity, is the ability of electric charges to do work. Although this process may seem mysterious, it is familiar to all of us. We use it to light our homes, run our computers, and make toast, for example. Electric energy also may exist in the form of potential energy. Potential electric energy exists in a battery or at an unused wall socket. When we turn on a flashlight or plug in an appliance, this potential energy is converted into electricity. Electric energy is important in producing x-rays because the standard low electric voltage is raised to very high levels in the x-ray machine.

Electromagnetic energy is the important energy we deal with every day in radiology. This energy consists of light, x-rays, radio waves, microwaves, and other forms of energy. These energies have both electric and magnetic properties, changing the field through which they pass both electrically and magnetically (Fig. 4.5). These changes in the field occur in the form of a repeating wave, a pattern that scientists call a *sinusoidal form* or **sine wave** (Fig. 4.6).

A more comprehensive understanding of electric energy and electromagnetic energy is essential to the limited operator. These energy forms are discussed in greater detail in the sections that follow.

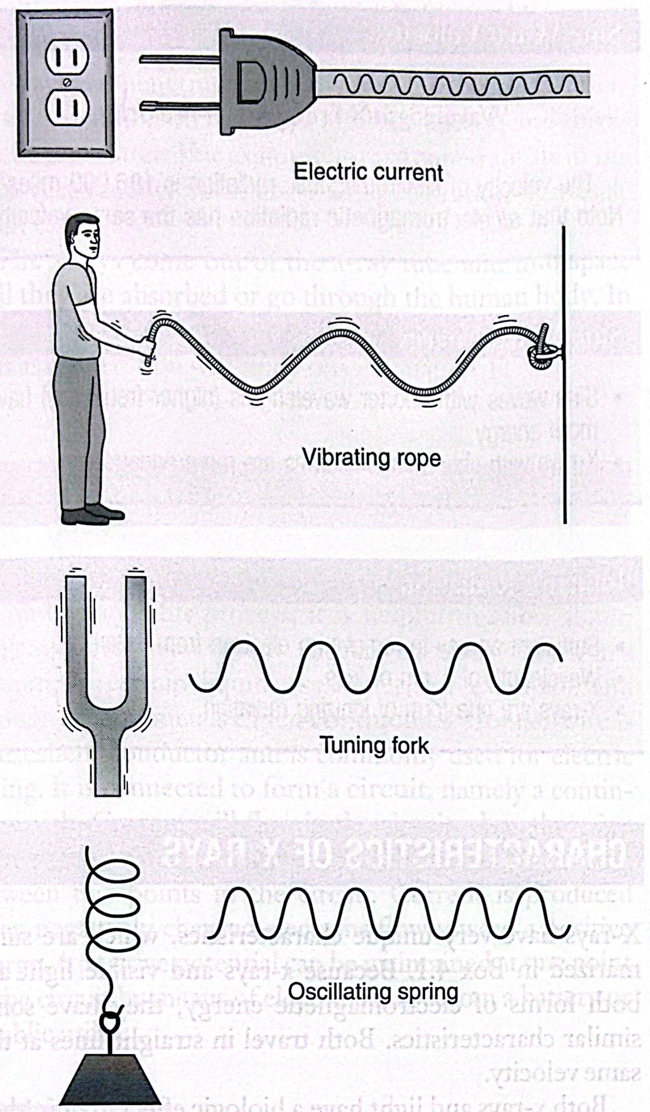


Fig. 4.6 Sine waves are energy expressed in a recurring waveform. Sine waves are associated with many naturally occurring phenomena, including electromagnetic radiation.

ELECTROMAGNETIC ENERGY

As stated earlier, electromagnetic energy occurs in the form of a sine wave. Several characteristics of this waveform are significant. The distance between the crest and the trough of the wave (its height) is called the amplitude (Fig. 4.7). More important in radiology is the distance from one crest to the next, or **wavelength** (Fig. 4.8). The **frequency** of the wave is the number of times per second that a crest passes a given point (Fig. 4.9).

Electromagnetic energy moves through space at the velocity (speed) of approximately 186,000 miles/s. All electromagnetic energy moves at the same velocity. When the wavelength is short, the crests are closer together, so more of them will pass a given point in a second, resulting in a higher frequency. Longer wavelengths will have a

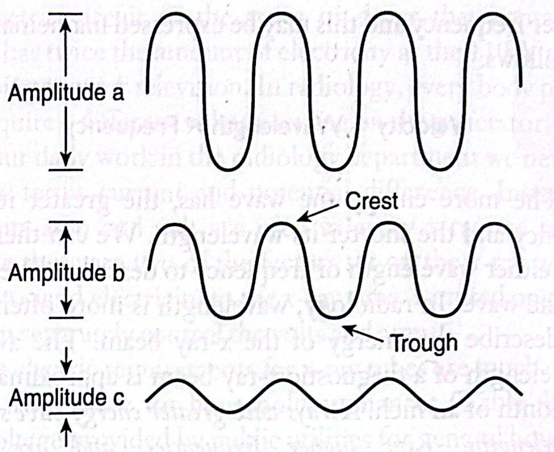


Fig. 4.7 Sine wave amplitude, the distance from crest to trough. These three sine waves are identical except for their amplitude.

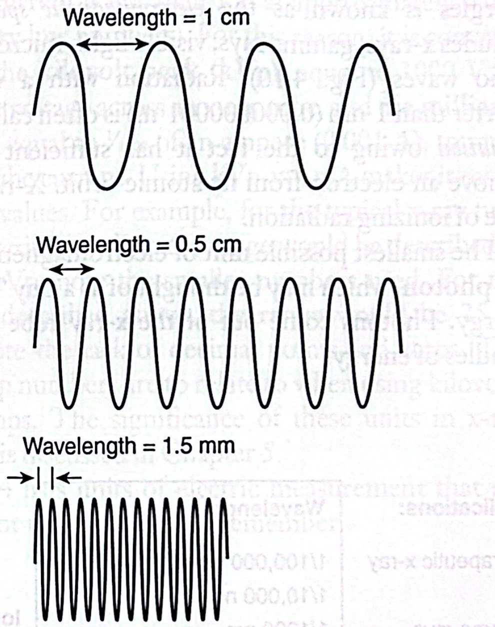


Fig. 4.8 Sine wave wavelength, the distance from crest to crest. These three sine waves have different wavelengths. The shorter the wavelength, the higher the frequency. An x-ray would appear like the bottom wavelength.

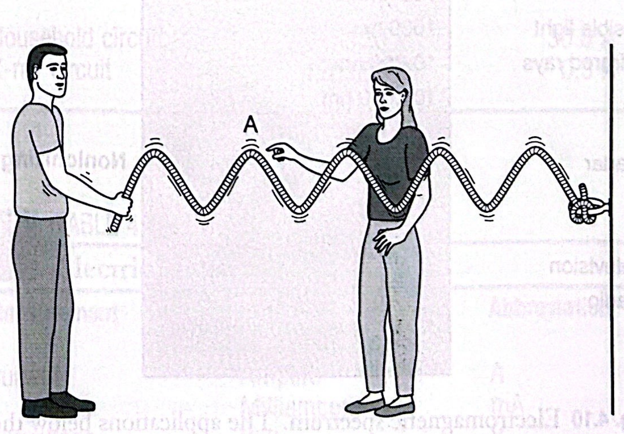


Fig. 4.9 Sine wave frequency, the number of crests or troughs that pass a fixed point per unit of time. The unit of time is typically 1 second.

lower frequency and this may be expressed mathematically as follows:

$$\text{Velocity} = \text{Wavelength} \times \text{Frequency}$$

The more energy the wave has, the greater its frequency and the shorter its wavelength. We can therefore use either wavelength or frequency to describe the energy of the wave. In radiology, wavelength is more often used to describe the energy of the x-ray beam. The average wavelength of a diagnostic x-ray beam is approximately a billionth of an inch. *X-rays with greater energy have shorter wavelengths, have higher frequencies, and are more penetrating.*

The wavelength of electromagnetic radiation varies from exceedingly short (even shorter than that of diagnostic x-rays) to very long (more than 5 miles). This range of energies is known as the *electromagnetic spectrum* and includes x-rays, gamma rays, visible light, microwaves, and radio waves (Fig. 4.10). Radiation with a wavelength shorter than 1 nm (0.000000001 m) is often called *ionizing radiation* owing to the fact it has sufficient energy to remove an electron from its atomic orbit. X-rays are one type of ionizing radiation.

The smallest possible unit of electromagnetic energy is the **photon**, which may be thought of as a tiny "bundle" of energy. Photons come out of the x-ray tube as discrete bundles of energy.

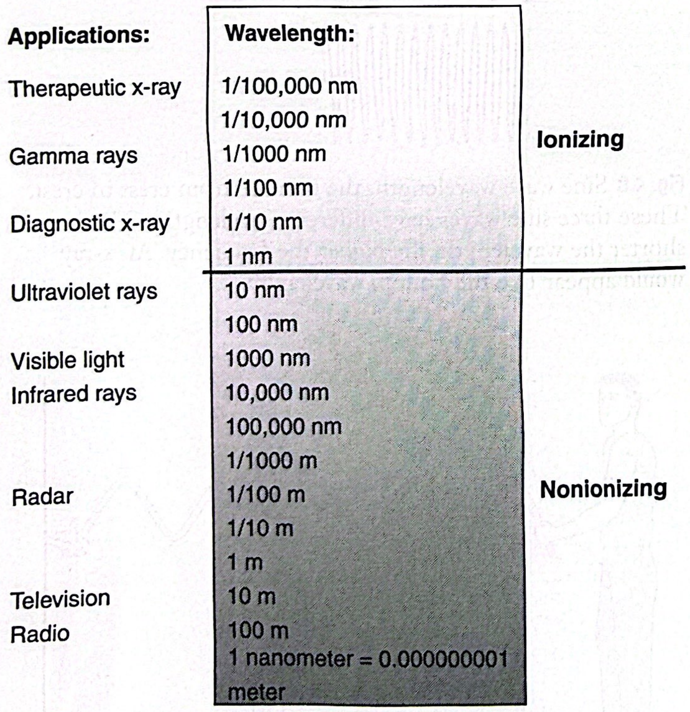


Fig. 4.10 Electromagnetic spectrum. The applications below the bold line are nonionizing because they have longer wavelengths. Note x-rays appear above the bold line. X-rays' very short wavelengths enable them to ionize tissues.

Sine Wave Velocity

Wavelength × Frequency = Velocity

The velocity of electromagnetic radiation is 186,000 miles/s. Note that *all* electromagnetic radiation has the same velocity.

Sine Wave Energy

- Sine waves with shorter wavelengths (higher frequency) have more energy.
- X-rays with shorter wavelengths are more penetrating.

Ionizing Radiation

- Sufficient energy to remove an electron from its orbit.
- Wavelength of 1 nm or less.
- X-rays are one form of ionizing radiation.

CHARACTERISTICS OF X-RAYS

X-rays have very unique characteristics, which are summarized in Box 4.1. Because x-rays and visible light are both forms of electromagnetic energy, they have some similar characteristics. Both travel in straight lines at the same velocity.

Both x-rays and light have a biologic effect; that is, they can cause changes in living organisms. For example, excessive exposure to either sunlight or x-rays may cause burns to the skin. X-rays are capable of producing more harmful effects than light because of their greater energy.

Unlike light, x-rays cannot be detected by the human senses. This fact may seem obvious, but it is important to consider. If x-rays could be seen, felt, or heard, we would have an increased awareness of their presence, and radiation safety might be much simpler. Because x-rays are undetectable, safety requires that you learn to know when

Box 4.1
Characteristics of X-Rays

- Have no mass
- Are highly penetrating and invisible
- Are electrically neutral
- Produced over a wide range of energies and wavelengths
- Travel in straight lines at the speed of light
- Can ionize matter
- Produce biologic changes in tissues
- Produce secondary and scatter radiation

and where x-rays are present despite being unable to perceive them.

X-rays can penetrate matter. This penetration is differential, depending on the mass, atomic number, and thickness of the matter. For example, x-rays penetrate air in the lungs very readily, but there is less penetration of muscle or bone.

The x-rays come out of the x-ray tube and into space until they are absorbed or go through the human body. In the body they can produce biologic changes in tissues, such as cancer. You will study this in Chapter 11.

ELECTRICITY

X-ray energy is human made and is produced electrically. To understand this process, it is helpful to know something about electric current. Electric current will flow in a vacuum, in certain liquids (saltwater, for example), and through certain metals called **conductors**. Copper wire is an excellent conductor and is commonly used for electric wiring. It is connected to form a **circuit**, namely a continuous path. Current will flow in the circuit when there is a difference in electric charge – a **potential difference** – between two points in the circuit. Current is produced when negatively charged electrons flow toward a positive charge. A positive potential can be maintained at one point in the circuit by means of electric energy from a battery or a public utility.

Electric Units

Three electric factors are part of an electric circuit: resistance, current, and potential difference. Practically, only current and potential difference are important in our understanding of how x-rays are created from an electric circuit.

Resistance is any property of the circuit that opposes or hinders the flow of current. The unit used to measure resistance is the ohm, represented by the Greek letter omega (Ω). Resistance depends on several factors: the material of the conductor, its length, and its diameter. The longer the conductor, the more resistance it will provide. Resistance is decreased when the wire diameter is greater.

Current is the *quantity* of electrons flowing in a circuit. The **ampere**, abbreviated A, is the unit used to measure the *rate*, or *volume*, of *current flow* in the circuit. In your home the electric circuit to the toaster may require 8 amps and the circuit to a lamp may require only 1 amp. In radiology, every body part will require a different amperage setting on the generator.

Potential difference is the *force*, or *speed*, of the electron flow in the current. The **volt**, abbreviated V, is the unit used to measure potential difference. In your home the electric circuit to the stove or dryer that contains 220 V has twice the amount of electricity as the 110 V circuit going to your television. In radiology, every body part will require a different voltage setting on the generator.

In our daily work in the radiology department we never use the terms current and potential difference. Instead, the units amp and volt are used in every x-ray we take because these are two of the factors set on the x-ray generator to send electricity to the x-ray tube. Limited operators can separately control the volts and amps.

The electric requirements for x-ray tubes are much different from those for household appliances (Table 4.3). The voltage provided by public utilities for general household use is 120 V, and a common household circuit has a current of 15 to 30 A. X-ray tubes use much greater voltage and less amperage. A typical x-ray tube operates at a range of 40,000 to 125,000 V (very high numbers). The x-ray tube current is less than 1 A at approximately 0.025 to 0.5 A (very low numbers). For this reason, it is convenient to use the **kilovolt peak (kVp)**, equal to 1000 V, to measure the voltage across an x-ray tube, and the **milliampere (mA)**, equal to 1⁄1000 of an ampere (0.001 A), to measure x-ray tube current. Using kVp and mA makes it easier to relate to values. For example, for the typical x-ray tube voltages described earlier, the range would be described as 40 to 125 kVp; note the smaller numbers used. For the amperages described above, the range would be 25 to 500 mA; note the lack of decimal points and zeros. The volt and amp numbers are to relate to when using kilovolts and milliamps. The significance of these units in x-ray production is discussed in Chapter 5.

Table 4.4 lists units of electric measurement that are important for radiographers to remember.

TABLE 4.3
Electric Supply Requirements: Household Versus X-Ray Tube

	Volts	Amps
Household circuit	120 V	30.0 A
X-ray circuit	120,000 V	0.3 A

TABLE 4.4
Electric Units

Measurement	Unit	Abbreviation
Current	Ampere	A
	Milliampere	mA
Kilovoltage	Volt	V
	Kilovolt peak	kVp

Electric Circuits

An electric circuit is a continuous path for the flow of electric charges from the power source through one or more electric devices and back to the source (Fig. 4.11). Electric circuit diagrams are "maps" of circuits that show how current flows through the devices connected in the circuit. Table 4.5 contains some common symbols used in these diagrams. Circuit diagrams are used in this text to demonstrate electric principles and to explain the function of the x-ray machine, so it will be helpful for you to become familiar with these symbols.

Direct Current and Alternating Current

The electric service provided by a public utility is in the form of alternating current (AC). The polarity (positive or negative electric potential) of the power source reverses at regular intervals, causing the current to flow first in one direction, then in the opposite direction (Fig. 4.12). The change is not instantaneous. In a household circuit, for example, the electric cycle begins with the voltage at 0, increases to a *positive* 120 V, where it peaks, and then declines to 0 again. At this point the polarity changes and the voltage increases from 0 to a *negative* 120 V, peaks, and again returns to 0 (Fig. 4.13). In the United States and Canada, public utilities deliver AC at a frequency of 60 cycles/s. The unit of electromagnetic frequency is the *hertz (Hz)*; thus the duration of each cycle is 1/60 second. Half a cycle is called an *impulse*. There are 120 impulses/s with 60 Hz AC, so the duration of 1 impulse is 1/120 s. In radiology, high-frequency generators are used and for these the frequency is increased from 60 Hz to as high as 6000 Hz. These are described in Chapter 6.

This alternating polarity produces electric current that is constantly changing. The current flow increases, peaks, and declines as the voltage changes. The current flow changes direction when the polarity changes.

AC can be converted so that it flows in one direction only. This process is called **rectification.** The x-ray tube cannot produce x-rays unless the current is rectified. Rectified AC is sometimes also referred to as *direct current*; it differs from direct current (DC) produced by a battery in that it is pulsating rather than constant (Fig. 4.14). In the x-ray room, electricity comes in as AC, 120 V, 90 As, 60 Hz. The **transformer** of the x-ray machine will change

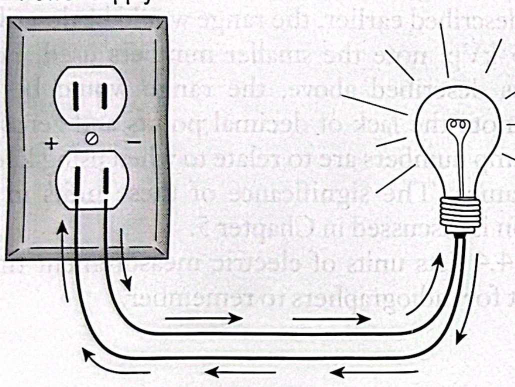


Fig. 4.11 Current flow through a circuit.

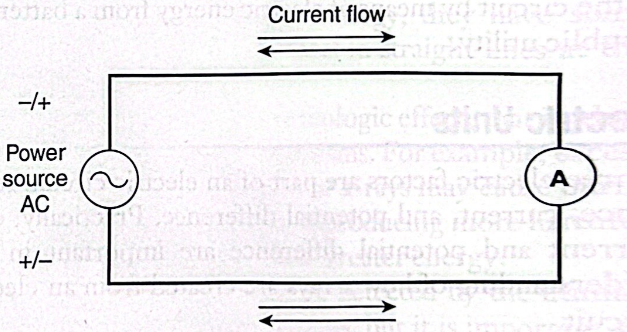
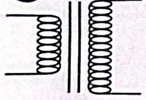


Fig. 4.12 Simple electric circuit, alternating current *(AC)*. The polarity of the power source alternates between positive and negative at regular intervals. *A*, Ammeter.

TABLE 4.5
Electric Circuit Elements: Their Symbols and Functions

Circuit Element	Symbol	Function
Ammeter	(A)	Measures electric current
Voltmeter	(V)	Measures electrical potential
Transformer		Increases or decreases voltage by fixed amount (alternating current only)
Diode		Allows electrons to flow in only one direction

Modified from Bushong SC: *Radiologic science for technologists*, ed 10, St Louis, 2013, Mosby.

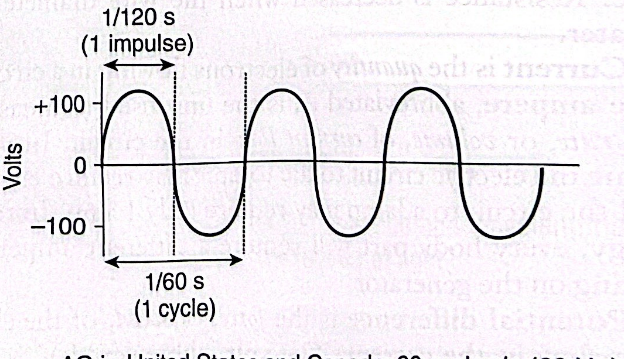


Fig. 4.13 Voltage waveform of alternating current *(AC)*.

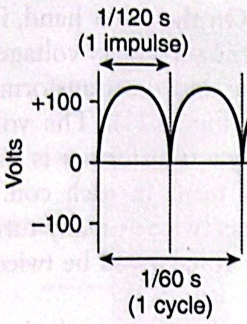


Fig. 4.14 Voltage waveform of rectified alternating current.

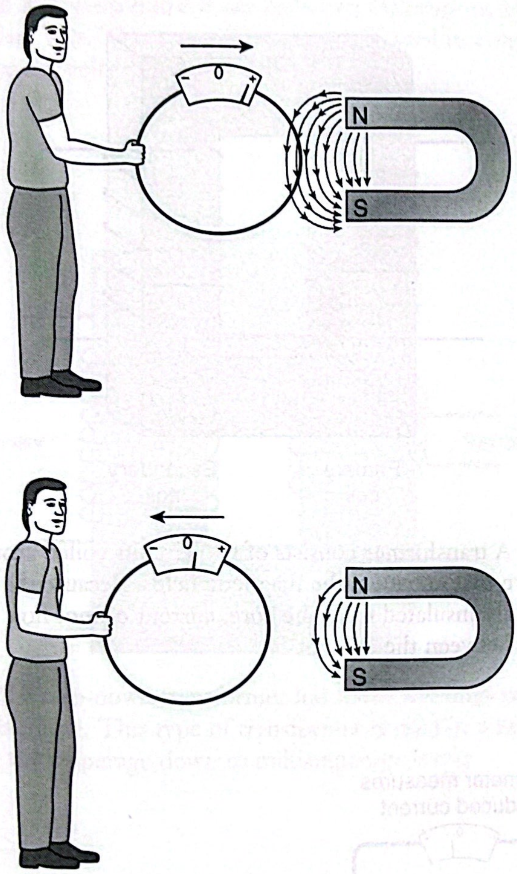


Fig. 4.15 When a conductor moves in and out of a magnetic field, alternating current will flow in the conductor. *N*, North magnetic pole; *S*, south magnetic pole.

this to DC, variable 40 to 125 kVp, variable 50 to 500 mA, and up to 6000 Hz. This transformation of electricity is discussed in Chapter 6.

ELECTROMAGNETIC INDUCTION AND TRANSFORMERS

Magnetic fields and electric energy are interrelated. Magnetic fields can be used to produce electricity and, conversely, electric currents create magnetic fields.

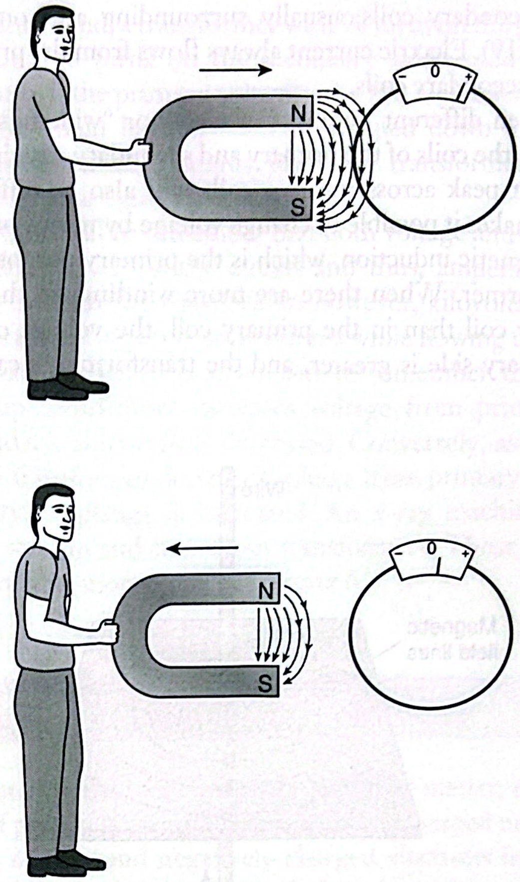


Fig. 4.16 When a magnetic field moves in relation to a conductor, alternating current will flow in the conductor. *N*, North magnetic pole; *S*, south magnetic pole.

When a conductor is placed in a magnetic field and there is movement between the lines of magnetic force and the conductor, electric current will flow in the conductor. This principle can be demonstrated by moving a circuit in and out of the force field surrounding a magnet (Fig. 4.15). The same result is obtained by moving the magnet in relation to the conductor (Fig. 4.16). This process is called **electromagnetic induction.** When the direction of the movement changes, the direction of the current flow is reversed, creating AC. This effect also occurs with a change in the influencing pole of the magnet. For these reasons, *induced current is always AC*. This is the principle used to generate electric power. When current is flowing through a circuit, it creates a magnetic field surrounding the conductor (Fig. 4.17). If this current is alternating, its magnetic field will be in constant motion. This moving magnetic field can be used to *induce* current to flow in another conductor (Fig. 4.18). The circuit that is connected to the power supply is called the *primary circuit*, and the circuit that carries the induced current is called the *secondary circuit*. Note that the two circuits are not connected to each other.

Electromagnetic induction is the basis for the transformer, the device used to produce the high voltage required for x-ray production. A transformer consists of primary and secondary coils, usually surrounding an iron core (Fig. 4.19). Electric current always flows from the primary to the secondary coils.

When different numbers of turns, or "windings," are used in the coils of the primary and secondary circuits, the kilovolt peak across the two coils will also be different. This makes it possible to change voltage by means of electromagnetic induction, which is the primary purpose of a transformer. When there are more windings in the secondary coil than in the primary coil, the voltage on the secondary side is greater, and the transformer is called a *step-up* transformer (Fig. 4.20). On the other hand, if the secondary side has fewer turns, the secondary voltage will be less than the primary voltage and the transformer is called a *step-down* transformer (Fig. 4.21). The voltage increase or decrease produced by a transformer is *directly* proportional to the number of turns in each coil. For example, if the secondary side has twice as many turns as the primary side, the secondary voltage will be twice the primary voltage.

A transformer always increases or decreases the incoming voltage by a set multiple called the *transformer ratio*. The first number in the ratio is always the number of

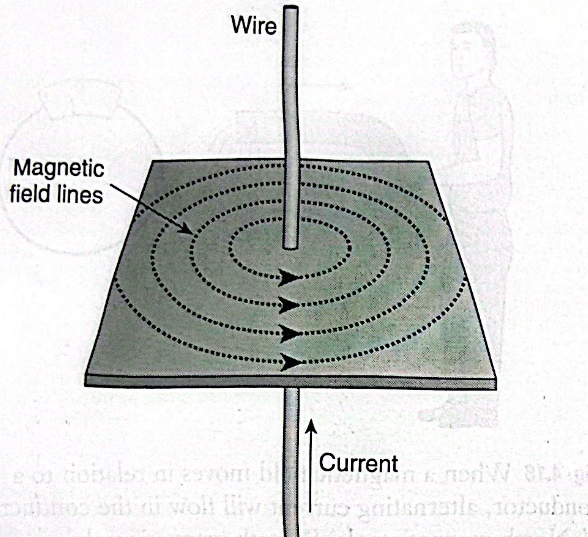


Fig. 4.17 A magnetic field is created around a conductor when current flows through the circuit. When the current is alternating, the magnetic field is in constant motion.

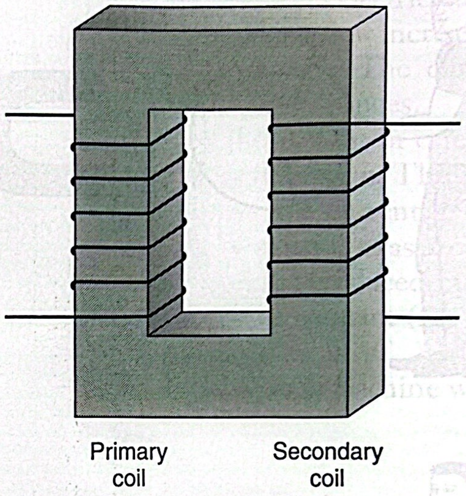


Fig. 4.19 A transformer consists of two circuits coiled around an iron core that enhances the magnetic fields. Because the circuits are insulated from the core, current cannot flow directly between the circuits.

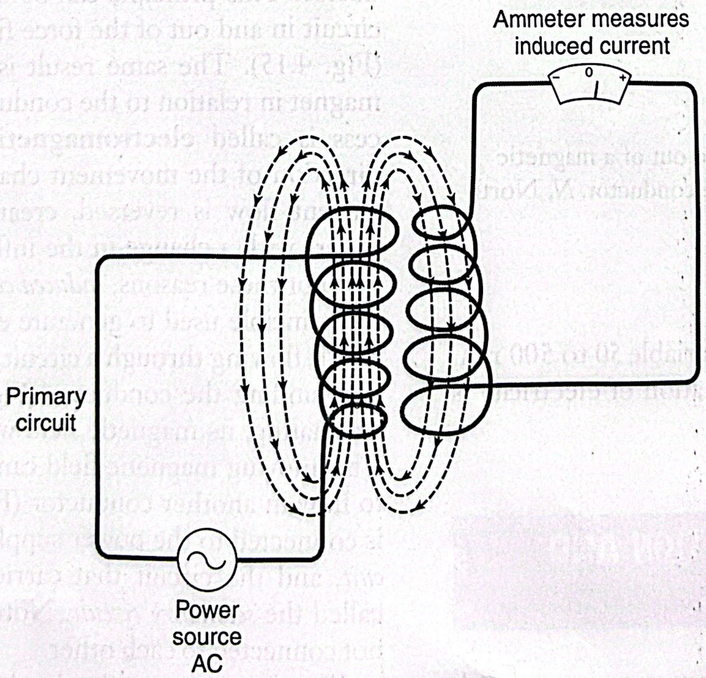


Fig. 4.18 When a conductor is placed in the magnetic field of an alternating current *(AC)* circuit, induced current will flow through the conductor.

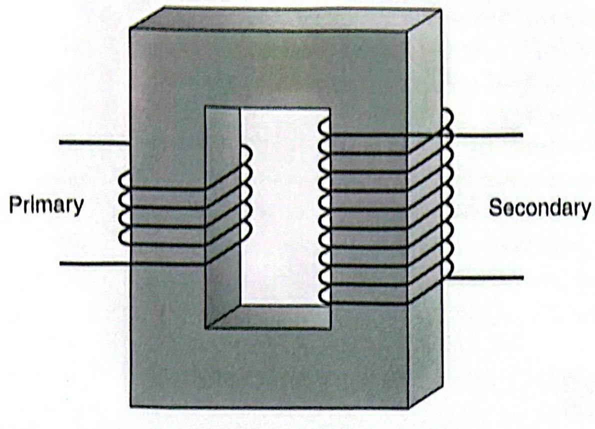


Fig. 4.20 A step-up transformer has more windings on the secondary side. This type of transformer is used in x-rays to increase the volts to kilovolts.

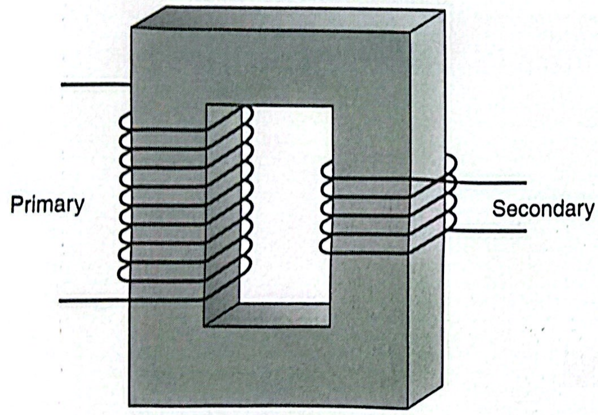


Fig. 4.21 A step-down transformer has fewer windings on the secondary side. This type of transformer is used in x-rays to reduce the amperage down to milliamperage levels.

windings on the secondary side. For example, if the voltage across the primary side were 200 V and the transformer had 500 secondary turns for each primary turn, the ratio would be *500:1* and the secondary voltage would be 200 × 500, or stepped up to 100,000 V (100 kVp). On the other hand, a transformer with 90 turns on the primary side and 30 turns on the secondary side would have a *1:3* ratio. If the primary voltage were 150 V, the secondary voltage would be 150 ÷ 3 or stepped down to 50 V. Mathematical calculations involving transformer ratios and voltage are covered in Chapter 3.

It is helpful to remember that both voltage and amperage flow in an electric circuit and thus, amperage also flows through the transformer; however, kilovoltage and amperage are *inversely* proportional while flowing through the transformer. It is important to remember that as a step-up transformer increases voltage from primary to secondary, amperage is decreased. Conversely, as a step-down transformer decreases voltage from primary to secondary, amperage is increased. An x-ray machine uses both step-up and step-down transformers. These will be discussed in more detail in Chapter 6.

SUMMARY

The atom is the basic building block of all matter, consisting of positively charged protons and uncharged neutrons in its nucleus and negatively charged electrons in orbits around the nucleus. Ionization takes place when a neutral atom or molecule gains or loses an electron, which results in one or two charged particles.

Energy exists in many forms and can be converted from one form to another. X-rays are one form of electromagnetic energy. Electromagnetic energy exists in the form of sine waves, whose energy is a function of their wavelength. X-rays have no mass and are not visible. They travel in straight lines at the speed of light and can penetrate matter. They have a very short wavelength and very high frequency.

Electric current is the flow of electric charges in a circuit. Potential difference (voltage) causes current (amperage) to flow through resistance. A conductor in which AC flows is surrounded by a moving magnetic field. This field can induce current to flow in a circuit that is adjacent to it. This electromagnetic induction is the principle of the transformer, a device used to change voltage in the x-ray circuit.