# Essentials of Radiologic Science

First Edition

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11

1 2 3 4 5 6 7 8 9 10

# Preface

*Essentials of Radiologic Science* has been designed with students and educators in mind. The textbook is designed to distill the information in each of the content-specific areas down to the essentials and to present them to the student in an easy-to-understand format. We have always believed that the difference between professional radiographers and "button pushers" is that the former understand the science and technology of radiographic imaging. To produce quality images, a student must develop an understanding of the theories and concepts related to the various aspects of using radiation. They should not rely on preprogrammed equipment and blindly set technical factors, as this is the practice of "button pushers." We have made a special effort to design a text that will help the students achieve technical competence and build their professional demeanor. We have placed the chapters in an order to help the student and educator progress from one topic to another. The chapters can be used in consecutive order to build comprehension; however, each chapter can stand alone and can be used in the order that is appropriate for any program.

From the discovery of x-rays by Wilhelm Roentgen to modern day, there have been major changes in how radiography is performed and the responsibilities of the radiographer. The advancement of digital imaging and the elimination of film in a majority of imaging departments in the country have changed the required knowledge base for radiographers, which is different today than just a few years ago. This text addresses those changes and the way radiography students must be educated.

Our goal is to make this text a valuable resource for radiography students during their program of study and in the future. To this end, the text covers four of the five content-specific areas contained in the registry examination: Physics, Radiographic Image Production, Radiation Protection, and Patient Care. The sections are independent and designed to be combined in whatever fits the instructor's current syllabus. We believe the area of Patient Positioning and Procedures is so extensive and complex that it requires a separate text.

It is our hope that this text will exceed the expectations of students and educators in their use of this book. We hope that instructors find this book easy for their students to read and understand, and we know they will find it a useful addition to their courses.

## Features

The text has many features that are beneficial to students as they learn about the fascinating world of radiography. Key terms are highlighted with **bold text** and are located at the beginning of each chapter as well as inside the chapter material. A glossary provides definitions for each key term. Features include objectives, key terms, full-color design, in-text case studies with critical thinking questions, critical thinking boxes with clinical/practical application questions and examples, video and animation callouts, chapter summaries, and chapter review questions. One of the most exciting features of this text is the use of over 250 illustrations, radiographic images, photographs, and charts that provide graphic demonstration of the concepts of radiologic science while making the text visually appealing and interesting.

## Ancillaries

The text has ancillary resources available to the students to further assist their comprehension of the material. Student ancillaries include full text online, a registry

exam–style question bank, a chapter review question bank, videos, and animations. These animations complement the text with action-packed visual stimuli to explain complex physics concepts. For example, the topic of x-ray interactions contains an animation demonstrating the x-ray photon entering the patient and then undergoing photoelectric absorption, Compton scattering, or through transmission. Thus, the student can see how the exit radiation is made up of a combination of through transmitted and scattered photons. Videos provide the student with the "real world" example of different scenarios including venipuncture, taking vital signs, using correct body mechanics, hand hygiene, and patient rights.

We have also included valuable resources for educators to use in the classroom. Instructor resources include PowerPoint slides, lesson plans, image bank, test generator, answer key for text review questions, and Workbook answer key. Their purpose is to provide instructors with detailed lecture notes that tie together the textbook and all the other resources we are offering with it.

## Workbook

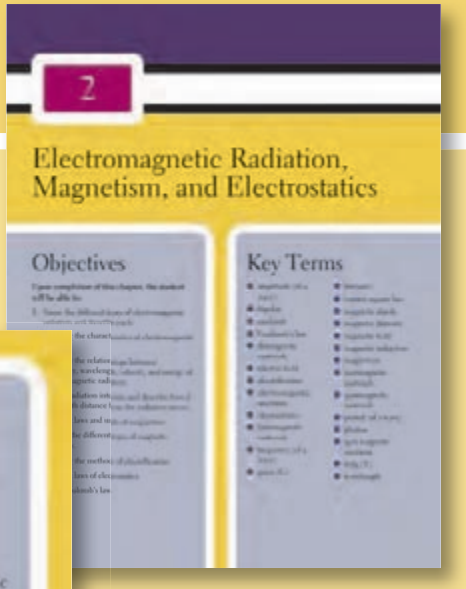
An ***Essentials of Radiologic Science Workbook*** is available separately to supplement the text and to help the students apply knowledge they are learning. The *Workbook* provides additional practice and preparation for the ARRT exam and includes registry-style review questions, as well as other exercises (crossword puzzles, image labeling) and a laboratory experiments section. All the questions in the *Workbook* are correlated directly with the text. Use of the *Workbook* will enhance learning and the enjoyment of radiologic science concepts.

*Robert Fosbinder*
*Denise Orth*

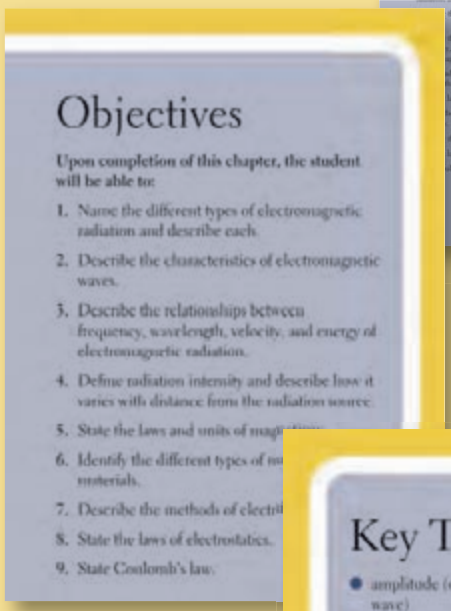
# User's Guide

This User's Guide introduces you to the helpful features of *Essentials of Radiologic Science* that enable you to quickly master new concepts and put your new skills into practice.

Chapter features to increase understanding and enhance retention of the material include:




**Objectives** help you focus on the most important information to glean from the chapter.



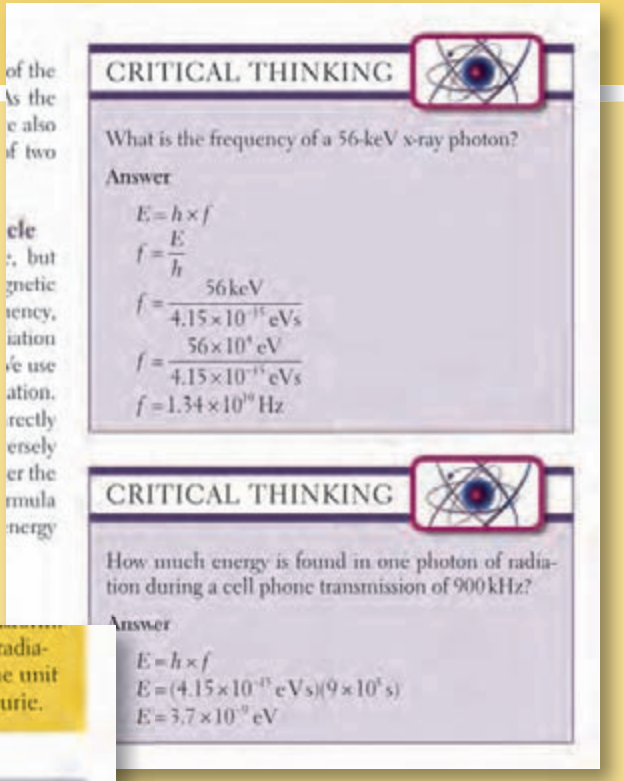




**Key Terms** for the most important concepts are listed at the beginning of the chapters, bolded when mentioned first in the chapter, and defined in the Glossary.

## Critical Thinking boxes

provide the opportunity to apply chapter material by answering practical application questions.



CRITICAL THINKING

What is the frequency of a 56-keV x-ray photon?

Answer

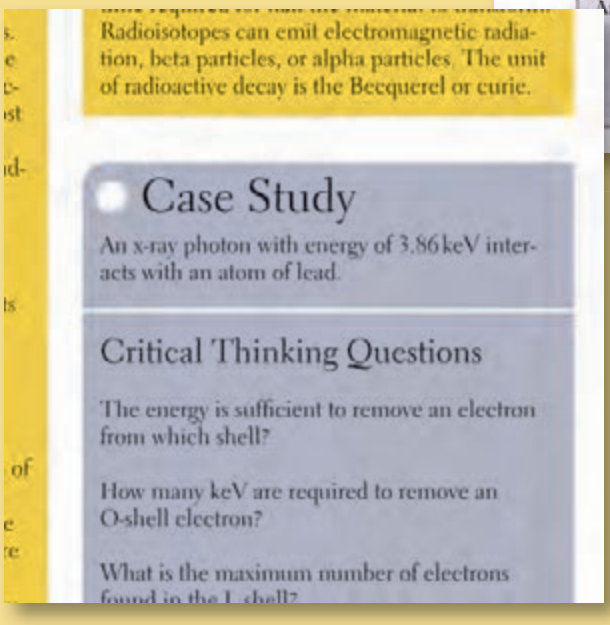
$$E = h \times f$$
$$f = \frac{E}{h}$$
$$f = \frac{56\,\text{keV}}{4.15 \times 10^{-15}\,\text{eVs}}$$
$$f = \frac{56 \times 10^{3}\,\text{eV}}{4.15 \times 10^{-15}\,\text{eVs}}$$
$$f = 1.34 \times 10^{19}\,\text{Hz}$$

CRITICAL THINKING

How much energy is found in one photon of radiation during a cell phone transmission of 900 kHz?

Answer

$$E = h \times f$$
$$E = (4.15 \times 10^{-15}\,\text{eVs})(9 \times 10^{5}\,\text{s})$$
$$E = 3.7 \times 10^{-9}\,\text{eV}$$



Radioisotopes can emit electromagnetic radiation, beta particles, or alpha particles. The unit of radioactive decay is the Becquerel or curie.

Case Study

An x-ray photon with energy of 3.86 keV interacts with an atom of lead.

Critical Thinking Questions

The energy is sufficient to remove an electron from which shell?

How many keV are required to remove an O-shell electron?

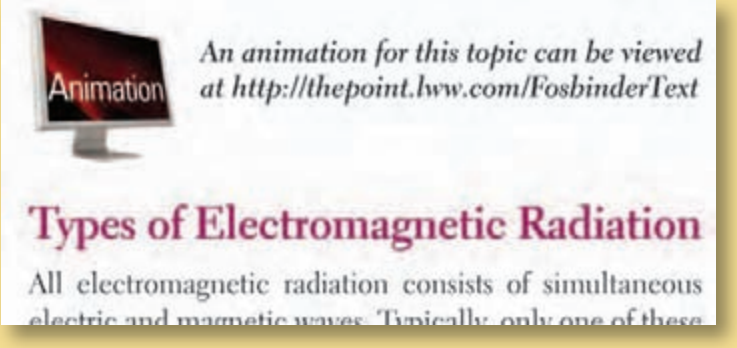
What is the maximum number of electrons

## Case Studies with Critical Thinking Questions

use real-life scenarios to encourage learning and application of chapter concepts.

## Video and Animation Callouts

identify topics for which there are videos or animations available as part of the online ancillaries.



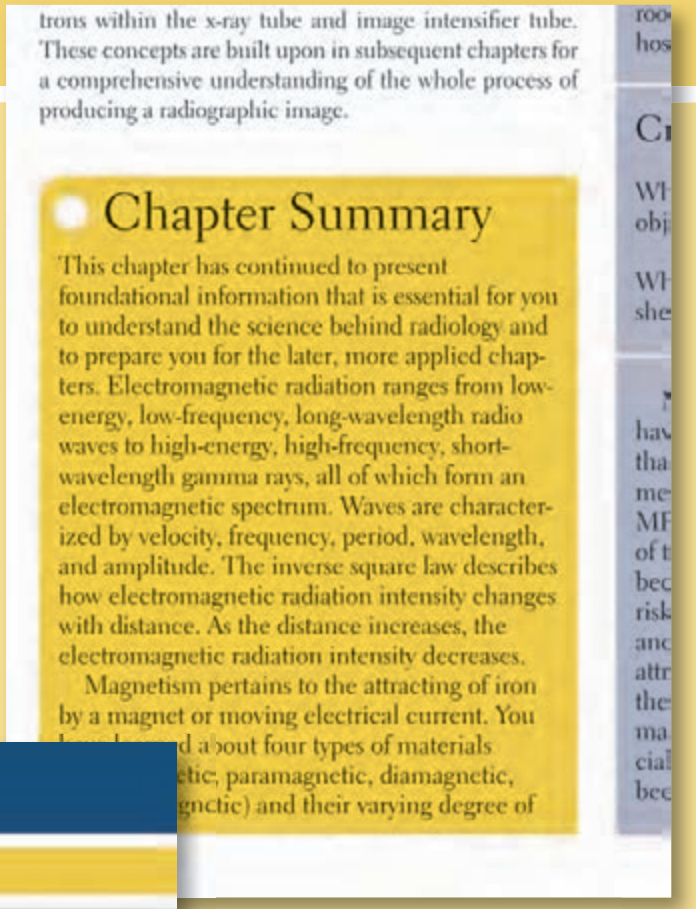
Animation

*An animation for this topic can be viewed at http://thepoint.lww.com/FosbinderText*

Types of Electromagnetic Radiation

All electromagnetic radiation consists of simultaneous

**Chapter Summaries** provide a synopsis of the chapter content and help to reinforce learning.

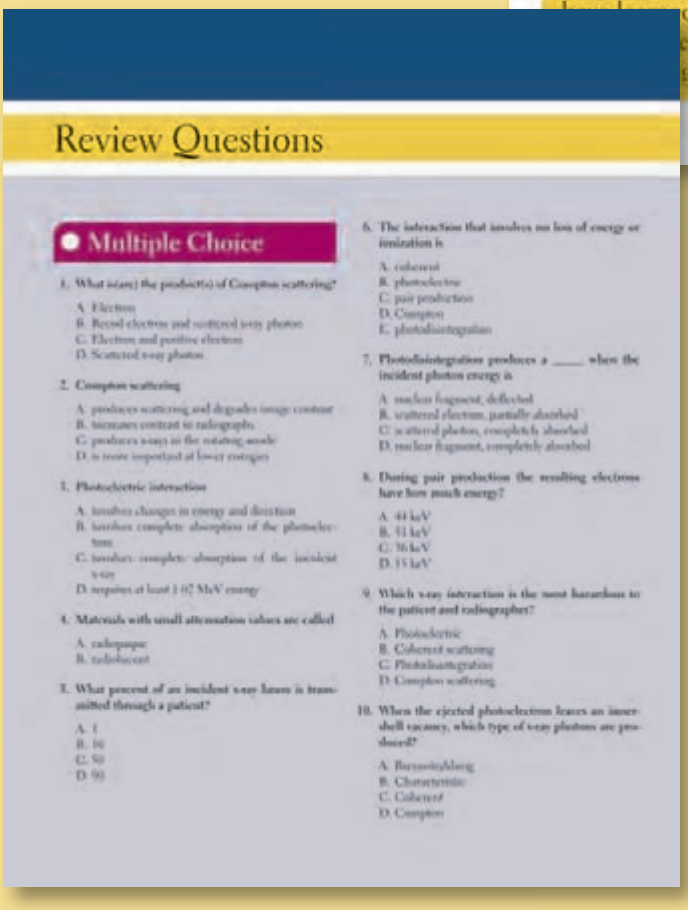


trons within the x-ray tube and image intensifier tube. These concepts are built upon in subsequent chapters for a comprehensive understanding of the whole process of producing a radiographic image.

## Chapter Summary

This chapter has continued to present foundational information that is essential for you to understand the science behind radiology and to prepare you for the later, more applied chapters. Electromagnetic radiation ranges from low-energy, low-frequency, long-wavelength radio waves to high-energy, high-frequency, short-wavelength gamma rays, all of which form an electromagnetic spectrum. Waves are characterized by velocity, frequency, period, wavelength, and amplitude. The inverse square law describes how electromagnetic radiation intensity changes with distance. As the distance increases, the electromagnetic radiation intensity decreases.

Magnetism pertains to the attracting of iron by a magnet or moving electrical current. You



## Review Questions

### Multiple Choice

**Review Questions** at the end of each chapter help you assess your knowledge.

## Additional Learning Resources

Valuable ancillary resources for both students and instructors are available on thePoint companion website at **http://thepoint.lww.com/FosbinderText**. See the inside front cover for details on how to access these resources.

Student Resources include a **registry exam-style question bank, a chapter review question bank, videos, and animations.**

Instructor Resources include **PowerPoint slides, lesson plans, image bank, test generator, answer key for text Review Questions, and answer key for Workbook questions.**

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Robert Fosbinder

We would like to acknowledge those individuals who have helped develop and publish this text. First, thank Q1 you, Peter Sabatini and Amy Millholen, for providing the assistance, encouragement, and support needed to complete this text. Thanks also to the production staff whose dedicated work and professionalism are evident in the quality of their work. Special thanks to Jonathan Dimes for his wonderful illustrations and vision. We would also like to extend our appreciation to Starla Mason for developing the workbook and ancillary resources. Many thanks to my colleagues for their encouragement and support.

Finally, to my husband Mark and our family, I wish to express my true appreciation for your unwavering support, encouragement, and understanding during the process of writing this text.

Denise Orth

# Contents

*Preface* v

*User's Guide* vii

*Reviewers* xi

*Acknowledgements* xii

## PART I: BASIC PHYSICS

**Chapter 1** Radiation Units, Atoms, and Atomic Structure 2

**Chapter 2** Electromagnetic Radiation, Magnetism, and Electrostatics 14

**Chapter 3** Electric Currents and Electricity 30

## PART II: CIRCUITS AND X-RAY PRODUCTION

**Chapter 4** Transformers, Circuits, and Automatic Exposure Control (AEC) 45

**Chapter 5** X-Ray Tubes 60

**Chapter 6** X-Ray Production 72

**Chapter 7** X-Ray Interactions 81

## PART III: IMAGE FORMATION

**Chapter 8** Intensifying Screens 92

**Chapter 9** Film and Processing 102

**Chapter 10** Density and Contrast 122

**Chapter 11** Image Formation 139

**Chapter 12** Grids and Scatter Reduction 164

## PART IV: SPECIAL IMAGING TECHNIQUES

**Chapter 13** Fluoroscopy, Conventional and Digital 184

**Chapter 14** Digital Imaging 204

**Chapter 15** Quality Control 221

**Chapter 16** Mammography 240

**Chapter 17** Computed Tomography 253

**Chapter 18** Magnetic Resonance Imaging 271

## PART V: RADIATION PROTECTION

**Chapter 19** Radiation Biology 286

**Chapter 20** Radiation Protection and Regulations 308

**Chapter 21** Minimizing Patient Exposure and Personnel Exposure 320

## PART VI: PATIENT CARE

**Chapter 22** Medical and Professional Ethics 335

**Chapter 23** Patient Care, Medications, Vital Signs, and Body Mechanics 346

*Glossary* 361

*Index* 367

2

# Electromagnetic Radiation, Magnetism, and Electrostatics

## Objectives

**Upon completion of this chapter, the student will be able to:**

1. Name the different types of electromagnetic radiation and describe each.
2. Describe the characteristics of electromagnetic waves.
3. Describe the relationships between frequency, wavelength, velocity, and energy of electromagnetic radiation.
4. Define radiation intensity and describe how it varies with distance from the radiation source.
5. State the laws and units of magnetism.
6. Identify the different types of magnetic materials.
7. Describe the methods of electrification.
8. State the laws of electrostatics.
9. State Coulomb's law.

## Key Terms

- amplitude (of a wave)
- bipolar
- coulomb
- Coulomb's law
- diamagnetic materials
- electric field
- electrification
- electromagnetic spectrum
- electrostatics
- ferromagnetic materials
- frequency (of a wave)
- gauss (G)
- intensity
- inverse square law
- magnetic dipole
- magnetic domain
- magnetic field
- magnetic induction
- magnetism
- nonmagnetic materials
- paramagnetic materials
- period (of a wave)
- photon
- spin magnetic moment
- tesla (T)
- wavelength

# Introduction

All radiologic equipment is based on the laws of electricity and magnetism. Thus, an understanding of the underlying principles of electricity and magnetism aids in understanding radiologic equipment and image production. In this chapter, we review the types and characteristics of electromagnetic radiation and discuss properties of magnetism, including types of magnetic materials, magnetic fields, and the laws and units of magnetism. Magnetic resonance imaging (MRI) has developed into a diagnostic imaging tool for imaging the body. In radiography, the properties of magnetism are used to make the anode rotate in the x-ray tube.

Finally, we consider the laws of electrostatics and the study of stationary electric charges. A thorough understanding of the principles of stationary charges will assist the student in understanding how electricity is used in the x-ray tube.

# Electromagnetic Radiation




*An animation for this topic can be viewed at http://thepoint.lww.com/FosbinderText*

## Types of Electromagnetic Radiation

All electromagnetic radiation consists of simultaneous electric and magnetic waves. Typically, only one of these waves is used in illustrations. These waves are really fluctuations caused by vibrating electrons within the fields. The amount of vibrations of the electrons will determine the frequency and wavelength for the various types of electromagnetic radiations. Electromagnetic radiation travels at the speed of light, and each type has its own unique frequency and wavelength (Fig. 2.1).

Electromagnetic radiation may appear in the form of visible light, x-rays, infrared, or radio waves, depending on its energy. The entire band of electromagnetic energies is known as the **electromagnetic spectrum**.

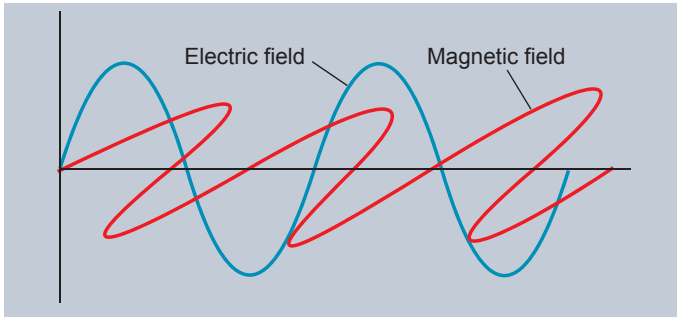



**Figure 2.1. Electromagnetic waveform illustrates the electric and magnetic waves which make up the electromagnetic waveform. Typically, only the electric wave is shown in illustrations.**

The electromagnetic spectrum lists the different types of electromagnetic radiations varying in energy, frequency, and wavelengths. The energy of the radiation is measured in electron volts or eV. Figure 2.2 illustrates the different forms of the electromagnetic spectrum from long-wavelength, low-energy radio waves, to short-wavelength, high-energy gamma rays. Although Figure 2.2 appears to indicate sharp transitions between the types of radiations, there are no clear boundaries between the various regions in the electromagnetic spectrum.

### Radio Waves

Radio waves are long-wavelength (1–10,000 m), low-energy radiation waves. A radio wave that is 10,000 m in length is equivalent to placing approximately 92 football fields end-to-end. Radio frequency radiation is used in MRI. Cell phones utilize radio waves to transmit information from one cell tower to another and finally to a cell phone. Television antennae receive the electromagnetic wave from the broadcast station and the image is displayed on the television screen. Music can be heard because it reaches our ears in the form of a radio wave.

### Radar and Microwaves

Radar and microwaves have shorter wavelengths ($10^{-1}$–$10^{-4}$m) and higher energy than radio waves. Microwaves are used in ovens, in transportation, and by law enforcement officers to monitor the speed of cars. In a microwave oven, the microwave energy forces the water molecules in food to rapidly vibrate, thus heating the food.

### Infrared Radiation

Infrared radiation, or heat, has shorter wavelengths and higher energy than radar and microwaves ($10^{-1}$–$10^{-4}$ m).

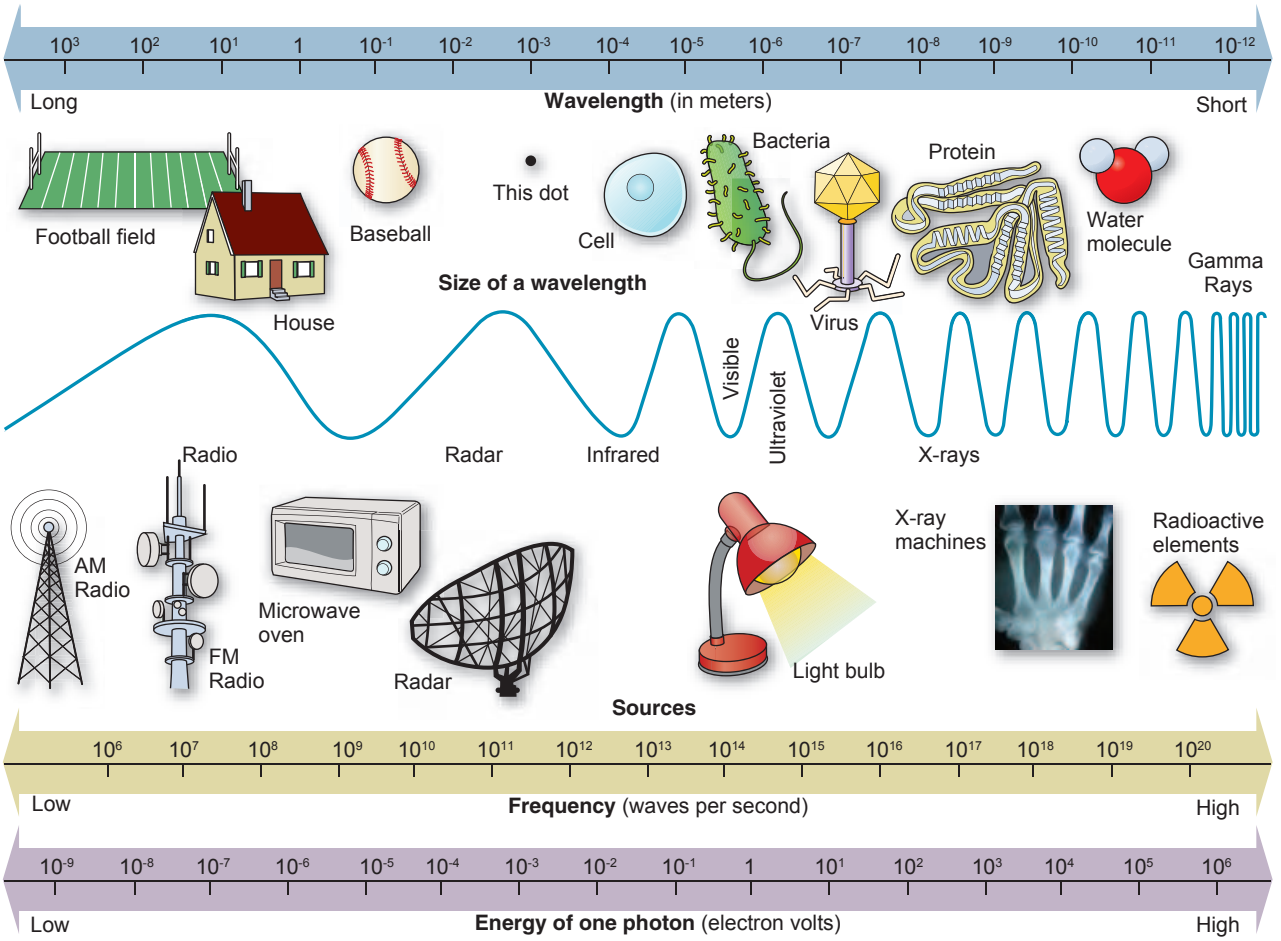



**Figure 2.2. Electromagnetic spectrum illustrates the range of electromagnetic radiation.**

Infrared radiation can heat nearby objects. For example, you can feel the heat from your toaster, which uses infrared radiation. The high-energy end of the infrared region is visible and can be seen in the red heating elements of your toaster.

## Visible Light

Visible light selectively activates cells in the eye. It occupies a narrow band in the electromagnetic spectrum, with wavelengths between $10^{-6}$ and $10^{-7}$ m. The color red has the longest wavelength and lowest energy. Blue and violet colors have the highest energy and the shortest wavelengths in the visible spectrum.

## Ultraviolet

Ultraviolet is the part of the spectrum just beyond the higher energy end of the visible light region. Ultraviolet wavelengths range from $10^{-7}$ to $10^{-9}$ m. Ultraviolet lights are used in biological laboratories to destroy airborne bacteria, and they are believed to be responsible for the majority of sunburn and skin cancer.

## X-Rays and Gamma Rays

X-rays and gamma rays have wavelengths between $10^{-9}$ and $10^{-16}$ m. They are very short wavelength, high-frequency, high-energy radiation. The energy is measured in thousands of electron volts (keV) and is capable of ionization. Ionizing radiation such as x-rays and gamma rays has enough energy to remove an electron from its orbital shell.

The only difference between x-rays and gamma rays is their origin. X-rays in radiology come from interactions with electron orbits. Gamma rays come from nuclear transformations (decay) and are released from the nucleus of a radioactive atom. Some x-rays in radiology have higher energy than some gamma rays and are used in radiation therapy to treat cancer. X-radiation is utilized in various industries including for screening baggage in

airport security and large crates of merchandise at ports of entry as well as for imaging chest plates the military will use in combat.

## Characteristics of Electromagnetic Radiation

Electromagnetic radiation consists of vibrations in electric and magnetic fields. It has no charge and no mass and travels at the speed of light. The waves move in a sinusoidal (sine) waveform in electric and magnetic fields. Electromagnetic radiation is described in terms of the following characteristics:

- Velocity: how fast the radiation moves
- Frequency: how many cycles per second are in the wave
- Period: the time for one complete cycle
- Wavelength: the distance between corresponding parts of the wave
- Amplitude: the magnitude of the wave
- Energy: the amount of energy in the wave
- Intensity: the flux of energy

### Velocity

All electromagnetic radiation travels in a vacuum or in air at $3 \times 10^8$ m/s (186,000 miles/s), regardless of whether it is in a wave or particle form. Even though this is incredibly fast, light requires some time to travel huge distances. For example, it takes 8 minutes for light from the Sun to reach the Earth.

### Frequency

The **frequency** of a wave is the number of cycles per second. That is, the frequency is the number of peaks or valleys occurring each second. The unit of frequency is hertz (Hz), which is one cycle per second. In the United States, electricity has a frequency of 60 Hz, that is, 60 cycles per second. A typical radio wave has 700,000 Hz (700 kHz). A 1,000 Hz is equal to 1 kHz. One megahertz (MHz) is equal to one million ($10^6$) Hz or cycles per second.

### Period

The **period** of a wave is the time required for one complete cycle. A wave with a frequency of two cycles per second has a period of one-half second; that is, one complete wave cycle occurs each half second. Figure 2.3 illustrates the relationship between frequency and period (time) in a sine wave.

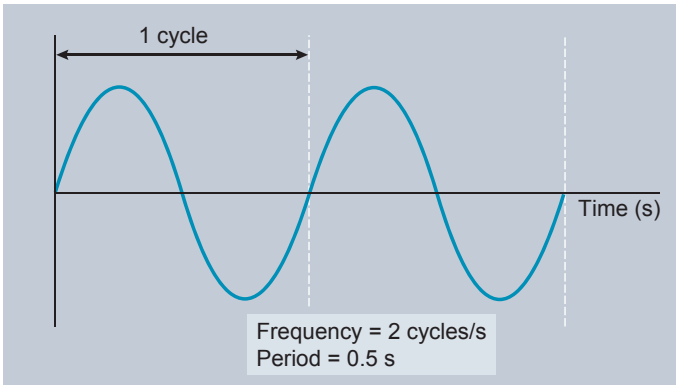



**Figure 2.3. The relationship between frequency and period of a waveform.**

### Wavelength

The distance between adjacent peaks or adjacent valleys of a wave is the **wavelength** and is represented by lambda ($\lambda$). Wavelength is one of the important characteristics in determining the properties of x-rays. Electromagnetic radiation with shorter wavelengths has higher energy and frequencies and greater penetration. Wavelength is measured in meters, centimeters, or millimeters. Figure 2.4 illustrates the relation between wavelength and frequency.

Electromagnetic wave velocity, frequency, and wavelength are related and a change in one factor causes a change in one or both of the other factors. The wave is demonstrated with this formula:

$$c = f\lambda$$

where $c$ (velocity) is the speed of light ($3 \times 10^8$ m/s, in air), $f$ is the frequency, and lambda ($\lambda$) is the wavelength. Note that the product of frequency and wavelength must always equal the velocity. Thus, frequency and wavelength are inversely proportional. Therefore, if the frequency increases, the wavelength must decrease, and if the frequency decreases, the wavelength must increase. For example, if frequency is doubled, the wavelength is halved, and if the frequency is tripled, the wavelength is reduced by one third.

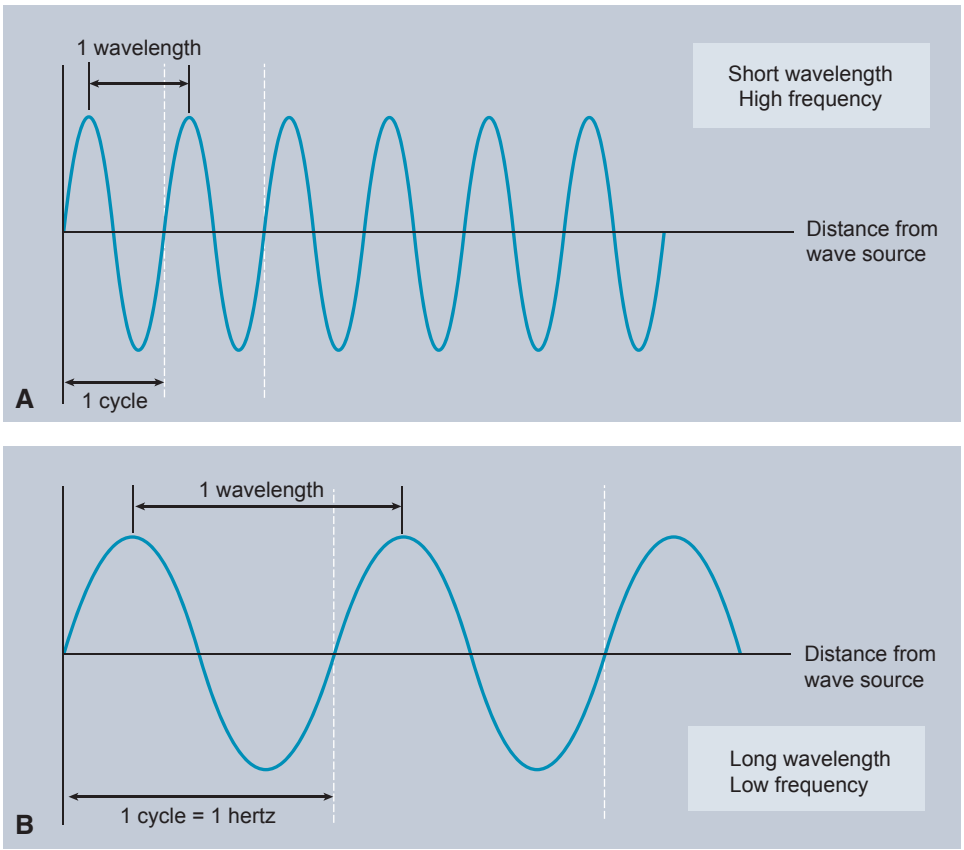



**Figure 2.4.** A: Demonstrates the relationship between frequency and wavelength. When a short wavelength is seen, there is a greater number of vibrations. Note how the peaks are closer together. This waveform has high penetrability and represents an x-ray waveform. B: In the bottom waveform, note the distance between the peaks. As the distance between the peaks increases, the wavelength becomes longer and there are fewer peaks. This waveform has low penetrability.

## CRITICAL THINKING

A radio station is broadcasting a signal with a frequency of 27,000 kHz. What is the wavelength of the signal in meters?

**Answer**

$$c = 3\times10^{8}\ \text{m/s}$$
$$f = 27{,}000\ \text{kHz}$$
$$\lambda = \frac{3\times10^{8}\ \text{m/s}}{27{,}000\ \text{kHz}}$$
$$\lambda = \frac{3\times10^{8}\ \text{m/s}}{2.7\times10^{4}}$$
$$\lambda = 11.1\ \text{m}$$

## CRITICAL THINKING

What is the frequency in MHz of a cell phone signal if the wavelength is 333 mm = $3 \times 10^{8}$ m/s?

**Answer**

$$\lambda = 333\ \text{mm}$$
$$f = \frac{3\times10^{8}\ \text{m/s}}{333\ \text{mm}}$$
$$f = \frac{3\times10^{8}\ \text{m}}{333\times10^{-3}\ \text{m}} = \frac{1}{s}$$
$$f = \frac{3\times10^{8}\ \text{m}}{333\times10^{-3}\ \text{m}}$$
$$f = 0.009\times10^{5}\ \text{Hz or } 900\ \text{MHz}$$

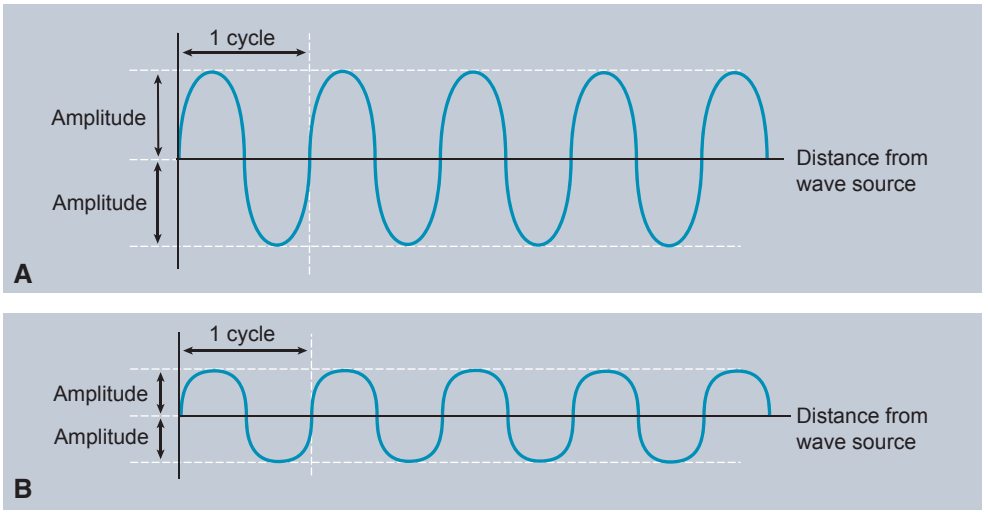



**Figure 2.5.** **A: A bowling ball is dropped into a tank of smooth water. The weight of the object causes the water to have large ripples with lots of energy. B: This wave represents the effect if a baseball were dropped into smooth water, and the ripples are smaller and therefore have less energy.**

## Amplitude

The **amplitude** of a wave is the maximum height of the peaks or valleys (in either direction) from zero. As the energy of the wave increases, the height of the wave also increases. Figure 2.5 compares the amplitudes of two electromagnetic waves as a function of time.

## Energy: Electromagnetic Radiation as a Particle

Electromagnetic radiation usually acts as a wave, but sometimes it acts as a particle. When electromagnetic radiation acts as a wave, it has a definite frequency, period, and wavelength. When electromagnetic radiation acts as a particle, it is called a **photon or quanta**. We use the photons or bundles of energy to produce x-radiation. The energy and frequency of the photons are directly proportional, but wavelength and energy are inversely proportional. Thus, the higher the energy, the shorter the wavelength and the higher the frequency. The formula that describes the relationship between photon energy and frequency is expressed as

$$E = hf$$

where $E$ is photon energy in electron volts, $h$ is a conversion factor called Planck's constant ($4.15 \times 10^{-15}$ eVs), and $f$ is the photon frequency.

### CRITICAL THINKING

What is the frequency of a 56-keV x-ray photon?

**Answer**

$$E = h \times f$$
$$f = \frac{E}{h}$$
$$f = \frac{56\,\text{keV}}{4.15 \times 10^{-15}\,\text{eVs}}$$
$$f = \frac{56 \times 10^{4}\,\text{eV}}{4.15 \times 10^{-15}\,\text{eVs}}$$
$$f = 1.34 \times 10^{19}\,\text{Hz}$$

### CRITICAL THINKING

How much energy is found in one photon of radiation during a cell phone transmission of 900 kHz?

**Answer**

$$E = h \times f$$
$$E = (4.15 \times 10^{-15}\,\text{eVs})(9 \times 10^{5}\,\text{s})$$
$$E = 3.7 \times 10^{-9}\,\text{eV}$$

## Radiation Intensity and the Inverse Square Law

All electromagnetic radiation travels at the speed of light and diverges from the source at which it is emitted. **Intensity** is energy flow per second and is measured in watts/cm$^2$. The intensity of the radiation decreases with an increase in the distance from the source. This is because the x-ray energy is spread over a larger area. This relation is known as the inverse square law. It is called the **inverse square law** because the intensity is inversely proportional to the square of the distance. Figure 2.6 illustrates how the intensity decreases as the distance from the source increases.

Mathematically, the inverse square law is expressed as follows:

$$I_2 = I_1\left(\frac{d_1}{d_2}\right)^2 \text{ or } I_2 = \frac{I_1 \times d_1^2}{d_2}$$

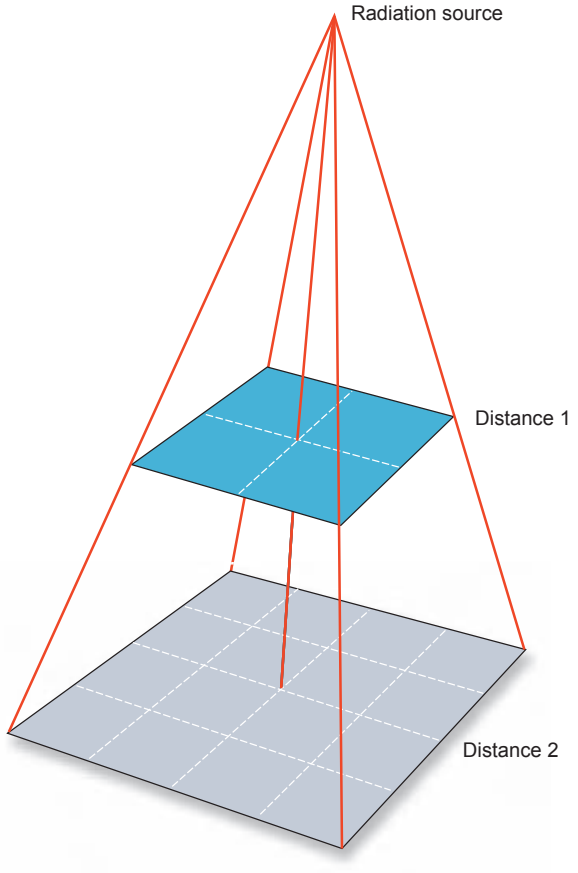



**Figure 2.6. The inverse square law relates the radiation intensity to the distance from the source. As distance is increased, the intensity of the radiation is decreased by one fourth.**

where $I_1$, old intensity; $I_2$, new intensity; $d_1^2$, old distance squared; $d_2^2$, new distance squared. If the distance from the x-ray source is doubled, the intensity decreases by a factor of 4. That is, the intensity at twice the distance is one-fourth the original value. If the distance from the x-ray source is halved, the intensity is four times greater. The exposure and exposure rate from an x-ray source also follow the inverse square law. To decrease radiation exposure during a fluoroscopic exam, a technologist needs to increase his or her distance from the x-ray tube. Every step away from the tube decreases the amount of radiation the technologist will be exposed to.

### CRITICAL THINKING

What is the exposure rate 4 m from a source that has an exposure rate of 32 mR/h at a distance of 1 m from the source?

**Answer**

If $I_1$ is the exposure rate at 1 m and $I_2$ is the exposure rate at 4 m, then

$$I_2 = I_1\left(\frac{d_1}{d_2}\right)^2 \qquad I_2 = I_1\left(\frac{1}{4}\right)^2$$
$$= 32\left(\frac{1}{16}\right)$$
$$= 2\,\text{mR/h}$$

### CRITICAL THINKING

The x-ray intensity is measured at 40 mR/h at 36 in. What is the intensity at 72 in?

**Answer**

$$I_2 = \frac{I_1 \times d_1^2}{d_2}$$
$$36^2 = 1{,}296$$
$$72^2 = 5{,}184$$
$$\frac{[40 \times 1{,}296]}{5{,}184} = 10\,\text{mR/h}$$

# Magnetism

Early man discovered that some rocks seemed to have magical powers. They were called lodestones. Lodestones are natural magnets and attract pieces of iron. **Magnetism** is the ability of a lodestone or magnetic material to attract iron, nickel, and cobalt. This magnetic property is used in medical imaging.

## Types of Magnetic Materials

Different types of materials respond differently to magnetic fields. There are four types of magnetic materials:

1. ferromagnetic materials, which react strongly with magnets or in a magnetic field
2. paramagnetic materials, which are weakly attracted to magnets
3. diamagnetic materials, which are weakly repelled by all magnetic fields
4. nonmagnetic materials, which do not react in a magnetic field

Each of these is discussed in detail below.

### Ferromagnetic Materials

**Ferromagnetic materials** are attracted to a magnet. Ferromagnetic materials—including iron, cobalt, and nickel—are made up of small groups of atoms called **magnetic domains**. These domains act like tiny magnets inside the material. In the nonmagnetized state the domains are randomly oriented, so there is no net magnetization. When a ferromagnetic material is placed in a magnetic field the domains are aligned. After the magnetic field is removed, the domains remain aligned forming a permanent magnet. Alnico is an alloy made of aluminum, nickel, and cobalt. It contains the magnetic properties of each metal to form a strong magnet. Figure 2.7 illustrates how ferromagnetic materials are magnetized by aligning the domains inside the material. Heating a magnet can destroy its magnetism because heat rearranges the domains into a random orientation, resulting in a loss of permanent magnetism.

### Paramagnetic Materials

**Paramagnetic materials** are weakly attracted to magnetic fields. When placed in a magnetic field, some of the domains are aligned in the same direction, which means they cannot be permanently magnetized and do not retain any magnetism after the magnetic field is removed. Aluminum and platinum are examples of paramagnetic materials. MRI contrast agent, gadolinium, is also a paramagnetic material.

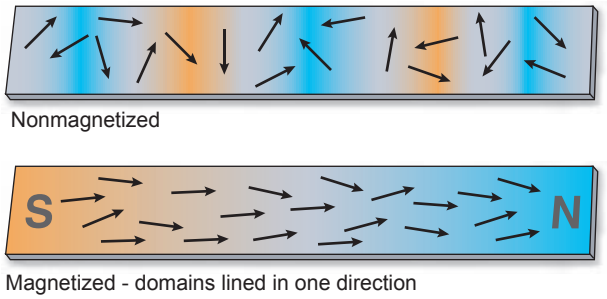



**Figure 2.7. Illustrates the magnetic domain alignment of magnetic and nonmagnetic materials.**

### Diamagnetic Materials

**Diamagnetic materials** are weakly repelled by a magnet. Copper, beryllium, bismuth, and lead are examples of diamagnetic materials.

### Nonmagnetic Materials

**Nonmagnetic materials** do not react with magnetic fields. Wood, glass, rubber, and plastics are examples of nonmagnetic materials. In this type of material, there is an equal number of dipoles spinning in both directions; therefore, the material is not attracted to magnetic fields. Materials in the magnetic resonance room must be nonmagnetic.

## Magnetic Fields

A **magnetic field** is the space surrounding a magnet or moving electric current in which magnetic forces are detectable. All magnets are surrounded by a magnetic field. A magnetic material placed in a magnetic field experiences a force. This magnetic force will align the domains along the magnetic field. To understand the phenomenon of magnetism, it is important to study atomic structure and the effects of particle movement around a nucleus.

When a charged particle is in motion, a magnetic force field is created. This force field moves perpendicular to the charged particle and is represented as field lines. In every magnet the lines of the magnetic field are in closed

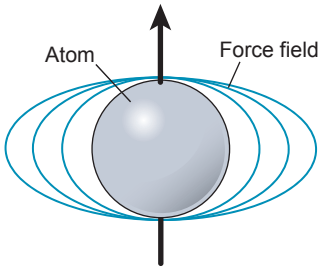



**Figure 2.8. Magnetic field lines around an atom. Demonstrates the path of the magnetic field lines surrounding a magnet.**

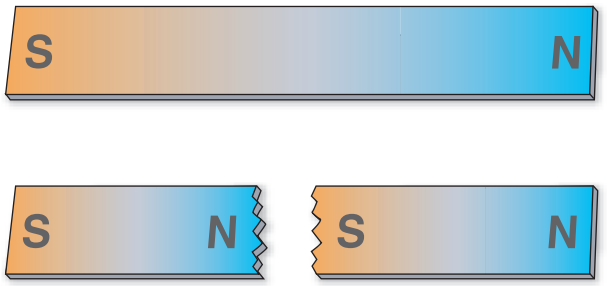



**Figure 2.9. Effect of dividing a magnet into increasing smaller pieces. Each piece, no matter how small, retains the original magnetic properties.**

loops (Fig. 2.8). Every magnet is **bipolar**, having two poles: a north pole and a south pole.

All atoms have orbital electrons which spin on their axes around the nucleus of the atom. This effect created by the movement of these electrons is called **spin magnetic moment**. The disruption of this axial spinning and the energy released as it reorients itself are the basis behind MRI. Each atom acts as a very small magnet and is called a **magnetic dipole**. A group of such atoms with their dipoles aligned in the same direction creates a **magnetic domain**. Atoms having an odd number of electrons which are all spinning in the same direction will exhibit a net magnetic field.

Typically, magnetic domains are arranged randomly in an object. When the object is acted upon by an external force field, the dipoles will become oriented to the field. If enough of the dipoles become aligned in the same direction, the object will exhibit a strong magnetic field and will then be called a magnet. These force fields are also called lines of force, lines of flux, or the magnetic field. These magnetic field lines flow from the north pole to the south pole on the outside of the magnet. Within the magnet the field lines flow from the south pole to the north pole. The number and concentration of field lines will determine the strength of the magnet; the stronger the magnetic field, the greater the number of field lines and the more concentrated the field lines are at the poles.

Breaking a magnet in half produces two smaller magnets, each with a north and a south pole. The pieces of the magnet can be divided multiple times and every time the pieces will be bipolar. Figure 2.9 illustrates how a magnet that is broken in half will produce two smaller magnets, each with its own north and south poles.

## Laws of Magnetism

The laws of magnetism include the following:

**Repulsion–Attraction:** Like poles repel, unlike poles attract.

**Magnetic poles:** Every magnet has a north pole and a south pole.

**Inverse square law:** The magnetic force between two magnetic fields is directly proportional to the product of their magnitudes and inversely proportional to the square of the distance between them.

The first law of magnetism, like poles repel and unlike poles attract, is true because when a magnet is placed in the force field of another magnet it is acted upon by that force field. An example of this law may be seen when the north pole of one bar magnet is placed near the south pole of another bar magnet their opposite field lines will be attracted to each other. Likewise, when the north poles of two bar magnets are placed close together, the lines of force are in the same direction and will repel each other (Fig. 2.10). It is critical that this law is observed in an MRI department where the strength of the magnet will attract metallic objects and the metal objects will be attracted to or pulled into the magnet.

The second law of magnetism, every magnet has a north pole and a south pole. No matter how many times the magnet is divided, even into individual electrons, both poles will continue to exist. Perhaps the most dramatic example of this law is the Earth itself, which is actually a giant magnet. Imagine that the Earth's core is a very large bar magnet, as illustrated in Figure 2.11.

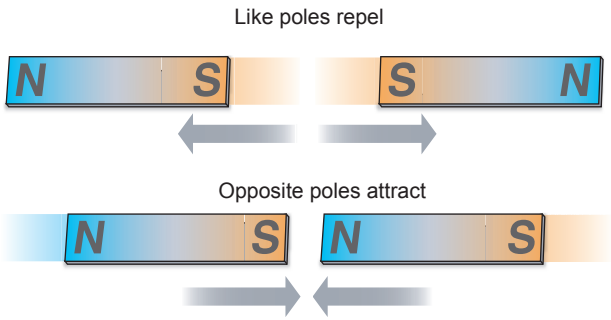



**Figure 2.10. Repulsion-attraction of magnets. When the like poles of two magnets are close to each other, their force fields will repel each other. No matter how hard you try, you will not be able to make the two magnets touch. If you take one of the magnets and turn it so that the opposite pole is now facing the other magnet, their unlike poles will attract each other and the magnets will slam together. It will take a lot of force to separate these two magnets.**

The Earth's south magnetic pole lies under the ice in northern Canada while the north magnetic pole lies near Australia. The Earth's magnetic poles should not be confused with the "geographic poles." The north magnetic pole of a compass (marked "N") will point toward the Earth's south magnetic pole.

The third law of magnetism, the magnetic force between two magnets decreases as the square of the distance between the magnets increases, is based on the inverse square law. An example of this law is demonstrated when opposite poles of two magnets are placed within 1 inch of each other. When the force fields of the two magnets influence each other, the magnets will be pulled together. Now take the two magnets and place them 2 inches apart, and if the force fields are strong enough, they may still interact with each other but first they must overcome the distance between the magnets. As distance is doubled between two magnetic objects, the attraction will be one-fourth the original attraction.

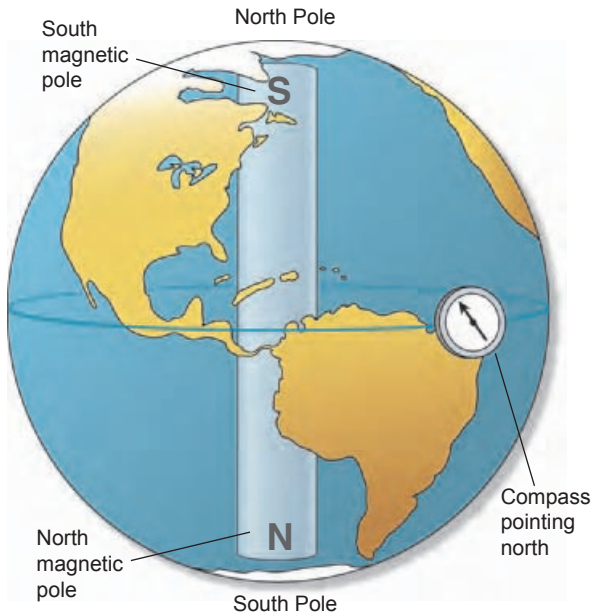



**Figure 2.11. The Earth is a giant magnet and like all other magnets, it has two magnetic poles, one north and one south.**

## Units of Magnetism

The SI units of magnetism are the gauss (G) and the tesla (T). One tesla is equal to 10,000 gauss. The Earth's magnetic field is about 0.5 G or $5 \times 10^{-5}$ T. A refrigerator magnet is about 10 G or 0.001 T. MRI units typically have magnetic fields of 0.1 to 3 T. MRI is discussed in Chapter 19.

## Magnetic Induction

When a nonmagnetized iron bar is brought within the flux lines of a strong magnet, the dipoles in the iron bar will temporarily align themselves with the flux lines passing through the iron bar. The iron bar will become temporarily magnetized. When the strong magnetic flux lines are removed, the dipoles in the iron bar will return to their original random state. This process is called **magnetic induction** and it will work with any ferromagnetic material.

# Electrostatics

**Electrostatics** is the study of stationary or resting electric charges. Another name for stationary charges is static electricity.

As we discussed in Chapter 1, the concept of electric charges can be seen at the atomic level, in positively charged protons and negatively charged electrons. The negatively charged electrons travel around atoms in orbital shells. Loosely bound electrons can be made to jump or move from one object to another object. The most familiar example of this is static electricity. In this chapter, we discuss how the movement of electrons, which are the basic charged particles, can cause electric charges on a larger level. A discussion of electrostatics

must begin with an understanding of electric fields and the various forms of **electrification**.

## Electric Fields

An **electric field** describes the electrical force exerted on a charge. An electric field exists around all electric charges. The electric field is directed away from positive charges and toward negative charges. When two charges are brought near each other, their fields interact. The resulting force of attraction or repulsion depends on the sign of the charges. There is no electric field around neutral objects, however; neutral objects are affected by strongly charged objects.

## Electrification

**Electrification** occurs when electrons are added to or subtracted from an object; therefore an object can be negatively charged or positively charged. An object having more electrons than another object is considered to be negatively charged. The concept of a positively charged object does not mean the object has only positive charges or protons. We know this is true because atoms have orbital electrons; therefore, a positively charged object has a weaker negative charge. When discussing electricity, it is important to remember that the two objects are being compared, not their actual atomic charges. The three methods of electrification include friction, contact, and induction (Fig. 2.12).

### Friction

Electrification by friction involves the removal of electrons from one object by rubbing it with another object. A familiar game that children play is to rub a balloon on their hair. Electrons from the hair will be transferred to the balloon causing the hair to be positively electrified. When the negatively electrified balloon is placed on a smooth wall, which has a primarily positive charge, the buildup of electrons will allow the balloon to stick to the wall.

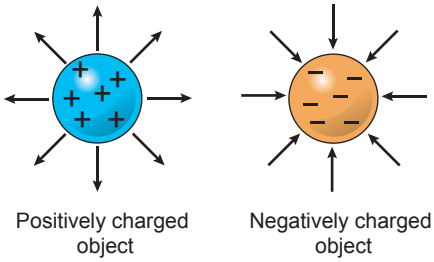



**Figure 2.12. Positively charged object. Negatively charged object.**

### Contact

Electrification by contact occurs when two objects touch, allowing electrons to move from one object to another. When an object charged by friction touches an uncharged object, the uncharged object will acquire a similar charge. If the first object is positively charged, it will remove electrons from the uncharged object, causing it to be positively charged. Likewise, if a negatively charged object touches an uncharged object, it will give up some of its electrons, making the second object negatively charged. Therefore, we conclude that a charged body confers **the same kind of charge** on any uncharged body with which it comes in contact.

Electrons move in an attempt to equalize the charged body. An example of this equalization can be seen when a person wearing socks walks across a wool rug and then touches a metal lamp. Electrons from the rug are transferred to the socks and eventually to the body, giving the person a negative charge. Reaching out toward a metal lamp will cause a static discharge to jump between your hand and the metal lamp. The electrons move from a location of a high negative charge to an area of low negative charge. This transfer of excess electrons will neutralize the person (Fig. 2.13).

### Induction

Electrification by induction is the process of electrical fields acting on one another without making contact. A charged object has a force field surrounding it, and if this force field is strong enough, it can cause electrification of a weakly charged object. The force field is called an electric field. A neutral metallic object experiences a shift in electrons in the direction toward an opposite charge when

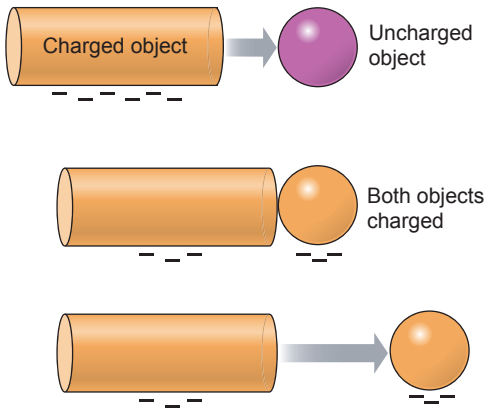



**Figure 2.13. Electrification by contact.**

brought into the electric field of a charged object. Keep in mind that a neutral object has an equal number of protons and electrons and when acted upon by a strongly charged metallic object, **only the electrons will move**.

As seen in Fig. 2.14, a negatively charged bar magnet is brought close to a neutral or uncharged metal ball but does not touch it. Excess electrons from the bar magnet will repel the electrons on the side of the ball which is closest to the bar magnet. This leaves the side of the ball closest to the bar magnet positively charged. The reverse occurs when a positively charged bar magnet is brought close to an uncharged metal ball. The electrons from the metal ball are attracted to the positive charge of the bar magnet, thus leaving the side of the ball closest to the bar magnet with a negative charge. In both examples, the electrification by induction is **a temporary opposite** charge and the electrons will return to their original positions when the charged object is withdrawn (Fig. 2.14).

Electrification by induction can also be used to semipermanently change the charge of an object. This is accomplished by connecting the end of a metallic object to the ground. The Earth is a huge neutral object and an infinite reservoir of electrons and can be used to neutralize any charged object. In Figure 2.15, a neutral metal ball is connected to ground. A negatively charged bar magnet is brought close to the neutral metal ball. The forces of repulsion move the negative charges from the side of the metal ball closest to the bar magnet to the opposite side of the metal ball. Because the metal ball is attached to ground, the excess negative charges will flow to the ground. If the ground connection and bar magnet are removed, the metal ball will remain positively charged. It will retain this charge until the metal ball is attached to ground at which point the electrons will move up from the ground to neutralize the metal ball.

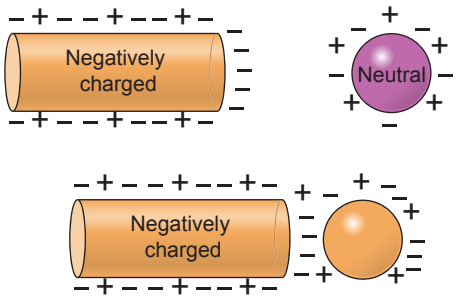



**Figure 2.14. Electrification by induction. The force of one magnetic field on another magnetic field can cause the objects to either repel or attract each other.**

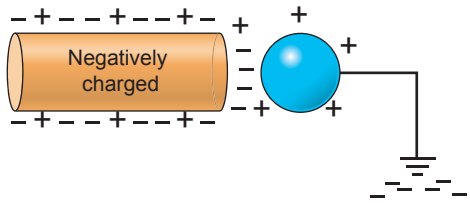



**Figure 2.15. Grounding of electrical charges will allow excess electrons to flow into the Earth. This principle can be used to temporarily magnetize a metal object.**

## Unit of Charge

To quantify these electric charges, a basic unit of measure is needed. Although the basic charged particle is the electron, the standard unit of charge is the **coulomb**. One coulomb is much larger than the charge on an electron. There are $6.3 \times 10^{18}$ electron charges in one coulomb. Thus, the charge of one electron is $1.6 \times 10^{-19}$ coulomb.

## Electrostatic Laws

Certain physical laws govern how these electrostatic charges interact. The major laws of electrostatics are as follows:

**Repulsion–Attraction:** Like charges repel and unlike charges attract.

**Coulomb's law:** The electrostatic force between two charges is directly proportional to the product of their quantities and inversely proportional to the square of the distance between them.

**Distribution:** Electric charges reside on the external surface of a conductor.

**Concentration:** Electric charges concentrate on the surface of a conductor.

**Movement:** Only negative charges move along solid conductors.

The first law, like charges repel and unlike charges attract, holds true because of the force field surrounding electrical charges. As previously discussed, the force field or lines of force act to repel like charged objects away from each other and to attract opposite charged objects together (Fig. 2.16).

The second law, the force between two charges is directly proportional to the product of their quantities

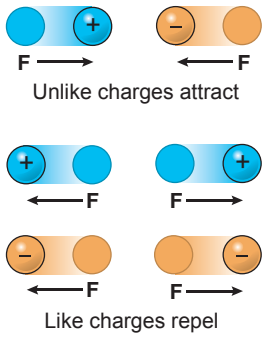



**Figure 2.16. The law of attraction and repulsion of electric charges.**

and inversely proportional to the square of the distance between them.

**Coulomb's law** describes the force between two charges. Coulomb's law states that doubling the distance between two charges reduces the force by a factor of 4. Two charges of the same sign, either positive or negative, always have a repulsive force between them. Two charges of opposite signs always have an attractive force between them. The force between two charges increases as the strength of the charge increases. Likewise, the force between the charges increases as the distance between them decreases (Fig. 2.17)

This law is written as follows:

$$F = k\frac{Q_1 Q_2}{d^2}$$

where $F$ is the force, $k$ is a proportionality constant, and $d$ is the distance between charges $Q_1$ and $Q_2$.

The third law, electric charges reside on the external surface of a conductor, is true because when a metal wire is charged, all the negative charges (electrons) move to the outside of the wire leaving the inside of the wire uncharged (Fig. 2.18). This distribution occurs as the electrons attempt to get as far away from each other as possible. In a solid conductor, this occurs on the surface because the surface area is larger which allows the electrons to be repelled from one another.

Figure 2.18 illustrates the electrostatic law of distribution of charged particles.

The fourth law, electric charges concentrate on the surface of a conductor. Figure 2.19 illustrates how the electric charges will concentrate at the sharpest point on an object. This is also caused by the law of repulsion-attraction. Each negative charge is repelled by other negative charges, which causes the charges to

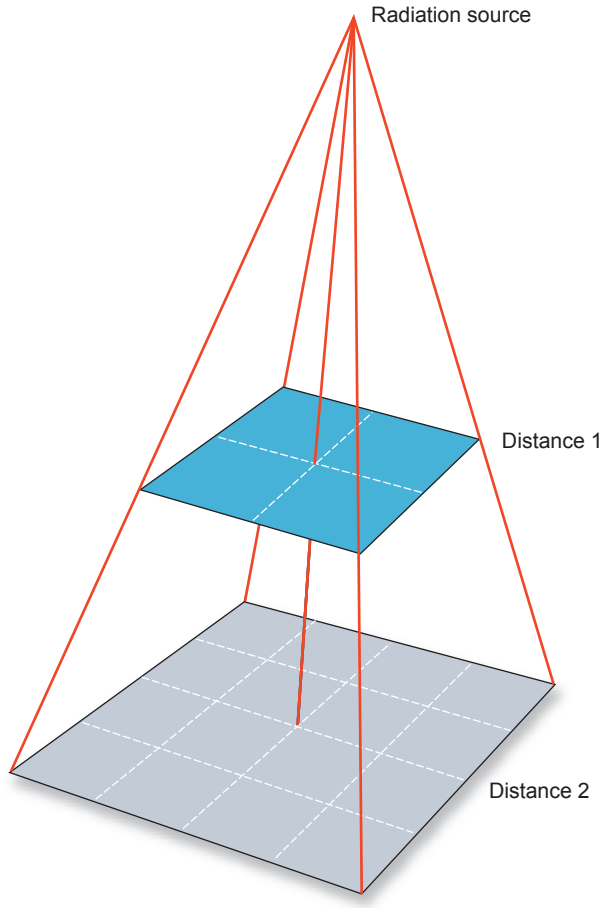



**Figure 2.17. Coulomb's law.**

collect at the sharpest point. If enough negative charges collect, they can cause ionization in the air and discharge to the closest point of low concentration in an attempt to neutralize the excess negative charges.

The fifth law, only negative charges move along solid conductors because the positive charges do not drift in solid conductors. The positive charges or protons are tightly bound inside the atom's nucleus and are not easily moved. The electrons, which orbit the atom, can be easily removed with the appropriate amount of force.

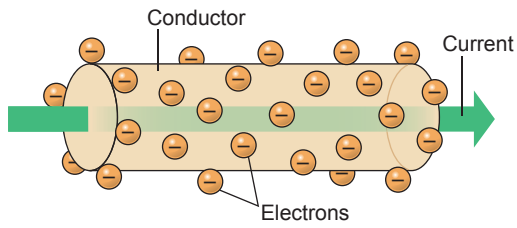



**Figure 2.18. Electrostatic law of distribution. Negative charges will reside on the surface of a solid conductor.**

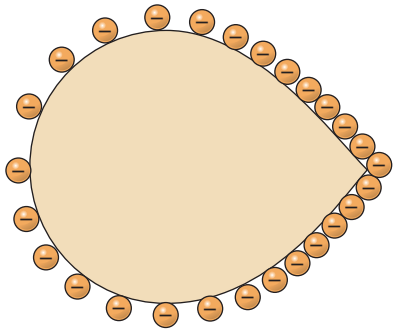


**Figure 2.19. Electrostatic law of concentration. Due to repulsion, negative charges will concentrate to the sharpest point on a curved object.**

These laws are used in radiographic imaging equipment, including image intensifier tubes, x-ray tubes, and image display systems. These systems can only operate through the use of electricity, and electricity cannot exist without utilizing the principles of electrostatics and moving negative charges. Radiographic equipment uses electricity to power equipment and to create, drive, and focus electrons within the x-ray tube and image intensifier tube. These concepts are built upon in subsequent chapters for a comprehensive understanding of the whole process of producing a radiographic image.

## Chapter Summary

This chapter has continued to present foundational information that is essential for you to understand the science behind radiology and to prepare you for the later, more applied chapters. Electromagnetic radiation ranges from low-energy, low-frequency, long-wavelength radio waves to high-energy, high-frequency, short-wavelength gamma rays, all of which form an electromagnetic spectrum. Waves are characterized by velocity, frequency, period, wavelength, and amplitude. The inverse square law describes how electromagnetic radiation intensity changes with distance. As the distance increases, the electromagnetic radiation intensity decreases.

Magnetism pertains to the attracting of iron by a magnet or moving electrical current. You have learned about four types of materials (ferromagnetic, paramagnetic, diamagnetic, and nonmagnetic) and their varying degree of attraction to magnets, magnetic fields, the laws that govern magnets, and the units used to measure magnetic flux.

Electrostatics is the study of stationary electric charges and is governed primarily by five laws, which describe how charges interact. You learned about the methods of electrification and how each influence electric charges. These concepts are further explored in Chapter 3: Electric Currents and Electricity.

## Case Study

John is being escorted into the MRI department for an exam. Prior to taking John into the exam room, Elizabeth, the MRI technologist, asked John to place his wrist watch, belt, keys, and any metal object he had into a locker in the dressing room. She explained that this was a policy of the hospital and was for the patient's safety.

### Critical Thinking Questions

Why did Elizabeth ask John to remove these objects and not take them into the MRI room?

Which law is Elizabeth thinking about when she makes this request?

MRI magnets are extremely powerful and have the ability to attract ferromagnetic objects that are brought into the MRI exam room. If a metallic object is brought into proximity of the MRI magnet, the powerful magnetic field lines of the magnet will attract the object and it will become a flying projectile! This poses a lethal risk to any person standing between the magnet and the metal object. The law of repulsion/attraction teaches us this lesson, and because of the impact of this law, only nonferromagnetic materials are allowed in the exam room. Special wheelchairs, IV poles, and crash carts have been developed for safe usage in the MRI room.

# Review Questions

## Multiple Choice

1. **What is the basic charged particle?**

   A. Electron
   B. Neutron
   C. Volt
   D. Coulomb

2. **The first electrostatic law states that**

   A. a proton will repel a neutron
   B. an electron will repel a proton
   C. an electron will repel an electron
   D. a neutron will repel a neutron

3. **Which statement is not one of the laws of magnetism?**

   A. Like poles repel
   B. Unlike poles attract
   C. Stronger magnets have larger poles
   D. The force between magnets decreases with the square of the distance between them

4. **The frequency of an electromagnet wave is measured in**

   A. the height of the wave
   B. the number of cycles per second
   C. the distance between adjacent peaks
   D. the length of time it takes to complete one cycle

5. **Which type of magnetic material is weakly repelled by other magnetic fields?**

   A. Diamagnetic
   B. Ferromagnetic
   C. Paramagnetic
   D. Nonmagnetic

6. **The field lines of a magnet flow _____ to the magnet.**

   A. parallel
   B. perpendicular
   C. either parallel or perpendicular
   D. neither is correct

7. **A spin magnetic moment is best described as**

   A. the domains in a magnetic material are all oriented in the same direction
   B. the spinning of electrons on their axes as they orbit an atom
   C. a group of atoms whose dipoles are aligned in the same direction
   D. the domains in a magnetic material are randomly oriented

8. **The Earth's north magnetic pole is located**

   A. at the north geographic pole
   B. in northern Canada
   C. near the south geographic pole
   D. near Australia

9. **One gauss is equivalent to _____ tesla?**

   A. $10^{-6}$
   B. $10^{-9}$
   C. $10^{-4}$
   D. $10^{-3}$

10. **The electric charges on a curved surface will concentrate**

    A. at the sharpest curvature
    B. at the area of least resistance
    C. near the widest curvature
    D. where the resistance is the greatest

## Short Answer

1. Which type of electromagnetic radiation has the lowest energy and frequency but the longest wavelength?

2. Describe the change in intensity if the distance between two magnified objects is doubled?

3. How do x-rays and gamma rays differ from each other?

4. Which electrostatic law deals with the force between two objects? Briefly describe this law.

5. Describe the third law of magnetism.

6. Give an example of electrification by contact and explain the principles of this type of electrification.

7. What properties of x-rays are suitable for producing an image?

8. If the frequency of a sine wave is decreased, what happens to the wavelength?

9. How is the amplitude of a sine wave related to the energy of the wave?

10. Which magnetic material is not affected by a magnetic field?

2

# Electromagnetic Radiation Magnetism, and Electrostatics

1. **The unit of electric charge is the**

   a. electron
   b. proton
   c. volt
   d. coulomb

2. **Which of the following are ways that an object can be electrified (i.e., have charge transferred to it)?**

   1. **Contact**
   2. **Rubbing it with a magnet**
   3. **Induction**

   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

3. **The force between two positive charges is**

   a. attraction
   b. repulsion
   c. zero

4. **The force between a positive and negative charge is**

   a. attraction
   b. repulsion
   c. zero

5. **The force between two negative charges is**

   a. attraction
   b. repulsion
   c. zero

6. **The force between two uncharged particles is**

   a. attraction
   b. repulsion
   c. zero

7. **According to the laws of electrostatics, charge is transferred by the movement of**

   a. protons
   b. neutrons
   c. electrons
   d. photons

8. **The units of magnetism are the**

   a. grass and tesla
   b. gauss and tesly
   c. gruss and tesly
   d. gauss and tesla

9. **Which of these materials is not ferromagnetic?**

   a. iron
   b. wood
   c. nickel
   d. cobalt

**10. Which of these materials is ferromagnetic?**

a. wood
b. glass
c. iron
d. plastic

**11. A ferromagnetic material is**

a. weakly influenced by a magnetic field
b. strongly influenced by a magnetic field
c. repelled by a magnetic field
d. not influenced at all

**12. Two magnetics with the same poles facing each other will**

a. be attracted
b. be repelled
c. experience a force times the distance
d. experience no force

**13. The Earth's magnetic pole under the ice north of Canada is a(n)**

a. north magnetic pole
b. south magnetic pole
c. ice pole
d. equatorial pole

**14. When a charged particle is put in motion,**

a. a magnetic field is created
b. an electric dipole has been ionized
c. gamma radiation results
d. it allows positive charges in a conductor to move, also

**15. Which of the following is not a form of electromagnetic radiation?**

a. microwaves
b. ultrasound
c. infrared
d. x-rays

**16. Electromagnetic radiation travels in packets of energy called**

a. photons
b. protons
c. rays
d. coulombs

**17. Place the following electromagnetic waves in order of increasing wavelength:**

**1. Visible light** **3. Gamma rays**
**2. Radio waves** **4. Infrared**

a. 3, 1,4,2
b. 4,1,2,3
c. 2,4,1,3
d. 3,4,1,2

**18. Place the following electromagnetic waves order of increasing energy:**

**1. X-rays** **3. Visible light**
**2. Microwaves** **4. Radio**

a. 1, 2, 3, 4
b. 4, 2, 3, 1
c. 1, 2, 4, 3
d. 4, 3, 2, 1

**19. All electromagnetic waves have what characteristic in common?**

a. they share the same wavelength
b. they have the same energy
c. they all have the same frequency
d. they all travel at *c*

**20. Light travels at a speed of**

a. 340 mi/s
b. 10,000 m/s
c. $3 \times 10^8$ m/s
d. $2.54 \times 10^{18}$ ft/s

**21. Because the speed of light is constant, an increase in frequency results in _____ in wavelength.**

a. an increase
b. a decrease
c. no change

**22. Which of the following statements best describes the relationship between frequency, wavelength, and energy?**

a. as energy increases, both wavelength and frequency increase
b. as energy increases, both wavelength and frequency decrease
c. as energy increases, wavelength increases and frequency decreases
d. as energy increases, wavelength decreases and frequency increases

**23. Using the formula, $c = f\lambda$, calculate the frequency of an x-ray photon that has a wavelength of $2.3 \times 10^{-10}$ m.**

a. $3 \times 10^{8}$ m/s
b. $6.9 \times 10^{-2}$ Hz
c. $1.3 \times 10^{18}$ Hz
d. $7.6 \times 10^{-17}$ m

**24. Using the formula, $c = f\lambda$, calculate the wavelength of an x-ray photon that has a frequency of $3.28 \times 10^{17}$ Hz.**

a. $1.09 \times 10^{9}$ m
b. $9.84 \times 10^{25}$ m
c. $3 \times 10^{8}$ m/s
d. $9.15 \times 10^{-10}$ m

**25. The number of wave cycles per second for electromagnetic radiation is the definition for**

a. wavelength
b. amplitude
c. frequency
d. intensity

**26. The distance between the same portions of adjacent waves is the**

a. wavelength
b. amplitude
c. frequency
d. intensity

**27. The variations between zero and maximum height of the wave is the**

a. wavelength
b. amplitude
c. frequency
d. intensity

**28. Hertz is a measure of**

a. the number of cycles per millimeter
b. the number of cycles per second
c. energy per centimeter squared
d. intensity per millimeter

**29. One kilohertz is**

a. 1 cycle per second
b. 1,000 cycles per second
c. 10,000 cycles per second
d. 1,000,000 cycles per second

**30. One megahertz is**

a. 1 cycle per second
b. 1,000 cycles per second
c. 10,000 cycles per second
d. 1,000,000 cycles per second

**31. One hertz is**

a. 1 cycle per second
b. 1,000 cycles per second
c. 10,000 cycles per second
d. 1,000,000 cycles per second

**32. Ionizing radiation is radiation that**

a. is continuously emitted from an MRI unit
b. has enough energy to remove an electron from its orbital shell
c. is created using ultrasound
d. causes charge to be transferred through induction

**33. If the original exposure rate to a technologist is 8 mR/h at a distance of 4 m, moving to a distance of 2 m results in a new exposure rate of**

a. 2 mR/h
b. 4 mR/h
c. 16 mR/h
d. 32 mR/h

**34. Calculate the original intensity given the following factors**

$I_2 = 270$ mR $\quad d_1 = 40''$ $\quad d_2 = 72''$ $\quad I_1 =$ _____

a. 83 mR
b. 150 mR
c. 486 mR
d. 875 mR

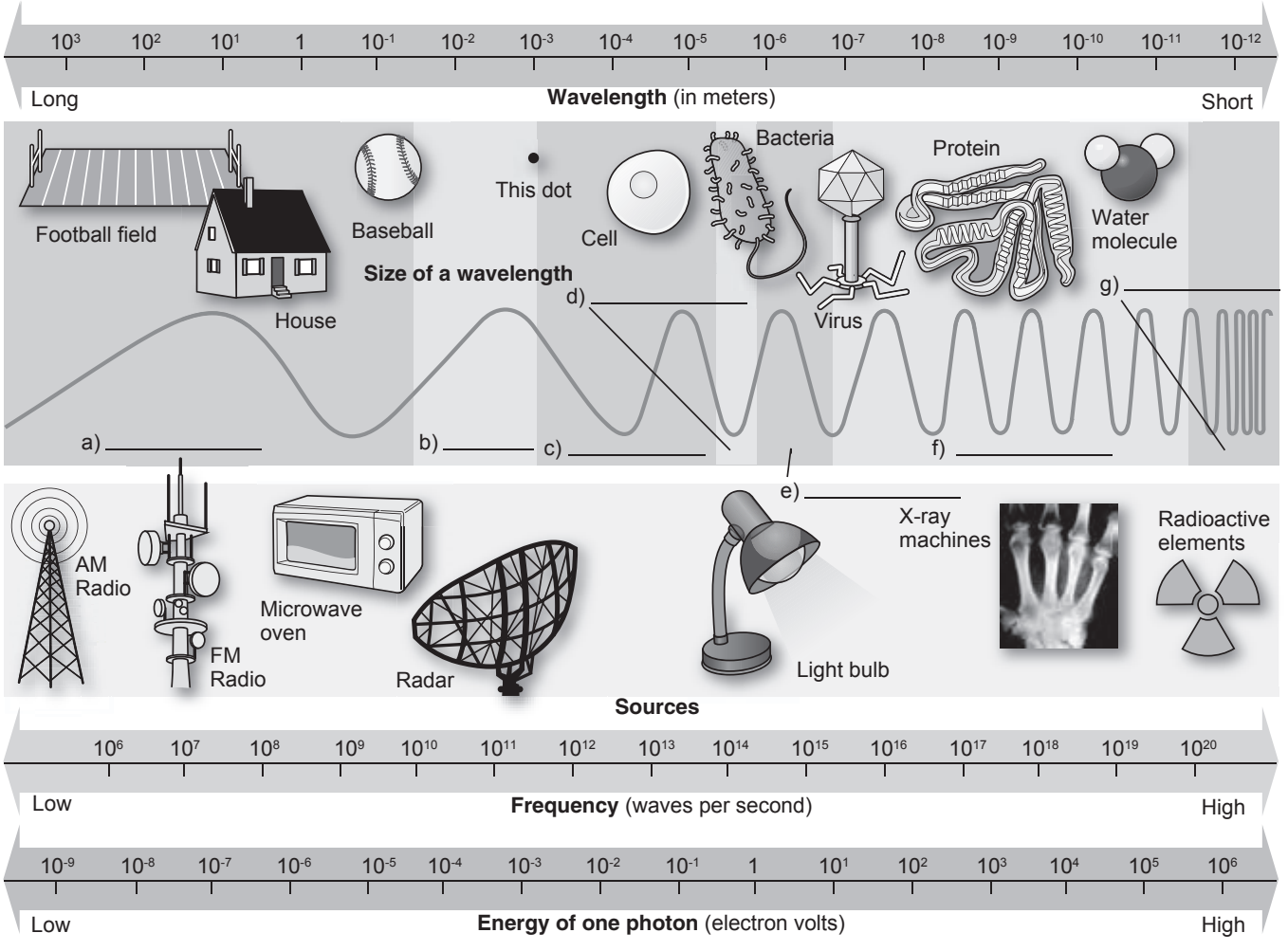
**35. Calculate the new distance given the following factors:**

$I_1 = 26$ mR $\quad I_2 = 295$ mR $\quad d_1 = 300$ cm $\quad d_2 =$ _____

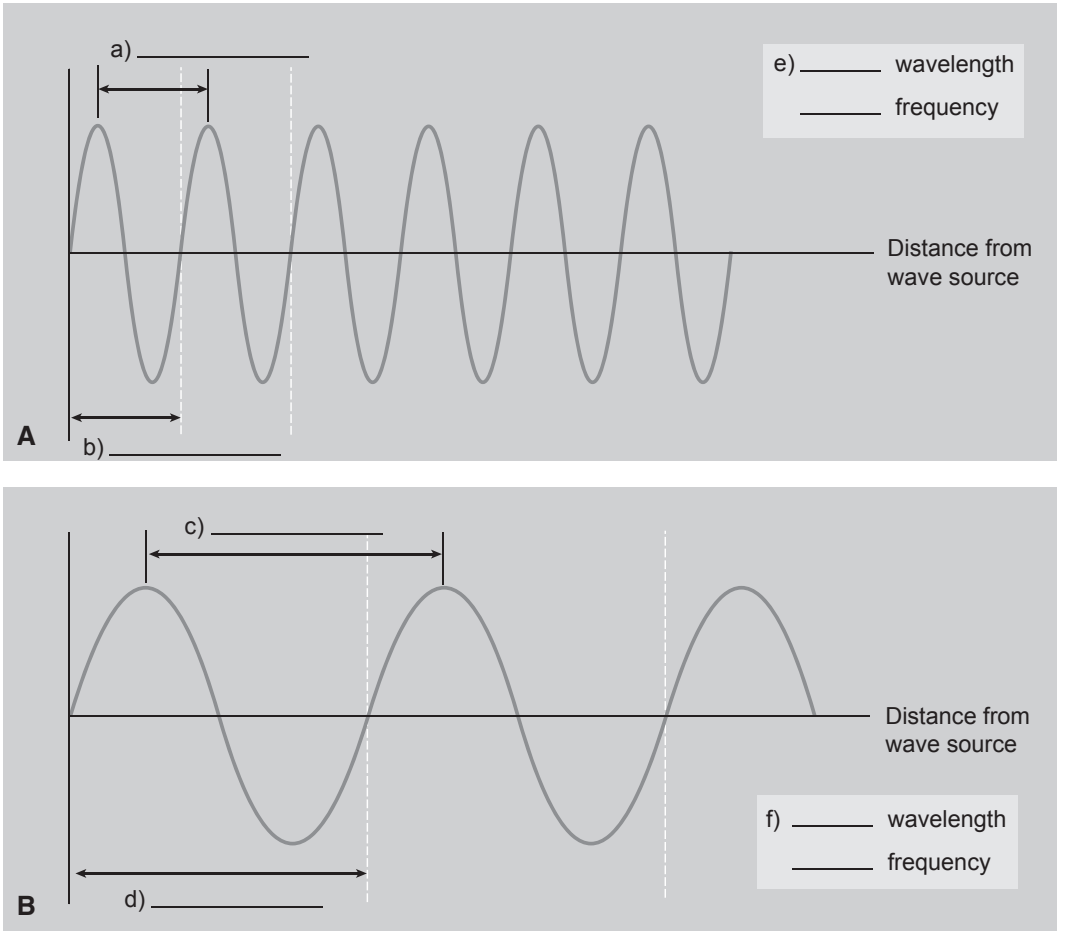
a. 30 cm
b. 89 cm
c. 600 cm
d. 1,000 cm

# Image Labeling

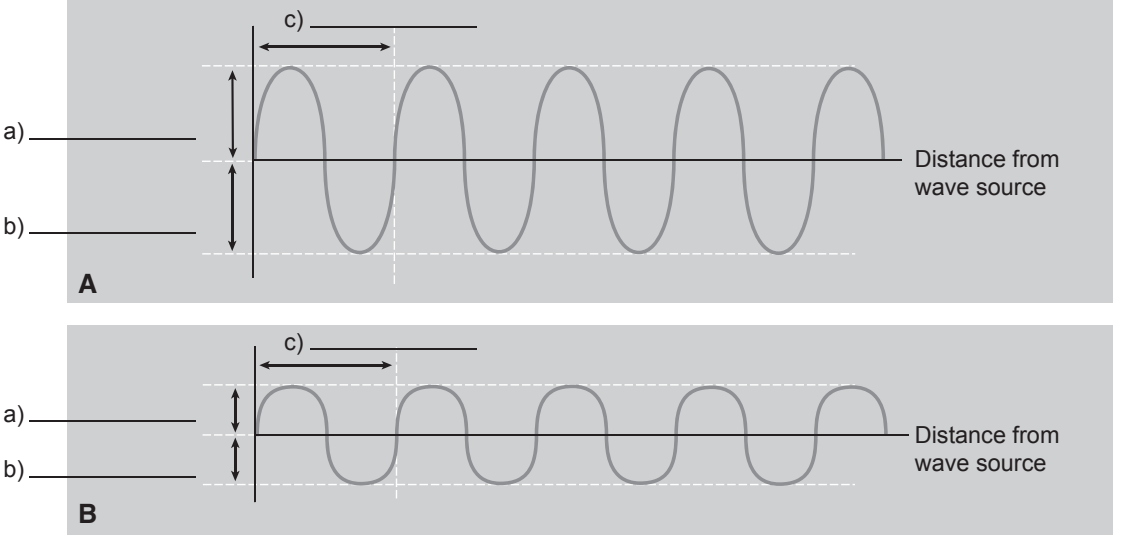
1. **Identify the representative portions of the electromagnetic spectrum identified by the letters below in the order of their increasing energy.**



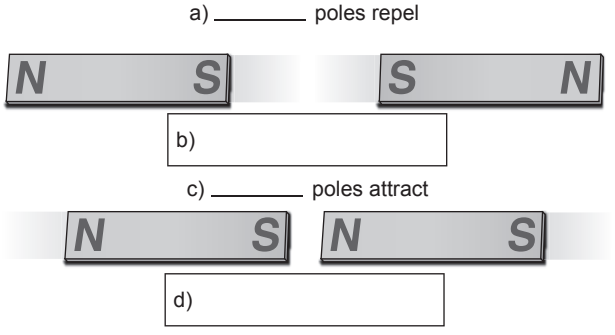
2. Label the identified parts of the wave.



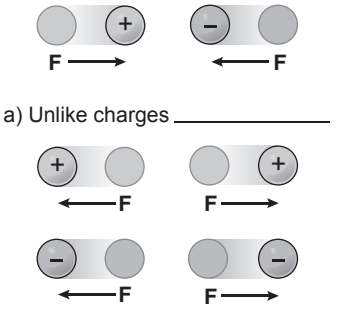

3. Label the identified parts of the wave.



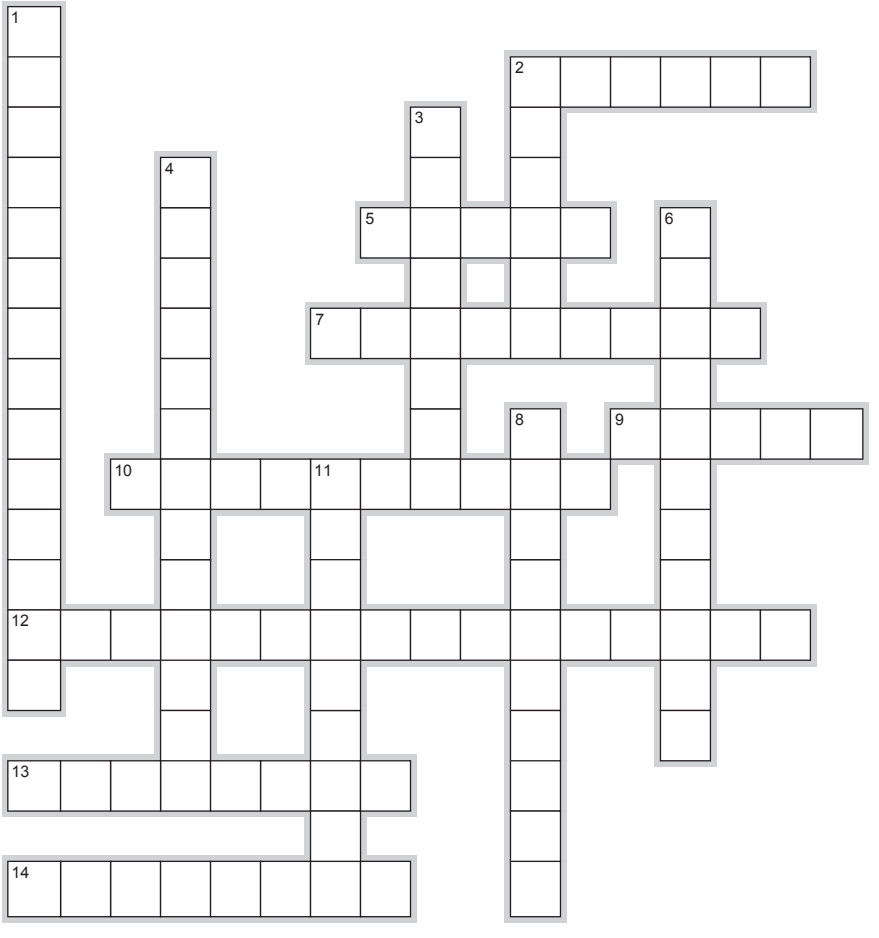
4. **Analyze the magnetic poles below and complete each label, indicating whether it attracts or repels. Also add arrows to indicate the direction of the magnetic force between the two poles.**




5. **Analyze the electric charges below and complete each label, indicating whether it represents attraction or repulsion. Also add arrows to indicate the direction of the force between the two charges.**



# Crossword Puzzle




## Across

**2.** The time required for one complete cycle of a wave
**5.** Unit that measures the frequency of a wave
**7.** The flux or flow of energy; measured in Wat/cm$^3$
**9.** The portion of the electromagnetic spectrum with the shortest wavelength.
**10.** The distance between adjacent peaks or adjacent valleys of a wave.
**12.** States that the intensity of the radiation is inversel proportional to the square of the distance (three words)
**13.** Electrification caused by rubbing two objects together
**14.** Heat energy

## Down

**1.** Group of atoms with their dipoles lined up in the same direction (two words)
**2.** A discrete packet of electromagnetic energy
**3.** The particle that is transferred during electrification
**4.** Materials that are attracted to a magnet
**6.** The electromagnetic wave that falls between visible light and x-rays
**8.** The force exhibited between two unlike charges
**11.** A natural magnet