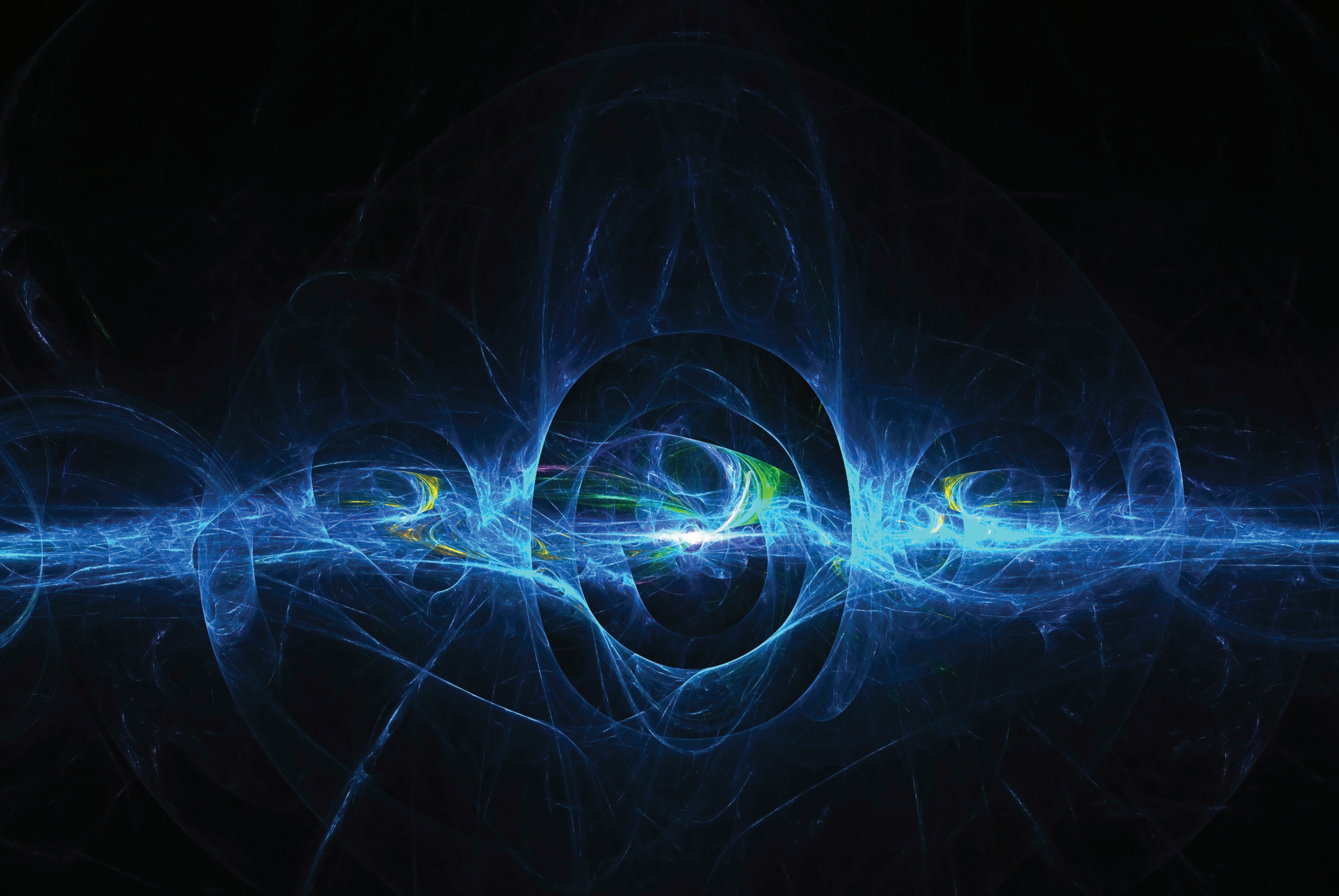
AN INTRODUCTION TO NON-IONIZING RADIATION



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An Introduction to Non-Ionizing Radiation

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FOREWORD

Radiation has been used in many fields and areas, including but not limited to astronomy, environmental analysis, industry, medicine, and the military. The use of radiation has brought a revolution in medicine and healthcare due to its astonishing therapeutic and diagnostic applications. It has also been a fact that radiation causes many complications and can harm the human body in many ways. Shielding and protection from radiation are equally important. Researchers, clinicians, and scientists have widely discovered the hazards and harms of ionizing radiation and mechanisms of protection from ionizing radiation. On the other hand, the harms and strength of hazards of non-ionizing radiation are yet to be discovered in detail. Due to the recently emergent uses and applications of non-ionizing radiation in many areas, it is important to investigate the adverse effects of non-ionizing radiation and mechanisms and strategies of protection from non-ionizing radiation. Several investigators have reported non-ionizing radiation. However, those reports are limited to a portion of non-ionizing radiation.

After reading and analyzing the book "An Introduction to Non-Ionizing Radiation" authored and edited by Muhammad Maqbool, Ph.D., along with other co-authors, I have reached the conclusion that this book provides detailed and to-the-point information about non-ionizing radiation. The book is unique because of the following reasons:

First, the book discusses and reports information about all types of electromagnetic non-ionizing radiation, from the most energetic ultraviolet radiation to the very low-energy electromagnetic fields and radio wave radiation. Second, the book has also discussed non-electromagnetic (mechanical) non-ionizing radiation, including ultrasound and audible sound. Third, the subject of this book is not just limited to the benefits or harms of non-ionizing radiation, but benefits and harms are discussed in a very systematic way. Fourth, the book is compiled based on the latest information provided about non-ionizing radiation by researchers, clinicians, educators, and scientists in the field. In addition, the style of each chapter of the book is very attractive. Each chapter provides an introduction to a certain type of non-ionizing radiation, the basic properties of that radiation, the benefits of the radiation, followed by the harms and hazards associated with each particular type of non-ionizing radiation. Strategies for how to protect from the adverse effects of each type of non-ionizing radiation have also been given in each chapter.

Overall, I believe that "An Introduction to Non-Ionizing Radiation" is a very informative and unique book that describes non-ionizing radiation in very detail and to the point. Moreover, the book is written in such a way that undergraduate students, graduate students, professors, clinicians, and researchers can take advantage of this book at the same time. I recommend this book to be a part of every library, university and institution.

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PREFACE

In the name of Allah, the Most Beneficent, the Most Merciful. I am very thankful to Allah Almighty for giving me the ability, the capabilities, the resources, and the courage to complete this task.

Medical and Health Physics is a broad and one of the fast-growing fields around the world, based on the safe use of radiation. The enormous benefits of radiation used in diagnostic, therapeutic, and healthcare applications have made researchers further explore this field. Because of its interdisciplinary nature, medical and health physics is open to researchers, investigators, and educators from many basic and applied fields. The entire area of medical and health physics is based on radiation and its proper uses. Radiation is a blessing due to its revolutionary pros, benefits, and use in many fields. In this regard, I and my friends and collaborators published the book 'An Introduction to Medical Physics', a few years ago. With the great popularity of the book around the globe and the demand from students, friends, and colleagues, I feel that it would be very important to move forward and publish more in this area. After looking at the requirements and demands in medical and health physics, radiation sciences, and applied electromagnetic waves, I decided to write another book in this series with the title 'An Introduction to Nonionizing Radiation.' Relatively little known about nonionizing radiation and very little published material in this area, I decided to write on the fundamental concepts, characteristic properties, uses, benefits, and especially the harms and hazards associated with nonionizing radiation. The frequent use of lasers, mobile phones, antennas, infrared radiation, visible light, and ultraviolet radiation compelled me to write about and report the latest findings on the harms and hazards associated with the use of nonionizing radiation with their beneficial applications. Thus, this book provides a brief understanding of the fundamental concepts of nonionizing radiation. The book talks about how nonionizing radiation can be used to serve and help people. The book also discusses the nature and strength of harms and hazards one can get from nonionizing radiation exposure. At the same time, this book also talks about how safety and protection from the adverse effects of nonionizing radiation can be attained during its beneficial use by following proper rules, regulations, and guidelines.

In completing this task, I am very thankful to all authors who contributed valuable ideas to flourish the beauty and depth of the subject matter discussed in this book.

I am very thankful to Humaira Hashmi and the Bentham Books publisher, who helped and cooperated to achieve this astonishing goal.

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DEDICATION

This book is dedicated to my late parents. May Allah (God) bless their souls and place them in Jannat-ul-Firdous. My success and achievements in life would not have happened without their help, support, love, and prayer. They were my inspiration in life. Though it has been many years since their souls departed, I feel like I still need them and their prayers in my life. I pray to Allah to bless their souls and award them the highest place in paradise along with my late brother.

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CHAPTER 1

Introduction and Classification of Radiation

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Abstract: We interact with several types of radiation in our daily life and on certain occasions. Even though all radiation carries some common properties but there are still several differences between them due to different characteristics and effects. Based on the characteristics and applications, radiation is divided into two main categories: ionizing and non-ionizing radiation. A brief introduction to both types of radiation is provided here. Similarities and differences in radiation are discussed in detail to justify why nonionizing radiation is different than ionizing radiation. Very little has been explored; nonionizing radiation needs more attention. Therefore, more emphasis is put on nonionizing radiation, its properties, classification, wavelength, and energy range, and why nonionizing radiation plays an important role in our lives, which are reported here.

Keywords: Acoustic wave, Bohr's atomic model, Energy, Electromagnetic wave, Nonionizing radiation, Wavelength.

INTRODUCTION

Radiation is a source of energy that originates from a source and travels through space or a medium. Upon interaction, radiation may be able to penetrate, scatter, or be absorbed by materials. Radiation energy can be electromagnetic or particulate. In general, when people hear the word radiation, they often think of nuclear power and radioactivity, and at the most, some people will pay attention to alpha (α) rays, beta (β) rays) and gamma (γ) rays), but radiation has many other forms. Visible light is a familiar form of radiation; other types include x-rays, ultraviolet radiation, infrared radiation (a form of heat energy), microwaves (used in microwave Owens at homes), and radio and television signals. Radiation may be obtained from various sources, including cosmic rays from the universe, and the earth, as well as man-made sources such as those from nuclear fuel and medical procedures. Radiation has been used in many industries, including diagnostic imaging, cancer treatment (such as radiation therapy), nuclear reactors

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with neutron fission, radioactive dating of objects (carbon dating), as well as material analysis. The biggest source, from which we get radiation, is the sun. Radiation carries and transmits energy in the form of waves or particles. Radiation possesses benefits and harms at the same time if overexposure occurs [1].

Though it possesses dual nature, radiation with zero rest mass is generally considered a wave, and radiation with some rest mass is considered a particle. X-rays, visible light and infrared rays all are waves. Electrons, protons, neutrons, and α-rays are particles since they possess rest mass.

Radiation with zero rest mass (waves) is classified into two categories: Electromagnetic waves (or electromagnetic radiation) and mechanical waves.

Electromagnetic and Mechanical Waves

There are many types of waves, and although they all have things in common, there are also characteristics and behaviors that distinguish them from each other. The two major classifications of waves, based on their nature and characteristics, are called electromagnetic waves and mechanical waves [2]. A brief description of those waves is given below:

Electromagnetic waves do not need a medium for their propagation and can pass through a vacuum. Visible light, ultraviolet (UV) rays, and microwaves are examples of electromagnetic waves or electromagnetic radiation. Big vacuums exist between the earth and the sun, but the light emitted from the sun can reach the earth because the light is electromagnetic in nature and passes through the vacuum. An electromagnetic wave carries electric and magnetic fields. Both fields oscillate perpendicular to each other as well as to the direction of propagation of the wave. Due to this behavior, electromagnetic waves or electromagnetic radiation are also called *Transverse Waves*. The propagation of an electromagnetic wave, with transverse electric and magnetic fields, is shown in Fig. (**1**).

Mechanical waves are those waves that need a medium for their propagation and cannot pass through a vacuum. The medium in which these waves propagate could be gas, liquid, or solid. Sound and other acoustical waves are examples of mechanical waves. When sound (mechanical waves) propagates, it oscillates the medium in a direction parallel to the direction of the wave propagation. Due to this behavior, mechanical waves are also called *Longitudinal Waves*. Propagation of sound (mechanical wave) with longitudinal oscillations, is given in Fig. (**2**). Mechanical waves are also called elastic waves, as their propagation depends on the elastic properties of the medium through which the waves pass.

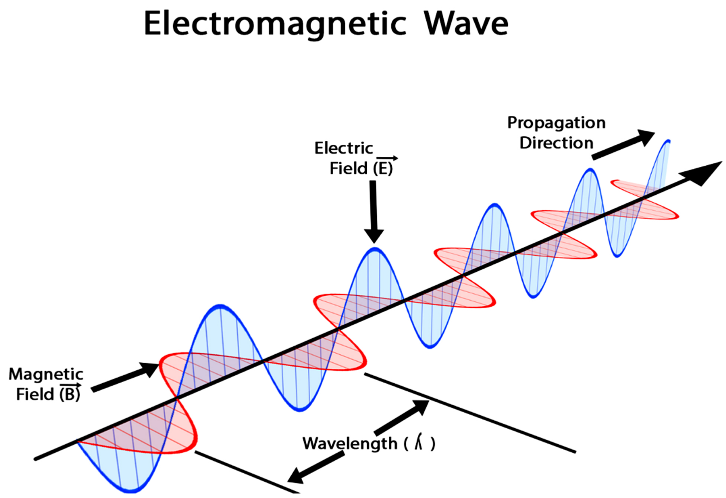

Fig. (1). Electromagnetic wave propagation with perpendicular electric and magnetic fields.

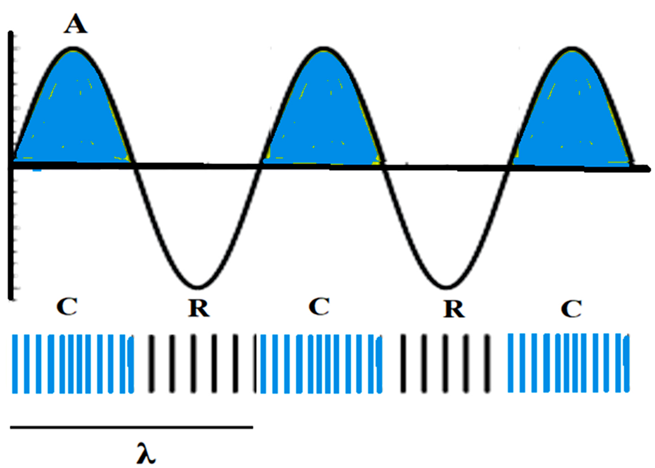

Fig. (2). Sound wave propagation, making compressions and rarefactions.

Electromagnetic waves are produced by the vibration of the charged particles, and are caused because of varying magnetic and electric fields. Maxwell's equations imply that a time-varying electric field generates a time-varying magnetic field and *vice versa*. These varying fields are thus described as "interdependent," and together they form a propagating electromagnetic wave. The ratio of the strength of the electric-field component to that of the magnetic field component is constant in an electromagnetic wave. It is known as the characteristic impedance of the medium (η) through which the wave propagates.

CHAPTER 2

Types of Non-Ionizing Radiation and its Interaction with Matter

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Abstract: We encounter radiation in our daily life. Emission or transmission of energy in the form of waves or particles is known as radiation. There are two types of radiation – ionizing and non-ionizing. The types and interactions of non-ionizing radiation with a medium, materials, or body tissue are discussed in this chapter. Non-ionizing radiation has less energy than ionizing radiation; it does not possess enough energy to produce ions or ionize body tissues and cells. Non-ionizing radiation includes Static fields, ultrasound, and a part of the electromagnetic spectrum. Sunlight, mobile phones, the earth's magnetic field and electrical appliances are some of the common sources of nonionizing radiation. Although these radiations have low energy, they have many useful applications, especially in medicine. Non-ionizing radiations originate from various natural and manmade sources. It has always been present and is all around us. These radiations cannot destroy human tissues by ionizing body atoms, instead, they can destroy body cells by excitations, heating, vibration, phonons generation, and chemical changes because of the relatively low energy of the particles of nonionizing radiation. Non-ionizing radiation has many beneficial applications, including uses in agriculture, medicine, industry, and research. As the use of nonionizing radiation increases, so does the potential for health hazards. In this chapter, we will look at non-ionizing radiation, the way it interacts with matter, and some of the potential biological health effects produced by various types of non-ionizing radiation.

Keywords: Biological effects, Electric and magnetic fields, Electromagnetic wave, Infrared, Interaction, Low energy radiation, Ultraviolet.

INTRODUCTION

The Electromagnetic (EM) spectrum is known to comprise a wide range of electromagnetic radiations. All electromagnetic waves travel at the speed of light in a vacuum; they do so at different frequencies, wavelengths, and photons energ-

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Muhammad Maqbool (Ed.)

ies. The EM spectrum is mainly classified into two portions, namely Ionizing radiation and non-ionizing radiation. Ionizing radiation is those electromagnetic radiation that carries enough energy per quantum to ionize atoms or molecules. Non-ionizing radiations are those electromagnetic radiations and mechanical waves that do not carry enough energy per quantum to ionize atoms or molecules. In the electromagnetic spectrum, non-ionizing radiation appears at a long wavelength and frequency lower than that of ionizing radiation. An energy of approximately 30 eV is required to ionize atoms in human tissues. Therefore, radiation with frequencies below 10^{16} Hz corresponding to 30 eV is termed non-ionizing radiation ionizing. The two main portions of the electromagnetic spectrum have been further categorized in sub-portions based on behavior in the emission, transmission, and absorption of the wave and according to their different practical applications. However, the transitions between the different characteristic ranges are not particularly well defined. This chapter deals with the first portion of the electromagnetic spectrum *i.e.*, Non-Ionizing radiation. Static fields and ultrasound will also be discussed. Static fields and ultrasound are those non-ionizing radiation that does not belong to the electromagnetic spectrum. The reason is that static fields are in no way radiated, and ultrasound is a mechanical wave, not an electromagnetic wave. In addition to non-ionizing electromagnetic radiation, mechanical waves of energy less than 30 eV are also referred to as non-ionizing radiation. Examples of non-ionizing mechanical waves are acoustic waves and ultrasound waves [1, 2].

Non-ionizing radiation differs from ionizing radiation in the way it interacts with matter. Unlike ionizing radiation, non-ionizing radiation does not have enough energy to cause ionization. Non-ionizing radiation has only sufficient energy to change the rotational, vibrational, or electronic valence configurations of molecules and atoms. Radiation can damage DNA directly or indirectly through reactive oxygen/nitrogen species. When this radiation is absorbed in human tissue biological effects may be observed hence, it is important to understand how radiation interacts. To recognize the presence of NIR and its ability to cause a hazard, first, one needs to understand the radiation itself and its nature [1 - 3].

Types of Non-Ionizing Radiation

Non-ionizing radiation is divided into 8 different types, with acoustic waves (audible sound and ultrasound) being the only mechanical waves. All other types of non-ionizing radiation belong to the electromagnetic waves class [4, 5].

1. Static fields

2. Ultrasound

3. ELF (extremely low frequency)

4. Radio Frequencies

5. Microwave Frequencies

6. Infrared

7. Visible Spectrum

8. Ultraviolet

Static Fields

Fields that do not vary with time are referred to as static fields. A static electric field (also known as an electrostatic field) is created by charges that are fixed in space, and a static magnetic field (also known as magnetostatic) is created by the magnet and steady currents.

A static electric field is the force field created by the attraction and repulsion of electric charges that are fixed in space ("static electricity").

A static magnetic field is a force field created by a magnet or by the steady flow of electricity, for example, in appliances using direct current (DC).

Static electric and magnetic fields occur naturally in the earth's atmosphere. For example, lightning results from the electrical transfer of the fields generated due to the charge imbalance between the cloud and the ground or within the clouds. The natural magnetic field originates from electric current flow in the upper layer of the earth's core. It consists of a static component due to the earth acting as a permanent magnet and several other small components, which differ in spectral characteristics and are related to such influences as solar activity and atmospheric events [6]. Man-made sources of static fields can be found in various facilities. In medicine, the most common use of manmade static magnetic field is for medical diagnosis. Examples are magnetic resonance imaging (MRI) and magnetic resonance spectroscopy (MRS) systems.

Ultrasound

Ultrasounds are mechanical waves that can easily transmit through materials like fluids, soft tissues, and solids. It has a frequency higher than the upper human auditory limit of 20 kHz [5].

Ultrasound is widely used in medicine in Cardiology, Urology, Obstetrics, and Gynecology. Medical ultrasound machines use waves with a frequency ranging

CHAPTER 3

Electromagnetic Fields and Radiation

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Abstract: Electromagnetic radiation is a form of energy that comprises electric and magnetic waves. It propagates in free space and contains neither mass nor charge but carries energy as a photon packet. The energy associated with electromagnetic radiation is directly proportional to the frequency from extremely low frequencies to visible light and above. The highly low-frequency electromagnetic field is generated by the electrical devices and power systems, while the radio and microwave signal radiates by the mobile tower, microwave oven, heater, radar, *etc.* The extremely high-frequency radiation emitted from medical devices, radioactive decay, nuclear weapons, *etc.* Therefore, environmental exposure to electromagnetic radiation increases gradually due to increasing electricity demands, advanced technologies, mobile communications, *etc.* However, exposure to electromagnetic radiation has an adverse biological effect depending on the current intensity, strength of the magnetic field, and duration of exposure. This book chapter introduces electrostatics and magneto-statics, the formation of electromagnetic fields and waves, frequency spectrum, source of radiations, and their exposure limits.

Keywords: Electric & magnetic fields, Electromagnetic energy/radiation, Frequency spectrum, & Exposure limits, Ionizing/non-ionizing radiation, Sources of radiation.

INTRODUCTION

An electromagnetic field is a property of space that combines the invisible forces of electric & magnetic fields. Four elemental forces exist in physics, known as the fundamental interactions, *i.e.*, the gravitational force, the electromagnetic force, and the strong & weak forces. Typically, these forces govern how the particle interacts with each other based on the strength of the power, ranges of energy, and the particles' nature [1]. In the 19th century, Scottish physicist James Clerk Maxwell's discovered the concept of electromagnetic force (EMF) theory. It relates to the repulsion/attraction, the chemical behavior of the matter, and the lig-

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ht properties [2]. In the 1960s, Steven Weinberg and Sheldon Lee Glashow proposed the quantum field theory of electromagnetism that treats EMF everywhere in our environment. Environmental exposure increases significantly either human-made sources by household devices or workplace equipment that radiates electromagnetic energy (EME) from low to extremely high-frequencies [3].

The emission of EME is the source of electromagnetic radiation (EMR). Typically, the EME describes all the energies released from the source of energy and travel through the propagation media with a constant speed of light, 3×10^8 m/sec. It comprises two independent components known as electric energy and magnetic energy [4]. Literature shows that around 0.01% of the total universe's energy occurs as the EMR [5]. For instance, human life immersed by EMR that emits from household equipment, personal electronic devices, radio, and television operates with EMR, modern communication technology depends on EMF, medical science uses EMR to observe the internal organ, *etc* [6 - 8]. Human eyes, including many animals, are sensitive to seeing the Sun's EMR, simply called the light ray. It comprises the visible portion of the wide range of frequencies. Usually, all living organs on the earth depend on EMR received from natural or artificial (human-made) sources.

Our daily lives are affected by human-made EMR significantly, for instance, food heated in microwave ovens, airplanes guided by radar waves, infrared waves invisible to human eyes, *etc.* Similarly, electronic devices such as mobile phones, Wi-Fi devices, radio, and television transmitters emit high frequencies of EMR that cause the thermal effect [6 - 9]. These high frequencies of EMR damage the body cell by raising the temperature of tissues and organs. Even all the electrically powered devices and the power transmission lines generate lower frequency, 50 Hz to 60 Hz radiation. This low-frequency EMR also has a negative biological impact on human organisms and may cause incurable effects on the human body [10 - 12]. The ultraviolet (UV) light and X-rays represent another kind of EMR that can harm human life [13]. However, X-rays also have an essential impact in medicine to observe the critical inner parts of the human body [14]. High-energy gamma rays come from radioactive materials such as radioactive decay and nuclear weapons *via* nuclear reactions that are also harmful to our life.

Since all types of EMR have adverse health effects, it is significantly necessary to learn the formation of electromagnetic radiation and the tolerance limits. This book chapter presents the basic concept of the formation of electromagnetic field & wave, EMR, types of radiation, and sources of EMR with the exposure tolerance limits on health. The rest of the book chapter is organized as follows: Sections (3.1) and (3.2) describe the nature of electromagnetic fields and wave formation, respectively. The electromagnetic spectrum and the sources of ionizing and non-ionizing radiations are presented in sections (3.3) and (3.4), respectively. Finally, we summarize and conclude the book chapter in section (3.5).

ELECTROMAGNETIC FIELDS

Electromagnetic field theory describes how the charged particles interact electrically among themselves and with the magnetic fields. This section starts the force interactions between classical electrostatics, and the classical magneto-statics and introduces the corresponding electric and magnetic fields. Before studying EMF, it is essential to know the basic idea of static and dynamic fields with their formation and sources of origin. There are four main electromagnetic interactions such as:

i. The attraction or repulsion force between electrically charged particles is inversely proportional to the square of the distance between them.

ii. Magnetic poles come in pairs that attract and repel each other.

iii. Electric fields produce the magnetic field and *vice versa*.

iv. The field direction depends on the flow of electric current.

Electrostatics

Electrostatics describes the physical phenomena related to the interactions between static electric charges in stationary boundaries. The Electrostatics principle plays a vital role in different fields, such as battery technology, fuel cells, photocells, radio detector diodes, electroplating, thermocouples, and light-emitting diodes (LEDs). However, the undesirable charge accumulation creates a problem and can cause to damage to the electronic components. Coulomb's law describes the forces acting between two electrically charged particles for presenting the electric field concept at a distance.

Coulomb's Law

In 1775, Charles-Augustin de Coulomb postulated that the force acting on a static charge, $\boldsymbol{q}$, at an observation point, $\boldsymbol{x}$, for another static charge, $\boldsymbol{q'}$, at the source point, $\boldsymbol{x'}$, is directed along the connecting line of two points. This postulation is called Coulomb's law. Thus, Coulomb's law states that the electrical force between two charged particles is directly proportional to the product of the magnitude of electric charges on the objects and inversely proportional to the square of the separation distance, $\boldsymbol{r}$. Fig. (**1**) describes the experimental observati-

CHAPTER 4

Ultraviolet Radiation: Benefits, Harms, and Protection

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Abstract: Ultraviolet (UV) radiation is used in several devices for various applications. These applications include medical, research and industrial uses. Some of these applications are fundamental tools for our modern era. These applications range from visualization of DNA to eradication of dangerous diseases and microorganisms in the air and water. While UV radiation is not energetic enough to be considered ionizing radiation and is treated as less hazardous, it is the form of non-ionizing radiation that is closest to the ionization region. UV radiation does have the ability to break chemical bonds and can pose significant hazards to humans. These hazards may include discomfort, temporary loss of sight or impairment, permanent loss of sight, or cancer. To mitigate the hazards from UV exposures, the hazards must be assessed, and administrative controls and engineering controls should be utilized. Federal regulations and guidance regarding UV hazard assessment and mitigation for the end-users of UV devices are not currently robust, but the American Conference of Governmental Industrial Hygienists (ACGIH) has provided some useful information for assessment.

Keywords: Administrative controls, Biosafety cabinet, Crosslinker, Engineering controls, Germicidal lamp, Transilluminator, Ultraviolet, UV hazards.

INTRODUCTION

Ultraviolet (UV) radiation is a type of electromagnetic radiation with energy lower than X-ray radiation and higher than visible light. It is the beginning of the non-ionizing region of photons. Since photons are waves, another way of expressing the energy of UV radiation is in terms of wavelength and frequency. UV light has a wavelength of 100 -400 nm. UV radiation is subdivided into 3 categories based on wavelength. 100-280 nm is the UVC region, 280-315 is the

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UVB region, and 315-400 nm is the UVA region. One of the most recognized sources of UV radiation is the sun, which emits all three regions of UV [1 - 4].

UV radiation is present in sunlight and constitutes about 10% of the total electromagnetic radiation output from the Sun. It is also produced by electric arcs and specialized lights, such as mercury-vapor lamps, tanning lamps, and black lights. Although long-wavelength ultraviolet is not considered ionizing radiation because its photons lack the energy to ionize atoms, it can cause chemical reactions and causes many substances to glow or fluoresce. Consequently, UV's chemical and biological effects are greater than simple heating effects. Many practical applications of UV radiation derive from its interactions with organic molecules [2 - 4].

UV radiation was discovered by German physicist Johann Wilhelm Ritter in 1801. He observed an accelerated darkening of silver-chloride-soaked paper when it was exposed to invisible rays just beyond the visible spectrum on the violet end. To distinguish these rays from the "heat rays" (IR) discovered the previous year on the other end of the visible spectrum, he called the UV radiation "oxidizing rays," which emphasized the chemical reactivity he observed. This was quickly replaced by the term "chemical rays," which remained popular throughout the rest of the 19th century. Eventually, the chemical and heat ray terms were replaced with the now common ultraviolet and infrared designations, respectively [5].

UV radiation is used extensively for medical, industrial, and academic purposes. Medical uses include drug development and discovery, DNA sequencing, and medical imaging of cells. Industrial uses include speed curing materials, label tracking, micromachining, semiconductor processing, and decontamination of surfaces and water. Academic uses include ultraviolet photoelectron spectroscopy, DNA visualization, lithography, biological safety, and anticontamination purposes. The source of UV radiation that all humans are exposed to is the sun, which is critical to life on earth. Other notable uses of UV radiation include drug detection, dental uses, and forensic analysis.

Types of UV Radiation

Electromagnetic radiation with wavelengths between 400 nm (4×10^{-7} m) and 100 nm (1×10^{-7} m) constructs the ultraviolet part of the spectrum as shown in Fig. (**1**). There are 3 types of UV radiation: Ultraviolet A (UVA), Ultraviolet B (UVB), and Ultraviolet C (UVC).

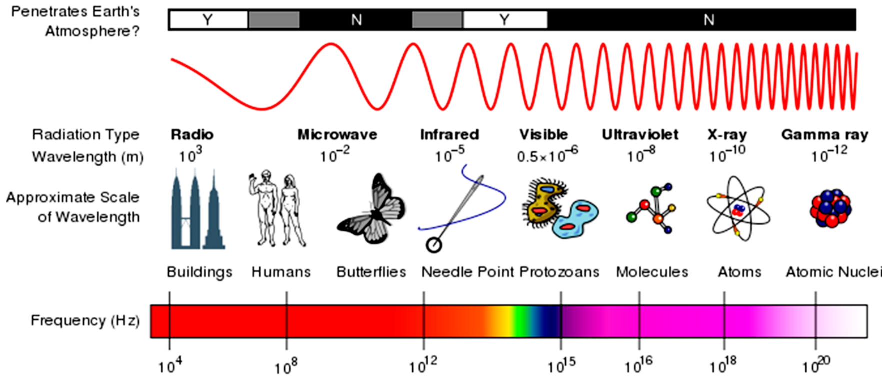

Fig. (1). Electromagnetic Radiation Spectrums.

UV-A radiations have a wavelength range of 400 nm – 315 nm. UVA radiation account for 95 percent of UV radiation that reaches the earth's surface and causes wrinkles, and other types of premature aging. *UVB* radiation has a wavelength range of 315 nm – 280 nm. UVB rays affect the skin's top layer and cause skin cancer and most sunburns. *UV-C* radiations have a wavelength range of 280 nm – 100 nm. These are the most dangerous type of UV radiation. People who work with welding torches or mercury lamps may be exposed to UVC rays.

Ultraviolet Radiation Type A (UVA)

UVA radiation (315-400nm) is about 1000 times less damaging to the skin than UVB as measured by sunburn (Erythema) or damage to cell DNA. On the other hand, 20 times more UVA than UVB reaches the earth in the middle of a summer's day. It is not greatly affected by absorption and scattering in the atmosphere when the sun is low in the sky, and is now known to contribute significantly to the total exposure at moderate levels throughout the whole day and year. UVA penetrates deeper into the skin and leads to deeper damage than UVB does. It penetrates cloud cover, light clothing and untinted glass relatively easily, and may induce a degree of continuing skin damage over long periods, even when UV exposure is not obvious. Ultraviolet radiation in the range of 315nm to 400nm is thought to contribute to premature aging and wrinkling of the skin and has recently been implicated as a cause of skin cancer. UV-A light (315-400nm) is the longest wavelength, and the least harmful. It is more commonly known as "black light", and many use its ability to cause objects to emit fluorescence in artistic and celebratory designs. Many insects and birds can preceive this type of UV radiation visually, along with some humans in rare cases such as Aphakia (missing optic lens).

CHAPTER 5

Visible Light: Benefits and Harms

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Abstract: Electromagnetic radiation with a wavelength between 380 nm and 760 nm is called visible light. Electromagnetic radiation within the mentioned wavelength range is called visible because we can see the world around us with the help of this radiation. A misconception usually exists that light is visible and exists in multiple colors. Light is not visible; it gives the feeling and sensation of various colors. For example, light with a wavelength of 450 nm gives the sensation of blue color, and light with a wavelength of 530 nm gives the sensation of green color; hence, we simply call it blue and green light. Light is very useful in our daily lives in many areas other than just seeing the world around us. Despite the enormous benefits of visible light, there are also some harms and hazards associated with this part of electromagnetic waves. Along with the basic understanding of daily life phenomena based on light and several benefits of light, this chapter also reports harms and hazards accompanied by visible light that we should be aware of and should protect ourselves from. Several examples of the hazards of visible light are provided in this chapter

Keywords: Benefits, Electromagnetic waves, Hazards, Visible light, Wavelength.

INTRODUCTION

What is Visible Light?

Visible light can be defined as a form of electromagnetic radiation with wavelengths between approximately 380–400 nanometers (nm) and approximately 760 nm, as found on the electromagnetic spectrum. Other forms of electromagnetic radiation include radio waves, microwaves, infrared, ultraviolet, x-rays, and gamma rays. Humans can see visible light due to its wavelength. Visible light radiation is essential to life on Earth, and without it, many adverse

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effects would occur. Consider this, green plants appear green because they reflect green color while absorbing the other colors of the spectrum. A red wall is red to your eyes because it is not absorbing light from the red wavelengths. Mirrors, however, reflect all of the colors of visible light [1, 2].

Living organisms tend to see the world in different ways or, as some would say, through different lenses. Black, white, and gray are the colors that dogs can see, while humans are unable to see specific colors that some insects can see. Visible light means visible to humans. It is important to note that all humans cannot see all colors due to a genetic defect of the eye called color-blindness. The sun's visible light appears white, but it is the combined light of all the rainbow colors of the spectrum ranging from violet at 380 nm to red at 760 nm. Specialized cells found in the eyes, referred to as cones, act as receptors for specific wavelengths.

INTRODUCTION TO THE ELECTROMAGNETIC SPECTRUM

To appreciate a further discussion of visible light, it is prudent to first achieve a healthy understanding of the electromagnetic spectrum. The Electromagnetic Spectrum includes energies that are distributed according to frequencies or wavelengths. They encompass all electromagnetic radiations and have ranges and subranges called portions. The span of the electromagnetic spectrum ranges from lowest frequencies (longest wavelengths) to highest frequencies (shortest wavelengths).

All of the colors of the visible spectrum can be depicted by using the acronym ROY-G-BIV, a phrase credited to Sir Isaac Newton. ROY-G-BIV means R (red) - O (orange) - Y (yellow) - G (green) - B (blue) - I (indigo) - V (violet). These are the colors that humans can see. The longest wavelength is Red, while the shortest wavelength is violet. Red carries the most energy, while violet carries the least energy in the visible spectrum. Infrared radiation, which is heat, is next to the red portion of the spectrum range. Scientists use infrared light sensing optics when they want to see temperature differences. Ultraviolet radiation (UV) is just beyond the violet end of the visible spectrum. UV light is given off by the sun and absorbed by ozone in the atmosphere, and it can also mutate cells in your skin, which can lead to skin cancer. It is interesting to note that the complete absence of light is represented as black. Isaac Newton was the first to realize that the rainbow presented all the colors within white light. Then in 1666, he conducted an experiment that required him to shine sunlight through a small opening and then project it onto a prism showing the spectrum on the wall. The projection revealed that the white light was indeed comprised of a variety of wavelengths displaying different colors.

The Earth's atmosphere stops most types of space-originating electromagnetic radiation from reaching the surface. However, different parts of the EM spectrum can travel very far before experiencing atmospheric absorption, such as radio and visible light, which do reach the surface, while radio frequencies (RF), visible light, and some ultraviolet light can reach sea level. To more richly observe how spectra emanate from their numerous origins, astronomers strategically place sophisticated telescopes on mountains and other locales to create the optimum environment conducive to collecting light-capturing data from an orbiting satellite. The spectral range of various electromagnetic radiation is given in Fig. (**1**).

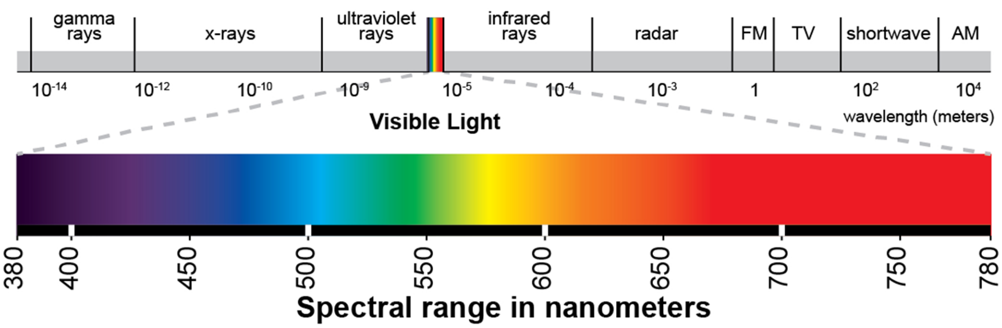

Fig. (1). Above illustrates the electromagnetic spectrum ranging from 10000 m, which is the longest wavelength (radio waves), to 10^{-14} m, the shortest wavelength encompassing x-radiation.
https://eyehortilux.com/grow-lighting-guide/measuring-light-for-plant-growth/evaluating-quality-g-ow-light-using-spectrum/visible-light-spectrum/

Electromagnetic radiation, considered a stream of mass-less particles, is called photons, which propagates as a wave at the speed of light at varying ranges of photon energies, frequencies, and wavelengths. Though each photon carries an outstanding amount of energy, the energies are what define the photon. The various amounts bear different names based on differences in behavior in the emission, transmission, and absorption of the corresponding waves and practical applications. There are no precise accepted boundaries between these contiguous portions, so the ranges tend to overlap [1, 3].

The wavelengths of ultraviolet, X-ray and gamma-ray regions of the EM spectrum are tiny. Instead of using wavelengths, astronomers that study these portions of the EM spectrum usually refer to these photons by their energies, measured in electron volts (eV). Ultraviolet radiation falls in the range from a few electron volts to about 100 eV. X-ray photons have energies in the range 100 eV to approximately 100,000 eV (or 100 keV). Gamma-rays are photons with energies greater than 100 keV.

CHAPTER 6

Laser and Safety from Laser Beams

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Abstract: A laser is an intense and amplified beam of light that is used in many applications. The use of lasers in medicine, astronomy, industries, defense, information technology, and oceanography is common and known to many people. The use of lasers in eye treatment, especially the technique of LASIK in eye surgery, shows the successful use of lasers in many fields. However, along with so many outstanding benefits, the intense beam of visible or invisible light also brings many complications while handling laser beams. Several harms and damages are associated with the use of laser beams. Skin injuries and eye defects are common complications caused by laser beams. If proper shielding and safety protocols are not followed, a laser can bring many harms ranging from minor skin irritations to blindness of the eyes. This chapter reports the benefits as well as harms and hazards associated with the use of laser beams. A detailed description of the harms associated with various classes of lasers is provided here. For the safe use of a laser beam, it is important to follow the established rules and regulations. A detailed description and discussion of the hazards associated with the use of laser beams, rules to be followed while using a laser beam, and laser emergency protocols are reported here.

Keywords: Benefits, Hazards, Laser, Laser safety, Laser types, Regulations.

INTRODUCTION

The term LASER stands for Light Amplification by Stimulated Emission of Radiation. A laser is a device that emits a highly intense and narrow beam of light through a process of stimulated emission and optical amplification of electromagnetic waves. The laser is one of the most important inventions of the 20th century, with applications in many fields.

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The principle of the laser dates back to 1917, when Albert Einstein first described the theory of stimulated emission. German physicist Rudolf Walther Ladenburg first observed stimulated emission in 1928, although at the time it seemed to have no practical use. In 1951 Charles H. Townes, at Columbia University, thought of a way to generate stimulated emission at microwave frequencies. At the end of 1953. Gordon, Zeiger, and Townes produced and observed the first stimulated emission in microwave wavelength of electromagnetic radiation. In 1960 Theodore Maiman invented the first Ruby laser. Ruby laser uses a solid ruby crystal as a laser medium with an emission wavelength of 694.3 nm associated with a red color. The same year Ali Javan also invented the first Helium-Neon (He-Ne) laser. The He-Ne laser uses two gases, He and Ne, with a laser emission wavelength of 632.8 nm. The first semiconductor laser was produced by Robert Hall at General Electric Laboratories in 1962; the first working Neodymium-doped Yttrium aluminum garnet (Nd:YAG) laser and CO_2 laser by Bell Laboratories in 1964, Argon-ion laser in 1964, chemical laser in 1965, and metal vapor laser in 1966. In each case, the 'name' of the laser was annotated about the lasing medium (source of laser photons) used [1, 2].

A laser can be produced in both continuous wave and pulse modes. In the first type, a beam of laser comes out of its cavity continuously, while in the second type, a laser is emitted from its cavity in the form of highly energetic pulses.

Since its invention, the laser has been used in many fields, including medicine and surgery, dentistry, astronomy, industry, and academia. Laser has also been used in security, military applications, printing technology, and many other fields and applications. Ruby laser was used in retinal surgery in the mid-1960s. In 1964, the argon-ion laser was developed. This continuous wave 488 nm (blue-green) gas laser was easy to control, and its high absorption by hemoglobin made it well suited to retinal surgery [1, 2].

Being a very important device with many applications it is important to know about the physics of laser, its production, and its characteristics. Like other types of radiation, lasers carry hazards and harms if proper safety and protection are not adopted during their use. Experiments with lasers and the reported laser mishandled cases show that high-power lasers are highly dangerous and damaging to the human body. In some cases, damage caused by the laser is not even reversible. Therefore, it is mandatory to understand the hazards and damages associated with the use of lasers and how to provide and maintain laser safety and protection while working with lasers. This chapter aims to report the in-depth hazards and damages of lasers and explain in detail how safety and protection can be achieved while utilizing the benefits of lasers in many fields.

LASER PHYSICS

It is very important to understand the physics behind laser radiation in order to understand the characteristics of the laser. Once the characteristics of the laser are understood, it would be easier to avoid hazards associated with the laser beam [2 - 6]. The word LASER is an acronym for Light Amplification of Stimulated Emission of Radiation. According to the acronym, the laser is simply defined as an "amplified and focused light beam". Although a laser is composed of electromagnetic light waves, it has different properties than visible light. Regular light is composed of different light wavelengths and all different colors on the spectrum of light. This composition gives the light its white luminous color. However, laser radiation has different characteristics than regular light. The laser is produced by exciting atoms of a specific element using some exciting mechanism such as electricity or light energy. This process takes place in a chamber, causing the atoms to oscillate back and forth and release energy in the form of photons between two mirrors, which in turn causes it to excite other atoms and produce more photons. The process of photons' emission in this way is called stimulated emission. The process is also called resonance emission since the emission follows the phenomenon of resonance due to matching properties. These produced laser photons are then directed out of the chamber by one of the mirrors.

Stimulated Emission

The random light emission from light bulbs or other sources of light is called spontaneous emission. Light emission as a result of spontaneous emission has multiple wavelengths and frequencies and may emit in random directions. Stimulated emission, on the other hand, requires the presence of a photon. An "incoming" photon stimulates a molecule in an excited state to decay to the ground state by emitting a photon. Fig. (**1**) shows stimulated emission in which the incoming photon causes resonant emission of the photon as a result of the electronic transition from a higher energy state into a lower energy state. Stimulated emission is also called negative absorption because all absorptions are stimulated, and the process of stimulated emission is opposite to the absorption process.

Conditions for Stimulated Emission

The first thing one can think about when making a laser is the stimulated emission [2 - 4]. However, to make a laser beam, four other conditions are required to be fulfilled. To fully understand laser construction and operation it is important to identify and discuss those four conditions. The four required conditions are *Gain Medium; Population Inversion; Metastable State; and Cavity.*

CHAPTER 7

Infrared Radiation: Benefits, Hazards, and Protections

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Abstract: Infrared radiation falls on the electromagnetic spectrum between microwaves and red visible light with a wavelength of ~750 nm-1 mm. Infrared radiation is emitted from materials as heat and can be used for medical, industrial, and military purposes. Infrared can be used to reduce swelling, increase tissue repair in sports injuries and help treat patients with cardiovascular disease. The industrial sector uses infrared tomography to image inside buildings, electrical equipment, and fuel processing plants. There are few known harms when it comes to infrared radiation effects. Infrared radiation can cause skin damage, eye damage, and greenhouse effects. Not much research is known on the appropriate dosage or the body's response to doses of infrared radiation. There are a few preventative ways to reduce the harm caused by infrared radiation. People can follow the three cardinal rules of radiation and the ALARA principle. They can also wear personal protection equipment when working or around infrared radiation sources. People can also learn and try to help the planet by reducing their carbon footprint to stop global warming from getting worse.

Keywords: Infrared radiation, IR benefits, IR risks, Shielding and protection.

INTRODUCTION

Radiations are tiny, invisible, charged, uncharged particles, waves, and energy packets that come from atoms, radioactive materials, the sun, optical and photonic devices, and many other sources. Experts in the field have been trying to classify and divide radiation into various types and categories based on their characteristic properties, mode of propagation, source of emission, and nature of interaction with mater and the human body [1 - 4].

Before the scientific innovations and contributions of James Clerk Maxwell, physicists considered light waves coming from the sun to be like mechanical

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waves which that need a medium for propagation. These mechanical waves need something to physically interact with through the world to propagate and spread out. This something is typically referred to as a medium and can take on many forms [6 - 8]. For instance, a sound wave is a mechanical wave that needs a medium, such as air, to travel from one location to another. The sound wave interacts, or better stated, vibrates, with various particles and particulates in the air. This physical interaction is why when two people start walking away from each other, the intensity of the sound decreases as well. The mechanical process of interaction uses or deposits the source energy from particle to particle, reducing the energy, or intensity, of the wave [5 - 8]. Other mechanical waves, such as water and seismic waves, also behave in this way. These properties of wave nature were the standard of how all waves should behave until the early 1860's when a mathematical physicist James Clerk Maxwell threw a pebble in the standing water of the old ideas. Maxwell poked and prodded Ampere's equations of electric and magnetic fields and discovered something that would change the world of physics [6 - 8]. His fascination led him to formulate 4 equations that would combine all the knowledge of electric and magnetic fields. Those equations are given below [8 - 10].

$$\nabla \cdot \mathbf{E} = \frac{1}{\varepsilon_0} \rho \tag{7.1}$$

$$\nabla \times \mathbf{E} = -\frac{\delta \mathbf{B}}{\delta t} \tag{7.2}$$

$$\nabla \cdot \mathbf{B} = 0 \tag{7.3}$$

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \mu_0 \varepsilon_0 \frac{\delta \mathbf{E}}{\delta t} \tag{7.4}$$

Where ∇ is a mathematical operation called the gradient, E is the electric field at a given density ρ, B is the magnetic field due to the motion of electric charges, $\varepsilon_0 = 8.85 * 10^{-12} \frac{C}{N \cdot m^2}$ is a constant of the permittivity of free space, not to be confused with the constant of the permeability of free space $\mu_0 = 4\pi * 10^{-7} \frac{N}{A^2}$ [9].

These would then be famously known as Maxwell's equations would produce a new kind of thinking when it came to the physics of wave nature. Using these equations, Maxwell and other physicists could conceive waves that could travel without the need for a medium and reach speeds up to the speed of light. It was determined that even light abides by these physical laws. Maxwell himself said

"This velocity is so nearly that of light that it seems we have strong reason to conclude that light itself (including radiant heat and other radiations if any) is an electromagnetic disturbance in the form of waves" [11]. These waves would thus be referred to as electromagnetic waves (EM waves). A wave would be a combination of electric and orthogonal magnetic waves, as shown in Fig. (**1**).

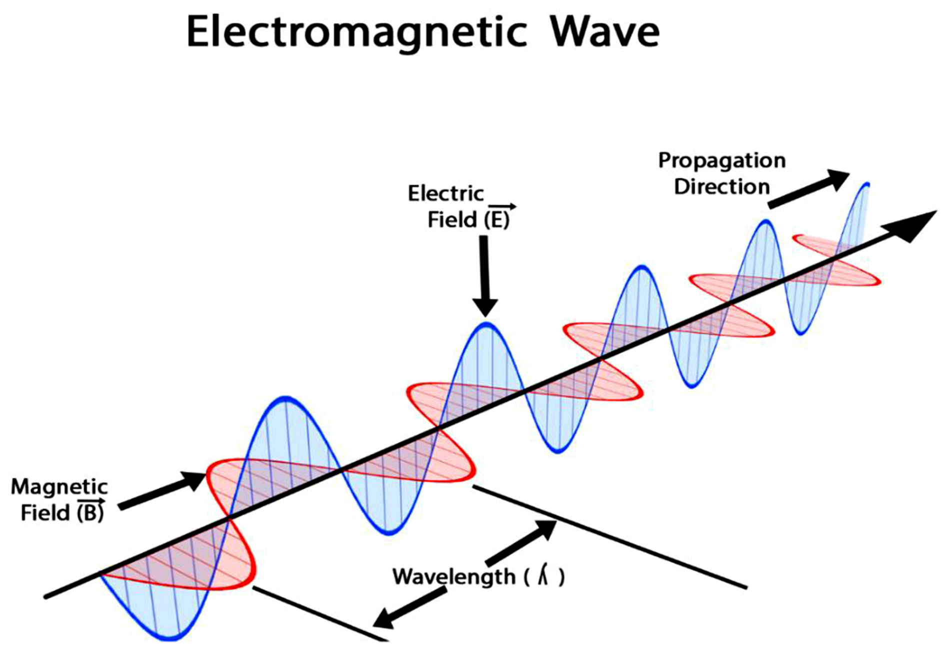

Fig. (1). Electromagnetic wave propagation with electric and magnetic fields oscillating perpendicular to each other and the direction of propagation.

Using Maxwell's equations, John Henry Poynting derived an equation for the energy transferred per unit area per unit time by an electromagnetic wave. The Poynting equation is given below,

$$\mathbf{S} = \mathbf{E} \times \mathbf{H} \tag{7.5}$$

The solar spectrum consists of electromagnetic radiation emitted by the sun in many different forms and wavelengths. People are exposed to radiation every day in many ways from many different sources. Electromagnetic radiation is the form of energy carried by oscillating electric and magnetic fields, hence radiation is called electromagnetic radiation [5, 8, 12]. There are two different types of electromagnetic radiation: ionizing and non-ionizing radiation. The dividing line between these two forms of radiation is ultraviolet radiation [2]. The higher

CHAPTER 8

Microwaves and Radiofrequency Radiation: Benefits, Risks and Protection

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Abstract: Radiofrequency and microwave radiation are part of the electromagnetic spectrum. They occupy the lower end of the spectrum with respect to frequency and are on the higher end with respect to wavelength. They have lower energy than the rest of the forms of electromagnetic energy on the spectrum, and as a result, they do not have enough energy to ionize the materials they irradiate. Radiofrequency and microwave radiation have been used in many applications, including communications and the use of radar to be able to predict weather patterns, medicine in both diagnostic and therapeutic uses, and industry. A major development in recent years has been the development of the 5G mobile network, which uses millimeter waves to transmit data to and from mobile phones that operate in the radiofrequency region. However, the rise of the 5G mobile network has many concerns that high exposures to these levels of radiation can be harmful to humans. This has been a point of discussion in the past and has led to decades of research into the potential health effects of radiofrequency and microwave radiation on humans. Even with a large amount of research that has been done, the health effects of radiofrequency and microwave radiation are still a highly debated subject. The IARC classifies radiofrequency electromagnetic energy coming off from mobile phones as a Group 2B substance, which means that it is not clear whether it causes cancer. Overall, radiofrequency and microwave radiation can be harmful, but research shows that it is mainly in the really high levels of exposure. Oftentimes, the public does not come close to approaching the limits established from the regulatory exposure limits set forth by various regulatory bodies around the world.

Keywords: Antennas, Microwave, Mobile phones, Radiofrequency, Risks and hazards, Regulations, 5G network.

INTRODUCTION

Health Physics is a field that was created during the Manhattan Project during World War II. The primary focus of the field of Health Physics is to promote safe

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use and protection from radiation. Traditionally the types of radiation health physicists focused on were ionizing radiation. Ionizing radiation is the radiation that possesses enough energy that it causes ionizations within the medium it travels through or interacts with. Ionizations are phenomena that occur in atoms and molecules in which an electron is removed from the orbital of the atom or molecule it was bound to, forming a positively charged cation and a negatively charged free electron. These ions can go and interact with other molecules within the medium and cause different effects that can be dangerous to individuals exposed to such events. There are 4 types of ionizing radiation: Alpha particles, Beta particles, Gamma rays, and Neutrons. Alpha particles are the equivalent of a Helium atom's nucleus with 2 protons and 2 neutrons with a +2 charge.

$$^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}\alpha$$

Beta particles come in 2 types: negatrons and positrons. Negatrons are very similar to electrons in that they are negatively charged and have an atomic number of 0. The difference between a negatron and an electron is their origin. Electrons are found in orbitals around the nucleus of an atom, while negatrons are found within the nucleus. Positrons are the same as negatrons, except they are positively or negatively charged. Also emitted during beta decay are neutrinos and antineutrinos, along with some energy. Neutrinos and antineutrinos are both subatomic particles with the antineutrino being the antiparticle of the neutrino. Neutrinos are emitted during positron emission, and antineutrinos are emitted during negatron emission.

$$^{A}_{Z}X \rightarrow {}_{Z+1}^{A}Y + {}_{-1}^{0}\beta + {}_{0}^{0}\bar{\upsilon} + energy$$

$$^{A}_{Z}X \rightarrow {}_{Z-1}^{A}Y + {}_{+1}^{0}\beta + {}_{0}^{0}\upsilon + energy$$

Gamma radiation is emitted as a result of the settling process of an exciting nucleus of an atom. The process is very similar to how x-rays are produced from the de-excitation of an electron from a high-energy orbital to a lower energy orbital. The change in energy from the transition of orbitals is released as a packet of energy, or x-ray. It is believed that a very similar process occurs within the nucleus of an atom, and the result is a packet of energy or gamma-ray. This type of radiation is different from the others in that it is not particulate, and it does not carry a charge. This means that gamma radiation does not result in a change of the atomic number or charge number of the original isotope. This does not mean that isotopes that emit gamma radiation do not undergo those changes, as they can potentially also undergo alpha and/or beta decay and emit neutrons as well.

$$^{A}_{Z}X \rightarrow ^{A}_{Z}Y + ^{0}_{0}\gamma$$

Neutrons are usually the result of fission reactions of highly unstable isotopes. Fission is when a large nucleus splits into 2 or smaller nuclei.

While the discovery of these types of ionizing radiation has been very beneficial to mankind in many ways, it is also very important to understand the dangers they pose as well. Thus, the field of Health Physics was established to understand these dangers and to help prevent the serious damage these types of radiation can cause to humans and other creatures. While the threat of ionizing radiation has largely dominated the focus of health physicists for much of the field's history, there has been sort of a shift in focus in recent decades to nonionizing radiation. Nonionizing radiation, just like the name implies, is radiation that does not have enough energy to ionize atoms and molecules. There are many different forms of nonionizing radiation. On the electromagnetic spectrum, radiation that is nonionizing is on the low frequency and high wavelength end of the spectrum. In terms of energy, it takes about 34 Electronvolt (ev) to produce an ionization event, so any form of radiation that does not deliver that amount of radiation to an electron on an atom or molecule will not cause an ionization [1]. These consist of radiofrequency, microwaves, infrared, visible light, and ultraviolet radiation. There are other forms of radiation, such as sound waves, but they will not be covered in this paper.

The focus of this review paper will be to go over a few of the types of nonionizing radiation, namely radiofrequency (RF) and microwave radiation. RF and microwave radiation are at the low end of the electromagnetic spectrum in terms of frequency and are a good starting point to begin exploring the physical properties of nonionizing radiation. After discussing the physical properties, the next important focus will be the various uses of RF and microwaves and how they are beneficial to mankind. Perhaps the most important information for health physicists would be what the risks associated with RF and microwaves are and how they can be minimized, or even eliminated.

Background and Interaction with a Medium

There are different kinds of radiation, and the majority can be classified on a spectrum. This spectrum is the electromagnetic spectrum, and it ranges from low-energy radio waves to high-energy gamma and x-rays. Each region of the spectrum can be classified on a variety of different parameters such as wavelength, frequency, and energy range. Each of these regions also exhibits varying penetration and absorption abilities. For the purposes of this review, the radiofrequency and microwave region will be focused on.

CHAPTER 9

Radiation from Mobile Phones and Cell Towers, Risks, and Protection

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Abstract: Modern life is strongly associated with new technologies such as telecommunication and wireless devices. These new technologies strongly affect the way people communicate, learn, train, think and solve their problems. Today, modern cell phones not only send and receive phone calls, but they also allow people to send and receive short messages, and e-mails, share photos and videos, write, edit and share documents, play games, listen to music, watch movies, surf the Internet, find an address using GPS (Global Positioning Systems) and use a wide range of applications. Given this consideration, excessive use of smartphones is associated with growing global concerns over the health effects of radiofrequency electromagnetic fields (RF-EMF) generated by these devices. As discussed by WHO, considering the very large number of people who use mobile phones, even a small increase in the risk of adverse health effects, either cancer or other health effects, could have key public health implications. WHO believes that research about these health effects is mostly focused on potential adverse effects of mobile phones, not their base stations, because the RF-EMF levels of mobile phones are 3 orders of magnitude higher than those of base stations. Therefore, in this chapter, due to the greater likelihood of adverse health effects of handsets, we mainly focused on reviewing the current scientific evidence on health risks associated with mobile phones. However, the health effects of RF-EMF exposure on people living in the proximity of mobile base stations are also reviewed.

Keywords: Electromagnetic Fields, Mobile phones, Mobile base stations, Radiofrequency.

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INTRODUCTION

The revolution in telecommunication technology and wireless devices has caused a rapid rise in the usage of smartphones, cordless phones, tablets, and laptops, and the widespread use of cellphone-based internet technologies (mobile data and Wi-Fi) [1]. Besides smartphones and cordless phones that can be introduced as a key source of human brain exposure to radiofrequency electromagnetic fields (RF-EMF), mobile phone base stations and broadcast antennas have dramatically increased the exposure of humans to RF-EMF [2, 3].

Mobile phones operate at frequencies between 500 and 2700 MHz with peak powers between 0.1 and 2 Watts. Telecommunication frequency bands vary in different countries. However, generally for mobile phones, the Global System of Mobile Communications (GSM) uses 900 / 1,800 MHz frequency bands [4]. As people usually hold their mobile phones 1–2 cm away from their bodies, they are exposed to RF-EMFs generated by mobile phones. RF-EMFs generated by these devices are strongly non-uniform around the body. Moreover, the strength of these fields decreases rapidly with increasing distance. Compared to holding the handset against the head, when people use their smartphones 30–40 cm away from their bodies for text messaging, accessing the internet, or when they use a “hands-free”, the RF-EMF exposure level would be much lower [5]. The health effects of exposure to RF-EMfs from mobile phones include headache, burning sensation in ears and facial skin, and alteration in the blood-brain barrier (BBB) [6]. Over the past decades, the interest in studies on the health effects of exposure to RF-EMFs has largely increased, mostly due to the growing global use of mobile phone telecommunication technologies [7].

Concerns over possible carcinogenic risks of mobile phone RF-EMFs date back to early 2000 when the first reports on the increased risk of developing vestibular Schwannoma and brain tumors in mobile phone users were published [8]. In 2011, RFR was classified as a possible human carcinogen (Group 2B) by the International Agency for Research on Cancer (IARC) [9]. The thermal effect of RF-EMFs emitted by mobile phones with safe SAR levels (< 2 W/kg) is negligible [10]. However, many studies show that even low-power RF-EMfs may cause adverse biological effects [11 - 13].

Recent reports on the role of EMF in the induction of oxidative stress and DNA damage are also discussed. Not only is DNA damage involved in carcinogenesis [14], it may cause cell death, reproductive problems, or neurodegenerative diseases [15, 16]. The biological effects of RF-EMFs on the human body, including cancer as well as the potential therapeutic effects and future perspectives, are discussed in this chapter [11].

Oxidative Stress and DNA Damage

While some of the biological effects of RF-EMF are possibly linked to thermal effects [17 - 19], the production of reactive oxygen species (ROS) mediated by RF-EMFs can be considered a key mechanism behind the observed effects [20]. When ROS reaches pathophysiological levels, it may interfere with crucial cellular processes and functions. This interference is believed to be caused by changes in biochemical and signaling processes that eventually can lead to oxidative damage in DNA, RNA, and proteins as well as fatty acids peroxidation [21, 22]. It is worth noting that dysregulation of ROS levels and alterations in biomarkers of oxidative stress is associated with a wide range of diseases, from congenital anomalies, and neurodegenerative syndromes to diabetes and cancer [23, 24]. Besides RF-EMFs, extremely low frequency electromagnetic fields (ELF-EMF) can also increase the production of free radicals such as hydroxyl free radicals, which in turn leads to double-strand breaks of DNA [25 - 27]. In this book chapter, the health effects of ELF-EMF are out of the scope of the chapter and should be discussed in other publications.

Modulation of immune responses is also frequently reported after exposure to RF-EMFs emitted by mobile phones [28]. As reported by Singh *et al*., chronic exposure to mobile phone radiation may induce oxidative stress, inflammatory response, and hypothalamic-pituitary-adrenal (HPA) axis dysregulation [29]. Reports show that in microglial cells and some other cells, ROS levels can be increased, which further increases pro-inflammatory cytokines (IFN-gamma, TNF-alpha, and IL-1beta) [30 - 33]. Cumulative evidence indicates that mobile phone radiation may cause learning and memory problems [34 - 40]. However, there are also reports on the lack of any detrimental effect on memory or even positive effects [41 - 45]. Reaction time plays a crucial role in doing tasks better to cope and manage different threats and hazards in our environment and increased reaction time may lead to fatal accidents. Mortazavi *et al.* have previously shown that the visual reaction time of university students significantly decreased after a ten-minute exposure to RF-EMFs emitted by a commercial smartphone [46]. Furthermore, the reaction time in radar workers was significantly shorter than those of the control group [47]. Thus, improved cognitive functions, such as decreased reaction time are of paramount importance.

The biological effects of 900 MHz RF-EMFs on the levels of intracellular reactive oxygen species (ROS) in human mononuclear cells, monocytes and lymphocytes have been studied by Kazemi *et al*., who showed a statistically significant increase in ROS production after radiofrequency exposure. The findings of Kazemi *et al.* showed that the oxidative stress induction capability of RF-EMF

CHAPTER 10

Ultrasound and Human Body Safety

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Abstract: Ultrasound is very safe when used at the diagnostic frequency and intensities. However, a temperature rise of 1.5 – 2.5 °C or more above the normal temperature of the human body exposed to ultrasound for longer than 1 hour may cause thermal induced effects. For most diagnostic ultrasounds, the Mechanical Index should not exceed 1.9. The Mechanical Index should not exceed 0.23 when performing an ultrasound on the eyes. Using diagnostic ultrasound with Mechanical Index above, these limits may cause cavitation in tissues. This chapter mostly covers the possible hazards and harms associated with ultrasound. For the benefits and uses of ultrasound in our lives, you may read chapter 13 of our previously published book: An introduction to Medical Physics, edited by Muhammad Maqbool.

Keywords: Clinical ultrasound, Diagnostic ultrasound, Therapeutic ultrasound, Ultrasound, Ultrasound safety.

INTRODUCTION

Ultrasound waves are vibrations at a frequency higher than the human ear can perceive. Diagnostic ultrasound waves are propagated through the human body with little even potentially harmful energy deposition or molecular interactions, making ultrasound a very safe medical imaging modality [1 - 4]. However, ultrasound waves do have some biological effects, which can be distinct under certain circumstances [5] or specifically used for therapeutic purposes chapter will highlight a few of the clinical aspects in which ultrasound and human[2, 6]. This body safety issues are at play.

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Ultrasound principles

Ultrasound was originally made possible by the discovery of piezoelectric crystals, which expand and contract in the presence of an alternating current or produce current in response to expansion and contraction. Newer technology using microelectromechanical capacitive micromachined ultrasonic transducers (or CMUTs [7]) will undoubtedly progress. We will refer to the probe as the device that houses the piezoelectric crystal transducer or CMUT and associated electrical connections and various acoustic interfaces.

Due to the electronics and physical nature of the high-frequency vibrator, diagnostic ultrasound probes send out mechanical waves of pressure over a range of frequencies around a central peak frequency. The transducer frequency reported by manufacturers is this central peak frequency. In addition to the frequency of ultrasonic waves, the amplitude and duty cycle (how long the transducer is emitting relatively to how long it is receiving) are other factors that contribute to safety considerations. Safety is ensured in medical ultrasound devices by compliance with industry and FDA standards.

Acoustic intensity

As an ultrasound beam propagates through tissue, the energy reduces with the depth traveled—that is, it is attenuated. Some energy is reflected by tissue structures in the beam path, and some are absorbed. The required ultrasound image is formed from the scattered energy received at the imaging probe, with the time of its arrival being a measure of the depth of the reflecting structure, and its amplitude giving information about the structure itself. The amount of energy absorbed depends on the composition of the tissue and the frequency of the ultrasound beam. Broadly, bone absorbs more ultrasound energy than soft tissue and reflects more strongly. Ultrasound absorption in tissue rises with increasing frequency.

In a plane wave, the relationship between the intensity incident on the surface of the tissue (I_0) and the intensity at a depth x into tissue ($I(x)$) may be written as

$$I(x) = I_0 e^{-\mu x} \quad \textbf{(10.1)}$$

where μ, the intensity attenuation coefficient, is a sum of contributions from absorption (μ_a) and scatter (μ_s) such that $\mu = \mu_a + \mu_s$. The contribution of absorption to attenuation maybe 60–80% of the total [1, 8].

The amount of energy reflected by a structure, such as bone, that lies in the ultrasound beam path is determined by the change in acoustic impedance at its surface. The acoustic impedance, Z, is given by $Z = \rho c$, where ρ is the tissue density and c is the speed of sound. The greatest impedance mismatches in clinical ultrasound usage occur at soft tissue–bone and soft tissue–gas interfaces. These are seen as the brightest echoes on an ultrasound image.

The mechanisms of interaction of ultrasound with tissue that may lead to biological effects are often broadly divided into two categories—thermal and non-thermal. In reality, these mechanisms are interrelated since, as will be seen below, tissue heating may facilitate non-thermal effects by reducing the threshold for cavitation, and non-thermal effects such as cavitation may, in turn, affect local tissue heating.

Diagnostic ultrasound devices send out intermittent pulses of high-frequency sound waves; the sound waves themselves generally have a frequency of 1 to 20 MHz. Slight pause between pulses of ultrasound allows the transducer to "listen" for returning echoes; pulse repetition frequency (PRF) also plays a role. Ultrasound probes generate acoustic energy (measured in Joules, J) produced over time. Energy delivered over a period of time is called power and is measured in Watts (J/s). When applied to a surface as is done with an ultrasound probe, the flux of power is called the acoustic intensity, and in diagnostic ultrasound, is measured in mW/cm^2. But because of the transducer "listening" time, the acoustic intensity can be measured by the peak acoustic intensity during the "pulsing" time, and the average acoustic intensity that incorporates both the "pulsing" and "listening" times. The American Institute of Ultrasound in Medicine (AIUM) has published guidelines for limits up to which ultrasound clearly has been demonstrated to be safe [3].

Ultrasound is generally considered a safe imaging modality in obstetrics. However, when ultrasound travels through tissue, energy is absorbed by the tissue components and converted to heat, dependent on frequency and intensity. These thermal effects may alter the equilibrium between chemical reactions and therefore may consequently harm the surrounding tissue.

-A diagnostic exposure that produces a 1°C or less temperature elevation above normal.

-An exposure intensity less than 1 W/cm2 for focused ultrasound beams.

The total amount of acoustic intensity of an ultrasound device depends on the pulse frequency, amplitude, and duration of the pulse packet, as well as the pulse repetition frequency (akin to the duty cycle, as mentioned above). Continuous wave Doppler ultrasound, on the other hand and as the name implies, uses a continuous pulsation of ultrasound and measures only the frequency shift of the

CHAPTER 11

Nonionizing Radiation Safety and Regulations

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Abstract: Nonionizing radiation cannot ionize the human body tissues due to its low energy; however, its thermal, mechanical, chemical, vibrational, and several other effects can create complications. To avoid hazards and complications from nonionizing radiation, it is mandatory to establish and follow proper rules and regulations while dealing with such radiation. This chapter reports an overview of various rules and regulations regarding the uses and limits of nonionizing radiation, provided by various organizations.

Keywords: Hazards, Nonionizing radiation, Regulations, Safety and protection.

INTRODUCTION

Electromagnetic radiation is all around us, though we can only see some of it. All EM radiation (also called EM energy) is made up of minute packets of energy or 'particles,' called photons, which travel in a wave-like pattern and move at the speed of light. The EM spectrum is divided into categories defined by a range of numbers. These ranges describe the activity level, or how energetic the photons are, and the size of the wavelength in each category, as shown in Fig. (**1**).

For example, at the bottom of the spectrum, radio waves have photons with low energies, so their wavelengths are long with peaks that are far apart. The photons of microwaves have higher energies, followed by infrared waves, UV rays, and X-rays. At the top of the spectrum, gamma rays have photons with very high energies and short wavelengths with peaks that are close together [1].

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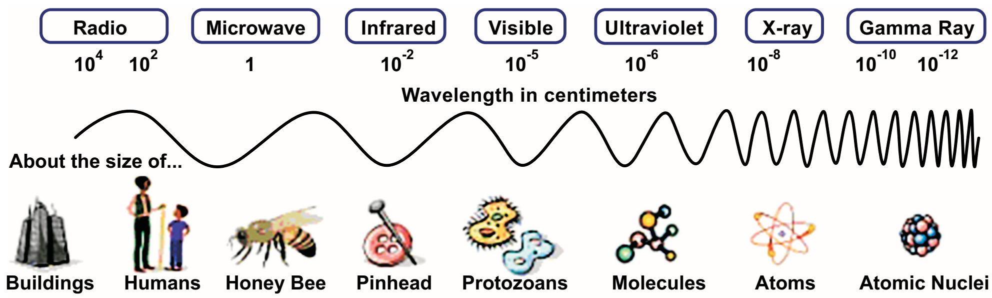

Fig. (1). Comparison of the wavelengths of electromagnetic radiation with various objects.

RADIOFREQUENCY REGULATIONS

From the United States Code of Federal Regulations Title 47 subpart 1.1310:

§ 1.1310 Radiofrequency Radiation Exposure Limits

(a) Specific absorption rate (SAR) shall be used to evaluate the environmental impact of human exposure to radiofrequency (RF) radiation as specified in § 1.1307(b) of this part within the frequency range of 100 kHz to 6 GHz (inclusive).

(b) The SAR limits for occupational/controlled exposure are 0.4 W/kg, as averaged over the whole body, and a peak spatial-average SAR of 8 W/kg, averaged over any 1 gram of tissue (defined as a tissue volume in the shape of a cube). Exceptions are the parts of the human body treated as extremities, such as hands, wrists, feet, ankles, and pinnae, where the peak spatial-average SAR limit for occupational/controlled exposure is 20 W/kg, averaged over any 10 grams of tissue (defined as a tissue volume in the shape of a cube). Exposure may be averaged over a time period not to exceed 6 minutes to determine compliance with occupational/controlled SAR limits.

(c) The SAR limits for general population/uncontrolled exposure are 0.08 W/kg, as averaged over the whole body, and a peak spatial-average SAR of 1.6 W/kg, averaged over any 1 gram of tissue (defined as a tissue volume in the shape of a cube). Exceptions are the parts of the human body treated as extremities, such as hands, wrists, feet, ankles, and pinnae, where the peak spatial-average SAR limit is 4 W/kg, averaged over any 10 grams of tissue (defined as a tissue volume in the shape of a cube). Exposure may be averaged over a time period not to exceed 30 minutes to determine compliance with general population/uncontrolled SAR limits.

(1) Evaluation with respect to the SAR limits in this section must demonstrate compliance with both the whole-body and peak spatial-average limits using technically supported measurement or computational methods and exposure conditions in advance of authorization (licensing or equipment certification) and in a manner that facilitates independent assessment and, if appropriate, enforcement. Numerical computation of SAR must be supported by adequate documentation showing that the numerical method as implemented in the computational software has been fully validated; in addition, the equipment under test and exposure conditions must be modeled according to protocols established by FCC-accepted numerical computation standards or available FCC (Federal Communications Commission) procedures for the specific computational method.

(2) For operations within the frequency range of 300 kHz and 6 GHz (inclusive), the limits for maximum permissible exposure (MPE) is derived from the whole-body SAR limits and listed in Table 1 in paragraph (e)(1) of this section. This may be used instead of the whole-body SAR limits as set forth in paragraphs (a) through (c) of this section, to evaluate the environmental impact of human exposure to RF radiation as specified in § 1.1307(b) of this part, except for portable devices as defined in § 2.1093 of this chapter. For portable devices, as defined in § 2.1093 of this chapter, these evaluations shall be performed according to the SAR provisions in § 2.1093.

Table 1. Limits for Maximum Permissible Exposure to Radiofrequency Electromagnetic Fields adapted from Title 47 CFR 1.1310(e)(1).

Frequency Range in MHz	Electric Field Strength in V/m	Magnetic Field Strength in A/m	Power Density in mW/cm^2	Average Time in Minutes
Limits for Occupational-Controlled Exposure				
0.3-3.0	614	1.63	Plane-wave equivalent power density of 100	Less than or equal to 6 minutes
3.0-30	1842/frequency in MHz	4,89/frequency in MHz	Plane-wave equivalent power density of 900/frequency in MHz squared (f^2)	Less than 6 minutes
300-1,500	-	-	Frequency in MHz/300	Less than 6 minutes
1,500-100,000	-	-	5	Less than 6 minutes
0.3-1.34	614	1.63	Plane-wave equivalent power density of 100	Less than 3 minutes

CHAPTER 12

Nonionizing Radiation Risk Management and Safety

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Abstract: The applications of Nonionizing radiation (NIR) has increased in recent years. Safety authorities and the public were concerned about the use of devices that emit NIR. Questions about acute or chronic effects have subsequently become more important. According to many studies and experiments carried out, EMF does not affect the functioning of a living organism, provided that those certain established acceptable standards are not exceeded. It comprises lower quantum energies and, therefore, has different biological effects and interactions with matter. It displays its unique personality, although it shares the same wave characteristics as ionizing radiation. We can describe this in terms of its frequency, energy, and wavelength. It is longer, less frequent, and lazier compared to 'IR', but it can still inflict a good deal of damage. This Chapter will cover the effect of NIR interaction with matter, risk management, and safety associated with its application.

Keywords: Nonionizing radiation safety, Radiation risk, Risk management.

INTRODUCTION

In the early twentieth century, the use of Electromagnetic Radiation (EMR) was enhanced rapidly and spread widely in all areas, including industry, medicine, research, commerce, and homes. EMR now surrounds us. We can categorize it into two forms: Non-ionizing radiation (NIR) and ionizing radiation (IR). Particles or photons with energies less than 30 eV (some reports give 10 eV) are non-ionizing radiation. It encompasses a long wavelength and low photon energy, whereas IR has a short wavelength and high photon energy portion of the electromagnetic spectrum. NIR is most often described as being bound by the following characteristics:

• Wavelengths: 100 nm to 300,000 km

• Frequencies: 3.0 PHz to 1 Hz

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• Photon energy: 1.987 x 10-18 J to 6.6 x 10-34 J

Natural sources of NIR include sunlight, lightning discharge, *etc.*, whereas artificial sources include wireless communication, industrial, scientific, and sources medical applications. NIR does not have enough energy to ionize atom-like ionizing radiation, it can only excite the electron within an atom, and it does not break bonds that hold molecules in cells together. Thus, it does not damage DNA when it passes through the tissue of the living organism [1]. However, the hazards from NIR exist; it got attention after the advancement in technology and usage of equipment using NIR in various areas of human activity, including industry, medicine, research, commerce, and homes. It is important to evaluate the interaction and biological effects of NIR. Therefore, various research programs started after World War II by USA and USSR to investigate the effect on health associated with NIR. Later in 1968, an act was passed by the U.S congress for hazards associated with consumer electronic products, and in 1970, passed Occupational Safety and health act protected workers from their occupational hazards. Because of the importance of the subject, An International Non-Ionizing Radiation Committee was formed later in 1977, which is now responsible for the publication and implementation of health criteria documents related to risk management and safety associated with NIR. It recommends exposure limits for NIR in areas accessible by the public. The principal aim of this is to "establish guidelines for limiting EMF exposure that will protect against known adverse health effects" [2].

Most people are not aware that they are being exposed to non-ionizing radiation. There are many types of non-ionizing radiation, as given in Table **1**.

Table 1. Types and sources of nonionizing radiation.

NIR Radiation	Sources
Infrared light	Generated by sunlight, thermal radiation, incandescent light bulbs, lasers, remote controls
Visible light	Generated by sunlight, LEDs, light bulbs, lasers
Ultraviolet light	Generated by black light, sunlight
Microwave radiation	Generated by microwaves, cellphones, and data transmission
Extremely low-frequency radiation	Generated by transmission lines, old CRT comp
Radiofrequency radiation	Generated by AM and FM radio signals, cellphone and data communications, and by radio frequency heaters used to bond vinyl and plastics
Ultrasound	Generated by a transducer made out of a piezoelectric material.

In recent years, many studies were conducted and are in progress all around the world. Probing the effect of NIR on human health, that is how these NIR interact and what are the biological effect [3, 4]. Some references are shared.

"Italian National Institute" of Health evaluates the effect of electromagnetic interference (EMI) and Radiofrequency (RF) generated from Wi-Fi devices on a pacemaker, they found EMI has no effect, but Wi-fi signal exceeds the defined limit set by international regulation, so it should be avoided near the pacemaker [5].

"Sichuan University China" has characterized and measured the exposure to RF by electronic appliances; they found that measured levels are below the limit of public exposure in ICNIRO guidelines [3].

American Conference of Governmental Industrial Hygienists (ACGIH), 1993. Worked on effects of Magnetic Resonance Imaging (MRI). In conclusion they showed no deleterious effect in magnetic field up to the level of 2Tesla. Also, in 2003 FDA declared "no significant risk status" for MRI clinical systems generating static fields up to 8T. Sometimes magnetic interference can occur with cardiac pacemakers and other precision electronic equipment, so it must follow safety measures.

A paper published in 2017 on recent advances in the effect of microwave radiation on the brain concludes that there is no conclusive evidence showing that microwaves have carcinogenic effects. The problem with these studies is that different parameters, such as the frequency, modulation, and power density of the radiation and the irradiation time, were used to evaluate microwave radiation between studies. As a result, the existing data exhibit poor reproducibility and comparability [6].

Biological effects of static Electric Field of High-voltage direct current (HVDC) lines evaluate for environmental limit. Its systematic review of evidence strongly supported the role of superficial sensory stimulation of hair and skin as the basis for the perception of the field, as well as reported indirect behavioral and physiological responses. Physical considerations also prevent any direct effect of static EF on internal physiology, and other factors may explain reports they affected some physiological processes in minor ways. While this literature does not support a level of concern about the biological effects of exposure to static EF, the conditions that affect thresholds for human detection and annoyance at suprathreshold levels must be investigated.

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