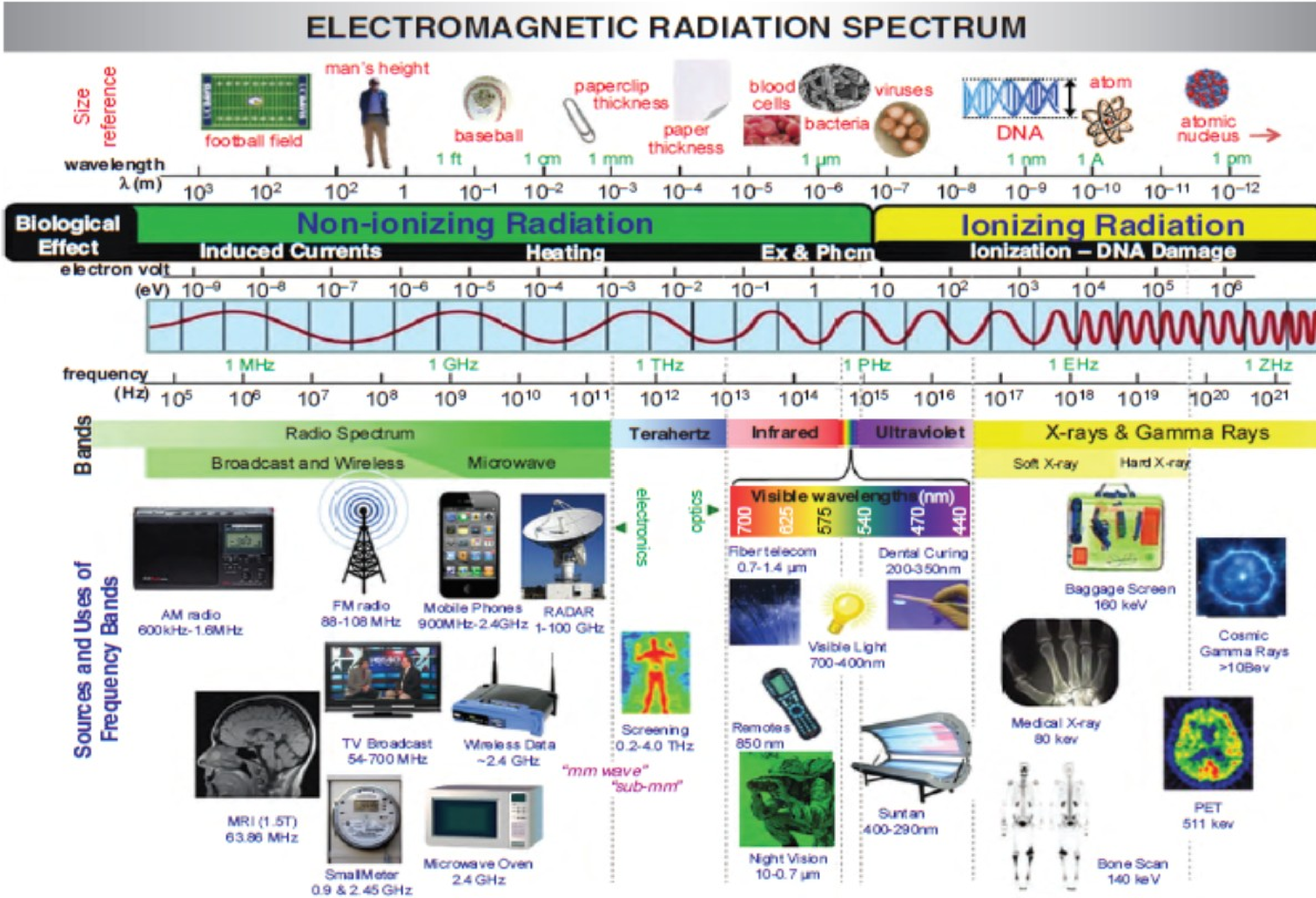
Electromagnetic Radiation

Introduction



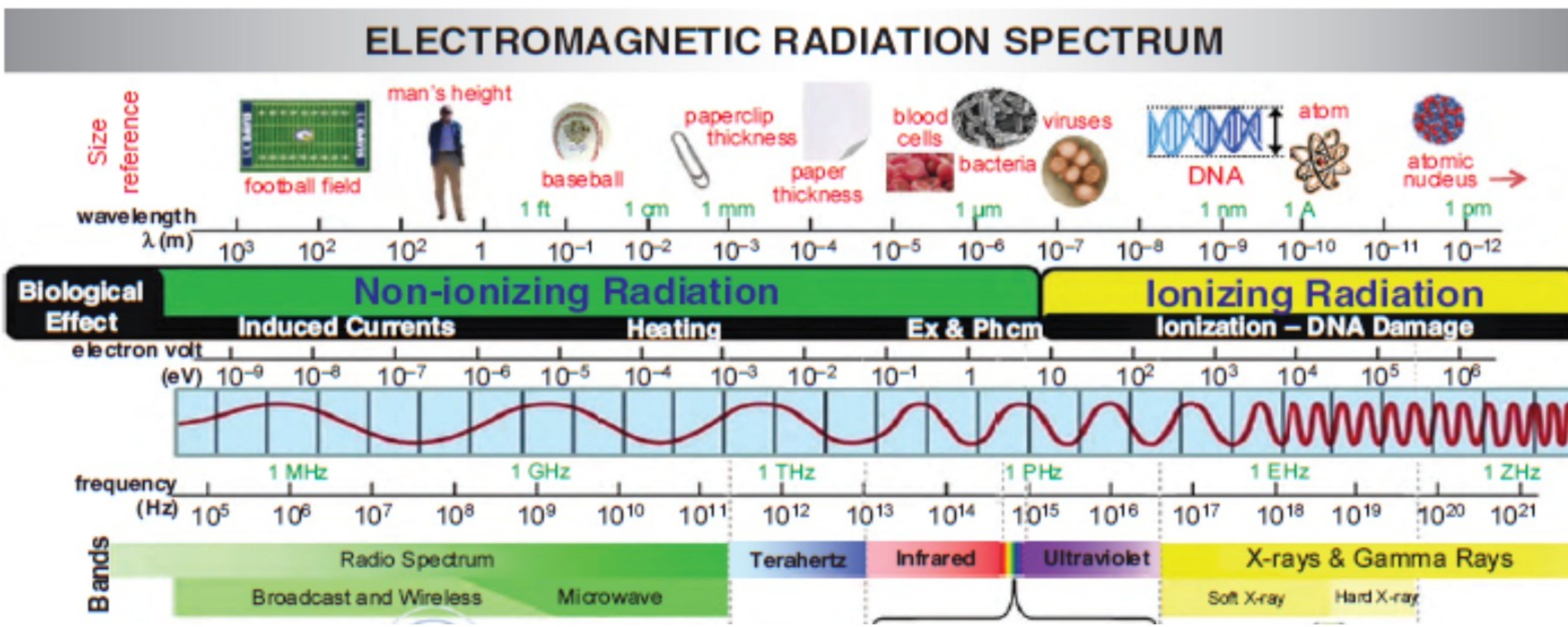
Introduction

- Radio waves, visible light, x-rays, and gamma rays are different types of EM radiation.
- EM radiation has no mass and has a constant speed in a given medium.
- Although EM radiation propagates through matter, it does not require matter for its propagation.
- Its maximal speed $(2.998 \times 10^8\ m/s)$ occurs in a vacuum. In matter such as air, water, or glass, its speed is a function of the transport characteristics of the medium.
- EM radiation travels in straight lines; however, its trajectory can be altered by interaction with matter.
- The interaction of EM radiation can occur by *scattering* (change in trajectory), *absorption* (removal of the radiation), or, at very higher energies, *transformation* into particulate radiation (energy to mass conversion).

Introduction

- EM radiation is commonly characterized by wavelength (λ), frequency (f), and energy per photon (E). EM radiation over a wide range of wavelengths, frequencies, and energy per photon comprises the EM spectrum.

- For convenient reference, the EM spectrum is divided into categories including the radio spectrum (that includes transmissions from familiar technologies such as AM, FM, and TV broadcasting; cellular telephone systems; as well as other wireless communications technologies); infrared radiation (i.e., radiant heat); visible, ultraviolet (UV); and x-ray and gamma-ray regions (Figure).



Introduction

- Several forms of EM radiation are used in diagnostic imaging and Radiothrapy.
- Gamma rays, emitted by the nuclei of radioactive atoms, are used to image the distributions of radiopharmaceuticals.
- X-rays, produced outside the nuclei of atoms, are used in radiography, fluoroscopy, and computed tomography.
- Visible light is produced when x-rays or gamma rays interact with the detectors used in several imaging modalities and is also used to display images.
- Radiofrequency EM radiation, near the FM frequency region, is used as the excitation and reception signals for magnetic resonance imaging.

Physics of Medical Imaging

- Medical imaging of the human body requires some form of energy.
- The energy used to produce the image must be capable of penetrating tissues.
- Visible light, which has limited ability to penetrate tissues at depth, is used mostly outside of the radiology department for medical imaging.
- Visible light images are used in dermatology (skin photography), gastroenterology and obstetrics (endoscopy), and pathology (light microscopy).
- In diagnostic radiology, the electromagnetic spectrum outside the visible light region is used for medical imaging, including x-rays in mammography and computed tomography (CT); radiofrequency (RF) in magnetic resonance imaging (MRI), and gamma rays in nuclear medicine.
- Mechanical energy, in the form of high-frequency sound waves, is used in ultrasound imaging.

Physics of Medical Imaging

- With the exception of nuclear medicine, all medical imaging requires that the energy used to penetrate the body's tissues also interacts with those tissues.
- If energy were to pass through the body and not experience some type of interaction (e.g., absorption or scattering), then the detected energy would not contain any useful information regarding the internal anatomy, and thus it would not be possible to construct an image of the anatomy using that information.
- In nuclear medicine imaging, radioactive substances are injected or ingested, and it is the physiological interactions of the agent that give rise to the information in the images.

Biological Effects

- The EM spectrum is categorized into regions, such as the radio spectrum, infrared, visible, ultraviolet (UV), x-ray, and gamma-ray regions.

- This spectrum is divided based on the energy level, which determines how the radiation interacts with biological tissue:

1. Non-ionizing Radiation (Lower Energy):

This radiation has longer wavelengths and lower frequencies.

- Its biological effects include induced currents and heating.
- Examples include radio waves, microwaves, infrared, and visible light.

Biological Effects

2. Ionizing Radiation (Higher Energy): This radiation has shorter wavelengths, higher frequencies, and high energy per photon.

- ◦ Its primary biological effect is Ionization – DNA Damage.
- ◦ Ionizing radiation (like gamma rays and X-rays) has sufficient energy to disrupt atomic bonds by removing electrons from atoms, which ionizes them and breaks up molecules.
- ◦ The most critical damage occurs when radiation directly damages the DNA of cells. If this damage is not properly repaired, the cells may divide uncontrollably and cause cancer.
- ◦ The severity of the biological effect depends heavily on the dose received (measured in Gray, or Gy). For example, 1–2 Gy may increase cancer risk later, while 15+ Gy typically leads to death from acute radiation sickness.