RADIATION

Radiation

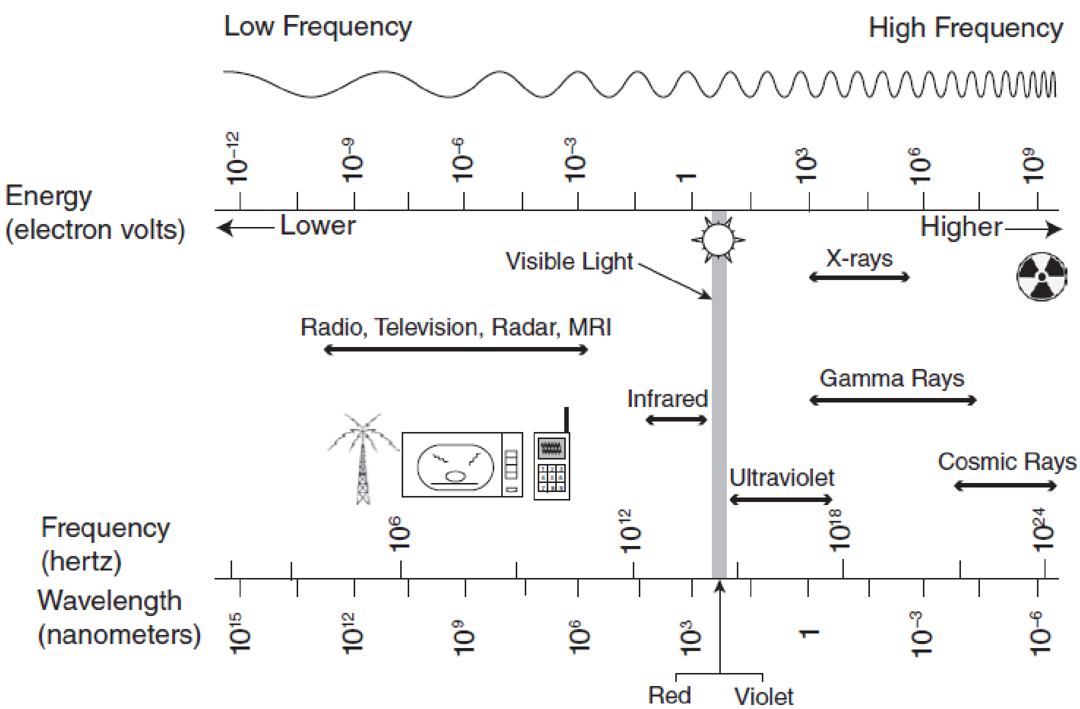
Radiation is energy transmitted through a medium (vacuum, air, tissue, or some other material) as either electromagnetic (EM) waves or subatomic particles.

Types of radiation

Radiation can be either ionizing or non-ionizing, depending on its energy and ability to penetrate matter.

1. Ionizing radiation (IR) is radiation with sufficient energy to liberate some of the electrons out of the atoms or molecules in a material that it passes through. The process of changing the number of electrons in an atom (adding or removing) is referred to as ionization; an atom with unequal numbers of protons and electrons is an ion.

When ionization occurs in living tissue, the electron may quickly recombine with its atom, and little damage may occur; but in some cases, significant damage at the cell, organ, or organism level may occur. A fundamental process caused by ionizing radiation is the splitting of atoms or molecules into positively and negatively charged fragments. These ions may then participate in chemical reactions, resulting in chemical changes that can lead to disruption of cellular function in living tissue. Ionizing radiation comes from a variety of sources, including cosmic rays, natural radioactivity in the soil and in building materials, industrial sources (e.g., airport scanners), and medical devices (e.g., diagnostic X-ray or radiation therapy machines).



Types of ionizing radiation

There are two basic types of ionizing radiation: EM radiation and particulate radiation.

a) Particulate radiation

Alpha Particles

Alpha particles are emitted during the decay of radioactive nuclei. The alpha particle is comprised of two protons and two neutrons (with a net positive charge of (+2). Due to their charge and mass, alpha particles interact strongly with matter and only travel a few centimeters in air. Alpha particles are unable to penetrate the outer layer of dead skin cells but are capable, if an alpha-emitting substance is ingested in food or air, of causing serious cell damage (figure 1).

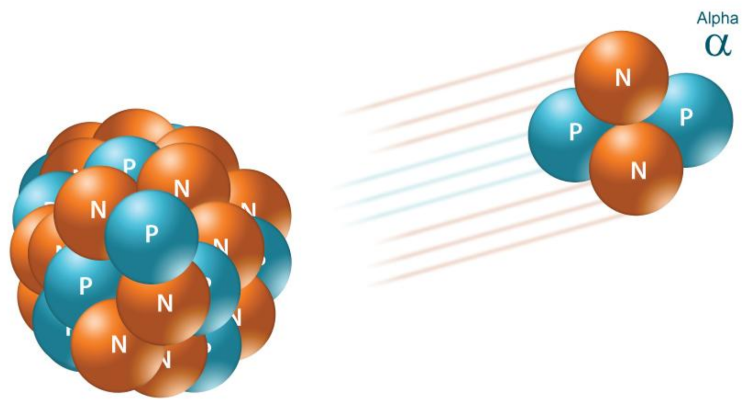


Fig 1: The emission of an alpha particle from the nucleus of an atom

Beta Particles

Beta particles are nearly 8000 times less massive than alpha particles, and they have a charge of (-1). Compared with alpha particles, beta particles are more easily scattered due to their much lower mass. Because of their lower charge, beta particles are not as effective at causing ionization. Therefore, a beta particle travels further before giving up all its energy (several centimeters in human tissue) compared with an alpha particle of the same energy (figure 2).

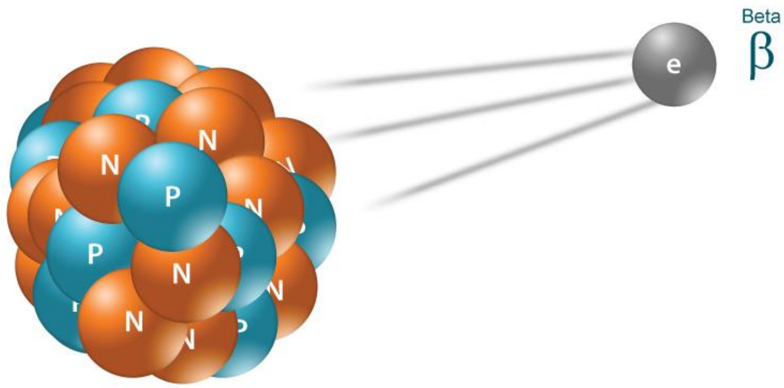


Fig 2: The emission of a beta particle from the nucleus of an atom

Neutrons

Neutron radiation consists of neutrons that are not contained in a nucleus and are instead moving through a medium. Neutron radiation can be complicated because when a neutron has lost enough energy, it can be absorbed by a target nucleus, which causes the nucleus to become radioactive. The radioactive nucleus will then emit an alpha particle, a beta particle, or a gamma ray in order to become more energetically stable.

Neutrons are about 2000 times more massive than electrons but less massive (by a factor of 4) than alpha particles. They interact with charged particles only by colliding with them, because neutrons are not charged. Collisions lead to multiple scattering events as they travel through a material, with some energy lost during each scattering event. They can penetrate deeply into a material and are relatively difficult to stop. The neutron interactions that lead to the greatest energy loss are collisions between neutrons and hydrogen nuclei in hydrogenous materials. Therefore, materials such as water or plastic are usually effective for stopping neutrons.

In general, the penetration of neutrons is greater than electrons but smaller than X-rays of the same energy (figure 3).

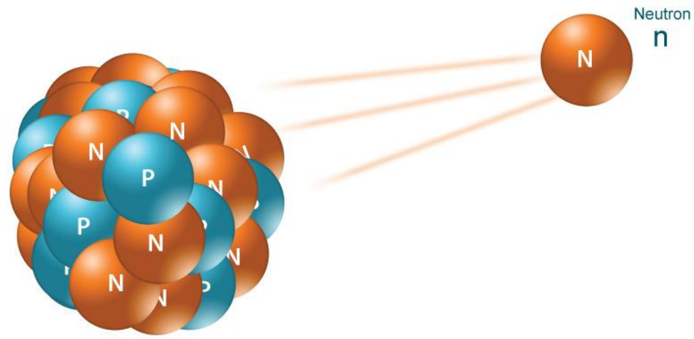


Fig 3: The emission of a neutron from the nucleus of an atom

Protons

Proton ionizing radiation is not a product of natural radioactive decay and is therefore encountered only very infrequently. High-energy protons can be produced in particle accelerators (by ionizing hydrogen and then exposing it to a high voltage). In the United States, protons are used for radiation therapy at only a few highly specialized facilities with accelerators specifically designed for proton therapy. Protons are more penetrating than alpha particles due to having half the charge and are scattered less than electrons due to their greater mass.

b) EM radiation (high energy)

X-rays and gamma rays

X-rays and gamma rays are the forms of ionizing EM radiation that are the most important to consider for a course in radiobiology applied to medicine.

Gamma rays and high-energy X-rays are physically identical. The reason for the different names arises from differences in their origin (inside vs. outside the nucleus). X-rays are produced in the orbital electronic shells of an atom or by interactions between charged particles and the nucleus, whereas gamma rays are emitted from an unstable nucleus after rearrangement of the particles inside the nucleus. Gamma rays and X-rays are photons, which possess zero electrical charge and zero mass and therefore have a relatively low probability of interacting in the matter. As a result, photons can penetrate deeply into the matter, because the interactions required to dissipate their energy are infrequent. Photons carry energy and can ionize atoms or molecules via direct interactions with orbital electrons. They do not have a well-defined maximum penetration depth in the matter, but we can define an average penetration depth for a given material (figure 4).

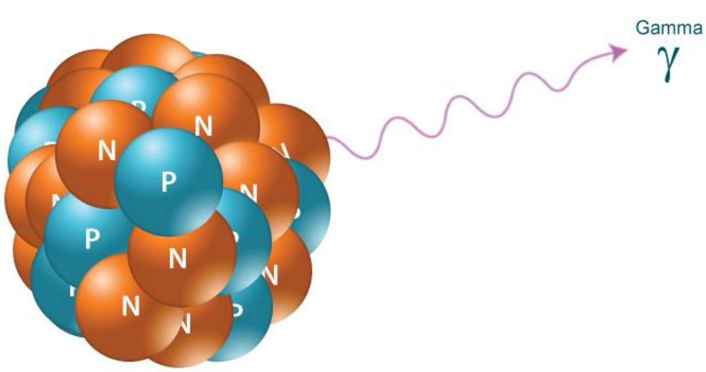


Fig 4: The emission of an high-energy wave from the nucleus of an atom

2. **Non-ionizing radiation** (NIR) refers to radiative energy that, instead of producing charged ions when passing through matter, has sufficient energy only for excitation. Nevertheless, it is known to cause biological effects. Non-Ionizing radiation originates from various sources: Natural

origin (such as sunlight or lightning discharges etc.) and man-made (seen in wireless communications, industrial, scientific and medical applications)

Types of non-ionizing radiation

The NIR is divided into two main regions, optical radiation, and electromagnetic fields. The optical can be further sub-divided into ultraviolet, visible, and infrared. The electromagnetic fields are further divided into radiofrequency (microwave, very high frequency and low-frequency radio wave).

Ultraviolet

Ultraviolet (UV) radiation comes from the sun, welding, black lights and UV lasers. The sun emits UVA, UVB and UVC rays. UVC rays are absorbed by the ozone layer and never actually reach the Earth. Both UVA and UVB light are important for humans in the production of Vitamin D. However, the effects of overexposure to UV rays can be negative and can be immediate or delayed. Sunburn, skin cancer and cataracts develop over time with excessive exposure.

Visible light

Visible light is a very narrow range of electromagnetic radiation of a wavelength that is visible to the human eye (about 400–700 nm), or up to 380–750 nm. This type of light consists of seven colors: red, orange, yellow, green, blue, indigo and violet. When all the colors are present at one time, the light is white. Rainbows are created when visible light passes through raindrops. The raindrops act like a prism and break the light down into its individual colors. Overexposure to visible light can damage both the eyes and skin.

Infrared light

Infrared light (IR) is electromagnetic radiation with a wavelength between 0.7 and 300 micrometers, which equates to a frequency range between approximately 1 and 430 THz. Infrared light wavelengths are longer than that of visible light. The human eye can’t see most of the Infrared spectrum, but we can feel it as heat. Infrared radiation is used in furnaces, heat lamps, toasters and the lasers seen on the TV remote controls. About half of the total energy the sun gives off is in the form of IR radiation, which we feel as heat. In large amounts, this type of radiation can damage the eyes and even cause blindness.

Microwave

Microwaves are electromagnetic waves with wavelengths ranging from as long as one meter to as short as one millimeter, or equivalently, with frequencies between 300 MHz (0.3 GHz) and 300 GHz. Microwave radiation comes from microwave ovens, radar, transmission towers, satellite transmissions, the sun and Cosmic Microwave Background (CMB) radiation. CMB is radiation left over from the Big Bang when the universe began. A microwave oven works because microwaves excite the water molecules in food and cause them to vibrate, generating heat and cooking the food. Atoms and molecules can also emit and absorb MW radiation. Overexposure to MW radiation can cause cataracts and skin burns.

There are three subcategories of Microwaves radiation. Extremely high frequency (EHF) waves are used in remote sensors and radio astronomy. Super high frequency (SHF) waves are commonly used in microwave ovens, radar transmitters, cell phones and satellite communications. Finally, the ultra-high frequency (UHF) is used in television broadcasts, walkie-talkies, and cordless phones. Microwaves are sometimes grouped with radio waves because these two types of non-ionizing radiation have some overlap on the electromagnetic spectrum.

Radio waves

Radio waves are a type of electromagnetic radiation with wavelengths in the electromagnetic spectrum longer than infrared light. Like all other electromagnetic waves, they travel at the speed of light. Naturally-occurring radio waves are made by lightning, or by astronomical objects. Artificially-generated radio waves are used for fixed and mobile radio communication, broadcasting, radar and other navigation systems, satellite communication, computer networks and innumerable other applications. Different frequencies of radio waves have different propagation characteristics in the Earth's atmosphere; long waves may cover a part of the Earth very consistently, shorter waves can reflect off the ionosphere and travel around the world, and much shorter wavelengths bend or reflect very little and travel on a line of sight.

REFERENCES

Kelsey C. A., Heintz P. H., Sandoval D. J., Chambers G. D., Adolphi N. L., and Paffett K. S. (2014): Radiation biology of medical imaging. First Edition. John Wiley & Sons, Inc. Chapter 3.

Kwan-Hoong Ng (2003): Non-Ionizing Radiation – Sources, Biological Effects, Emissions, and Exposures. Proceedings of the International Conference on Non-Ionizing Radiation at UNITEN ICNIR2003 Electromagnetic Fields and Our Health.