MOMENTUM OF EM WAVE AND ELECTROMAGNETIC SPECTRUM

Momentum of EMW

Ex. A red LED emits light uniformly in all directions with a wattage of 0.1. At a distance of 1 meter from the LED, the amplitude of the electric field of the emitted light is.

Solution:

The intensity of light at a distance r from a light source emitting radiation.

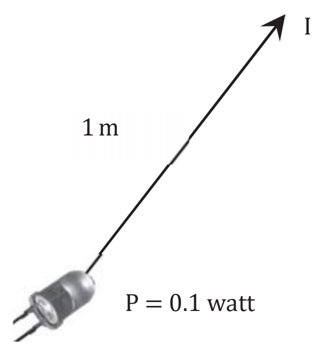
$$I = \frac{P}{4\pi r^2}$$

$$I = \frac{0.1}{4\pi 1^2} = \frac{1}{2}E_0 E_0^2 C$$

Rearranging,

$$= 2.45 V/m$$

$$E_0 = 2.45\ V/m$$

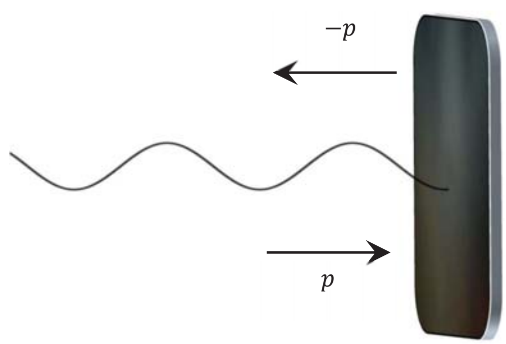


An electromagnetic wave transports both energy and momentum as it propagates through space. Momentum is quantified or expressed by the following equation or expression.

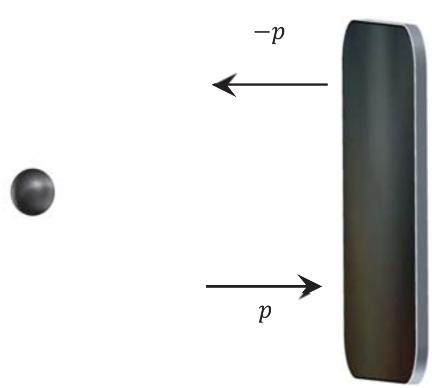
$$E = \frac{hc}{\lambda} \Rightarrow P = \frac{h}{c}$$

Depending on the context or circumstances, electromagnetic waves (EMW) are regarded both as waves and particles.

Wave nature



Particle nature



Electromagnetic Spectrum

During the period when Maxwell initially postulated the presence of electromagnetic waves, our knowledge was limited primarily to visible light waves. At that time, our understanding of electromagnetic radiation was evolving, with the recent recognition of ultraviolet and infrared waves.

Towards the end of the 19th century, further advancements led to the discovery of X-rays and gamma rays. Over time, our comprehension of electromagnetic waves expanded significantly. Today, we acknowledge a diverse spectrum of electromagnetic radiation encompassing visible light waves, X-rays, gamma rays, radio waves, microwaves, ultraviolet, and infrared waves.

The categorization of electromagnetic waves into various types is determined by their frequency, forming what is known as the electromagnetic spectrum. It's crucial to understand that the classification isn't characterized by distinct boundaries between different types of waves. Rather, it's about the methods of generation or detection of these waves.

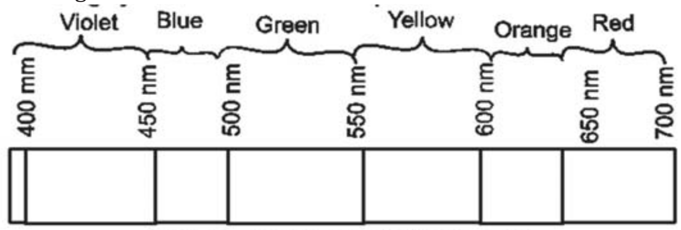


Figure - spectrum of visible light

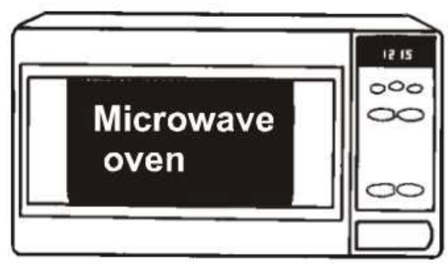
Now, we will offer a concise overview of different kinds of electromagnetic waves, arranged in descending order based on their wavelengths.

Radio waves

Radio waves emerge from the accelerated movement of charges within conducting wires, serving as integral components in radio and TV communication systems. Their frequency spans from about 500 kHz to 1000 MHz. The AM band, ranging from 530 kHz to 1710 kHz, represents a subset, while shortwave bands encompass frequencies up to 54 MHz. Television waves operate within the 54 MHz to 890 MHz range. The FM radio band, between 88 MHz and 108 MHz, is distinct. UHF radio waves, in the ultrahigh frequency range, facilitate voice transmission in cellular phones.

Microwaves

Microwaves, akin to abbreviated radio waves, operate within the gigahertz (GHz) frequency range. Their generation relies on specialized vacuum tubes such as klystrons, magnetrons, and Gunn diodes. Their shorter wavelengths make them ideal for radar systems utilized in aircraft navigation.



Microwave ovens present an intriguing domestic utilization of microwaves. In these devices, the microwave frequency is precisely selected to align with the resonant frequency of water molecules, facilitating efficient energy transfer to their kinetic energy. Consequently, foods containing water experience a rise in temperature.

Infrared waves

Infrared waves, also known as heat waves, originate from hot objects and molecules. These waves occupy the lower-frequency, longer-wavelength region of the visible spectrum. Their association with heat stems from the efficient absorption by most materials containing water molecules. This absorption triggers an increase in thermal motion within the material, thereby raising its temperature and warming its surroundings.

In numerous applications, such as in the field of physical therapy, infrared lamps find extensive use. Additionally, infrared radiation plays a pivotal role in regulating the Earth's average temperature through the mechanism of the greenhouse effect.

When incoming visible light from the Sun penetrates the atmosphere, it is absorbed by the Earth's surface and subsequently re-emitted as longer-wavelength infrared radiation. Greenhouse gases, such as carbon dioxide and water vapor, trap this infrared radiation, contributing to the maintenance of Earth's warmth.

Infrared detectors serve various functions in Earth satellites, encompassing military applications and the monitoring of crop growth. Furthermore, electronic devices, like semiconductor light-emitting diodes, emit infrared radiation, commonly utilized in remote controls for household electronics such as television sets, video recorders, and hi-fi systems.

Visible rays

Visible light represents the most commonly encountered form of electromagnetic wave. It resides within the segment of the spectrum detectable by the human eye, encompassing frequencies ranging from approximately 4×10^{14} Hz to about 7×10^{14} Hz. This frequency range corresponds to wavelengths spanning from approximately 700 to 400 nanometers (nm). The emission or reflection of visible light by objects offers valuable insights into the surrounding environment, with our eyes finely tuned to perceive this specific range of wavelengths.

It's noteworthy that various animal species exhibit differing sensitivities to distinct wavelength ranges.

For example, snakes possess the capability to detect infrared waves, which are imperceptible to humans, while many insects perceive a 'visible' range that extends into the ultraviolet portion of the spectrum. This diversity in light sensitivity among different species enables them to interpret and interact with their surroundings in unique ways.

Ultraviolet rays

Ultraviolet (UV) radiation encompasses a spectrum of wavelengths ranging from approximately 4×10^{-7} m (400 nm) to 6×10^{-10} m (0.6 nm). This form of light is generated by specialized lamps and exceptionally hot objects. While the sun serves as a prominent natural source of ultraviolet light, a substantial portion of it is absorbed by the ozone layer situated in the Earth's atmosphere, positioned at an altitude of approximately 40-50 kilometers.

Exposure to elevated levels of UV radiation can pose risks to human health. For instance, increased UV exposure prompts our bodies to produce more melanin, resulting in skin tanning. Notably, standard glass effectively blocks UV radiation, hence preventing tanning or sunburns through glass windows. In scenarios involving significant UV exposure, such as in welding, individuals wear specialized glass goggles or face masks equipped with UV-blocking windows to safeguard their eyes.

Due to its shorter wavelength, UV radiation can be concentrated into highly focused beams for precision applications such as LASIK (Laser Assisted in Situ Keratomileusis) eye surgery. UV lamps also serve in disinfecting water by eliminating germs within water purifiers.

The ozone layer within the Earth's atmosphere plays a crucial protective role by shielding us from excessive UV radiation. The depletion of this ozone layer, primarily attributed to the release of chlorofluorocarbons (CFCs), remains a significant international concern.

X-rays

The X-ray segment of the electromagnetic spectrum extends beyond the UV region and is renowned for its significant medical applications. This range encompasses wavelengths ranging from approximately 10–8 m (10 nm) to 10–13 m (10–4 nm). One prevalent method utilized to generate X-rays involves directing high-energy electrons towards a metal target.

X-rays find extensive usage in the medical field for diagnostic purposes and are also employed in the treatment of specific cancer types.
It's imperative to recognize that X-rays possess the capability to cause harm or destruction to living tissues and organisms. Therefore, it is crucial to exercise caution and avoid unnecessary or excessive exposure to them.

Gamma rays

Gamma rays represent a category of electromagnetic waves characterized by exceptionally high frequencies and remarkably short wavelengths. Positioned at the uppermost end of the electromagnetic spectrum, their wavelengths span from about 10–10 m to less than 10–14 m. Processes such as nuclear reactions and the emissions from radioactive materials contribute to the production of gamma rays.

In the realm of medicine, gamma rays serve a crucial role in targeting and treating cancer cells, thanks to their elevated energy levels. This treatment involves precisely focusing the gamma rays on the cancerous tissue, aiming to inflict damage and ultimately eliminate the harmful cells. This method offers a meticulous approach to addressing and eradicating detrimental cells.
In summary, electromagnetic waves encompass a broad spectrum of frequencies and wavelengths, with gamma rays occupying the high-energy end. The transition between different types of electromagnetic waves may not always be sharply delineated, leading to some degree of overlap between them.