region of electromagnetic spectrum

The electromagnetic spectrum, in simple terms, is defined as the range of all types of electromagnetic radiation. We shall learn about the concept in detail and understand all its underlying aspects in this lesson.

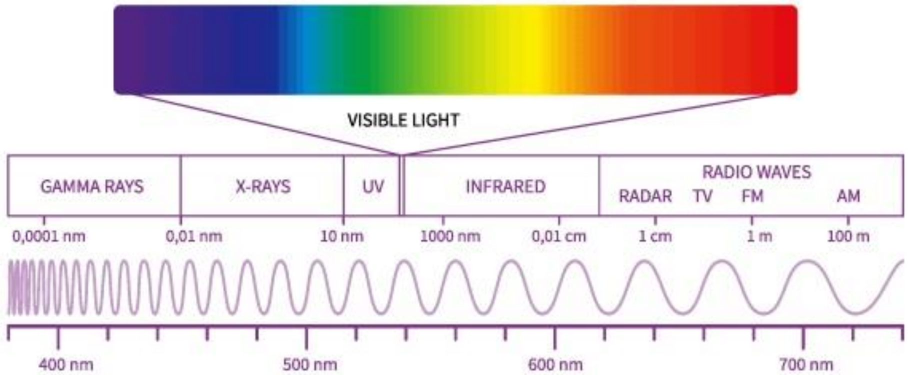
What Is the Electromagnetic Spectrum?

The electromagnetic spectrum is a range of frequencies, wavelengths, and photon energies covering frequencies from below 1 hertz to above 10^{25} Hz, corresponding to wavelengths that are a few kilometers to a fraction of the size of an atomic nucleus in the spectrum of electromagnetic waves. Generally, in a vacuum, electromagnetic waves tend to travel at speeds similar to that of light. However, they do so at various wavelengths, frequencies, and photon energies.

The electromagnetic spectrum consists of a span of all electromagnetic radiation, which contains many subranges, which are commonly referred to as portions. These can be further classified as infrared radiation, visible light, or ultraviolet radiation.

Electromagnetic Waves in the Electromagnetic Spectrum

The entire range (electromagnetic spectrum) is given by radio waves, microwaves, infrared radiation, visible light, ultra-violet radiation, X-rays, gamma rays, and cosmic rays in the increasing order of frequency and decreasing order of wavelength. The type of radiation and their frequency and wavelength ranges are as follows:



Type of Radiation	Frequency Range (Hz)	Wavelength Range
Gamma-rays	$10^{20} – 10^{24}$	$< 10^{-12}$ m
X-rays	$10^{17} – 10^{20}$	1 nm – 1 pm
Ultraviolet	$10^{15} – 10^{17}$	400 nm – 1 nm
Visible	$4 \times 10^{14} – 7.5 \times 10^{14}$	750 nm – 400 nm
Near-infrared	$1 \times 10^{14} – 4 \times 10^{14}$	2.5 µm – 750 nm
Infrared	$10^{13} – 10^{14}$	25 µm – 2.5 µm
Microwaves	$3 \times 10^{11} – 10^{13}$	1 mm – 25 µm
Radio waves	$< 3 \times 10^{11}$	> 1 mm

Prefixes of the metric system:

Factor	Prefix	Symbol	Factor	Prefix	Symbol
10^{12}	Tera	T	**10^{-2}**	centi	c
10^{9}	Giga	G	**10^{-3}**	Mili	M
10^{6}	Mega	M	**10^{-6}**	Micro	μ
10^{3}	kilo	K	**10^{-9}**	Nano	n
10^{2}	hecto	h	**10^{-12}**	Pico	p
10^{1}	deca	da	**10^{-15}**	femto	f
10^{-1}	deci	d	**10^{-18}**	atto	a

Let us look into the uses of electromagnetic waves in our daily lives.

Radio: A radio captures radio waves that radio stations transmit. Gases and stars can also emit radio waves in space. Radio waves are mainly used for TV and mobile communication.

Microwave: This type of radiation is found in microwaves and helps cook at home or in the office. Astronomers use it to determine and understand the structure of nearby galaxies and stars.

Infrared: It is used widely in night vision goggles. These devices can read and capture the infrared light emitted by our skin and objects with heat. In space, infrared light helps to map interstellar dust.

X-ray: X-rays can be used in many instances. For example, a doctor can use an X-ray machine to take an image of our bones or teeth. Airport security personnel use it to see through and check bags. X-rays are also given out by hot gases in the universe.

Gamma-ray: It has a wide application in the medical field. Gamma-ray imaging is used to see inside our bodies. Interestingly, the universe is the biggest gamma-ray generator of all.

Ultraviolet: The Sun is the main source of ultraviolet radiation. It causes skin tanning and burns. Hot materials that are in space also emit UV radiation.

Visible: Visible light can be detected by our eyes. Light bulbs, stars, etc., emit visible light.

Spectroscopy: Spectroscopy is used to study the way different electromagnetic waves interact with matter.

We can learn about a substance by analysing the EM spectrum given by it. When light scatters or passes through matter, it tends to interact with molecules and atoms. Since atoms and molecules have resonance frequencies, they directly interact with those light waves having the exact frequencies. When collisions occur in an excited state, the atoms and molecules emit light with a certain set of characteristic frequencies. This further results in a line spectrum. Here, only light with detached wavelengths is produced. The spectrum is also not continuous, but it consists of a set of emission lines.

In cases where light with continuous wavelengths passes through a low-density material, the atoms and molecules of the material will absorb light waves with the same set of characteristic frequencies. This results in the production of the absorption spectrum, which is a nearly continuous spectrum with missing lines.

Significance of the Electromagnetic Spectrum

The electromagnetic waves in these different bands have different characteristics depending upon how they are produced, how they interact with matter and their practical applications. Maxwell's equations predicted the existence of an infinite number of frequencies of electromagnetic waves, all travelling with the speed of light. This is the first indication of the existence of the entire electromagnetic spectrum.

Nonetheless, the main significance of the electromagnetic spectrum is that it can be used to classify electromagnetic waves and arrange them according to their different frequencies or wavelengths.

Practical Applications of Electromagnetic Waves

● The radio waves and microwaves discovered by Hertz paved the way for wireless television, radio and mobile communication.

● The visible light portion of the electromagnetic spectrum is the reason for all visual aids in daily life. This is the portion of the electromagnetic spectrum that helps us to see all objects, including colors.

● The X-rays discovered by Roentgen proved to be useful in medicine for detecting many ailments or deformities in bones.

● The high ultraviolet radiation has energies to ionise the atoms causing chemical reactions.

● The gamma rays discovered by Paul Villard are useful for ionisation purposes and nuclear medicine.

Formulas for the Electromagnetic Radiation

The frequency(f), speed(c), energy(E) and wavelength(λ) of electromagnetic waves are related as

Formulas for Electromagnetic Radiation

$$E = hf = h\frac{c}{\lambda}$$

Where,

● c = 299792458 m/s is the speed of light in a vacuum

● h = 6.62607015×10−34 J·s = 4.13566733(10)×10−15 eV·s is Planck's constant.

Solved Questions

Question 1: What are the frequency and wavelength of an EM wave of energy 6.626 x 10-19 J?

Answer: Frequency(f) = E/h = 1015 Hz. Wavelength(λ) = c/f = 3 x 108 / 1015 = 3 x 107 meters

Question 2: What are the uses of X-rays?

Answer: X-rays can be used to detect medical ailments and bone deformities in medical diagnosis. They are useful for ionization purposes also.

Question 3: Can we use X-rays and gamma rays for broadcasting radio/TV/mobile signals?

Answer: No, X-rays and gamma rays are short-range. Moreover, they are harmful and have penetrating power on the matter with which they interact and can damage the tissues of living bodies.

Question 4: Which among the following is not a property of electromagnetic waves?

1) Momentum 2) Energy 3) Pressure 4) Heat energy

Answer:

1) EM waves can impart momentum (and angular momentum) to the material with which it interacts.

2) Electromagnetic waves carry energy. EM waves are the only waves able to carry energy across a vacuum.

3) EM waves also exert pressure, which is shown by a radiometer. One side of the panels is black, the other side is white, and the panels spin due to the pressure differences under the light.

4) EM waves do not carry heat energy, but any EM radiation can heat an object when it is absorbed.

Question 5: A ray from the sun, passing through your kitchen window, hits a prism that casts a rainbow on the windowsill. Supposedly, there is a hand-held radiometer on the table. Now, you place the instrument on a specific colour of the rainbow with your eyes closed. When you open your eyes, you see that the radiometer measured the energy from that colour at 4.0 x 10-19 joules. If we take Planck's constant of 6.6256 x 10-34 joules/sec, what possible colour did the instrument measure? How can we determine this?

Answer:

We should use the equation involving energy change, Planck's constant, and frequency. Next, we need to figure out what we are solving for. In this problem, they ask for the possible colour that you measured. If we relate the energy with Planck's constant, we can solve for frequency. We are given the energy, 4.0 x 10-19 joules, as well as Planck's constant, 6.6256 x 10-34 joules/sec. Also, we are given the frequencies emitted by the visible spectrum, from red to violet. This problem is easy to solve now. If we solve for the frequency, we can then relate it to the energy emitted, measured in either sec-1.

Let’s solve it.

– What is the best equation to use? E = h* *f*

– Solve for the intended variable. E/ h = *f*

– Energy measured = 4.0 x 10-19 joules

Planck’s constant = 6.6256 x 10-34 joules/sec

Visible spectrum frequency

(4.0 x 10-19 joules) / 6.6256 x 10-34 joules/sec = *f*

– Joules cancel out with joules, and one is left with sec-1, a frequency.

Answer = 6.03 x 1014 sec-1

This falls within the given visible spectrum frequencies. Being a high frequency on the visible spectrum, close to the frequencies emitted by blue colour, one could assume that you measured a colour close to blue, though cyan and green cannot be out of question as the given frequencies are a bit vague. It is closest to the green colour. Hence, we measured the green colour.

Frequently Asked Questions on Electromagnetic Spectrum

Q1

Which electromagnetic spectrum has the highest wavelength?

An electromagnetic spectrum is a collection of a range of waves in sequential order. Radio waves have the highest frequency, and gamma rays have the shortest wavelength.

Q2/ Which part of the electromagnetic spectrum carries the least energy?

Radio waves have the lowest frequency and, hence, have the least energy.

$$E = hf$$

E = Energy

f = Frequency

h = Planck's constant

Q3

Where in the electromagnetic spectrum is visible light?

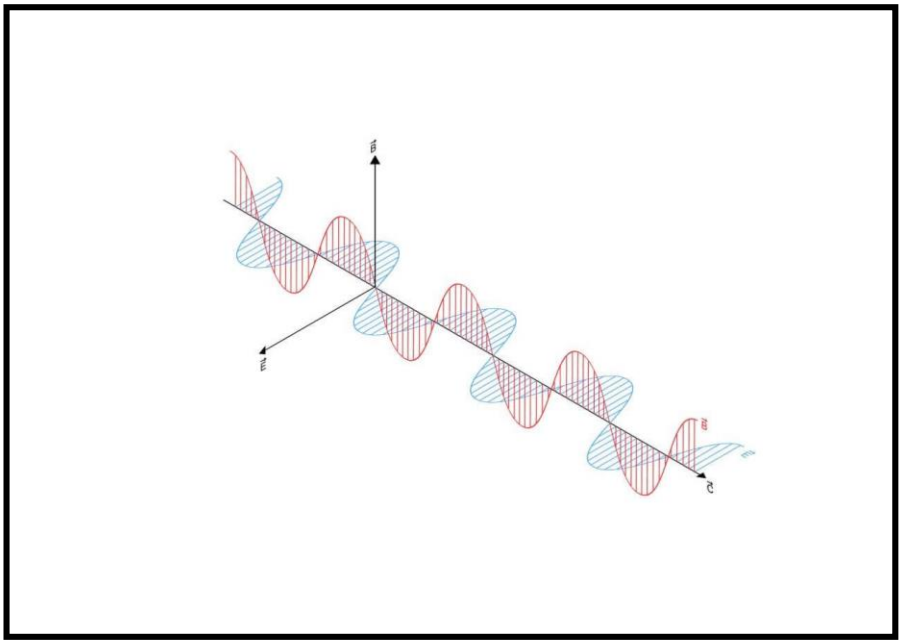
Visible light falls in the range of the electromagnetic spectrum between infrared rays and ultraviolet rays. It has frequencies of about 4 × 1014 to 8 × 1014 hertz (Hz) and a wavelength of about 740 nanometers (2.9 × 10−5 inches) to 380 nanometers (1.5 × 10−5 inches).

Q4

Which part of the electromagnetic spectrum has the highest frequency?

Gamma rays have the highest frequency and the least wavelength

What is Light? we described light as both a wave and a particle under conditions of wave-particle duality. Light is often thought of as a ray when discussing reflection and refraction. Only when we talk about diffraction and wavelength do we mention the wave property of light. While the wave property of light requires more technical knowledge, it answers the question of why white light emerges from a prism in the form of a rainbow.



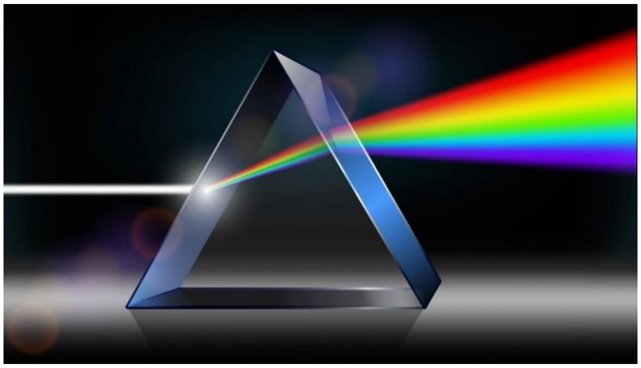
Transverse Wave Diagram

To start, light travels as a transverse wave, meaning that its direction of vibration is perpendicular to the direction of propagation. While we indicate the direction of propagation with an arrow, light is in fact oscillating perpendicular to the direction of propagation. In discussing the oscillation aspect, we go back to concepts of frequency, wavelength, and the index of refraction (n) mentioned in “How to Describe Light” and “How Does Light Travel?”.

A good analogy of the relationship between these three variables is a drill bit. Let the spiraling motion of the drill bit remain constant which is analogous to the frequency of light. The speed at which the bit advances through a particular substance is analogous to the speed at which light travels. So if the bit starts spiraling in air and makes contact with wood, it encounters resistance and moves forward at a slower speed, even as its spiraling speed remains constant. This is analogous to light entering glass where the speed of light slows down but the frequency remains the same.

$$\text{Frequency} = f = \frac{1}{T} = \frac{c}{\lambda}$$
$$\text{Velocity} = v = \frac{c}{n}$$
$$\rightarrow$$
$$f = \frac{v\, n}{\lambda}$$

For 2 different frequencies of light, their speed in a vacuum is the same, just as if we had 2 drill bits with different spiraling speeds, but traveling forward at the same speed. To travel forward at the same speed, the slower bit would have to travel more distance forward in one turn. Therefore, the faster the speed of the drill, the greater the resistance, and the greater the forward speed change. For light, the higher the frequency of light, the greater the influence of the medium and the slower the forward speed in the medium.



Prism and Rainbow

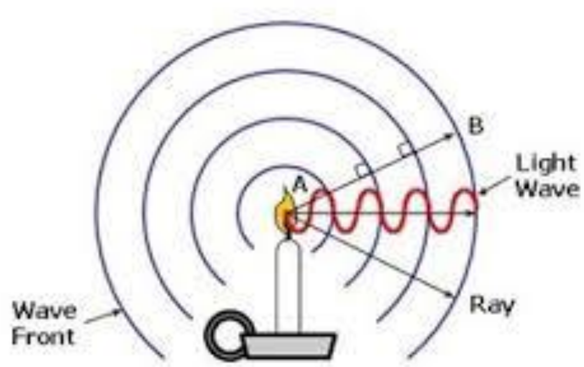
The different forward speeds of light when traveling through a medium explains why white light breaks into a rainbow after traveling through a prism. Since the colors of light have different wavelengths (and thus frequencies), this causes colors with lower frequencies (red) to travel faster than colors with higher frequencies (violet). A white beam of light thus breaks apart into the different colors- a more detailed explanation than white light refracts when traveling through a prism.

What Type of Wave is Light?

Light is a transverse wave, where the movement of the particle is perpendicular to the propagation of the wave. It is formed by alternating electric and magnetic fields produced by accelerating charged particles. These alternating electric and magnetic fields propagate perpendicular to the direction of propagation of a wave. Another characteristic of light is that it can propagate even in the absence of a medium. This is why sunlight can easily reach Earth even if there is only an empty space between the planet and the sun. All forms of light waves are electromagnetic waves; thus, they all travel at the same speed of (3×10^{8} m/s).

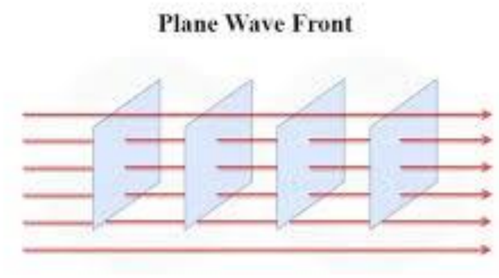
Property	Longitudinal Wave	Transverse Wave
Direction of Vibration	Parallel to wave propagation	Perpendicular to wave propagation
Example	Sound waves	Light waves, water waves
Distinctive Features	Compressions and rarefactions	Crests and troughs
Amplitude	Extent of particle displacement in the longitudinal direction	Extent of particle displacement in the perpendicular direction

Wave front: is defined as the locus of point. All of which are in the same phase. The electromagnetic wave radiated by a point light source may be represented by a spherical surface Concentric with the source. as in Fig 1.



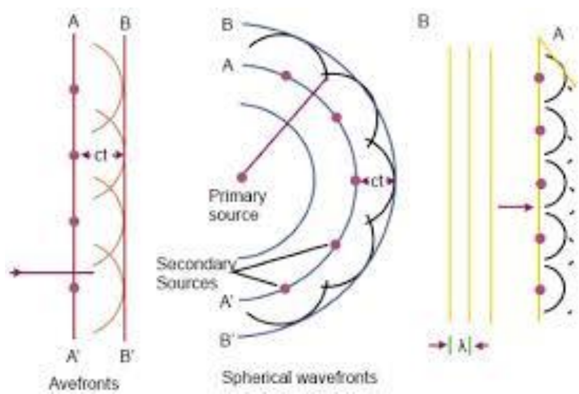
Wave Fronts Propagating From a Point Source

At a sufficiently great distance from the source where the radi of the sphere has become very large, spherical surfaces can be considered plane, and we have a train of the plane Wave as in Fig2.



A train of lightweight waves may often be represented more simply by means of ray than by Wavefront.

Huygens Principle: The principle states that every point of the Wavefront may be considered as the source of some small secondary wavelets



Optical path if a ray of light travels distance **"d"** in medium with a velocity **"v"** The rays of light have covered that distance and time **"t"**

$$\boldsymbol{t = \frac{d}{v}} \qquad \textbf{the path} \quad \textbf{d= v.t}$$

$$\because n = \frac{c}{v} \qquad v = \frac{c}{n}$$

$$\therefore d = \frac{c}{n} t$$

$$nd = ct$$

The product (nd) is called the optical path (Δ)

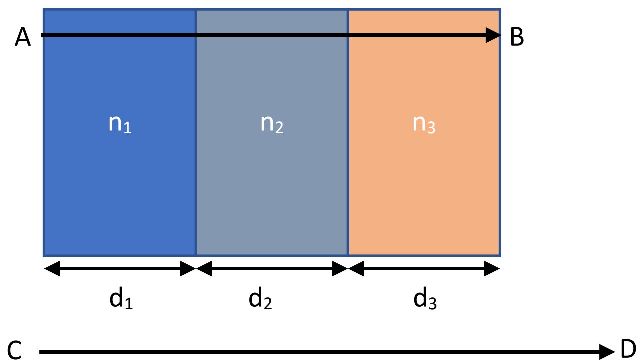
i.e., $\Delta = nd$

$$\therefore \ \Delta = nd = ct$$

If a light ray travels through a series of optical medium of thicknesses d_1, d_2, d_3, ……. and the refractive index n_1, n_2, n_3 ……., the total optical bath is just the sum of the separated value

$$\Delta = n_1 d_1 + n_2 d_2 + n_3 d_3 + \cdots$$

The meaning of the optical path appears in the figure below, where, at the same time, we notice that the beam travels a longer distance than through the material.



equivalent optical path in vacuum Δ

Whereas the optical path represents the distance that light travels in a vacuum, at the same time that light travels the distance d in the physical medium.

Q/ A glass plate of 3mm thickness.of index 1.5 is place between a point source of light of wavelength (600 m) in vacuum and a screen.The distance from source to screen is 3 cm.

a- How many waves are there between source and screen?

b- Calculate the optical bath in a glass plate in this case?