The Nature of Light

Notes_1_SNC2DE_09-10

Light is a form of energy.
Light is the only form of energy that can travel like a wave through empty space and through some materials.

Light behaves like a special kind of wave, called an electromagnetic wave.

(1801: Thomas Young demonstrated that under certain conditions light shows wave-like properties.)

(1864: James Clark maxwell predicted that light energy is an electromagnetic wave, such that the light energy constantly changes its form between electrical energy and magnetic energy. He also predicted this electromagnetic wave does not require a medium for transmission and that this wave travels at the speed of light.)

The existence of electromagnetic waves was confirmed by Heinrich Hertz, in 1887 who discovered low-energy electromagnetic waves that we now call radio waves. Additional proof came when William Konrad Roentgen discovered high-energy electromagnetic waves called X-rays.

Electromagnetic waves are very similar to water waves.
Light can be modelled and compared with water waves.

Both types of waves involve the movement of energy from one point to another.

What is a Wave?

A wave is a means by which energy is transferred between two points in a medium without any net transfer of the medium itself.

(FYI: a medium refers to any substance or object in which the wave is travelling.)

Light does not require a medium for transmission, light energy is transferred through radiation.

When a wave travels in a medium, parts of the medium do not end up at different places.

The energy of the source of the wave is carried to different parts of the medium by the wave: only energy moves forward.

(Think of a corn field: when you see a field of corn waving in the wind, you actually see a wave carry across the field without the actual corn moving to another part of the field.)

(Think of a lake; a wave on a lake does not transport water, but water can actually be blown across the lake by the wind.)

(Imagine that a duck sits on the surface of a lake. The duck moves up and down with the wave, which means that the wave transfers energy to the duck. The wave moves up and down, but the water does not move forward with the wave. Only energy moves forward.)

The movement of energy allows the wave to do work.

As an electromagnetic wave, light has some characteristics in common with all forms of electromagnetic energy. These include amplitude, frequency ad wavelength. These characteristics are related to each other, so that any one can be calculated if the other are known.

Definitions Associated With Waves

The following definitions are given in terms of the particles that make up the medium through which the wave travels.

Amplitude, A, a: is the wave height from its position of rest to the crest, or the wave depth from the rest position to the trough.
The energy transferred by a wave depends, in part, on its amplitude. The larger the amplitude, the more energy that is carried by the wave. The smaller the amplitude, the less energy that is carried by the wave.

Frequency, f: is the number of cycles of the waveform that occur in one second of time. It is the rate of repetitions or the number of oscillations made per seconds by a wave. (Example: if 10 wave crests pass in a minute then the frequency of the wave is 10 cycles /minute.)

The energy transferred by a wave often depends on the frequency of the wave as well as its amplitude.
The higher the frequency, the more energy the wave passes along.
The symbol for frequency is ‘f’.
The SI unit of frequency is the hertz, Hz, which is cycles per seconds.

Wavelength, ?: is the distance from one place in a wave to the next similar place on the wave, for example, the distance from one crest (or trough) to the next crest (or trough).
The symbol for wavelength is ?, the Greek letter lambda.
Wavelength is measured in meters.
[note: in the case of light, the wavelength is so short that a specific distance, called the angstrom (D), has been defined.
One angstrom = 10^{-10} m or 10^{-8} cm.]

Crest: this is a term coined from water waves and refers to the maximum height of the wave.

Trough: A term coined from water waves referring to the lowest point of the wave.

Assignment 1

1. What is the difference between a crest and a trough in a wave ?
2. What is the difference between amplitude and wavelength ?
3. Draw a wave and label:

i. crest, ii. trough, iii. amplitude, iv. wavelength v. resting position

4. Draw a wave that has a wavelength of 3 cm and an amplitude of 1 cm.
5. Why does a dental technician put a lead apron over you when you are getting dental X– rays?

Relationship between Frequency and Wavelength

If there are more wave crests per seconds, the frequency of the wave increases, so more energy is in the wave, thus the wavelength is shorter.

Hence frequency and wavelength have an inverse relationship, which means one value increases, the other decreases.

As frequency increases, wavelength decreases.

There is a mathematical relationship between the speed v, of the wave, the frequency f of the wave, and the wavelength ? of the wave:

$$v = f \times ?$$

Example

1. Water waves of wavelength 5.0 cm are travelling with a speed of 1.0 m/s. What is the frequency of the wave?

(Answer: 20 Hz)

2. Suppose that the waves now enter deeper water and their speed changes to 2.0 m/s. What is their wavelength?

(Answer: 10 cm).

Speed of Propagation of Light

Wave **speed** depends on the nature and properties of the medium only.
(Water waves actually do travel faster in deeper water).

The speed at which light travels through any medium is determined by the density of that medium.

The presence of matter, even transparent matter, will slow light down.

Even air will have some effect, and glass has a more significant effect on the speed at which light will travel through it.

The speed of light in a vacuum = 2.997925×10^{10} cm /sec

The letter c is used as a symbol for the speed of light. (Recall: Einstein's equation: $E = mc^2$)

The frequency of the wave depends on only the frequency of the source producing the wave and will therefore **not** change if the wave enters a different medium or the properties of the medium change.

The Electromagnetic Spectrum

The electromagnetic spectrum is the classification of electromagnetic waves by energy. (Spectrum in Latin means' appearance'.
Visible light is only a small fraction of the energy that surrounds us every day.
We are also surrounded by invisible light-like waves, which together visible light make up the electromagnetic spectrum.

Electromagnetic waves are invisible and can travel through a vacuum. They do not need particles in order to travel.

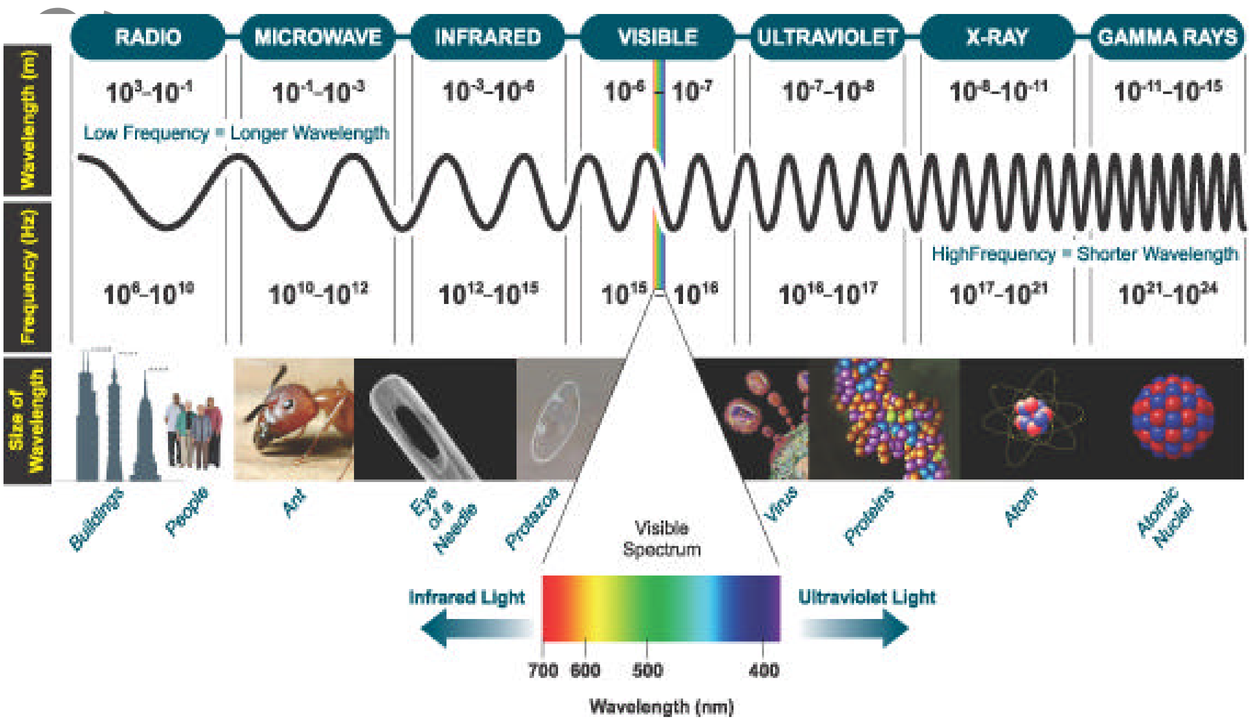
Electromagnetic waves do not require a material medium for transmission, as can be seen by the fact that we receive visible light from the sun through the vacuum of space.

Electromagnetic waves involve electric and magnetic fields that can travel through empty space.

Examples of electromagnetic waves are: radio waves, microwaves, infrared, visible light, ultraviolet, X– rays and gamma rays. (Radio waves have the longest wavelength and gamma rays are the shortest.)

The waves that make up the electromagnetic spectrum are classified in terms of frequency and wavelength, as shown in the spectrum below.

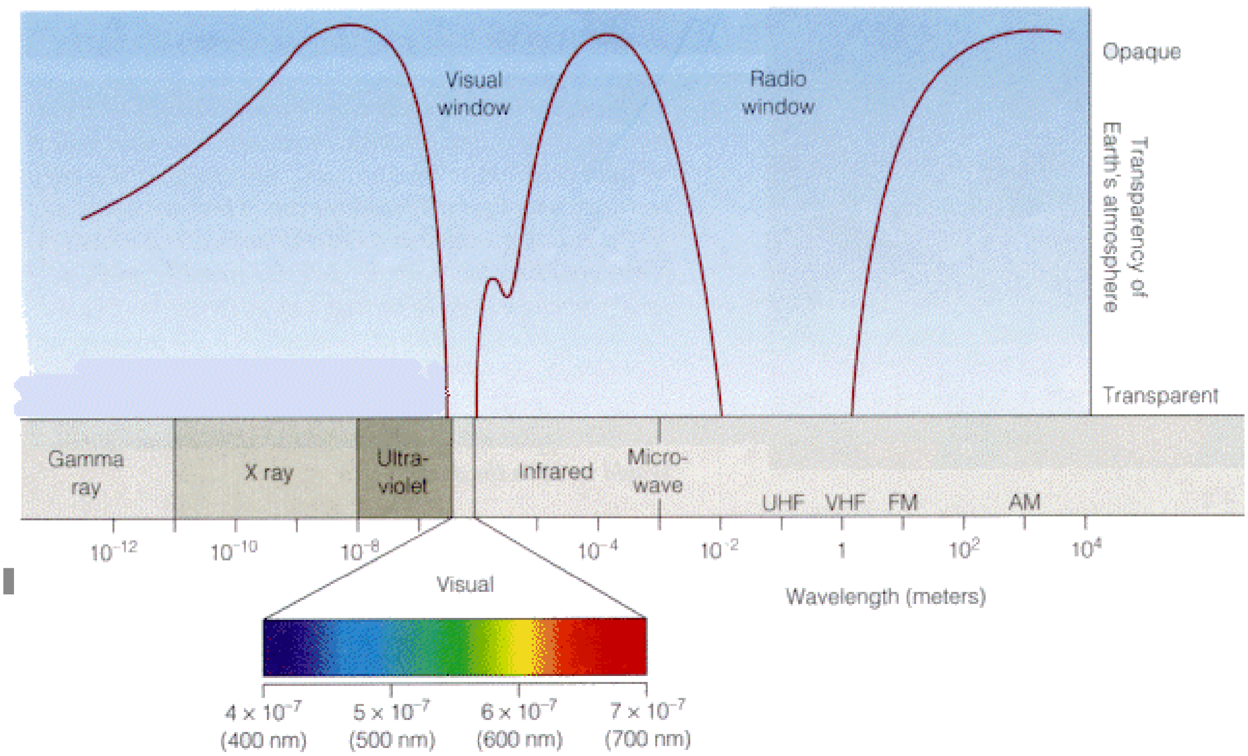
The electromagnetic spectrum is a diagram that illustrates the range, or spectrum, of electromagnetic waves, in order of wavelength or frequency.



The light that we can see forms a very small part of the electromagnetic spectrum — the visible spectrum..

The visible spectrum consists of the wavelengths that the eye can detect.

The visible portion of the spectrum has been expanded in the following diagram to show the range of colours:



Notice that the colours of light are just different wavelengths (or frequency) of light.

The colour red has the longest wavelength of visible light which is 700 nm (**nm** is the symbol for nanometer, or 10^{-9}), but the shortest frequency.

Violet light has the shortest wavelength of visible light , which is 400 nm, (but the highest frequency).

Visible light has a characteristic wavelength in the range of approximately 3900 D to 7700 D. Electromagnetic energy outside this range is no longer visible to the human eye.

Additive Colour Theory of Light

White light is composed of different colours (hence different wavelengths) of light.

white light may be produced by combining only three colours; red, green and blue. These three colours are known as primary colours of light. Upon mixing any two of these primary colours together, a secondary colour may be obtained..

Subtractive Colour Theory of Light

When a light wave strikes an object some wavelengths of light reflect, (i.e. they bounce off the object). Other wavelengths are absorbed by the object.

The colours that one sees when an object is viewed depends on the wavelengths that are reflected. Example, a red rose reflects red wavelengths of light and absorbs other colours.

According to the subtractive theory of light, coloured matter selectively absorbs colours or wavelengths of light. The colours that are absorbed are 'subtracted' from the reflected light that is seen by the eye.

A black object absorbs all colours whereas a white object reflects all colours. A blue object reflects blue and absorbs all other colours.

Assignment 2

1. Explain the term 'frequency' as it applies to a wave.

2. What is electromagnetic radiation?

3. (a) List three types of radiation of the invisible spectrum that have wavelengths longer than visible light.
   (b) Name one application for each of these three types of radiation.

4. (a) List three types of radiation of the invisible spectrum that have wavelengths shorter than visible light.
   (b) Name one application for each of these three types of radiation.

5. Identify six general categories of colour of the visible spectrum, from highest frequency to lowest frequency.

6. Which poses more of a danger to human health, very long wavelength radiation or very short wavelength radiation. Explain why.

7. What property of a light wave determines the colour of light.

8. What two properties do all electromagnetic waves have in common?

9. List these electromagnetic waves in order from lowest energy to highest energy:
   green light, microwaves, X-rays, ultraviolet light, infrared light, red light, and radio waves.

10. Many houses in warm climates have white walls and roofs. Explain why this is a good choice.

Experiment 1: Viewing the Visible Spectrum

Equipment and materials: a ray box, two triangular prisms, a sheet of white paper
(A prism is a transparent glass or plastic object with flat polished sides.)

Procedure:
1. Place one prism on a sheet of paper. Trace its outline.
2. Shine a single beam of light from the ray box on one side of the prism.
3. Observe the spectrum on the other side of the prism.
4. Use the second prism to recombine the spectrum back into a beam of white light.

Results:
The light separates into the colours of the rainbow: red, orange, yellow, green, blue, and violet. (ROY G BIV). The range of different colours of light is called the visible spectrum.

Explanation:
The above experiment is similar to one performed by Isaac Newton in 1666.
A triangular prism slows down the speed of light.
In a vacuum, each colour of the visible spectrum travels at the same high speed: the speed of light.
But within the prism, each of these colours travels at a slower speed than the speed of light in a vacuum.
Red light, with the lowest energy, lowest frequency is slowed the least, whereas violet light, with the highest energy, high frequency is slowed the most.
This is why a prism can separate white light into different colours.

Assignment 3

1. Identify six general categories of colour of the visible spectrum, from highest frequency to lowest frequency.

2. Compare red light with blue light.
a. Which has the longer wavelength?b. Which has the higher frequency?

3. Aid workers in tropical disaster areas have grave difficulties in providing safe drinking water. Scientists are testing a simple idea: place a closed, filled, clear plastic bottle in direct sunlight for a day.
a. Explain why this idea might work.
b. Discuss the advantages and disadvantages of this method over boiling water or adding chemicals.

4. Sunscreen, if used properly, can protect you from getting a sunburn. From which electromagnetic waves must sunscreen protect the skin.

5. Match each electromagnetic wave from List A with the term from List B that is most closely related.
List A: X-rays, ultraviolet light, radio waves, infrared light, microwaves, gamma rays, visible light

List B: vitamin D, telecommunication, cancer treatment, radar, theater/concert effects, baggage screening, DVD player remote control