Electromagnetic Waves

Electromagnetic waves (EM waves) travel at the speed of light (3×10^8 m/s or 300 million m/s or 1 billion km/hr). Their wavelengths range from picometers to kilometers.

Units of length:

- 1km — kilometer — 1000m
- 1m — meter — 1m
- 1 dm — decimeter — 0.1m (10cm/1 tenth of a meter)
- 1 cm — centimeter — 0.01m (1 hundredth of a meter)
- 1 mm — millimeter — 0.001m (1 thousandth of a meter)
- 1 μm — micrometer — 0.000.001m (1 millionth of a meter)
- 1 nm — nanometer — 0.000.000.001m (1 billionth of a meter)
- 1 pm — picometer — 0.000.000.000.001m (1 trillionth of a meter)

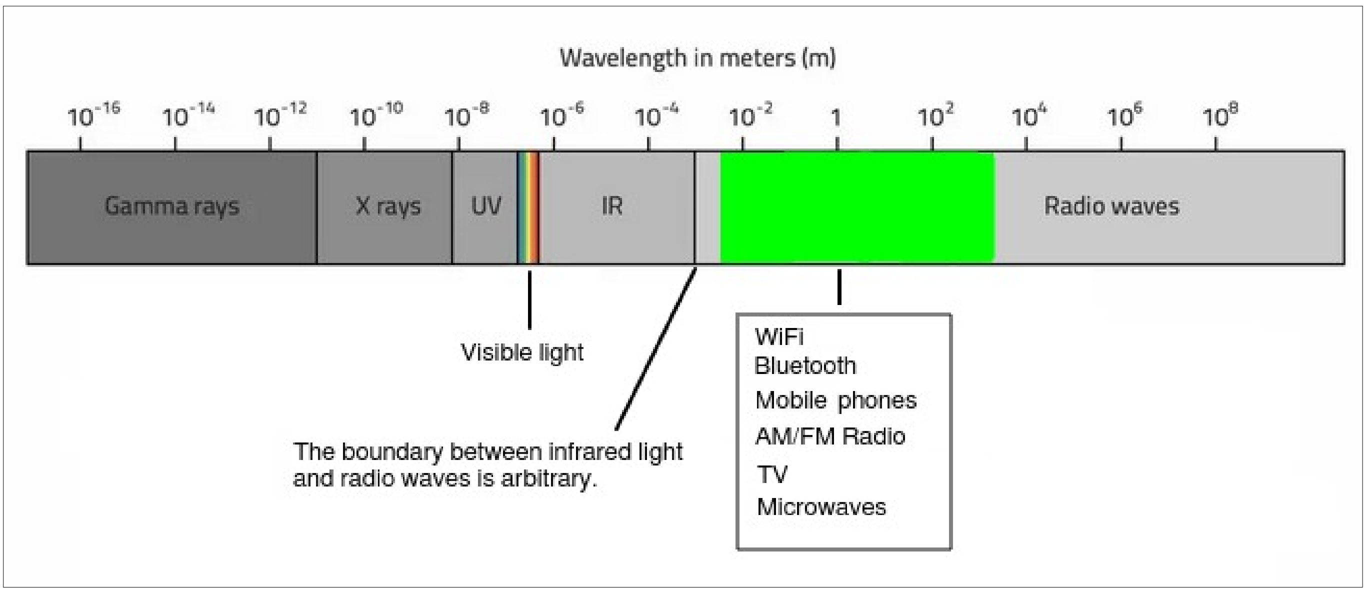
The wavelength of an EM wave is inversely proportional to its frequency. For example:

<u>Wavelength</u>	<u>Frequency</u>
1 pm	300 EHz (Exahertz) (1 EHz = 10^{18} Hertz)
1 nm	300 PHz (Petahertz) (1 PHz = 10^{15} Hertz)
1 μm	300 THz (Terahertz) (1 THz = 10^{12} Hertz)
1 mm	300 GHz (Gigahertz) (1 GHz = 10^{9} Hertz)
1 cm	30 GHz
1 m	300 MHz (Megahertz) (1 MHz = 10^{6} Hertz)
100 m	3 MHz
1 km	300 KHz (Kilohertz) (1 KHz = 10^{3} Hertz)
10 km	30 KHz
100 km	3 KHz

The relationship between wavelength and frequency is given by the equation:

velocity (speed) = frequency x wavelength

The full EM spectrum showing wavelengths:

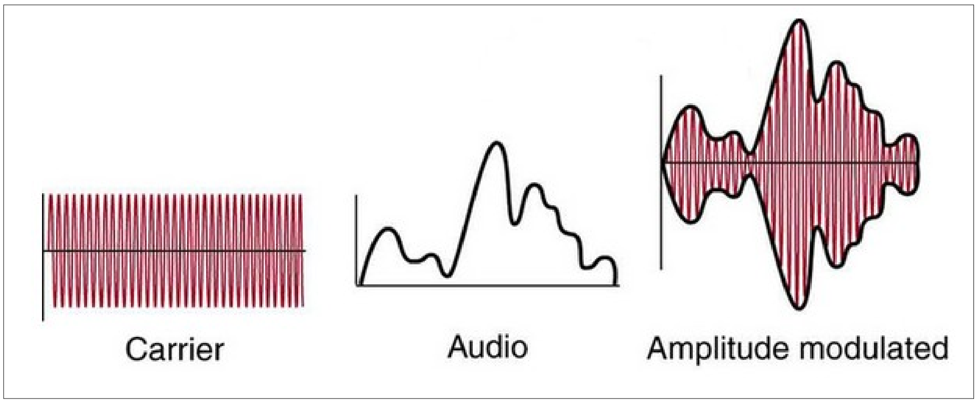


1. Radio Waves

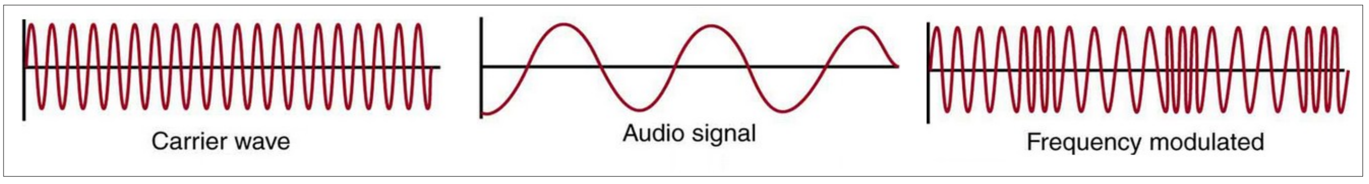
Guglielmo Giovanni Maria Marconi (1874-1937) was an electrical engineer and inventor. He is best known for the creation of a wireless telegraph system using radio waves. He is credited as being the inventor of radio. In 1909 he received the Nobel Prize in Physics for the development of wireless telegraphy. Based on the work of James Clerk Maxwell, he demonstrated, in 1888, that you could produce and detect EM radiation. At the time, this radiation was called "Hertzian" waves, but is now called "radio waves".

Today, radio waves are used for radio communication, radar, GPS, communication satellites, TV, radio, WiFi, Bluetooth, mobile phones, microwave ovens and many other applications. The lowest commonly used radio frequencies are produced by high-voltage AC power lines at frequencies of 50 or 60 Hz (wavelengths of about 6 km). Since salt water is a good conductor, extremely low frequency (ELF) radio waves (about 1 kHz) are used to communicate with submarines (wavelengths of about 300 km).

AM radio waves are used to carry commercial radio signals in the frequency range 540-1600 KHz. The abbreviation AM stands for "amplitude modulation". A carrier wave having the frequency of a radio station (e.g. 1530 KHz) is modulated in amplitude by an audio signal. The resulting wave has a constant frequency, but a varying amplitude.



FM radio waves are also used for commercial radio transmission, but in the frequency range 88-108 MHz. FM stands for "frequency modulation". In this case, a carrier wave having the basic frequency of the radio station (e.g. 93.9 MHz - Mundo Livre) is modulated in frequency by the audio signal, producing a wave of constant amplitude but varying frequency.

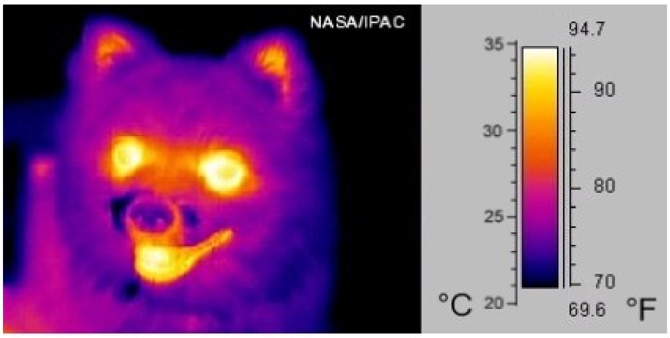


Analogue TV transmissions must carry a lot of information (audio and video), so each channel requires a large range of frequencies. TV channels use frequencies in the range 54-88 MHz and 174-222 MHz (FM radio frequencies are between 88 MHz and 174 MHz). The TV channels are called VHF (very high frequency). Other channels, called UHF (ultra high frequency), use an even higher frequency range of 470 to 1000 MHz. TV video signals use AM, while TV audio signals use FM. Note that these frequencies are those of free analogue transmissions utilizing old-fashioned roof antennas. Today, however, most TV services use digital technology, which uses "square waves".

Microwaves are electromagnetic waves with wavelengths of 1mm-1m. The microwave region overlaps with that of radio waves.

2. Infrared (IR)

The infrared portion of the spectrum is from 300 GHz (wavelength of 1mm) to 400 THz (wavelength of 750nm). Infrared radiation is known as “heat radiation”. The infrared emission of an object describes its thermal emissions, and therefore its relative temperature, compared to a “black body” (a cold object). Infrared radiation is used to determine the temperature of objects. This is called “thermography”, and is mainly used in military and industrial applications. Many astronomical objects emit IR radiation and astronomers use infrared telescopes to study such objects.



Thermography: A thermographic image of a dog

In December 2021, NASA launched the James Webb Space Telescope, which is an infrared telescope and will study the thermal emission of objects at a far greater distance, and with better resolution, than the Hubble Telescope. It is hoped that, with this new telescope, we will be able to see the first stars that formed in our universe! In other words, we will be able to witness the early stages of our universe. This is because - the farther distance we can see, the farther back in time we can see (due to the light from distant objects requiring billions of years to reach Earth). It is also hoped that, in the future, we will be able to produce a telescope which can “see” the beginning of the universe, and therefore help us to understand how the universe began. Here is a video about the James Webb Space Telescope and how it uses IR light to examine distant objects: https://www.youtube.com/watch?v=nadkOPhS-Bs

3. Visible Light

Visible light is the portion of the electromagnetic spectrum that is visible to the human eye, ranging in wavelength from 380 to 750 nm:

	violet	380-450 nm
	blue	450-495 nm
	green	495-570 nm
	yellow	570-590 nm
	orange	590-620 nm
	red	620-750 nm

When you see white light, it is, in fact, a mixture of all the wavelengths of visible light. In other words, it’s all the colours mixed together. Black however, represents the absence of light, so when you “see” black, you are, in fact, seeing an “absence of light”. Some people ask “Why is the sky blue?”. Well, gases in the air scatter the wavelengths of blue light more than other wavelengths, so blue is the predominant colour that we see. If we lived on a planet with different gases in the atmosphere, the sky would be a different colour.

Plants have evolved to photosynthesize visible light to produce chemical energy which fuels their growth.

4. Ultraviolet (UV)

UV light is electromagnetic radiation with a wavelength shorter than that of visible light in the range 10-400 nm. It's called UV because the waves have frequencies higher than the colour violet in the visible light spectrum. It is invisible to humans, but is visible to many animals, such as butterflies, owls, eagles, bees and scorpions. It is thought by some scientists that cats and dogs also see UV light. Here is a short video about bee vision:

https://www.youtube.com/watch?v=3Sb0LcNF1WI

UV light can have harmful effects on biological matter, such as causing cancers. This is because UV radiation can alter chemical bonds in molecules. Most UV light is absorbed by the ozone layer in the Earth's atmosphere, protecting us from its destructive power. Although most UV radiation is invisible to the human eye, we all know that some of it can get through the ozone layer and cause suntan and sunburn. To protect us from prolonged exposure we must use protection on our skin. Long term exposure can cause skin damage and cancer. There is however, something good for us in UV radiation – it helps to produce Vitamin D in our bodies, which is beneficial to calcium production, immunity, cell proliferation, insulin secretion and blood pressure.

5. X-Rays

X-rays are electromagnetic waves with wavelengths in the range of 0.01 to 10 nm. Since X-rays have very high energy they are known as "ionizing radiation" and can be harmful. A very high radiation dose causes radiation sickness, and a low dose can increase your risk of cancer. Low doses of X-rays are used in medical radiography and X-ray spectroscopy. The benefits of using X-rays for medical purposes far outweigh the risk.

6. Gamma Rays (γ Rays)

Gamma rays are very high frequency electromagnetic waves with wavelengths of less than 100 pm. They are produced from radioactive decay. They are commonly found in space, emitted from collapsed stars called "supernovas" or "hypernovas". Gamma rays are classified as "ionizing radiation" and are biologically hazardous. Astronauts need to be protected from them. They are absorbed by the Earth's atmosphere, and so are not a danger to us. Gamma radiation from radioactive materials is used in nuclear medicine. The effects of Gamma rays on a human body include radiation burns to the skin, damage to internal organs, radiation sickness, DNA damage, cell death and cancer.

Source: https://courses.lumenlearning.com/boundless-physics/chapter/the-electromagnetic-spectrum/