**Electromagnetic Spectrum**

From Wikipedia, the free encyclopedia

|  |  |  |  |
| --- | --- | --- | --- |
| **Class** | **Frequency** | **Wavelength** | **Energy** |
|   |   |   |   | 300 EHz | 1 pm | 1.24 MeV |
| γ | Gamma rays |   |
|   | 30 EHz | 10 pm | 124 keV |
| HX | Hard X-rays |   |
|   | 3 EHz | 100 pm | 12.4 keV |
| SX | Soft X-rays |   |
|   | 300 PHz | 1 nm | 1.24 keV |
|   |
|   | 30 PHz | 10 nm | 124 eV |
| EUV | Extremeultraviolet |   |
|   | 3 PHz | 100 nm | 12.4 eV |
| NUV | Nearultraviolet |   |
| Visible |   | 300 THz | 1 μm | 1.24 eV |
|   | NIR | Near Infrared |   |
|   | 30 THz | 10 μm | 124 meV |
| MIR | Mid infrared |   |
|   | 3 THz | 100 μm | 12.4 meV |
| FIR | Far infrared |   |
|   | 300 GHz | 1 mm | 1.24 meV |
| Radiowaves | EHF | Extremely highfrequency |   |
|   | 30 GHz | 1 cm | 124 μeV |
| SHF | Super highfrequency |   |
|   | 3 GHz | 1 dm | 12.4 μeV |
| UHF | Ultra-highfrequency |   |
|   | 300 MHz | 1 m | 1.24 μeV |
| VHF | Very highfrequency |   |
|   | 30 MHz | 10 m | 124 neV |
| HF | Highfrequency |   |
|   | 3 MHz | 100 m | 12.4 neV |
| MF | Mediumfrequency |   |
|   | 300 kHz | 1 km | 1.24 neV |
| LF | Lowfrequency |   |
|   | 30 kHz | 10 km | 124 peV |
| VLF | Very lowfrequency |   |
|   | 3 kHz | 100 km | 12.4 peV |
|   | VF / ULF | Voicefrequency |   |
|   | 300 Hz | 1 Mm | 1.24 peV |
| SLF | Super lowfrequency |   |
|   | 30 Hz | 10 Mm | 124 feV |
| ELF | Extremely lowfrequency |   |
|   | 3 Hz | 100 Mm | 12.4 feV |
|   |   |   |
| Sources: File:Light spectrum.svg  |

The **electromagnetic spectrum** is the range of all possible frequencies of electromagnetic radiation. The "electromagnetic spectrum" *of an object* has a different meaning, and is instead the characteristic distribution of electromagnetic radiation emitted or absorbed by that particular object.

The electromagnetic spectrum extends from below the low frequencies used for modern radio communication to gamma radiation at the short-wavelength (high-frequency) end, thereby covering wavelengths from thousands of kilometers down to a fraction of the size of an atom. The limit for long wavelengths is the size of the universe itself, while it is thought that the short wavelength limit is in the vicinity of the Planck length. Until the middle of last century it was believed by most physicists that this spectrum was infinite and continuous.

Most parts of the electromagnetic spectrum are used in science for spectroscopic and other probing interactions, as ways to study and characterize matter. In addition, radiation from various parts of the spectrum has found many other uses for communications and manufacturing (see electromagnetic radiation for more applications).

**History of electromagnetic spectrum discovery**

For most of history, visible light was the only known part of the electromagnetic spectrum. The ancient Greeks recognized that light traveled in straight lines and studied some of its properties, including reflection and refraction. Over the years the study of light continued and during the 16th and 17th centuries there were conflicting theories which regarded light as either a wave or a particle.

The first discovery of electromagnetic radiation other than visible light came in 1800, when William Herschel discovered infrared radiation. He was studying the temperature of different colors by moving a thermometer through light split by a prism. He noticed that the highest temperature was beyond red. He theorized that this temperature change was due to "calorific rays" which would be in fact a type of light ray that could not be seen. The next year, Johann Ritter worked at the other end of the spectrum and noticed what he called "chemical rays" (invisible light rays that induced certain chemical reactions) that behaved similar to visible violet light rays, but were beyond them in the spectrum. They were later renamed ultraviolet radiation.

Electromagnetic radiation had been first linked to electromagnetism in 1845, when Michael Faraday noticed that the polarization of light traveling through a transparent material responded to a magnetic field (see Faraday effect). During the 1860s James Maxwell developed four partial differential equations for the electromagnetic field. Two of these equations predicted the possibility of, and behavior of, waves in the field. Analyzing the speed of these theoretical waves, Maxwell realized that they must travel at a speed that was about the known speed of light. This startling coincidence in value led Maxwell to make the inference that light itself is a type of electromagnetic wave.

Maxwell's equations predicted an infinite number of frequencies of electromagnetic waves, all traveling at the speed of light. This was the first indication of the existence of the entire electromagnetic spectrum.

Maxwell's predicted waves included waves at very low frequencies compared to infrared, which in theory might be created by oscillating charges in an ordinary electrical circuit of a certain type. Attempting to prove Maxwell's equations and detect such low frequency electromagnetic radiation, in 1886 the physicist Heinrich Hertz built an apparatus to generate and detect what is now called radio waves. Hertz found the waves and was able to infer (by measuring their wavelength and multiplying it by their frequency) that they traveled at the speed of light. Hertz also demonstrated that the new radiation could be both reflected and refracted by various dielectric media, in the same manner as light. For example, Hertz was able to focus the waves using a lens made of tree resin. In a later experiment, Hertz similarly produced and measured the properties of microwaves. These new types of waves paved the way for inventions such as the wireless telegraph and the radio.

In 1895 Wilhelm Röntgen noticed a new type of radiation emitted during an experiment with an evacuated tube subjected to a high voltage. He called these radiations x-rays and found that they were able to travel through parts of the human body but were reflected or stopped by denser matter such as bones. Before long, many uses were found for them in the field of medicine.

The last portion of the electromagnetic spectrum was filled in with the discovery of gamma rays. In 1900 Paul Villard was studying the radioactive emissions of radium when he identified a new type of radiation that he first thought consisted of particles similar to known alpha and beta particles, but with the power of being far more penetrating than either. However, in 1910, British physicist William Henry Bragg demonstrated that gamma rays are electromagnetic radiation, not particles, and in 1914, Ernest Rutherford (who had named them gamma rays in 1903 when he realized that they were fundamentally different from charged alpha and beta rays) and Edward Andrade measured their wavelengths, and found that gamma rays were similar to X-rays, but with shorter wavelengths and higher frequencies.

**Range of the spectrum**

Electromagnetic waves are typically described by any of the following three physical properties: the frequency *f*, wavelength λ, or photon energy *E*. Frequencies observed in astronomy range from 2.4×1023 Hz (1 GeV gamma rays) down to the local plasma frequency of the ionized interstellar medium (~1 kHz). Wavelength is inversely proportional to the wave frequency, so gamma rays have very short wavelengths that are fractions of the size of atoms, whereas wavelengths on the opposite end of the spectrum can be as long as the universe. Photon energy is directly proportional to the wave frequency, so gamma ray photons have the highest energy (around a billion electron volts), while radio wave photons have very low energy (around a femtoelectron-volt). These relations are illustrated by the following equations:



where:

* *c* = 299,792,458 m/s is the speed of light in vacuum and
* *h* = 6.62606896(33)×10−34 J s = 4.13566733(10)×10−15 eV s is Planck's constant.

Whenever electromagnetic waves exist in a medium with matter, their wavelength is decreased. Wavelengths of electromagnetic radiation, no matter what medium they are traveling through, are usually quoted in terms of the *vacuum wavelength*, although this is not always explicitly stated.

Generally, electromagnetic radiation is classified by wavelength into radio wave, microwave, terahertz (or sub-millimeter) radiation, infrared, the visible region is perceived as light, ultraviolet, X-rays and gamma rays. The behavior of EM radiation depends on its wavelength. When EM radiation interacts with single atoms and molecules, its behavior also depends on the amount of energy per quantum (photon) it carries.

Spectroscopy can detect a much wider region of the EM spectrum than the visible range of 400 nm to 700 nm. A common laboratory spectroscope can detect wavelengths from 2 nm to 2500 nm. Detailed information about the physical properties of objects, gases, or even stars can be obtained from this type of device. Spectroscopes are widely used in astrophysics. For example, many hydrogen atoms emit a radio wave photon that has a wavelength of 21.12 cm. Also, frequencies of 30 Hz and below can be produced by and are important in the study of certain stellar nebulae and frequencies as high as 2.9×1027 Hz have been detected from astrophysical sources.

**Rationale for spectrum regional names**

Electromagnetic radiation interacts with matter in different ways across the spectrum. These types of interaction are so different that historically different names have been applied to different parts of the spectrum, as though these were different types of radiation. Thus, although these "different kinds" of electromagnetic radiation form a quantitatively continuous spectrum of frequencies and wavelengths, the spectrum remains divided for practical reasons related to these qualitative interaction differences.

|  |  |
| --- | --- |
| **Region of the spectrum** | **Main interactions with matter** |
| Radio | Collective oscillation of charge carriers in bulk material (plasma oscillation). An example would be the oscillatory travels of the electrons in an antenna. |
| Microwave through far infrared | Plasma oscillation, molecular rotation |
| Near infrared | Molecular vibration, plasma oscillation (in metals only) |
| Visible | Molecular electron excitation (including pigment molecules found in the human retina), plasma oscillations (in metals only) |
| Ultraviolet | Excitation of molecular and atomic valence electrons, including ejection of the electrons (photoelectric effect) |
| X-rays | Excitation and ejection of core atomic electrons, Compton scattering (for low atomic numbers) |
| Gamma rays | Energetic ejection of core electrons in heavy elements, Compton scattering (for all atomic numbers), excitation of atomic nuclei, including dissociation of nuclei |
| High-energy gamma rays | Creation of particle-antiparticle pairs. At very high energies a single photon can create a shower of high-energy particles and antiparticles upon interaction with matter. |

**Types of radiation**



The **electromagnetic spectrum**

**Boundaries**

A discussion of the regions (or bands or types) of the electromagnetic spectrum is given below. Note that there are no precisely defined boundaries between the bands of the electromagnetic spectrum; rather they fade into each other like the bands in a rainbow (which is the sub-spectrum of visible light). Radiation of each frequency and wavelength (or in each band) will have a mixture of properties of two regions of the spectrum that bound it. For example, red light resembles infrared radiation in that it can excite and add energy to some chemical bonds and indeed must do so to power the chemical mechanisms responsible for photosynthesis and the working of the visual system.

**Regions of the spectrum**

The types of electromagnetic radiation are broadly classified into the following classes:[6]

1. Gamma radiation
2. X-ray radiation
3. Ultraviolet radiation
4. Visible radiation
5. Infrared radiation
6. Terahertz radiation
7. Microwave radiation
8. Radio waves

This classification goes in the increasing order of wavelength, which is characteristic of the type of radiation.[6] While, in general, the classification scheme is accurate, in reality there is often some overlap between neighboring types of electromagnetic energy. For example, SLF radio waves at 60 Hz may be received and studied by astronomers, or may be ducted along wires as electric power, although the latter is, in the strict sense, not electromagnetic radiation at all (see near and far field).

The distinction between X-rays and gamma rays is partly based on sources: the photons generated from nuclear decay or other nuclear and subnuclear/particle process, are always termed gamma rays, whereas X-rays are generated by electronic transitions involving highly energetic inner atomic electrons. In general, nuclear transitions are much more energetic than electronic transitions, so gamma-rays are more energetic than X-rays, but exceptions exist. By analogy to electronic transitions, muonic atom transitions are also said to produce X-rays, even though their energy may exceed 6 megaelectron volts (0.96 pJ), whereas there are many (77 known to be less than 10 keV (1.6 fJ)) low-energy nuclear transitions (e.g., the 7.6 eV (1.22 aJ) nuclear transition of thorium-229), and, despite being one million-fold less energetic than some muonic X-rays, the emitted photons are still called gamma rays due to their nuclear origin.

The convention that EM radiation that is known to come from the nucleus, is always called "gamma ray" radiation is the only convention that is universally respected, however. Many astronomical gamma ray sources (such as gamma ray bursts) are known to be too energetic (in both intensity and wavelength) to be of nuclear origin. Quite often, in high energy physics and in medical radiotherapy, very high energy EMR (in the >10 MeV region) which is of higher energy than any nuclear gamma ray, is not referred to as either X-ray or gamma-ray, but instead by the generic term of "high energy photons."

The region of the spectrum in which a particular observed electromagnetic radiation falls, is reference frame-dependent (due to the Doppler shift for light), so EM radiation that one observer would say is in one region of the spectrum could appear to an observer moving at a substantial fraction of the speed of light with respect to the first to be in another part of the spectrum. For example, consider the cosmic microwave background. It was produced, when matter and radiation decoupled, by the de-excitation of hydrogen atoms to the ground state. These photons were from Lyman series transitions, putting them in the ultraviolet (UV) part of the electromagnetic spectrum. Now this radiation has undergone enough cosmological red shift to put it into the microwave region of the spectrum for observers moving slowly (compared to the speed of light) with respect to the cosmos.

**Radio frequency**

Main articles: Radio frequency, Radio spectrum and Radio waves

Radio waves generally are utilized by antennas of appropriate size (according to the principle of resonance), with wavelengths ranging from hundreds of meters to about one millimeter. They are used for transmission of data, via modulation. Television, mobile phones, wireless networking, and amateur radio all use radio waves. The use of the radio spectrum is regulated by many governments through frequency allocation.

Radio waves can be made to carry information by varying a combination of the amplitude, frequency, and phase of the wave within a frequency band. When EM radiation impinges upon a conductor, it couples to the conductor, travels along it, and induces an electric current on the surface of that conductor by exciting the electrons of the conducting material. This effect (the skin effect) is used in antennas.

**Microwaves**

Main article: Microwaves



Plot of Earth's atmospheric transmittance (or opacity) to various wavelengths of electromagnetic radiation.

The super-high frequency (SHF) and extremely high frequency (EHF) of microwaves are on the short side of radio waves. Microwaves are waves that are typically short enough (measured in millimeters) to employ tubular metal waveguides of reasonable diameter. Microwave energy is produced with klystron and magnetron tubes, and with solid state diodes such as Gunn and IMPATT devices. Microwaves are absorbed by molecules that have a dipole moment in liquids. In a microwave oven, this effect is used to heat food. Low-intensity microwave radiation is used in Wi-Fi, although this is at intensity levels unable to cause thermal heating.

Volumetric heating, as used by microwave ovens, transfers energy through the material electromagnetically, not as a thermal heat flux. The benefit of this is a more uniform heating and reduced heating time; microwaves can heat material in less than 1% of the time of conventional heating methods.

When active, the average microwave oven is powerful enough to cause interference at close range with poorly shielded electromagnetic fields such as those found in mobile medical devices and poorly made consumer electronics.

**Terahertz radiation**

Main article: Terahertz radiation

Terahertz radiation is a region of the spectrum between far infrared and microwaves. Until recently, the range was rarely studied and few sources existed for microwave energy at the high end of the band (sub-millimeter waves or so-called terahertz waves), but applications such as imaging and communications are now appearing. Scientists are also looking to apply terahertz technology in the armed forces, where high-frequency waves might be directed at enemy troops to incapacitate their electronic equipment.

**Infrared radiation**

Main article: Infrared radiation

The infrared part of the electromagnetic spectrum covers the range from roughly 300 GHz (1 mm) to 400 THz (750 nm). It can be divided into three parts:

* **Far-infrared**, from 300 GHz (1 mm) to 30 THz (10 μm). The lower part of this range may also be called microwaves. This radiation is typically absorbed by so-called rotational modes in gas-phase molecules, by molecular motions in liquids, and by phonons in solids. The water in Earth's atmosphere absorbs so strongly in this range that it renders the atmosphere in effect opaque. However, there are certain wavelength ranges ("windows") within the opaque range that allow partial transmission, and can be used for astronomy. The wavelength range from approximately 200 μm up to a few mm is often referred to as "sub-millimeter" in astronomy, reserving far infrared for wavelengths below 200 μm.
* **Mid-infrared**, from 30 to 120 THz (10 to 2.5 μm). Hot objects (black-body radiators) can radiate strongly in this range, and human skin at normal body temperature radiates strongly at the lower end of this region. This radiation is absorbed by molecular vibrations, where the different atoms in a molecule vibrate around their equilibrium positions. This range is sometimes called the *fingerprint region*, since the mid-infrared absorption spectrum of a compound is very specific for that compound.
* **Near-infrared**, from 120 to 400 THz (2,500 to 750 nm). Physical processes that are relevant for this range are similar to those for visible light. The highest frequencies in this region can be detected directly by some types of photographic film, and by many types of solid state image sensors for infrared photography and videography.

**Visible radiation (light)**

Main article: Visible spectrum

Above infrared in frequency comes visible light. The Sun emits its peak power in the visible region, although integrating the entire emission power spectrum through all wavelengths shows that the Sun emits slightly more infrared than visible light. By definition, visible light is the part of the EM spectrum to which the human eye is the most sensitive. Visible light (and near-infrared light) is typically absorbed and emitted by electrons in molecules and atoms that move from one energy level to another. This action allows the chemical mechanisms that underly human vision and plant photosynthesis. The light which excites the human visual system is a very small portion of the electromagnetic spectrum. A rainbow shows the optical (visible) part of the electromagnetic spectrum; infrared (if it could be seen) would be located just beyond the red side of the rainbow with ultraviolet appearing just beyond the violet end.

Electromagnetic radiation with a wavelength between 380 nm and 760 nm (400–790 terahertz) is detected by the human eye and perceived as visible light. Other wavelengths, especially near infrared (longer than 760 nm) and ultraviolet (shorter than 380 nm) are also sometimes referred to as light, especially when the visibility to humans is not relevant. White light is a combination of lights of different wavelengths in the visible spectrum. Passing white light through a prism splits it up into the several colors of light observed in the visible spectrum between 400 nm and 780 nm.

If radiation having a frequency in the visible region of the EM spectrum reflects off an object, say, a bowl of fruit, and then strikes the eyes, this results in visual perception of the scene. The brain's visual system processes the multitude of reflected frequencies into different shades and hues, and through this insufficiently-understood psychophysical phenomenon, most people perceive a bowl of fruit.

At most wavelengths, however, the information carried by electromagnetic radiation is not directly detected by human senses. Natural sources produce EM radiation across the spectrum, and technology can also manipulate a broad range of wavelengths. Optical fiber transmits light that, although not necessarily in the visible part of the spectrum (it is usually infrared), can carry information. The modulation is similar to that used with radio waves.

**Ultraviolet radiation**

Main article: Ultraviolet



The amount of penetration of UV relative to altitude in Earth's ozone

Next in frequency comes ultraviolet (UV). The wavelength of UV rays is shorter than the violet end of the visible spectrum but longer than the X-ray.

UV in the very shortest range (next to X-rays) is capable even of ionizing atoms (see photoelectric effect), greatly changing their physical behavior.

At the middle range of UV, UV rays cannot ionize but can break chemical bonds, making molecules to be unusually reactive. Sunburn, for example, is caused by the disruptive effects of middle range UV radiation on skin cells, which is the main cause of skin cancer. UV rays in the middle range can irreparably damage the complex DNA molecules in the cells producing thymine dimers making it a very potent mutagen.

The Sun emits significant UV radiation (about 10% of its total power), including extremely short wavelength UV that could potentially destroy most life on land (ocean water would provide some protection for life there). However, most of the Sun's most-damaging UV wavelengths are absorbed first by the magnetosphere and then by the atmosphere's oxygen, nitrogen, and ozone layer before they reach the surface. The higher ranges of UV (vacuum UV) are absorbed by nitrogen and, at longer wavelengths, by simple diatomic oxygen in the air. Most of the UV in this mid-range is blocked by the ozone layer, which absorbs strongly in the important 200–315 nm range, the lower part of which is too long to be absorbed by ordinary dioxygen in air. The range between 315 nm and visible light (called UV-A) is not blocked well by the atmosphere, but does not cause sunburn and does less biological damage. However, it is not harmless and does cause oxygen radicals, mutation and skin damage. See ultraviolet for more information.

**X-rays**

Main article: X-rays

After UV come X-rays, which, like the upper ranges of UV are also ionizing. However, due to their higher energies, X-rays can also interact with matter by means of the Compton effect. Hard X-rays have shorter wavelengths than soft X-rays. As they can pass through most substances with some absorption, X-rays can be used to 'see through' objects with thicknesses less than equivalent to a few meters of water. One notable use in this category is diagnostic X-ray images in medicine (a process known as radiography). X-rays are useful as probes in high-energy physics. In astronomy, the accretion disks around neutron stars and black holes emit X-rays, which enable them to be studied. X-rays are also emitted by the coronas of stars and are strongly emitted by some types of nebulae. However, X-ray telescopes must be placed outside the Earth's atmosphere to see astronomical X-rays, since the atmosphere of Earth is a radiation shield with areal density of 1000 grams per cm2, which is the same areal density as 1000 centimeters or 10 meters thickness of water.[19] This is an amount sufficient to block almost all astronomical X-rays (and also astronomical gamma rays—see below).

**Gamma rays**

Main article: Gamma rays

After hard X-rays come gamma rays, which were discovered by Paul Villard in 1900. These are the most energetic photons, having no defined lower limit to their wavelength. In astronomy they are valuable for studying high-energy objects or regions, however like with X-rays this can only be done with telescopes outside the Earth's atmosphere. Gamma rays are useful to physicists thanks to their penetrative ability and their production from a number of radioisotopes. Gamma rays are also used for the irradiation of food and seed for sterilization, and in medicine they are occasionally used in radiation cancer therapy. More commonly, gamma rays are used for diagnostic imaging in nuclear medicine, with an example being PET scans. The wavelength of gamma rays can be measured with high accuracy by means of Compton scattering. Gamma rays are first and mostly blocked by Earth's magnetosphere then by the atmosphere.