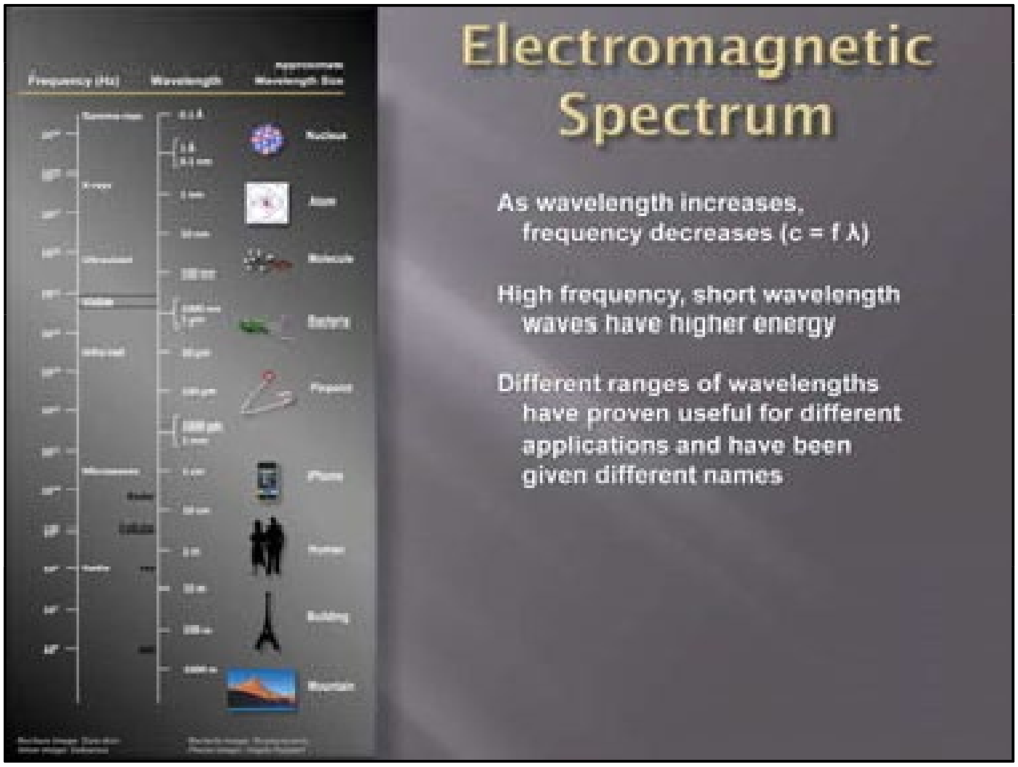
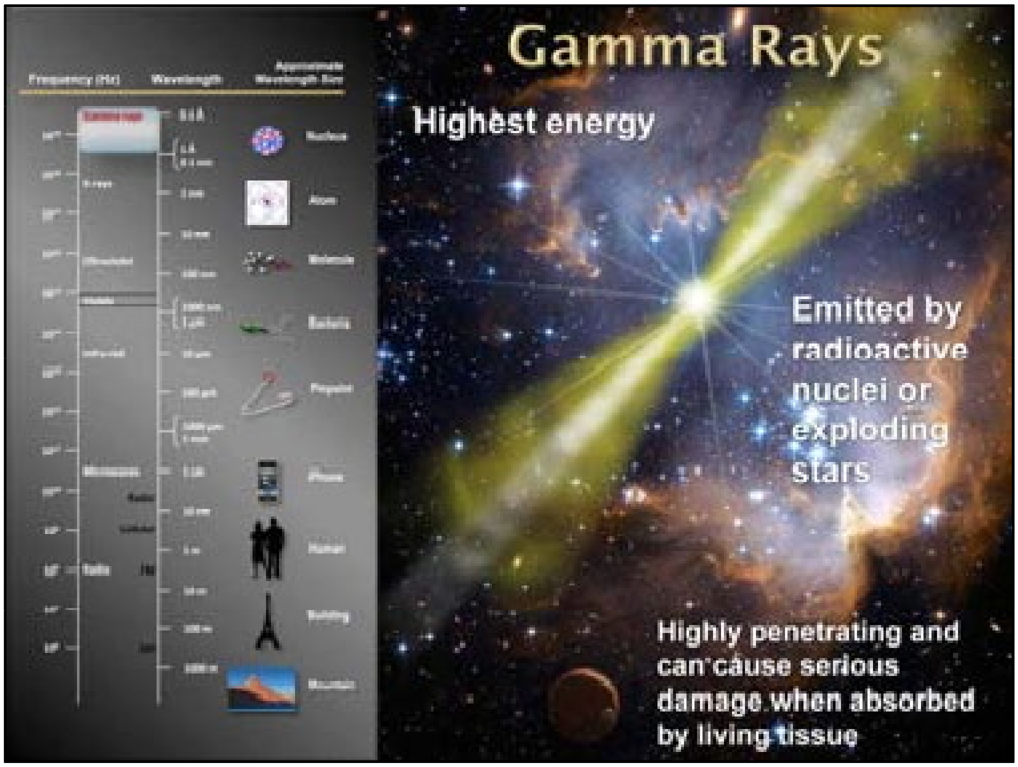
Module 6: Waves
Topic 5 Content: Electromagnetic Spectrum Presentation Notes



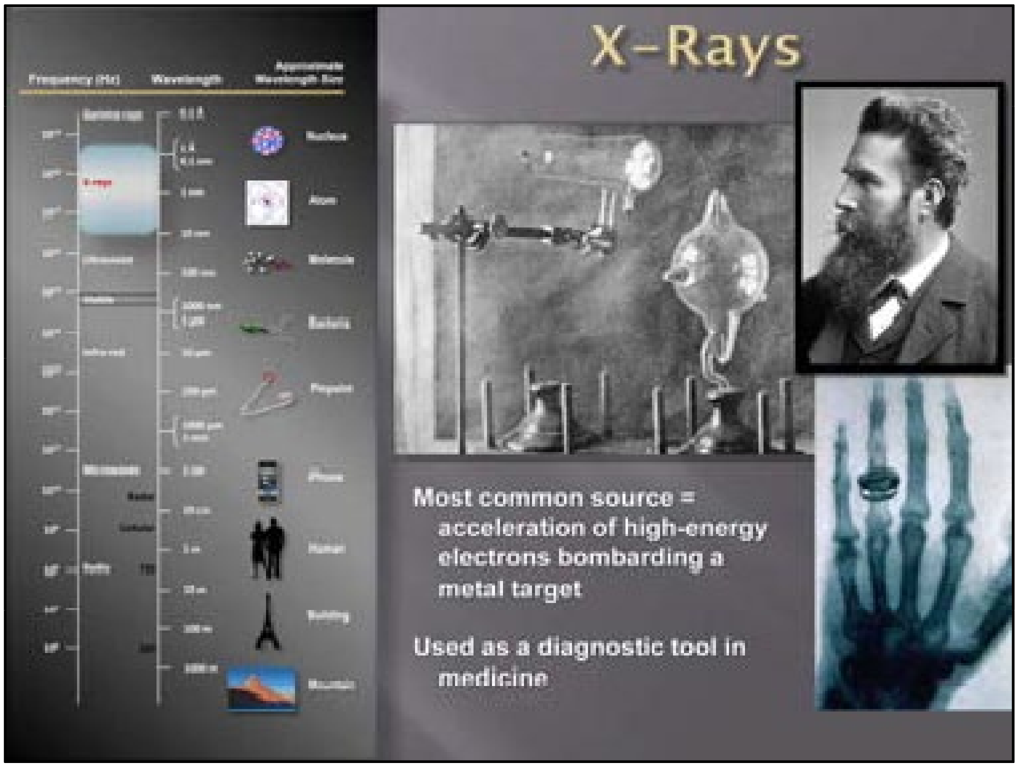
The wavelength of electromagnetic waves can vary from smaller than the nuclei of atoms to larger than mountains. As the wavelength gets longer, the frequency decreases because frequency and wavelength are inversely related. It is also known that higher frequency waves carry more energy since higher frequency means more waves per second.

As different ranges of wavelengths were discovered, they have proven useful in different applications. These ranges have identifying names. The dividing line between these categories is arbitrary, since all are electromagnetic waves and the range of wavelengths is continuous. However, the order in which you find the different types of waves is generally accepted. We will explore the spectrum from the shortest wavelengths to the longest.



Electromagnetic waves with the shortest wavelength, highest frequency and highest energy are called gamma radiation or gamma rays. These were discovered in 1900 by French scientist Paul Villard, but were named by Ernest Rutherford who had already discovered and named alpha and beta radiation. Gamma rays can be emitted through natural radioactive decay processes on earth. However, these are relatively weak compared to the gamma rays we measure coming from space, that are thought to be created in the violent explosions of dying stars.

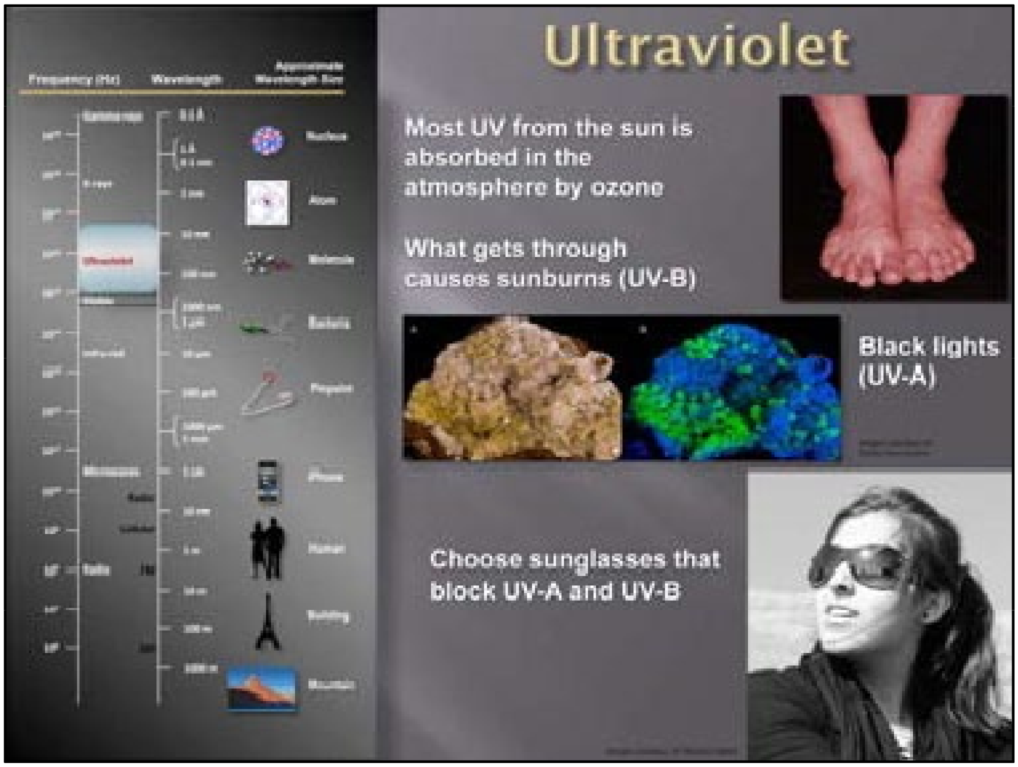
The high energy gamma rays can penetrate living tissue to a far greater extent than alpha or beta particles, so gamma rays have the capability of doing significant damage to the cell or the DNA it contains. This could lead to severe health effects such as radiation sickness or cancer, so exposure to gamma radiation should be limited.



X-rays are somewhat less energetic than gamma rays. These were first investigated by Wilhelm Roentgen in 1895, as he was experimenting with a device called a Crooke's tube where electrons are accelerated with high voltages inside an evacuated glass tube.

Roentgen noticed that a phosphor-coated screen in his lab would glow when the tube was in use, and he quickly realized that these invisible rays could penetrate books or other items from his desk. It turns out that as the electrons collided with the end of the tube, x- rays were produced. Roentgen studied these new rays, calling them x-rays with the x simply standing for an unknown. Within two weeks he published a paper on his investigation, and was later awarded the first ever Nobel Prize in Physics for his work.

He also passed these rays through his wife's hand onto a piece of photographic film, resulting in the very first x-ray image of a human body part, which is shown here. Notice Mrs. Roentgen's wedding ring. We continue to produce x-rays by similar methods. X-rays are widely used in medical diagnostics.



Waves in the ultraviolet portion of the spectrum are less energetic than x-rays. While most of the ultraviolet radiation from the sun is absorbed by the ozone in our atmosphere, a portion gets through the atmosphere. Ultraviolet is further categorized into UV-B and UV-A radiation. The UV-B portion carries more energy, is responsible for sunburns and is suspected as a cause of skin cancer. The lower energy portion is called UV-A and is not considered particularly harmful. UV-A rays are produced by black lights and can result in fluorescence of certain minerals and other substances. In fluorescence, the ultraviolet rays are absorbed and re-emitted at wavelengths at which they are visible to the human eye, producing remarkable colors. When choosing sunglasses it is important that they block both UV-A and UV-B rays to protect your eyes.

Note that referring to electromagnetic waves as radiation is not meant to imply that such rays are harmful. Radiation in this sense just means that these waves can transfer energy through space from one point to another. Electromagnetic waves carry radiant energy, so are often referred to as electromagnetic radiation.

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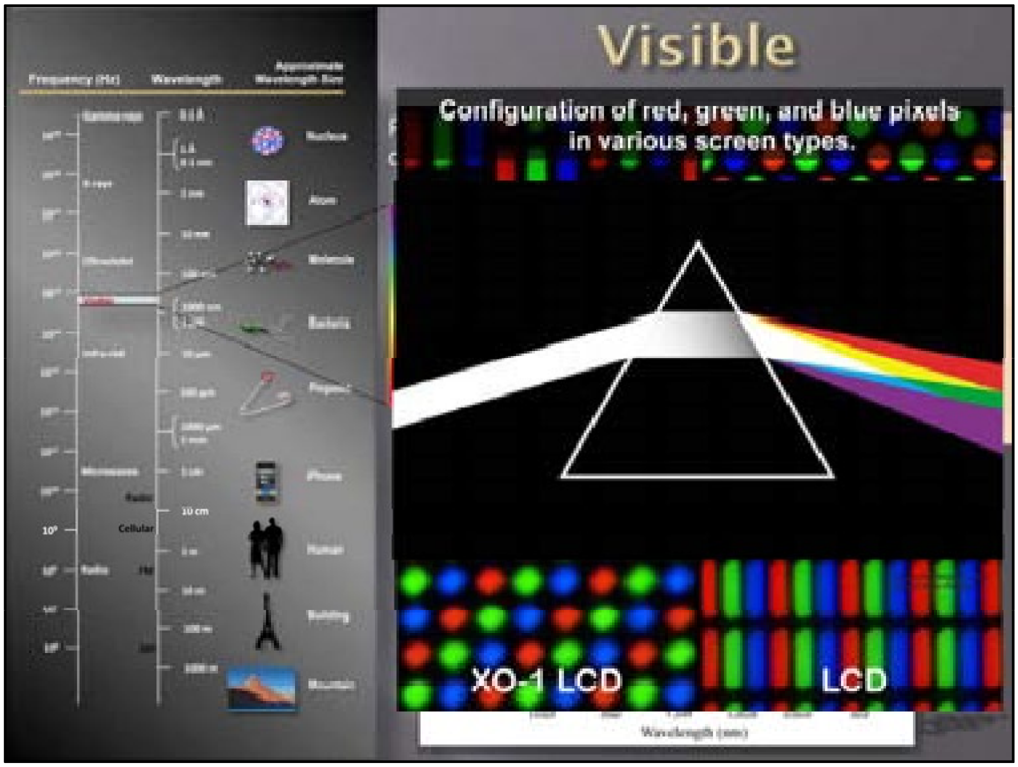
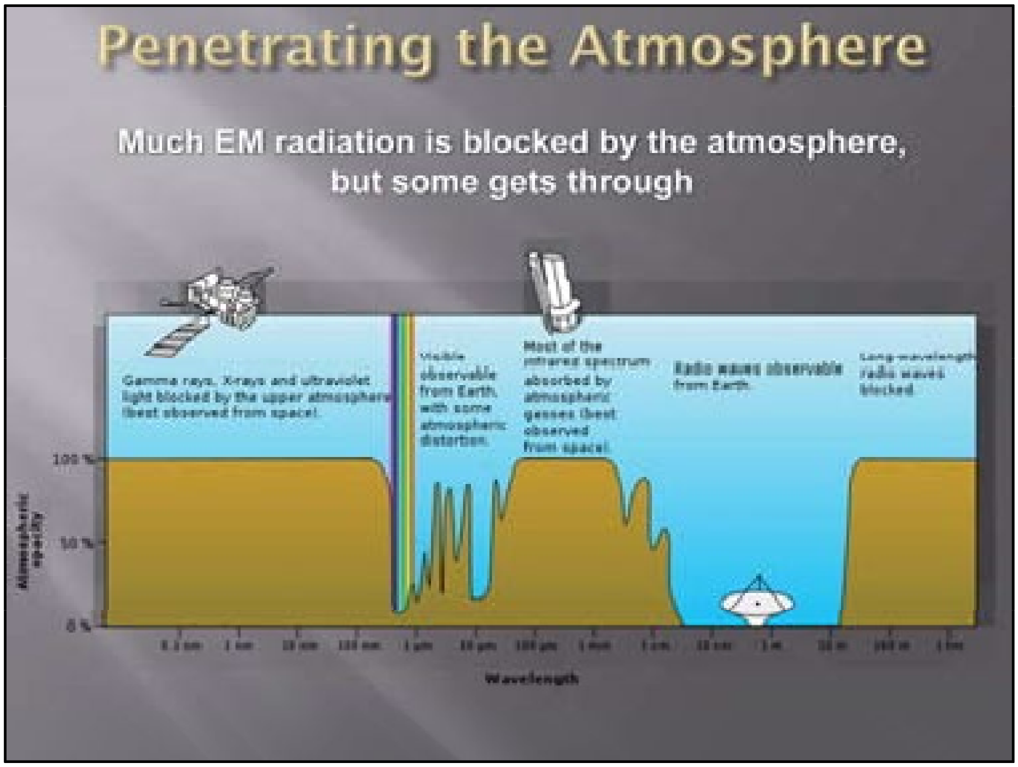


The word ultraviolet means that the light frequency is above that of violet light. Light is defined as the visible portion of the electromagnetic spectrum. Light ranges from higher frequency violet light to lower frequency red light. To call it visible light is redundant because if it is visible it is light, and if it is light, it is visible.

The back of the human eye contains cells called rods and cones that react to light in different ways. Each rod or cone will fire once it has absorbed radiation within a specific range of frequencies. When these four signals coming from the rods and three different types of cones reach the brain, it interprets the different combination of inputs to perceive different colors. Each type of cone has a peak sensitivity that is in a different part of the spectrum, corresponding to the colors red, green, and blue. Engineers have learned to design television and computer displays to combine these three colors of light in such a way that the brain will perceive an infinite range of colors.

Light from the sun contains a nearly continuous spectrum of wavelengths within the visible range, and as these reach the eye, the combination is perceived as white.
Utilizing refraction, white light can be separated into its constituent wavelengths by a prism.

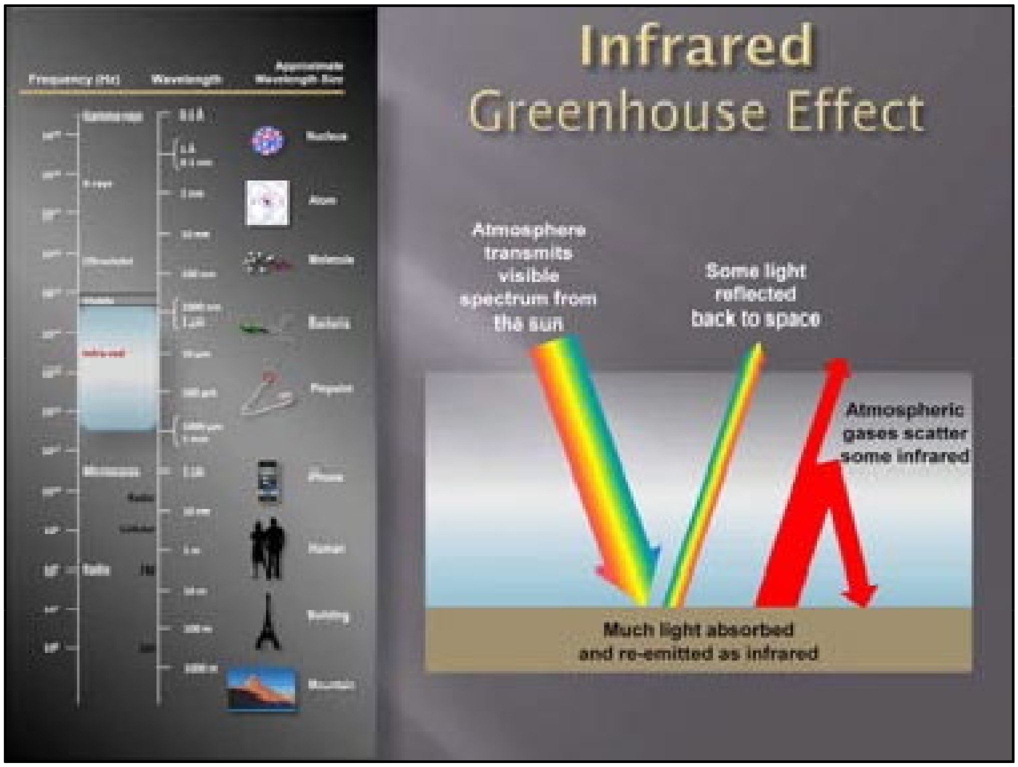


Not all of the electromagnetic radiation from the sun or from space makes it to the Earth's surface. Much is absorbed or blocked by the atmosphere. Since a significant portion of the gamma, x-ray and ultraviolet radiation is blocked, the atmosphere protects us from these harmful rays. Since light gets through, it is no coincidence that these are the wavelengths that the human eye is sensitive to. Mutations that allowed sensitivity to these wavelengths would have provided a survival advantage to the offspring that have passed on these adaptations.

Scientists wishing to explore the universe through various forms of astronomy can observe visible and radio waves from earth, but must launch satellites and telescopes into orbit around the earth in order to view the universe at other wavelengths.

Infrared means below the frequency of red light. Infrared is found below the red portion of the visible spectrum. Infrared radiation is often associated with heat, as these wavelengths are produced by warm objects and molecules. They are also absorbed easily by objects, which warm up when taking in the energy from these waves. Infrared thermometers can be pointed at distant objects to determine their temperature.

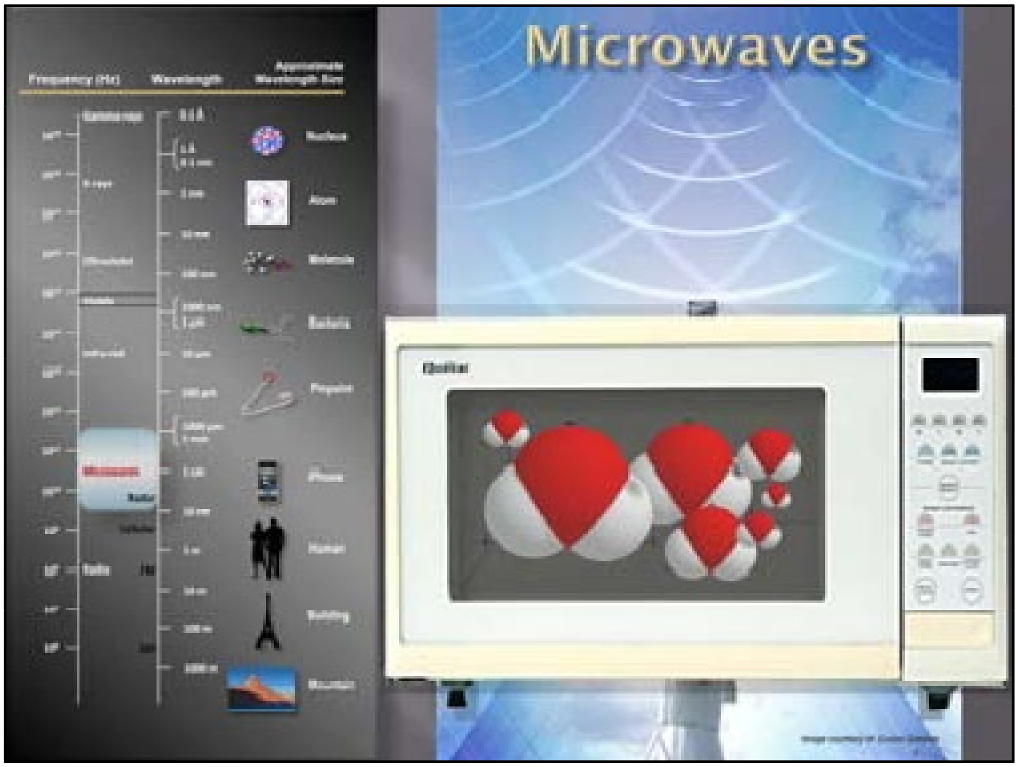
Night vision goggles make use of sophisticated electronics to detect infrared radiation and produce visible images allowing the user to see in the dark. Thermal cameras read the intensity of infrared radiation to create false-color images that represent the range of temperatures found over entire buildings. These images provide information that allows energy efficiency analysts to improve the building's insulation.



As visible light is transmitted through the atmosphere, most reaches the ground and is absorbed, while some is reflected back to space. The ground heats up and with a higher temperature, it emits more infrared radiation. Certain components of the atmosphere, including carbon dioxide, water vapor, methane and other gases absorb and re-emit infrared in all directions, returning some to the surface of the earth and making the earth warmer than it would be otherwise.

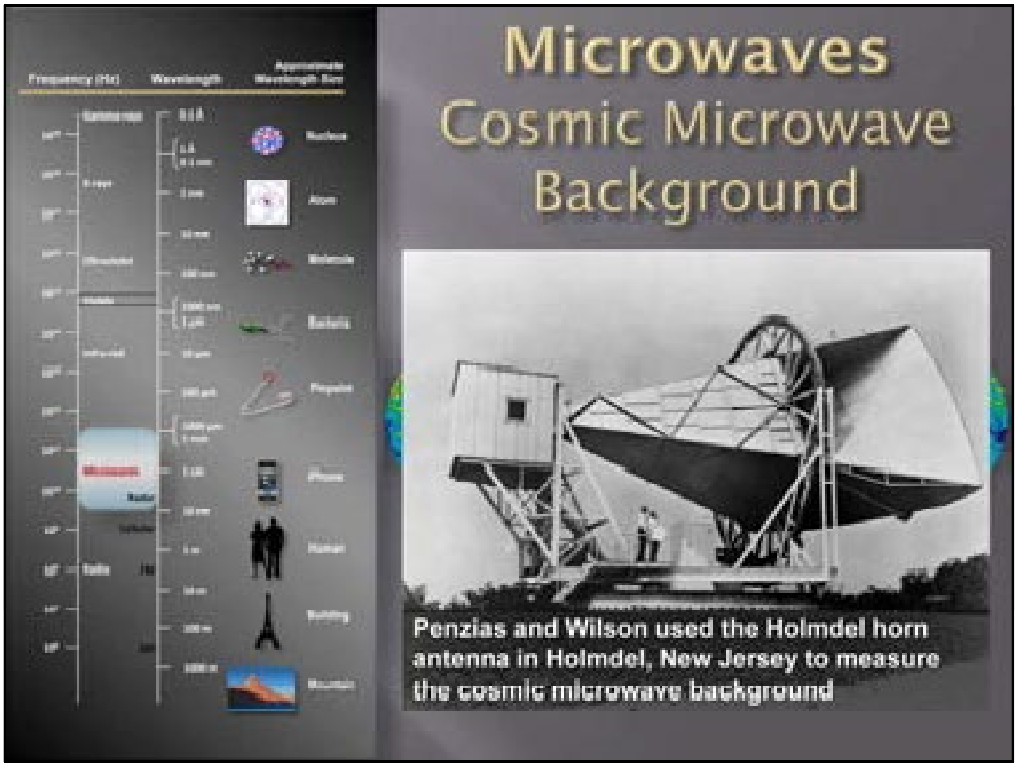
This phenomenon is called the greenhouse effect and was discovered in 1824 by French physicist Joseph Fourier. The atmosphere's ability to trap energy was later calculated to keep the earth on average about thirty three degrees Celsius or about sixty degrees Fahrenheit warmer than it would be without the atmosphere present. The gases with an ability to absorb and re-emit infrared are called greenhouse gases.

Measurements indicating an increase in the amount of greenhouse gases present in the atmosphere have led many scientists to conclude that this increase logically corresponds to a rise in average global temperatures.



Beyond the infrared lie microwaves, with wavelengths from about one millimeter to about thirty centimeters. These waves are well suited for communication systems, both because their wavelengths allow them to be focused in tight beams by reasonably sized antennas and because the atmosphere is relatively transparent to microwaves. Both point-to-point communications on land as well as land-to-satellite communications generally use microwaves.

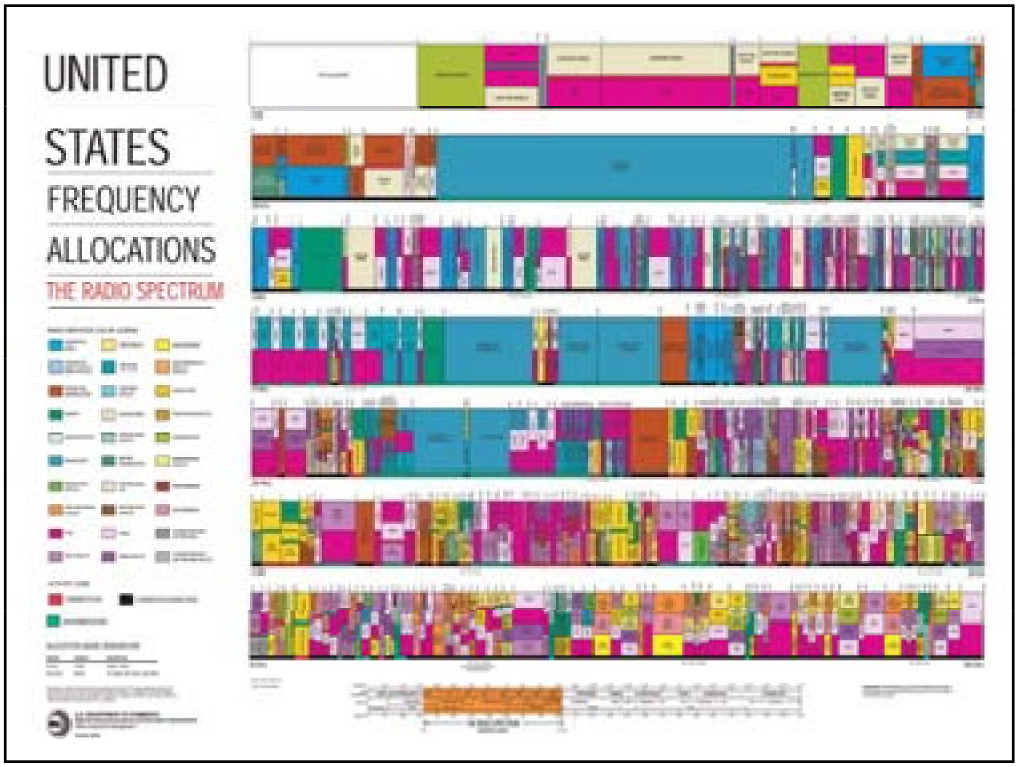
Microwaves also have been well utilized in microwave ovens. Microwaves cause certain polar molecules that have distinct positive and negative sides, such as water, to vibrate and rotate as they try to line up with the electric field of the wave. This motion translates into kinetic energy and heats up the surrounding food. This principle was discovered accidentally in 1945 by American Percy Spencer as he was working on a radar transmitter and noticed the chocolate bar in his pocket begin to melt. Within two years, the first microwave oven, standing nearly six feet tall and weighing seven hundred fifty pounds, was installed in a restaurant in Boston for testing.



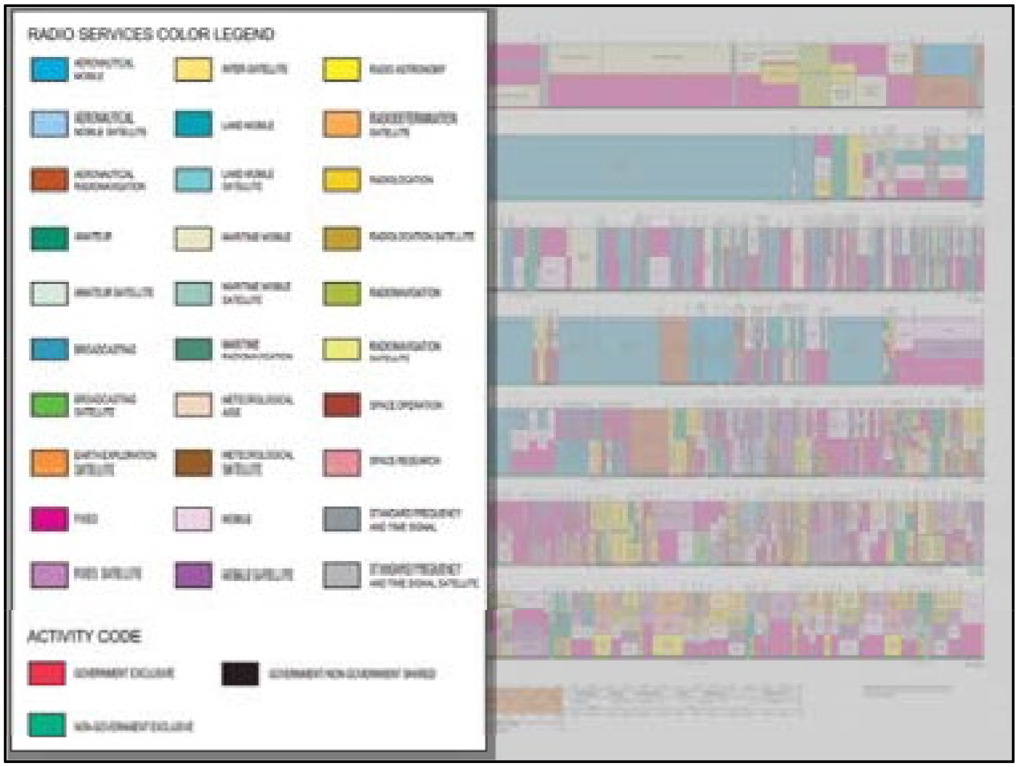
Another accidental discovery involving microwaves was made in 1964 by Arno Penzias and Robert Wilson as they were working with an antenna they had built which they intended to use for radio astronomy and satellite communications. They measured a constant hiss in the microwave region of the spectrum that they could not explain. It was later confirmed that this hiss was precisely what earlier physicists had predicted as the signal emitted by incredibly hot atoms shortly after the big bang that had been stretched out with the expansion of the universe through the Doppler effect. This is known as the cosmic microwave background, as it comes nearly uniformly from all directions. Penzias and Wilson received the 1978 Nobel Prize in physics for their discovery.

In the years since, many devices have been used to map the fine structure of this radiation throughout space in an attempt to better understand the big bang. The picture displayed is the result of seven years of the Wilkinson Microwave Anisotropy Probe, or W map, a satellite that mapped slight variations in the frequency of the radiation, corresponding to 13.7 billion-year-old temperature differences in the big bang.

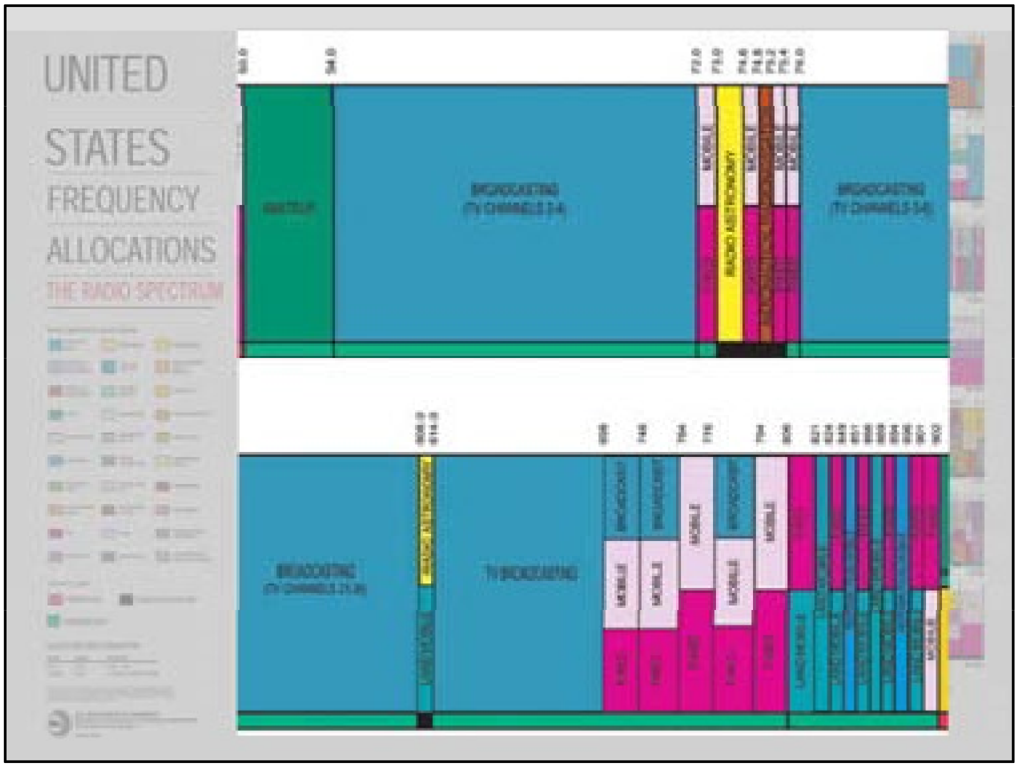
Radio waves constitute the remainder of the electromagnetic spectrum. These longer wavelengths have been used in radio and television communication systems for the past hundred years. Cellular communication primarily occupies the shorter wavelengths of the radio portion of the spectrum, with waves on the order of about ten to sixty centimeters. This includes most cell phones and other mobile devices.



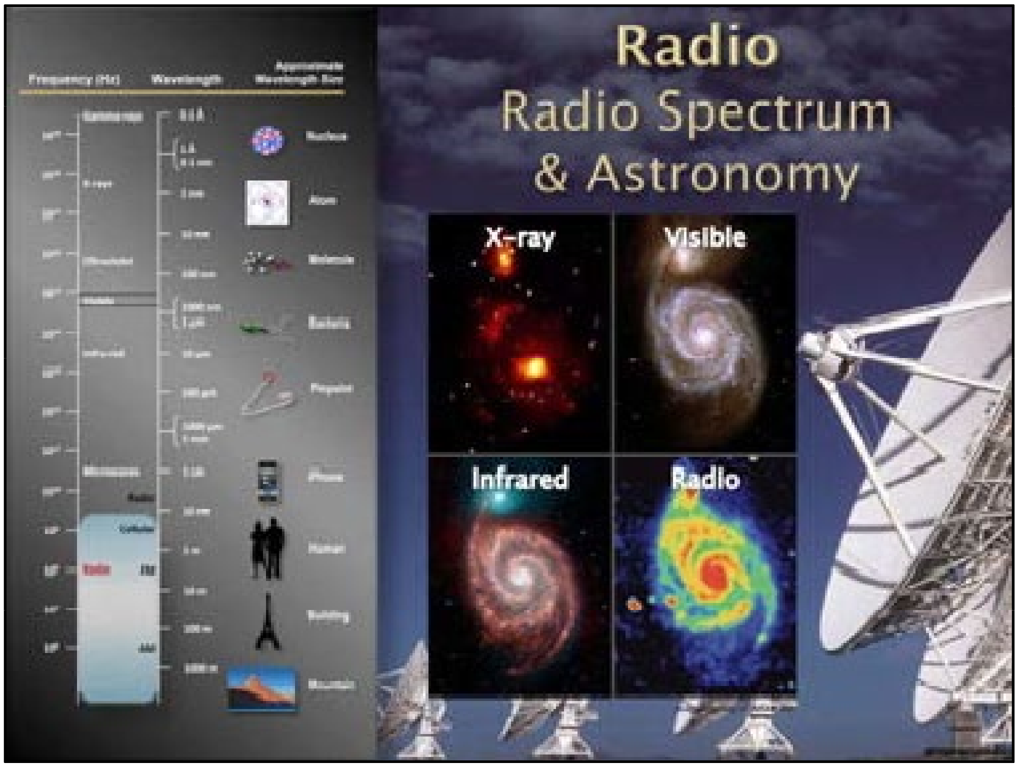
In the United States, as in many countries, the federal government allocates portions of the radio spectrum for various uses, in order to minimize interference between devices and reserve certain frequencies for special uses. This chart displays the radio spectrum as it was allocated by the United States in 2003. You'll notice many thin slices, each available for a certain purpose, often leased to a specific company as the result of a government auction.



Each color represents a different specific use, with some areas exclusively reserved for military or government use.

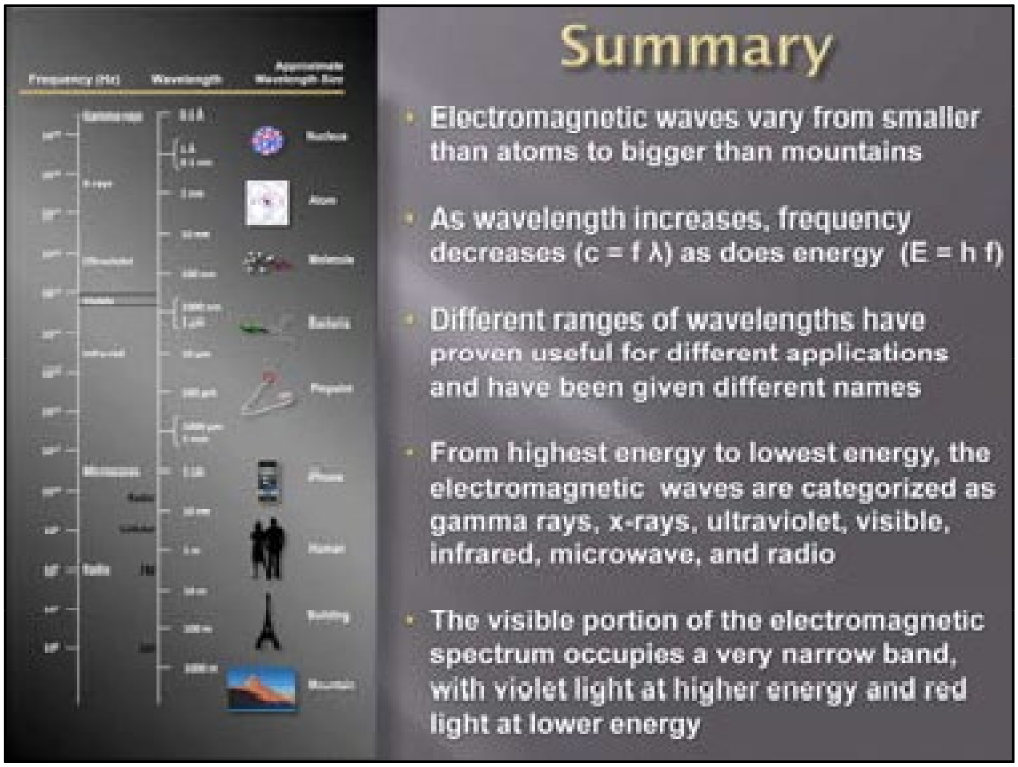


The bands allocated to television broadcasts here are rather wide. Analog television signals were established long before the invention of the cell phone and digital communications. There was recently a mandated switch from analog to digital television broadcasts, which required users of older televisions to purchase converter boxes in order to receive the new signals. In switching from analog to digital, these wide bands of the spectrum will be available to be sliced up to many more thinner bands, as digital communications require narrower spectrum than analog. Thinner slices will allow for additional allocation for many more digital communication uses.



One important use of the radio spectrum is radio astronomy. Like the visible portion of the spectrum, radio waves reach the earth from space, which allows us to view the universe using these frequencies.

The Very Large Array is a collection of twenty-seven receivers whose combined signals act like a single antenna of over twenty-two miles in diameter. As different parts of the spectrum may be emitted from different types of objects in space, astronomers are interested in looking across the electromagnetic spectrum as they observe distant galaxies. The views here are of the whirlpool galaxy, also known as M-51, as viewed in x-rays by the Chandra x-ray observatory, in visible light by the Hubble space telescope, in the infrared by the Spitzer Space Telescope, and in radio frequencies by the Very Large Array.



In summary, electromagnetic waves vary from smaller than atoms to bigger than mountains. As the wavelength increases, the frequency of the waves decreases, as does the energy of each wave.

Different ranges of wavelengths have proven useful for different applications and have been given different names over time as they have been discovered. The portions of the electromagnetic spectrum, in order from highest to lowest energy, are gamma rays, x-rays, ultraviolet, visible, infrared, microwave, and radio. The visible portion of the electromagnetic spectrum occupies a very narrow band of wavelengths, with violet light at the higher energy, shorter wavelengths and the red light at the lower energy, longer wavelengths.