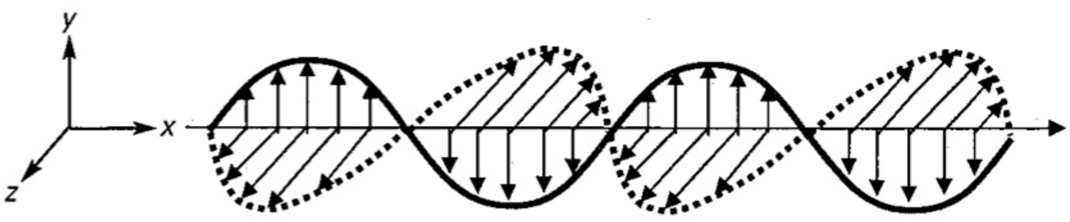
Electromagnetic Waves

If an electric charge is made to vibrate up and down, it will produce an electric field that oscillates up and down in a wave pattern. In addition, because the charge is moving, it will produce a magnetic field that oscillates side-to-side in a wave pattern.

This arrangement of an electric field and a magnetic field that oscillate perpendicular to one another is known as an **electromagnetic wave**. The diagram below is a representation of such a wave.



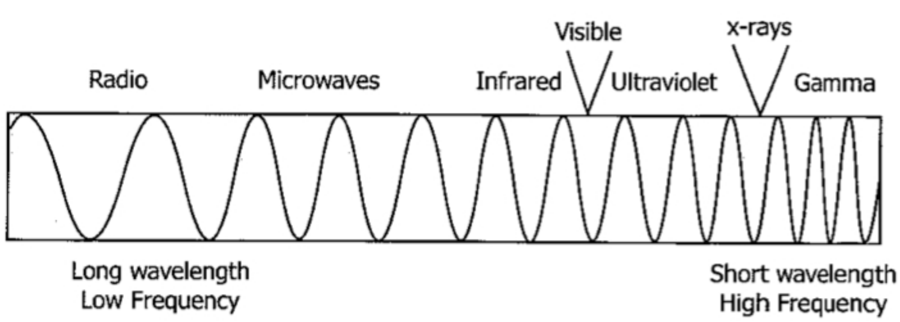
The solid line represents the electric field, which is vibrating up and down. The dashed line represents the magnetic field, which is vibrating into and out of the page. The wave itself moves to the right along the *x*-axis.

As with all waves, the frequency of the electromagnetic waves is the same as the frequency of their source. Unlike other waves, electromagnetic waves do not require a medium to travel through.

The Electromagnetic Spectrum

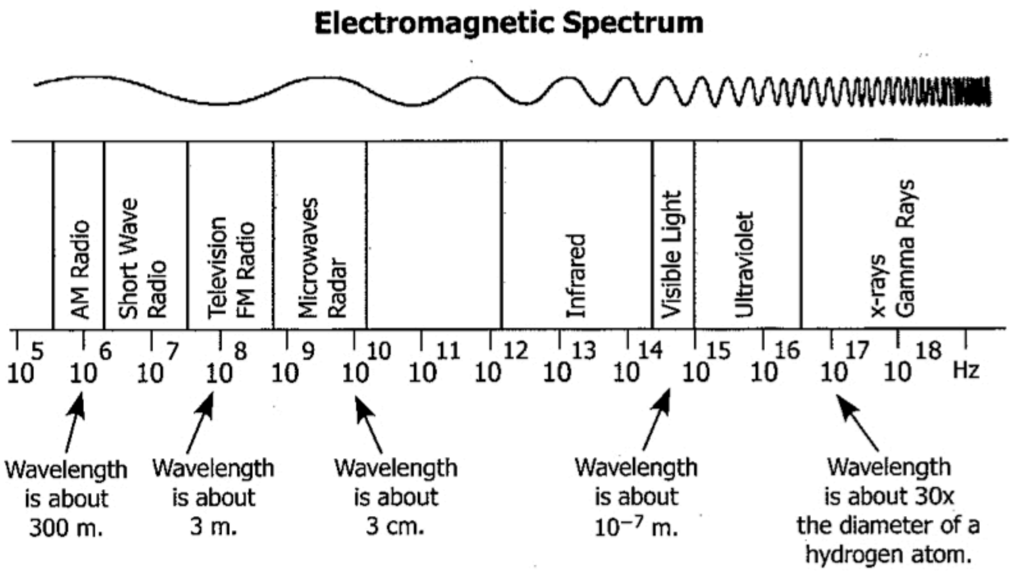
Electromagnetic waves can have many different frequencies. When we include all of the frequencies of electromagnetic waves, the result is called the **electromagnetic spectrum**.

The diagram below shows how the electromagnetic spectrum is arranged, with low-frequency waves on the left and high-frequency waves on the right.



Electromagnetic waves of different frequencies (and different wavelengths) have different names. This is because electromagnetic waves tend to have special uses or properties, depending on their frequencies.

The graphic below gives a more detailed look at the electromagnetic spectrum.



Radio Waves
Commonly used for communication. Not only for radios, but also for television, remote control toys, and cordless phones.

Microwaves
Most famous for their use in microwave ovens. Also used for communication, most notably in cell phones. Satellite and space communication uses microwaves. Airplanes communicate with each other and with ground stations using microwaves.

Infrared
Used in night vision, burglar alarms, and remote controls.

Light
Light is a form of electromagnetic wave, but that's a topic for our next unit…

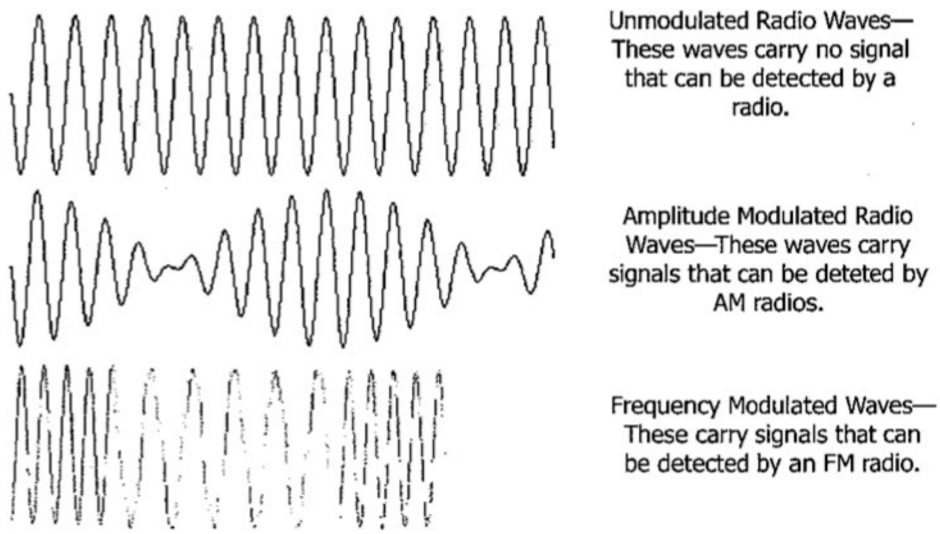
Ultraviolet
UV is naturally present in sunlight, and is responsible for suntans and sunburns. UV is used in black lights, where they cause certain objects to fluoresce, or glow in the dark.

X-Rays
Used in dental and medical imaging because they transmit quite well through soft tissue, but not through bones or teeth.

Gamma Rays
These waves are more penetrating than x-rays, and can also be quite harmful to living things. They are used in sterilizing medical equipment, detecting internal defects inside of important structures (such as weld joints on aircraft), and are used to kill tumors.

AM Radio and FM Radio

The radios we listen to are most often either AM (amplitude modulation) or FM (frequency modulation). AM and FM radio wave are a type of electromagnetic wave traveling at $3.0 \times 10^8\ m/s$.



AM radio stations broadcast waves that are in the kilohertz (10^3) range. For example, 580 AM refers to radio waves that have a frequency of $580\ kHz$. The frequency range for AM waves is $545\ kHz$ to $1605\ kHz$.

FM radio stations broadcast waves in the megahertz (10^6) range. For example, 103.1 FM refers to radio waves that have a frequency of $103.1\ MHz$. The frequency range for FM waves is $88\ MHz$ to $108\ MHz$.

How Radios Work

Sound is a type of wave. A song is a wave with a particular pattern of crests and troughs. When the radio station plays a song, electronics in the **transmission tower** force electrons to move up and down the tower. The frequency of this vibration is very precisely controlled. As the charges move up and down the tower, they generate electromagnetic waves that travel outward from the tower in all directions.

By varying the amplitude (for AM radio) or frequency (for FM radio), a signal can be sent out that carries information about the song it is transmitting. This is similar to encoding music on a CD.

If the electromagnetic radio waves encounter an **antenna**, such as on your car, the charges within the antenna will experience forces as a result of the electric field component of the radio waves. These forces will cause the charges in the antenna to vibrate up and down in the exact same pattern as the way those in the transmission tower are vibrating. Since the pattern of vibration was based on the song being transmitted, equipment in the radio can translate this vibration back into the original song.

The Wave Behavior of Radio Waves

Radio waves can reflect, refract, superimpose, interfere, and diffract, just like water waves. The effects of several of these are observable.

Superposition – In most places, you can tune your radio to one of several stations. This means the radio waves from many towers are moving through the same space together, and yet they don't hit each other.

Your radio is able to tune in the correct station using **resonance**. By changing the characteristics of the circuits inside the radio (adjusting the station), the circuitry inside the radio can be given a natural frequency that matches the station you are trying to tune in. Only the correct frequency will significantly affect the radio circuitry (by having a large enough amplitude of vibration).

Interference – This is most observable as reception problems. If a radio wave interferes with its own **reflection**, and there happens to be a 0.5λ path length difference between the original wave and the reflected wave hitting the antenna, then the two waves will interfere destructively (forming a **node**). In such a case, there will be no radio reception at the location.

Two radio waves with very similar frequencies will also interfere. This is observable, for example, when power tools produce static on a radio.

Diffraction – This can't be directly observed, but in certain situations we can notice its effects. If a large object is directly between the transmission tower and the antenna, the radio waves will diffract around the object and you will still receive a signal. This is most noticeable when comparing AM to FM radio. Since AM has a lower frequency (and a longer wavelength), AM radio waves will diffract better around obstacles. In other words, FM radio is more likely to have areas where you simply can't receive a signal due to obstacles blocking the signal.