Electromagnetic Waves

April 13, 2020

We live in a world and universe full of electromagnetic waves.

When you transmit and receive with your cell phone, you are transmitting and receiving electromagnetic waves.

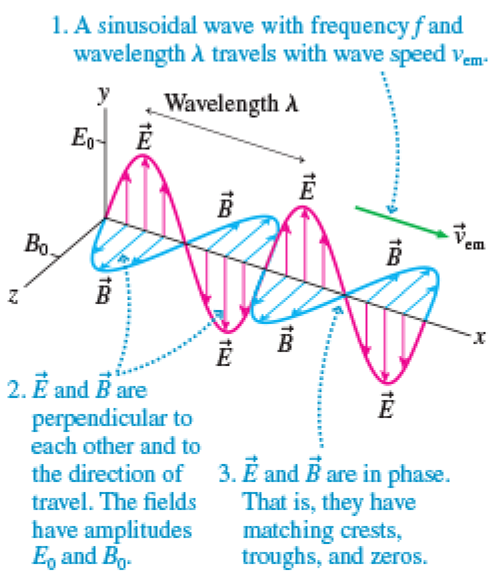
The light you see is electromagnetic waves.

The X-rays that are used to diagnose injuries and diseases are electromagnetic waves.

The microwaves that cook your food are electromagnetic waves.

The light coming from quasars at the edge of the universe is electromagnetic waves that were transmitted billions of years ago.

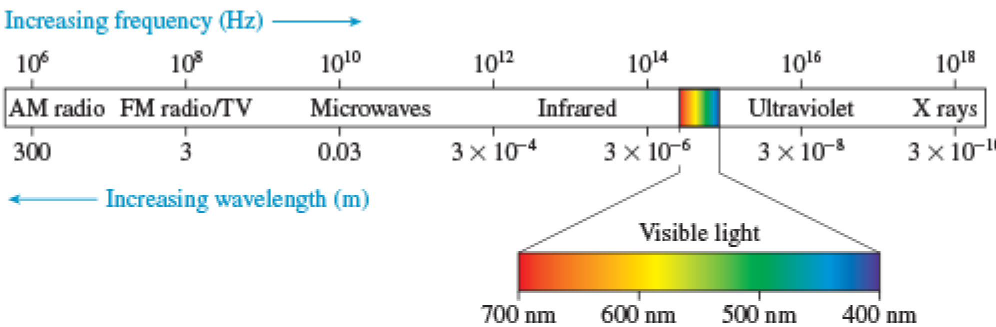
In all of these cases, the waves are traveling oscillations of electric and magnetic fields. The illustration below, from your textbook, shows what's what.



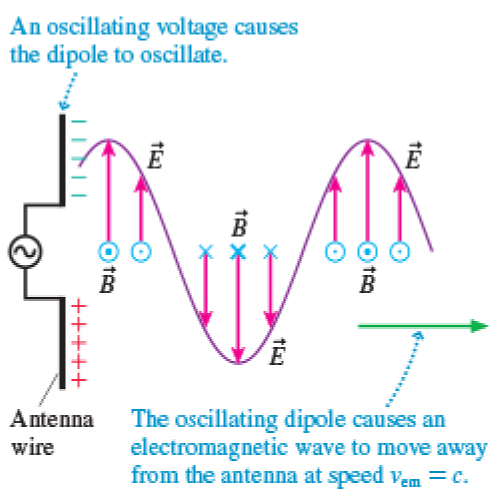
Two things to note here:

1) The wave travels at the speed of light c=3.0 x 10^8 m/s, regardless of the wavelength of the wave.
2) There is a fixed ratio between the amplitudes of the electric and magnetic fields: $E/B=c$.

The “type” of electromagnetic waves depends on the wavelength. As you can see from the illustration of the electromagnetic spectrum below (from your textbook), radio waves have long wavelengths and small frequencies, while X-rays have short wavelengths and high frequencies.



The generation of radio waves – and how that involves electric and magnetic fields – is relatively straightforward to understand in the context of our work earlier this semester on such fields.



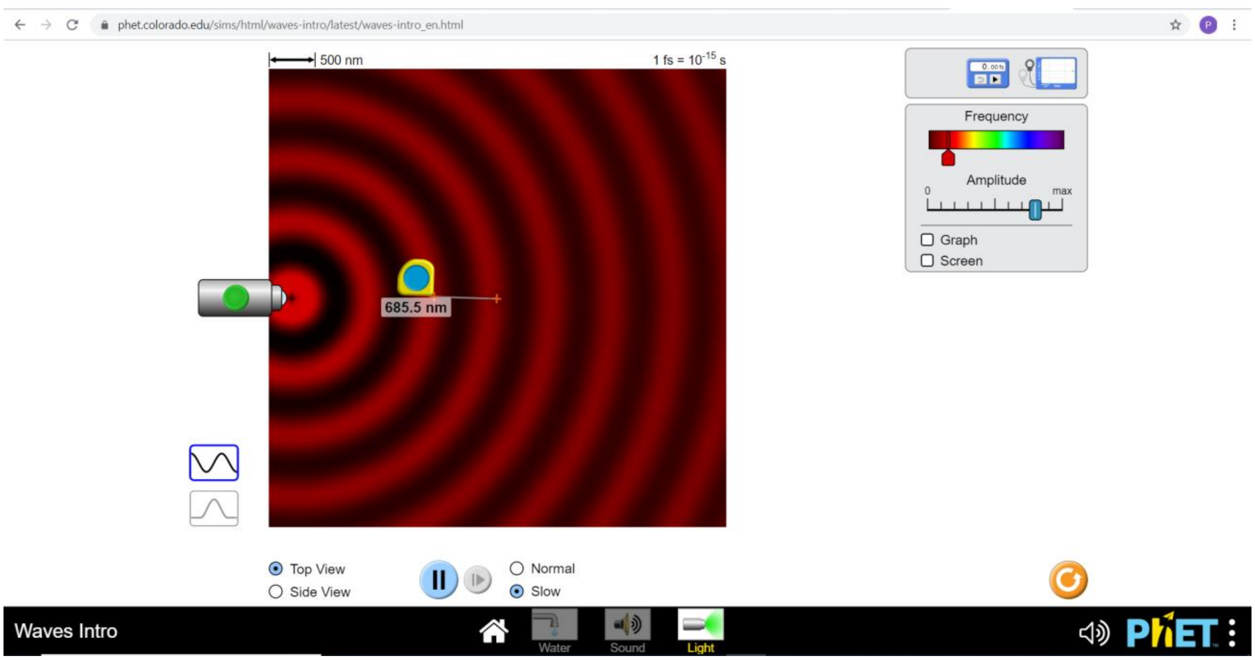
As the illustration from your textbook above shows, a radio antenna works by sloshing charge back and forth, giving an oscillating electric field and (because moving charges produce magnetic fields) an oscillating magnetic field.

Much of your work during our two-week electromagnetic wave unit will use visible light from a monochromatic source – that is, a source of light that produces precisely one wavelength. In practice, the only monochromatic light sources are lasers. A laser is a device that uses a single transition between two quantum states in an atom to produce the single wavelength. For these labs, you will be able to choose any visible wavelength – a luxury that people working with real lasers don’t have.

Start here:

https://phet.colorado.edu/sims/html/waves-intro/latest/waves-intro_en.html and then click twice on “Light”. If you click the green button on the flashlight-looking thing on the left side of the screen, you will start making light waves. You can change the color (and the wavelength) by sliding the “Frequency” control in the upper right part of the screen. The distance between the bright wave fronts corresponds to the wavelength. You can slide the frequency control between colors and see how the wavelength changes. Blue and violet correspond to short wavelengths while red corresponds to long wavelengths.

There are three odd-looking devices in a box in the upper right hand part of the screen. One is a tape measure that measures in nanometers (nm). You can use that to measure the wavelength by placing the two crosses on consecutive wave fronts. It might be easier to do this if you click the button on the bottom of the screen that says “Slow” (the default setting is “Normal”).



The wave fronts close to the light source are brighter than those farther away. This is not surprising – each wave carries a certain amount of electromagnetic energy. The wave expands as it propagates, spreading that amount of energy out over a larger area. Therefore, the density of energy along the wave front is inversely proportional to the square of the distance from the source.

Of course, the brightness of the light – that is, the energy density – is associated with the amplitude of the electric field in the wave. The stronger the electric field, the larger the energy density and the brighter the light.

The same box in the upper right hand part of the simulation screen as the frequency control has a check box labeled “Graph”. Click on the box. What you get when you click on that box is a graph of the electric field along the center line of the display of the light waves. The amplitude of the electric field drops quickly as a function of the distance from the source, as you'd expect. The electric field graph also shows you the wavelength.