11.2: Electromagnetic Waves Overview

In an earlier chapter we described transverse and longitudinal mechanical waves and how those waves depended on the material or environment in which the energy propagated (traveled). We also explored how electrical and magnetic fields could be described. We saw that electrical charges created electrical fields, and moving electrical charges (currents) created magnetic fields. Discovering and investigating these fundamental aspects of the universe was the result of decades of investigation by physicists including Gauss, Coulomb, Ampere and Faraday.

A Scottish physicist named James Clerk Maxwell was able to use the work of these pioneers to develop an overarching model, describing the ways that electric and magnetic fields are related to each other. Maxwell's Equations involve mathematics that go far beyond the scope of this textbook, but the ideas they represent are simple, yet profound.

- Electric fields can be visualized by arrows (field lines) that point away from positive charges and point towards negative charges. Electric fields determine the strength and direction of an electric force acting on an object with net charge. The electric field strength is also related to the environment. For the vacuum of space or the atmosphere of earth, the electric constant is written as ϵ_0. Different environments have different values of ϵ.
- Magnetic fields have no beginning or end, appearing as 'loops' of magnetic field. Magnetic fields determine the strength and direction of a magnetic force acting on a moving object with net charge. The magnetic field strength is also related to the environment. μ_0 is used for magnetic fields in a similar way that ϵ_0 is used for electric fields.
- A changing magnetic field creates a changing electric field.
- A changing electric field creates a changing magnetic field.

Maxwell was able to show that electrical and magnetic fields are not separate 'things'. Instead, electrical and magnetic fields are two aspects of a bigger 'thing' called the electromagnetic field. Likewise, electrical and magnetic forces are two aspects of the electromagnetic force. The idea that what appeared to be two different things were actually one had a profound effect on the philosophy of physics, and is what drives the current attempts to unify the four known forces of the universe, namely: Gravitational Force, Electromagnetic Force, Weak (Nuclear) Force, and Strong (Nuclear) Force.

Oscillating Charges Make Waves

An electric force can cause an electric charge to move. That moving electric charge will generate a changing electric field, and that changing electric field will generate a changing magnetic field. But, a changing magnetic field generates a changing electric field, and so on. The net effect is that if we 'wiggle' (oscillate) a charged object, we create a chain reaction of electric and magnetic fields that move away from the wiggling charge.

We've seen that electric and magnetic fields can exert forces, and that means that electric and magnetic fields can do work on charged objects. As we defined earlier, work is the transfer of energy between objects. So, we wiggle a charge at location A and some time later a charge at location B will wiggle. This is consistent with our description of wave behavior. Further reinforcing our ideas of wave-like behavior is the fact that the frequency at which we wiggle the charge at point A is the same frequency that the charge at point B will wiggle.

Using what we know about the mathematical description of electric and magnetic fields, we arrive at a wave equation that describes the way that electromagnetic forces can do work, how fast the energy will move from one point to another and how the amount of charge used will affect how much energy is transferred. It can be shown that the following relationship is true for electromagnetic energy transfers (electromagnetic waves) on earth and in space:

$$\mathrm{v} = \frac{1}{\sqrt{(\epsilon_0)(\mu_0)}}$$

If we insert the known values for ϵ_0 and μ_0, we get a wave speed of 3 x 10^8 meters per second, the speed of light.

Maxwell was able to show that what we call light is a traveling electromagnetic wave. Beyond that, he was able to show that all electromagnetic waves travel at the speed of light. Radio waves, microwaves, gamma rays, etc. are all forms of electromagnetic radiation and they all travel at the same speed.