Chapter 3 Radiation

Information from the Stars

On a dark night away from the city lights, you can see the Andromeda Galaxy with the naked eye. It appears as a fuzzy glow in the sky, but realize that you are looking at an object that is about 2.5 million ly from the Earth. The light and as such the information has been traveling for about 2.5 million years to reach us. This light provides us with information about the galaxy.

Light and Radiation

How do we obtain information about an object in space? We look to the *electromagnetic radiation* that the object provides us. Radiation is any energy that is emitted by an object and the electromagnetic part simply refers to the electric and magnetic parts of the energy being carried. There are many parts to the EMS as it's called. The part that we are the most familiar with is called *visible light*. But there is a big part that is invisible: radio, infrared, UV, X-rays and gamma rays. The book will use the term light to refer to all parts of the EMS.

Wave Motion

The electromagnetic radiation moves through space in the form of *waves*. A wave is the transfer of energy with the physical movement of material from one location to another. The energy is carried by a disturbance of some sort. Ripples on a pond, sound waves in the air, and electromagnetic waves in space all share this property. If you watch a twig on a pond when waves reach it you will see the twig bob up and down, but the twig doesn't go anywhere. The energy is transferred by a series of *crests* and *troughs*. The wave's *period* is the number of seconds needed for the wave to repeat itself. The *wavelength*, λ, is the distance from a point on the wave to the next corresponding point on the next wave. The maximum height of the wave from its rest state is called the *amplitude*. And lastly, the *frequency* of a wave is how many waves go by a point in 1 second. Frequency, f, is measured in Hertz, Hz. The relationship is as follows:
Velocity = $\lambda \times f$

The Components of Visible Light

White light is a mixture of different colors. When we pass this light through a prism, we get out the colors that make up the light. This is the *spectrum* of the light. The wavelengths or frequencies determine the light that is there. The light is then refracted or bent so that we can see all the colors of light that is there. You will find that red light is the longest of the wavelengths and violet is the shortest. The unit of measure for this is the *nanometer* which is one billionth of a meter. Visible light is in the range of 400 to 700 nm.

Waves in What?

Electromagnetic waves don't travel through any medium while they are in space. Near the end of the 19^{th} century physicists invented the aether, the medium that they traveled through, but we now know that there is no such thing.

Interactions Between Charged Particles

To understand light we must look at charged particles such as the *proton* or *electron*. They are the building blocks of the atoms. The atoms exert an electrical force on other charged particles in the universe. The electrical force can attract or repel other particles just like a bar magnet. Just like that magnet, an *electric field* is found around that charged particle. This field determines the force exerted. As you move farther away, the force decreases. If the particle begins to vibrate, then its field also vibrates and it causes a particle next to it to start to vibrate. It is like a chain reaction. The information about the particle is transmitted through space by a changing electric field.

Electromagnetic Waves

Magnetic fields accompany the changing electric field. Magnetic fields exert a force on moving electric charges. Conversely the moving electric charges produce a magnetic field. The disturbance caused by moving charges is due to both the electric and magnetic fields moving together. These 2 fields are always perpendicular to each other. They do not exist separately; they depend on each other. It is called *electromagnetism*. How fast does the vibration move among the particles? We now know that it moves at the *speed of light*, c, for all waves on the EMS. This speed is approximately 3×10^8 m/sec. This is very fast, but it is still finite. This is why it takes 2.5 million years to get here from Andromeda.

The Electromagnetic Spectrum

When you look at the EMS, you will notice the only thing different between the different parts is the wavelength or frequency. The short wavelength waves are the highest energy; X-rays and gamma rays, and the long waves have the lowest energy, radio. All of these different regions belong to the *electromagnetic spectrum* or EMS. Only a small part of the spectrum actually reaches the Earth. Visible light and radio pass through the atmosphere while everything else is pretty much stopped. The term here is opacity which means how transparent the substance is to something else. The atmosphere is transparent to radio, but it is opaque to X-rays. Certain gases will absorb parts of the EMS and that is why it all doesn't get through.

Thermal Radiation

All objects emit some type of radiation. This is because microscopic charged particles are constantly changing their motions. *Temperature* is the measure of the microscopic motion within a substance. The more motion, the higher the temperature.

The Blackbody Spectrum

No natural object emits all of its radiation at one frequency. Because the particles collide at different speeds, the energy is spread out over a range of frequencies. By looking at how this energy is spread out, we can learn a lot about it. A *blackbody* is an object that absorbs all energy that strikes it. It will eventually reemit energy at the same rate that it is absorbing it. This will give you a *blackbody curve*. It is a graph that compares the frequency with the intensity at those frequencies.

The Radiation Laws

As the temperature increases, the blackbody curve shifts towards the higher frequencies (shorter wavelengths). If you place a piece of metal in the fire, you see it glow red, then orange, then yellow and finally white. Why? It follows the blackbody curve; as it gets hotter it emits at the shorter wavelengths. From all of this we get:

Wavelength of peak emission α 1/temperature This is called Wein's Law

As the temperature increases the total energy across all wavelengths increases.

Total energy emission α $temperature^4$ this means that if we double the temperature the total amount of energy given off will be 16 times more. If we triple the temperature the energy goes up 81 times. This is Stefan's Law.

Astronomical Applications

Blackbody curves are often used to determine things about an object like the temperature. Working with Wein's Law and Stefan's Law allows us to determine many things about the object that we are looking at.

The Doppler Effect

Each of us has experienced what we call the *Doppler Effect*. The Doppler effect is simply the stretching or compression of waves due to motion. We can listen to a train or ambulance's siren to experience it. As the train is coming towards us we hear the horn at a higher pitch due to the waves being compressed and when it goes by you hear the pitch drop as the waves are stretched out. The same can be done with light. As the spectrum is shifted to the red end (redshift) or blue end (blueshift), we know how the object is moving relative to us. This motion towards or away from us is called *radial velocity*. If an object is moving perpendicular to our line of sight we will measure no Doppler effect.