ASTR 1020

Look Over Chapter 5
Light and Matter:
Reading Messages from the Cosmos

Good Things to Know About

- Electromagnetic Radiation
- Energy
- Conservation of Energy
- Waves
- Wavelength
- Frequency
- Nanometer
- Photon
- Planck's Law
- Spectrum
- Doppler Shift

- Thermal Radiation
- Wein's Law
- Stefen – Boltzmann Law
- Spectrometer
- Continuous Spectrum
- Absorption Line Spectrum
- Emission Line Spectrum
- Protons
- Neutrons
- Electrons
- Excited states

Radiation: Information From Space

Astronomers are in the light business. Almost everything we know about the universe, we learn by analyzing the light gathered by telescopes.

So to Understand astronomy, we must understand Light.

Electromagnetic Radiation

Light is merely one form of radiation called **Electromagnetic Radiation** because it is associated with changing electric and magnetic fields.

The Speed of Light c

The oscillating electric and magnetic fields that constitute electromagnetic radiation moves through space at about:

$$c = 300,000\ km/s \quad \text{or} \quad 3\times10^{8}\ m/s$$
$$(186,000\ miles/s)$$

where c stands for the speed of light.

Electromagnetic Waves?

Electromagnetic radiation has all the properties of a wave.

A wave is a traveling periodically repeating disturbance.

Wavelength **λ**

The Wavelength of a wave is the distance from crest to crest (or peak to peak).

The Greek letter Lambda (λ) is used to represent the wavelength.

Frequency f

The **Frequency** (***f***) of a wave is the number of crests that pass by each second.

The frequency is measured in Hertz which is cycles (or peaks) per second.

Since all electromagnetic radiation travels at the speed of light, wavelength is related to the frequency.

How *f* and λ are Related

$$c = f\lambda$$

The speed of light is equal to the frequency of the electromagnetic radiation times it's frequency.

Angstroms Å

The wavelength of light is so short there are two special units used to measure it.

$$1nm = 1\times10^{-9}\,m$$

Another unit that is used is the Angstrom (Å).

$$1\text{Å} = 1\times10^{-10}\,m$$

The wavelength of visible light is between or 400 nm–700 nm 4000 Å–7000 Å.

Photons–Light as a Particle

What exactly is electromagnetic radiation?
We have been discussing its wavelength but it is incomplete, to say that electromagnetic radiation is a wave.

Sometimes electromagnetic radiation acts like a particle called a **Photon**.

Planck's Law

The amount of energy a photon carries depends on its wavelength.

We can express this relationship in a simple formula called Planck's Law:

$$E = \frac{hc}{\lambda} = hf$$

$$\text{where: } h = 6.62\times10^{-34}\,J\cdot s$$

$$c = 3\times10^{8}\,\frac{m}{s}$$

h is called Planck's constant.

The Spectrum of Light

A Spectrum is an array of electromagnetic radiation in order of wavelength

We are most familiar with the spectrum of visible light, which we see in a rainbow.

Radiation and Temperature

What determines the type of electromagnetic radiation emitted by the Sun, stars and other astronomical objects?

The answer turns out to often be their Temperature.

Moving Charged Particles

As atoms and molecules move about and collide, or vibrate in place, their charged particles generate electromagnetic radiation.

The characteristics of this radiation is determined by the temperature of the of the atoms and molecules that give rise to them.

Thermal Radiation

To understand thermal radiation better we are going to look at an idealized opaque object.

A perfect opaque object does not reflect any radiation, but absorbs (or emits when heated) all electromagnetic energy.

Properties of Thermal Radiation

The Thermal Radiation has several characteristics.

1) Thermal radiation is emitted at all wavelengths, or has a continuous spectrum.

More Heat, More Light

2) An object at a higher temperature emits more Thermal radiation at all wavelengths then does a cooler one.

Hot Stars Have The Blues

3) The higher the temperature, the shorter the wavelengths at which the maximum thermal Radiation is emitted.

Wein's Law

The wavelength at which an object emits its maximum thermal radiation can be calculated according to the equation:

$$\lambda_{\max} = \frac{W}{T}$$

$$W = 2.9 \times 10^7\ \text{Å} \cdot K \text{ or } .0029 m \cdot K$$

$$T = \text{ Temperature in Kevlin's } (K)$$

Stefen – Boltzmann Law

The total energy, emitted per second per square meter by an object at a temperature *T*, is proportional to the forth power of absolute temperature.

This is called the Stefen–Boltzmann Law:

$$E = \sigma T^4$$

$$\sigma = 5.67 \times 10^{-8} \frac{W}{m^2 K^4}$$

$$T = \text{ Temperature in Kevlin's } (K)$$

Spectrometer

A Spectrometer is any device that breaks light down into it's component colors (or spectrum).

There is a lot we can learn about stars by looking at the spectrum of their light.

Continuous Spectrum

A **Continuous Spectrum** is formed when a dense collection of gas or solid gives off radiation.

A continuous spectrum is an array of all wavelengths or colors of the rainbow.

Absorption Line Spectrum

A dark line, or **Absorption Line Spectrum** consists of a series or pattern of dark lines (i.e. missing colors) superimposed upon the continuous spectrum of a source.

Emission Line Spectrum

A bright line, or **Emission Line Spectrum** appears as a pattern or series of bright lines. It consists of light in which only certain discrete wavelengths are present.

The Atoms Fingerprint

Each particular chemical element produces its own unique pattern. No two patterns are alike.

Atoms

Atoms are composed of a positively charged nucleus orbited by negatively charged electrons.

The nucleus is made up of positively charged protons and uncharged neutrons.

Electron Orbits

In an atom electrons move only in orbits of certain size.

The lowest orbit is called the ground state and higher orbits are called Excited states.

How To Get Absorption Spectrums

When an electron moves from a lower orbit to a higher orbit the electron will absorb a photon of a particular wavelength.

The wavelength of the absorbed photon will depend on the energy the electron needs to move to the higher orbit.

How To Get Emission Spectrums

When an electron moves from a higher orbit to a lower orbit the electron will emit a photon of a particular wavelength.

The wavelength of the emitted photon will depend on the energy the electron needs to give off to drop to the lower orbit.

Kirchhoff's Laws

The three types of spectra are summarized in **Kirchhoff's Laws**:

Law I: The Continuous Spectrum
A solid, liquid or dense gas excited to emit light will radiate at all wavelengths and thus produce a continuous spectrum.

Law II: The Emission Spectrum
A low–density gas excited to emit light will do so at specific wavelengths and thus produce an emission spectrum.

Law III: The Absorption Spectrum
If light comprising a continuous spectrum is allowed to pass through a cool, low density gas, the resulting spectrum will have dark lines at certain wavelengths. That is, it will be an absorption spectrum

The Doppler Shift

The change in the observed wavelength due to the relative motion of the source and the observer is called the **Doppler Shift** or **Doppler Effect**.

The Doppler shift is seen in light as well as sound.

Blue and Red Shifts

The lines in a star's spectrum will be shifted toward the **Blue** end of the spectrum (**Blue Shifted**) if the star is approaching.

The lines in a star's spectrum will be shifted toward the **Red** end of the spectrum (**Red Shifted**) if the star is receding.

Finding the Velocity from the Doppler Shift

The radial velocity of an object can be measured using:

$$v = c\left(\frac{\Delta\lambda}{\lambda}\right)$$

Where: v is the radial velocity

c is the speed of light

λ is the laboratory wavelength

$\Delta\lambda$ is the shift in wavelength

The Doppler effect depends only on the part of the velocity directed away from or toward the earth called the **Radial Velocity**.