Astro 101 *Useful Physics Notes*

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Spring/Fall Semesters

We have learned that science is based on as reliable information as is available. Furthermore:

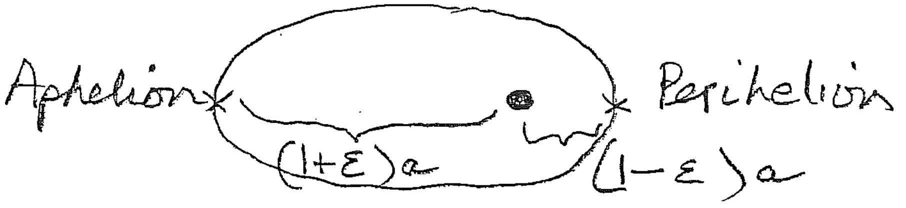
1. information comes to us in the form of light (electro-magnetic radiation) from virtually all objects in the universe
2. tested **physics** lets us interpret the information provided by the light

Important **physics** from Chapter 1:

1. Kepler's laws:
   (a) 1st law: orbits are ellipses. Thus the Earth's orbit about the Sun is an elliptical orbit. Similarly the orbit of the Moon about the Earth is an elliptical orbit. In astronomy we think of one *lighter* object, call it a satellite, orbiting a *heavier* object. Furthermore the characteristics of the orbit we call the *satellite's orbit parameters*.

   Elliptical orbits have two defining parameters: the semi-major axis, a, and the eccentricity parameter, ϵ.

   For ellipses there is one place on the orbit when the satellite is closest to the *heavier* object, called orbit *perihelion*, and one place on the orbit when the satellite is furthest from the *heavier* object, called orbit *aphelion*.



   (b) 2nd law: equal areas in equal times. What this means is that with elliptical orbits the satellite speed varies depending on position in the orbit having the highest speed at *perihelion* and slowest speed at *aphelion*.

   Note: for the special case when $\epsilon = 0$ then the ellipse is a circle and the satellite is always at the same distance from the *heavier* object and always moves at the same speed.

   (c) 3rd law: the period (time for one revolution), P, of a satellite is related to the semi-major axis, a, of the satellite's orbit.

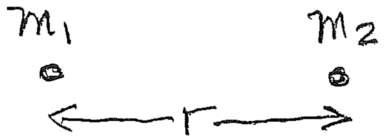
   For planet orbits with the period in Earth years and the semi-major axis in Astronomical Units (A.U.) [recall 1 A.U. is the distance of the Earth from the Sun, *viz.* the radius of the Earth's orbit] the relationship is given by:

$$P(years)^2 = a(A.U.)^3$$

As an example go to Table 4.1 on page 106 of the text. Assume you have measured the period of some planet (Mars) as 1.9 years. The using Kepler's 3rd law: $1.9^2 = X^3$ where X is the unknown semi-major axis for Mars. This equation is solved by inserting $X = 1.534 A.U.$ which is the correct semi-major axis for Mars!

2. Force of Gravity:

   All objects in the universe have mass, *e.g.* your weight is proportional to your mass. The law of gravity states that every pair of masses, with masses m_1 and m_2, and with their centers separated by a distance, r,

   experience an **attractive** gravitational force, F_g, given by:

   $$F_g = \frac{Gm_1m_2}{r^2}$$

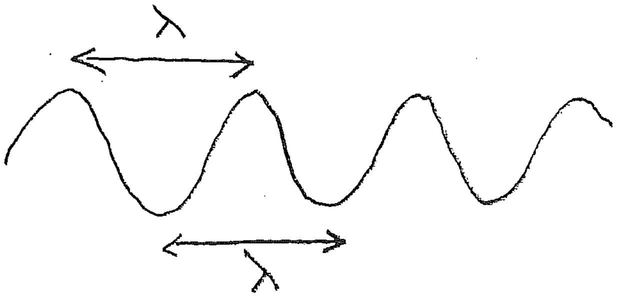
   where G is a known constant.

   Once a *satellite*, with mass m_1, is "launched", with some initial speed and direction with respect to some *heavier* object with mass, m_2, it is the force of gravity that (via Newton's laws of motion) then controls the entire future motion of the *satellite*!

Important **physics** from Chapter 2:

1. Light (*i.e.* electro-magnetic (EM) radiation) is a wave:

   Waves are characterized by the distance (called the wavelength, λ) between neighboring *similar* points on the wave: *e.g.* from peak to peak or from trough to trough, see sketch.

   The number of wave peaks (or troughs) that pass a fixed point per second is called the frequency, f. The product of the wavelength and frequency of a wave is the speed (velocity, v) of the wave: $v = \lambda f$. For light (in vacuum) the speed is a constant, c, thus for all EM radiation:

$$c = \lambda f$$

As a consequence only the frequency or the wavelength needs to be specified as:

- if you know f then: $\lambda = c/f$
- if you know λ then $f = c/\lambda$.

Thus EM waves with short λ have high fs. Conversely EM waves with long λ have low fs.

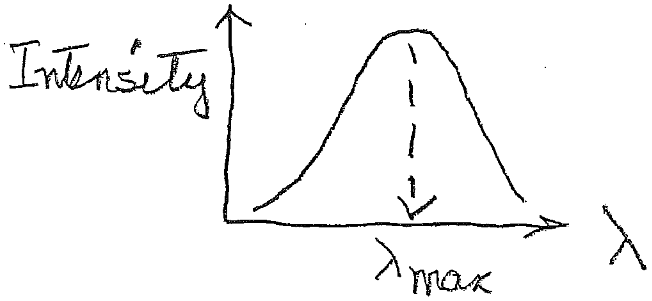
2. Sources of light:

   There are three types of light sources in the course: *black body* radiation from dense materials at temperature, $T(K)$, emission (absorption) *line* spectra from dilute gases, and (Chapter 15) *synchrotron radiation* from high energy electrons moving in magnetic fields.

   (a) *Black Body* radiation:

   All dense materials radiate *Black Body* radiation that depends only on their temperature, T, in Kelvin degrees [see 2-1 More Precisely, page 52 of the text].

   The radiation is over a range of wavelengths called the *Black Body spectrum*, see sketch.



   The maximum of the *Intensity* VS T spectrum curve is at a wavelength denoted, λ_{max}. The value of λ_{max} depends on the temperature of the *Black Body*:

$$\lambda_{max} = \frac{2900\mu m}{T}$$

   Thus the wavelength of maximum emission of a typical human with $T = 300K$ is about $9.7\mu m$ (or microns where $1 micron = 10^{-6} m$) in the near infrared and the wavelength of maximum emission of the photosphere of the Sun at $T = 5800K$ is about $0.5\mu m$ in the middle of the visible. **Thus objects with higher temperatures have smaller λ_{max} called *bluer*, and objects with lower temperatures have larger λ_{max} called *redder*.**

   To summarize: if we know the temperate of an object we can predict the wavelength of maximum emission, λ_{max}. Conversely IF we measure the *Black Body* spectrum of any object, *e.g.* a star or planet, and thus deduce λ_{max} as the wavelength with maximum emission (maximum brightness), then we can evaluate the temperature of the object using: $T = \frac{2900\mu m}{\lambda max}$ even if the object is millions of kilometers or millions of light years distant!

A second characteristic of *Black Body* radiation is that the total energy/second radiated by any object is known and given by the relation:

$$Intensity(energy/second) \;=\; \sigma\ A\ T^4$$

where A is the surface area of the object and σ is a known constant. As the intensity varies as the 4th power of the temperature, stars with (photosphere) temperatures that differ by "just" a factor of 2 differ in brightness by a factor of $2^4 = 16$! **Thus for all other details being equal: hotter is brighter and cooler is fainter.**

(b) *line* emission radiation:

The light emission from dilute gases occurs only at a few discrete wavelengths.

The wavelengths are characteristic of the specific types of the atoms in the gas. Thus *e.g.* hydrogen, H lines are unique and different from helium, He, lines, and/or from lithium, Li, lines, etc. As a consequence we often say that *line* spectra of atoms are unique identifiers similar to people's "fingerprints"!

The underlying physics is the (quantum) atomic structure of atoms (and molecules). Each atom (molecule) has a system of possible electron energy levels. When electrons make transitions from one quantized initial energy level, E_i to a final energy level, E_f, a *photon* of EM radiation is emitted (or absorbed) with *photon* energy: $E_\gamma \;=\; E_i - E_f$. Curiously the energy of a *photon* is related to the frequency, f, of the *photon*: $E_\gamma \;=\; h\ f$ where h is a known (Planck's) constant. **Thus quantized atomic electrons energies lead to quantized *photon* energies which lead to quantized *photon* frequencies (or wavelengths).** Light with only certain frequencies (wavelengths) when viewed with a spectrometer results in discrete *lines*.

3. *Doppler* effect (or shift):

If the observer and the light source are in relative motion (along the line joining them) the observed wavelength, λ_{obs} of the light will be different from the wavelength of the emitted light, λ_{source}, at the source! This is called the *Doppler* effect (or *Doppler* shift).

When light sources approach the observer then: $\lambda_{obs} < \lambda_{source}$ *viz.* the observed light has a shorter wavelength than the original wavelength at the source. As visible light with the "shortest" wavelength is at the blue end of the visible spectrum this is called *blue shift*.

In contrast when light sources recede from the observer then: $\lambda_{obs} > \lambda_{source}$ *viz.* the observed light has a longer wavelength than the original wavelength at the source. As visible light with the "longest" wavelength is at the red end of the visible spectrum this is called *red shift*.