Review Session Comments, Phy1301

Mechanics:

The starting point for mechanics is the concept of inertia, a property of matter described in the Law of Inertia from Galileo. This states that an object will continue with a constant velocity until acted upon by a force. Such a force will produce an acceleration (i.e. F=ma). Acceleration is a change per unit time in either the magnitude of velocity, its direction, or both.

Given the concept of inertia, we find it useful to talk about 'inertial reference frames' which are three-dimensional coordinate systems which travel at constant velocity. To determine the coordinates of an event in one frame, say S, when we know it's coordinates in another frame, say S', we employ the Galilean space and time transformations. If we have an object in frame S' moving with velocity, v, within that frame, and S' is moving with velocity V' relative to frame S, then the velocity of the object in the frame S is equal to v+V'. This is the Galilean velocity transformation. The Principle of Galilean Relativity states that the laws of mechanics are the same in all inertial reference frames.

Another pair of concepts which are important to discussing mechanics are momentum and energy. These two related properties of matter have larger values when there is an increase in either the mass of an object or its velocity. The specific manner of the dependence is different in the two cases, with momentum preserving knowledge of the direction of an object (or group of objects) while energy does not. In all situations, the total momentum and total energy of a group (or 'system') of objects is constant. Classically, energy may not be created from nothing or destroyed to nothing.

Lastly, the gravitational force between two objects with masses 'm' and 'M' is calculated classically as $F = -G (mM)/r^2$. The mass that enters here is termed the 'gravitational mass'. The mass which enters the generic force equation above (F=ma) is termed the 'inertial mass'. These two turn out to be the same and this is unexplained in classical physics.

Electromagnetism and Light:

Electricity consists of the range of physical phenomena which result from the presence of electric charge. Magnetism consists of phenomena which result from the motion of charge. The fields of electricity and magnetism are unified by Maxwell's equations. These equations describe a wave associated with these forces which is called an 'electromagnetic wave'. This wave is predicted to have the speed of 300,000 km/s, which is the same as the measured speed of light. In classical physics, waves were commonly viewed as requiring a medium to travel thru or in. Since Maxwell's equations did not provide the speed of light with respect to any reference frame, it was conjectured that a pervading 'ether' existed throughout the universe in which the light could travel. It was thought that the speed of light was with respect to this absolute reference frame.

Light itself had been determined to have wave properties, particularly as evidenced by the Double Slit Experiment. In this experiment, a source of light is shined simultaneously thru two narrow slits onto a screen. If one of the slits is covered up, then the pattern observed on the screen is just the illumination of one slit. If both slits are uncovered, however, the light passing thru the two slits interferes. This interference produces a pattern of several alternating bright and dark lines on the screen and is incompatible with a particle nature of light.

It is important to understand the nature of waves, i.e. that they have a wavelength which is the peak to peak distance. They also have a frequency, which is the number of times per second that a peak will pass a given location when a wave is moving. When frequency increases, wavelength decreases. For visible light, or electromagnetic waves, high frequency corresponds to blue light and low frequency corresponds to red light. The visible spectrum encompasses the full range of colors between these extremes. The full light spectrum goes beyond this to include radio, infrared, visible, ultraviolet, X-ray and gamma-ray frequencies if we go from low frequencies to high frequencies.

Problems with Classical Physics:

There are four experiments or observations which point to serious shortcomings in the classical perspective in physics. The Michelson-Morley experiment sought to measure the speed of light in two different reference frames and thereby determine the motion of the observer thru the absolute ether reference frame. The experiment used interference of two beams of light which were split into perpendicular directions and then recombined. If the velocity of light in one of the directions was greater with respect to the Earth's motion because of the relative motion of the ether reference frame, then this would result in a different number of wavelengths being traveled by that light. The intensity of the recombined light at the observer would be subject to interference of the light traveling the two paths. If there was an absolute ether reference frame, then one would expect to see a change in the observed light intensity with the orientation of the apparatus. The precision of the experiment is aided by the tiny wavelength of visible light, which is less than a millionth of a meter. No variation in light intensity was observed, indicating that no change in the velocity of light was observed for the different reference frames tested.

Another difficulty with the classical paradigm of physics arose when measurements of white light were passed thru gases. The spectrum of this light was observed to be missing very specific wavelengths, and the set of wavelengths missing (or 'absorbed') was unique to each chemical element in nature. Additionally, these elements could be made to emit light and the set of wavelengths of that emitted light was specific to each element and the same as the set of absorbed wavelengths. Since there was no model of an atom aside from a point-like particle, there was no way to understand the specificity of this behavior of light.

In attempting to understand the properties of light as emitted by matter, the concept of a 'blackbody' has become useful. Such an object absorbs all electromagnetic radiation that is incident on it and therefore heats up. The heated body then re-radiates this electromagnetic radiation in a characteristic spectrum called a 'blackbody spectrum'. The observed properties of this spectrum where that at small and large wavelengths, the intensity of emission were tiny. However, for some characteristic wavelength, the intensity of emission was a maximum. This 'peak wavelength' is correlated directly with the temperature of the blackbody – warm bodies radiate with a smaller peak wavelength than cooler bodies. Classically, the spectrum of blackbody radiation could only be calculated on the assumption that all wavelengths of light were possible in the emission. This lead to the calculation that the observed intensity should be infinite when approaching wavelengths of 0 size. This unphysical result was a major blow to classical physics.

A final fatal observation for classical physics came with the realization that light incident on a conducting metal plate caused electrical current to be released by the plate. This 'photoelectric' effect was expected to have a few properties based on the understanding of light, matter and current at the time. Essentially, the liberated current was believed to represent a substance which carried charge away from the material of the plate. To liberate the current required sufficient energy, and this energy was carried by the intensity of the light incident on the plate. If one turned up the light intensity, then the amount of energy being dumped into the plate would add up. Eventually, the current carrying material would have a high enough energy that it could escape the bonds that held it to the material of the plate. In this scheme, the intensity of the incident light should be the only thing dictating whether current flowed or not. The current should be independent of the frequency of the incident light. In actual experiment, it was observed that at high frequencies, the current did increase (to a point) with incident light intensity. However, at lower frequencies, the current was a strong function of the incident light frequency. More confusing, below some 'cutoff' frequency, no current was observed at all. The classical understanding was unable to come up with an explanation for this behavior.

Special Relativity:

Given the predictions of Maxwell's equations that the speed of light was a constant, and it's inconsistency with the Galilean statement of the Principle of Relativity, Einstein postulated a new concept of relativity to bring mechanical and electromagnetic phenomena under one roof. In this statement, he hypothesized that all physical phenomena, including electromagnetic, should proceed regardless of the intertial reference frame they in which they occur. This modification had the result that it stipulated the speed of light to be constant irrespective of inertial reference frame, and so 'explained' the Michelson-Morley experimental result.

The results of this hypothesis were a number of predications of how space and time would behave in cases where velocities approached the speed of light. The first impact was the removal of the concepts of an absolute space and an absolute time. For time, this may be most clearly seen in a discussion of simultaneity. Classically, if two events are observed to occur simultaneously by one observer, then all other observers will see them as simultaneous. Relativistically, however, the speed of light is constant. As a result,

Another manifestation of the relativity of time concerns the phenomenon of 'time dilation'. If an object is moving in a particular inertial reference frame, O, with a velocity approaching the speed of light in frame O, then a clock attached to that object will appear to run slower to an object stationary in frame O. We discussed an illustration of this using a flashlight and a mirror mounted on a train. In this illustration, the light takes longer to return to the flashlight as observed by a stationary observer in O when compared to the time measured by an observer on the train. This is because it must travel a longer distance in the O reference frame than just twice the distance from the flashlight to the mirror.

Space also becomes relative because as objects move faster, their apparent lengths appear to shrink. We discussed this issue with a description of the Pole in the Barn 'paradox'. In this situation, a pole-vaulter runs toward a barn with a pole which is longer than the size of the barn. Doors are set such that they momentarily close and open simultaneously (in the frame of the barn) when the pole-vaulter is at the center of the barn. Since the length of the pole shrinks with increased velocity, there is a velocity for which the pole will fit within the barn in the barn's reference frame and will clear the doors when they close. The 'paradox' arises when we consider that the pole-vaulter measures the proper length of her pole and sees the barn length contracted to be even smaller than its proper length. Since it's proper length is smaller than the pole's proper length, the pole cannot possible fit within the barn. However, we are saved by the fact that the doors which close simultaneously in the barn's reference frame, do not close simultaneously in the runner's reference frame. The back door closes and opens first, then the front door, thus allowing the runner thru without breaker her pole.

Finally, we described some of the implications of relativity on our concepts of energy. In classical physics, energy can come in several forms. For a moving particle, one form of energy is that of motion, i.e. its kinetic energy. An unheated particle at rest (velocity = 0) has no energy in the classical scheme. In relativity, it was realized that total energy of a particle is the sum of a kinetic term and a 'rest energy'. The rest energy is usually expressed as $E = mc^2$ and expresses the idea that energy and mass are equivalent.

These ideas of relativistic physics have been observed in some terrestrial situations (eg. time dilation with GPS satellite measurements). The rest of this course will provide examples of how we see relativistic effects in the universe around us.