1.4 Einstein's Relativity

1.4.1 Definition of Time and Synchronizing Clocks

In the spirit of Mach's thinking concerning physical theories, Einstein in 1905 introduced an empirical procedure for defining time and synchronizing clocks in an inertial frame rather than rely on the concept of absolute time. He used his definition of time to build the theory of special relativity. The "special" in special relativity refers to the fact that the theory applies to the relativity among inertial reference frames. Almost 10 years later, Einstein came up with a more general theory of relativity, which addresses non-inertial frames and gravitation.

Einstein noted that the concept of time is linked inextricably with the "judgments of simultaneous events." His example is simple and bears quoting: If, for instance, I say "That train arrives here at 7 o'clock," I mean something like this: "The pointing of the small hand of my watch to 7 and the arrival of the train are simultaneous events."

Thus, time at that location under observation can be given by the position of the small hand of the watch here. This empirical definition of time is satisfactory for the place where the watch is located. But, what about the time at places far away from there? Suppose you have a clock with you that reads 7 o'clock. What would be the time at the moon? One way to answer this question will be to place another identical clock on the Moon. You will have to take the clock to the moon and place it there and return to the Earth. Now, your clock says 7 o'clock, can you assume that clock at the moon says 7 o'clock also?

In pre-Einstein days, the answer used to be, since the two clocks are identical, they will display the time no matter where they are placed or if they are moving with respect to each other. This was an untested assumption and Einstein argued that clocks are physical objects and the process of moving them will change the speed with which the "hands" of the clocks will move. So, suppose you had both clocks with you at the moon and at the moon you made sure they showed identical readings, to arrive back at Earth you would have to carry your clock with you and the motion of that clock would change the speed of that clock in an unknown way. So, we need a different way to make sure clocks at all points in a stationary space give the same reading, i.e. are synchronized. Einstein suggested a different **procedure for synchronizing clocks**.

We can imagine placing identical clocks everywhere and synchronizing them with some signal whose speed would not depend on the state of the emitter. Einstein postulated that light was such an object which "always propagated in empty space with a definite velocity c which is independent of the state of motion of the emitting body." Therefore, we can use light signals to synchronize clocks at various space points of a stationary space.

Thus, to synchronize your clock on the Earth with the clock you placed on the Moon, we will send a light pulse from your location to the location of the clock on the Moon. Let the reading on your clock at the initial time be t_0 and the distance between the two clocks be l. Then, light would have traveled a distance l with speed c. Therefore, when the light pulse arrives at the clock on the Moon we will set that clock's reading to be $t_0 + \frac{l}{c}$. Since the two clocks are identical and neither clock will be moving after synchronizing we can safely assume that the two clocks will remain synchronized. [Of course, the observer at the Moon and the observer at Earth would have agreed prior to the synchronization that a pulse of light will go out from the Earth when the time in the clock at Earth reads t_0 so that he knows to add t_0 to $\frac{l}{c}$ in his clock.]

For instance, light takes approximately 1 sec to reach the Moon. Suppose we send a light pulse to the Moon at 7 o'clock on your clock on Earth. When the light arrives at the Moon, the observer on the Moon will set the time on the clock there to be 7 o'clock and 1 sec.

This procedure can be used to synchronize "clocks" at all points of a stationary space in which all points of space are at rest with respect to each other. We imagine the space to consist of fixed points in a three-dimensional world and attach identical clocks at all points. Now, we pick one arbitrary point in the stationary space and send light signals to all other points and use the distance over speed of light to set times at all points. This procedure gives one time for each frame of reference in which all clocks at all points of space are at rest with each other.

Since moving clocks affects the speed with which clocks run, two observers in relative motion with each other will find that the clocks in one observer's reference frame [i.e. the clocks that are at rest with respect to this observer] cannot be synchronized with the clocks on the other observer's reference frame. We will see below how to relate the time readings in the synchronized clocks in two different frames that are at uniform motion with respect to each other.

1.4.2 The Postulates of Special Relativity

The two postulates of Special Relativity are the Principle of Relativity and the Principle of the Constancy of Speed of Light. We will quote them from Einstein's paper, "On the Electrodynamics of Moving Bodies," published in Annalen de Physik, vol. 17, p 891, 1905.

1. **Principle of Relativity**. The laws by which the states of physical systems change are not affected, whether these change of state be referred to the one or the other of the two systems of coordinates in uniform translatory motion.

2. **Principle of the Constancy of Speed of Light**. Any ray of light moves in the "stationary" system of coordinates with the determined velocity c, whether the ray be emitted by a stationary or by a moving body.