

Hello students, welcome to the unit #8 of this course Electromagnetic Theory 2 and Theory of Relativity. This is part B of the Theory of Relativity. The name of this unit is Relativistic Kinematics and the name of the module is Relativity of Simultaneity. I'm Yatin Desai, Assistant Professor in physics, Chowgule College Margao.

The outline of this module is relativity of simultaneity and conclusions from the relativity of simultaneity.

Learning outcomes: at the end of this module, you'll be able to comprehend the synchronization of clocks for observers in different frames of reference and establish that simultaneity is a relative concept and not the absolute one.

Relativity of Simultaneity: suppose that the events occur at some place in one particular frame of reference, clock kept at that place registers the time of occurrence of each event. The events are set to be simultaneous if the reading in the clock is same for each event. But the question is what if the two events occur at different locations? To answer this question, let's imagine now that there is a clock at the positions of each event. The clock at A is of the same nature as there at B. These clocks can record a time occurrence of events and readings in both these clocks can be compared only if they are synchronized. That means these clock needs to be synchronized. There are many methods of synchronization. We'll look at the erroneous method of synchronizing and get rid of this method.

Let an observer A possess a clock in which a same time is set as in the clock possessed by an observer B. This means that whenever A looks at the B clock, it reads the same time to him as his clock. But the defect here is that, if observer B uses the same criteria, he will find that the clocks are not synchronized, even if A say that they are. This is because the method neglects the fact that light takes time to travel from B to A and vice versa. That is, if the distance between the clock is L , an observer will see the other clock lag his clock by $(2L/C)$ when other observer claims that they are synchronous. We certainly cannot have observers in the same reference frames disagree on whether the clocks are synchronized or not, and this is the reason why we reject this method.

So, there is an apparent way out of this difficulty. Set the two clocks to read the same time and then move them to the positions where the events occur. That is, in principle, we need clocks everywhere in our reference frame to record the time of occurrence of events. But once we know how to synchronize two clocks, we can synchronize all the clocks one by one. Since we do not know ahead of time, it is difficult to know the effect of motion of the clocks on their readings or their time-keeping ability. Because even in classical physics which is a low-speed mechanics, the motion can affect the rate at which clocks run.

So, what is the logical thing to do now? Put the clock into position and synchronize them by means of signals. There would no complications if we had a method of transmitting signals with infinite speed. The signals would go from clock A to clock B to clock C and so on, in zero time, because the speed is infinite. We could use such a signal to set all clocks at the same time reading. But no signal has this property. All known signals require a finite time to travel some distance, the time increasing with the distance travelled.

So the actual thing to do is the best signal to choose would be the one whose speed depends on as few factors as possible. We choose electromagnetic waves, because they do not require a material medium for transmission and their speed in vacuum does not depend on their wavelength, amplitude or direction of propagation. Furthermore, their propagation speed is the highest known and most important for finding a universal method of synchronization so an experiment shows their speed to be the same for all inertial observers. Now we must account for the finite time of transmission of signals and our clocks can be synchronized. To do this, let us imagine an observer at each clock A and B, with a light source that can be turned ON and OFF e.g., a flash bulb. Let L be the measured distance between two clocks or between

two observers. Both observers synchronized their clocks by using the procedure as follows: A will turn on his light source when his clock reads $t = 0$ and at that instant observer B receives the signal and he will set his clock to $t = \frac{L}{c}$. This method accounts for the transmission time and synchronizes the clocks in a consistent way. For example, if B turns on his light source at some later time t by his clock, the signal will arrive at A at a time $t + \frac{L}{c}$, which is just what A's clock will read when A receives the signal. An equivalent method to the above is to put a light source at the exact midpoint of the straight-line connecting A and B and when the light signal reaches them, they set their clocks at $t = 0$. The light will take an equal amount of time to reach A and B from the midpoint, so that this procedure does indeed synchronize the clocks. Now, that we have a procedure for synchronizing clocks in one reference frame, we can judge the time order of events in that frame. The time of an event is measured by the clock whose location coincides with that of the event. When the clocks at two different places record the same time for events, then, events occurring at these two different places are called simultaneous.

Suppose that one inertial observer does find that two separated events are simultaneous, the question is, will these same events be simultaneous for an observer on another inertial frame which is moving with the speed v with respect to the first? If not, then simultaneity is not independent of the frame of reference used to describe events. Instead of being absolute, simultaneity would be the relative concept. Indeed, this is exactly found to be true in direct contradiction to the classical assumption. To understand this, let us consider an example. Let there be two inertial frames S' and S having a relative velocity. Each frame has its own meter sticks and synchronized clocks. The observers note that two lightning bolts strike each, hitting and leaving a permanent mark in the frames. Assume that afterwards by measurements, each inertial observer finds that he was located exactly at the midpoint of the marks which were left on his reference frame. This is actually illustrated in this diagram. In figure 1 (a), these marks are left at A, B on the S -frame and at A' and B' on the S' frame. The observers being at O and O' . Because each observer knows he was at the midpoint of the mark left by these events, he will conclude that they were simultaneous if the light signals from them arrive simultaneously at his clock. This is as per our definition of simultaneity. If, one signal arrives before the other, he will conclude that one event preceded the other. Since each observer has a synchronized set of clocks, he can conclude either that the clocks at the marks read the same time when the marks were made that is the simultaneous case or that they read different times or non-simultaneous case. Many different possibilities exist in principle as to what the measurements might show. If S -observer finds that the lightning bolts struck simultaneously, will the S' -observer also find these events to be simultaneous? Now, consider figures 1(b), 1(c) and 1(d). Consider the point of view of S -frame or the observer in the S -frame and let the S' -frame moves to the right with a speed v . At the instant the lightning struck at A and A' , these points coincide and the instant lightning struck at B and B' those two points coincide but now S' -frame starts to move. The S -observer found that these two events occur at the same instant, so that at that instant O and O' must coincide also for him. However, the light signals from the events take a finite time to reach O and during this time O' travels to the right along this direction. This is shown in figure 1(b), 1(c) and 1 (d). O' has moved to the right. Hence, the signal from event BB' arrives at O' before it gets to O , whereas the signal from the event AA' arrives at O before it gets to B .

Consistent with our starting assumption, the S -observer finds that the events to be simultaneous because we see that the events both the wavefronts from the light signals reach O simultaneously. But the S' -observer, finds that event BB' precedes event AA' in time, they are not simultaneous for him. Therefore, two separated events which are simultaneous with respect to one frame of reference are not necessarily simultaneous with respect to another frame. Now, consider that the lightning bolts are struck such that S' -observer found them to be simultaneous. That means, we look at this case from the point of view of S' -observer. In that case, the light signals reach O' simultaneously rather than O .

So, figure 2 shows the point of view of S' -observer. The S -frame now moves to the left relative to the S' -observer with the velocity v . But, in this case, the signals do not reach O simultaneously, the signals from

event AA' reaches O before signals from event BB'. BB' will take more time to reach O. Hence S'-observer finds that the events to be simultaneous because at O', the signals from AA' and BB' reaches at the same time. But the S-observer finds that event AA' reaches before the event BB'. Hence, neither the frame is preferred and the situation is perfectly reciprocal and that is the reason why we say that simultaneity is a relative concept and not the absolute one.

Figures 1 and 2 become indistinguishable. (This is a figure 2), this is figure 1 and this is figure 2. Both these figures become indistinguishable if we turn them upside down. Neither observers can assert absolutely that he is at rest. Instead, each observer correctly states that other one is moving relative to him and the signals travel with finite speed c relative to him. If we had an infinitely fast signal, then simultaneity would be an absolute concept. Just because our signal has got a finite speed, the simultaneity is a relative concept.

Now there are few conclusions from the relativity of simultaneity:

Relativity of Time: Relativity of simultaneity leads to relativity of time, because in all measurements of time we use the idea of simultaneity. Time of occurrence of an event is different for the frames in different states of motion. Each frame has its own particular local time. Hence time is a relative quantity.

Next, relativity of Space: Relativity of simultaneity leads to relativity of space because in all measurements of space we use the idea of simultaneity. The length of an object is different for the frames in different states of motion. Each frame has its own local value of the length of an object. Hence space is a relative quantity.

These are the references for this module. Thank you.