LIGHT CLOCKS AND THE MICHELSON-MORLEY EXPERIMENT

MICHELSON-MORLEY EXPERIMENT

The first example of this kind is Michelson's well-known interference-experiment, the negative result of which has led Fitzgerald and myself to the conclusion that the dimensions of solid bodies are slightly altered by their motion through the ether.

H. A. Lorentz, Proceedings of the Academy of Sciences of Amsterdam, 1904

When the concept of electromagnetic waves was first developed, it was proposed that the propagation medium for these waves would be what was called the "aether". The aether filled all of space, and provided the background through which all objects in the universe moved. The aether provided an absolute benchmark against which all velocities could be measured, as the Earth does for trains and automobiles. Assuming the aether to be as large as the whole universe, it could be considered absolutely stationary, since there was no larger volume or reference frame which could contain it and in which it could be moving. Since Maxwell's equations seemed to predict a constant velocity, c, for the speed of light independent of any physical reference points, it was presumed that light traveled at c only relative to the aether.

As the Earth moves in an elliptical orbit about the sun, it actually reverses directions every six months, and over the course of its orbit passes through a full 360 degrees of velocity change. The velocity of the Earth in one direction differs from its velocity in the opposite direction by 36 miles/sec, or so. The importance of this is that an experiment to detect the aether might fail if the Earth were absolutely stationary within it, but since the planet reverses directions, at some point during the year it will be in motion with respect to the aether. There is always the possibility that the Earth *is* completely stationary in the aether, and the entire rest of the universe is in motion about the Earth. This is unlikely, though, and repeating the experiment on a space shuttle or on the moon would completely eliminate this possibility, unless of course the experiment failed.

The basis of the experiment performed by Michelson in 1881 and again by Michelson and Morley in 1887 involves the fact that when two light beams combine, they form rings of interference patterns. The cause of the interference pattern is attributable to the wave characteristics of light. One can think of a "light wave" as alternating peaks and troughs, much as a wave on the surface of a pond. By allowing two waves two interfere with each other, then at some points the peaks will coincide and the amplitude of the wave will be twice as high. Likewise, at some points a peak and a trough will coincide, and the two waves will cancel each other. In a light wave, the areas of constructive interference would be represented by a bright band of light, whereas the areas of destructive interference would be represented by a dark band, or the absence of light. By measuring the interference fringes, one can determine how far out of phase one beam is with another, or how many fractions of a wavelength one beam arrived behind another. The experiment involves sending a single beam of light into a half-silvered mirror oriented at 45 degrees to the source. In this way, half of the light passes straight through the mirror, while the other half is deflected at right angles to this path. Reflecting mirrors are placed at a fixed distance along each of these two paths from the half silvered mirror. The reflected light beams return to the half silvered mirror, with one beam passing straight through while the other is deflected ninety degrees so that the two beams once again follow the same path. This setup is depicted in frame A of figure 5-1. When the two beams combine, they form an interference pattern observed as concentric dark and light circles. By measuring these rings, one can determine how far out of phase the two beams are, or how much later one beam arrived than the other. It is not necessary to make the two path lengths exactly equal in this experiment. Once a baseline interference pattern is established, the experimenter simply looks for a change in this pattern caused by varying the direction of motion of the earth or the apparatus through the aether.

Now imagine that the apparatus is oriented such that the direction of motion of the earth through the aether is as depicted in frame B of figure 5-1. The light signal moving parallel to the direction of motion and traveling at a constant speed of c with respect to the aether, will encounter a receding mirror, thus it will have a longer path to cover. On the return trip, the half silvered mirror will be approaching, and the light will have a shorter distance to cover. These two effects do not exactly compensate each other, so the total path length differs from that for the stationary apparatus by a factor related to the square of the velocity in the direction of motion. When Michelson first performed this experiment in 1881, it was this effect which he was trying to uncover. His assumption was that, since the other arm of the interferometer was not moving directly through the aether in the direction of light travel, there would be no change in effective path length along this line. By rotating the equipment and making measurements in several orientations, various combinations of effective path lengths along each arm would be obtained, and the interference pattern would change slightly with each orientation. By carefully measuring the magnitude of the shift in each case, the velocity of the earth through the aether could be calculated.

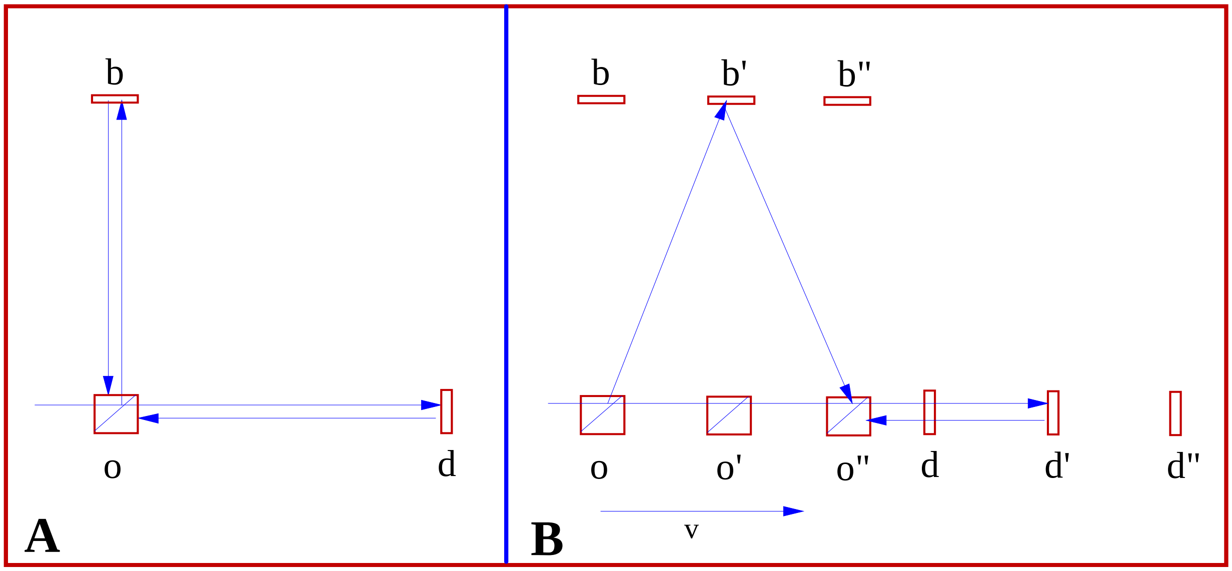

Figure 5-1 *The Michelson-Morley interferometer experiment demonstrated that the earth's motion through the aether is undetectable by any experimental means.*

Michelson was aware that there were other factors which must be controlled. First of all, if the motion of the earth were such that the apparatus was moving vertically through the aether, such that the only velocity was perpendicular to the plane of the equipment either up or down, no effect would be obtained. This possibility would be handled by performing the experiment at several times during the day. As the earth rotated on its axis, the orientation of the equipment with respect to the earth's motion through the aether would change, so that if it was vertical at one time of day, six hours later the motion would shift ninety degrees so as to be along one of the arms of the equipment. Secondly, it might be that the earth's motion through the aether exactly compensated for a motion of the entire solar system in the opposite direction. This could be compensated for by performing the experiment at several different times during the year. If the two motions exactly compensated each other in January, then six months later they would combine so as to double the effect. Though it was stated above that the two path lengths did not need to be equal, it was extremely important that the lengths not change over the course of a single test. Any change in length would cause a displacement of the fringes. Since the wavelength of the light was on the order of fractions of a millimeter, even a small change in physical path length would be as large as the expected displacement due to motion through the aether. Finally, a negative result, failure to detect any change in the fringe patterns, would indicate that there is no motion through the aether, or that there is no aether, but, of course, a negative result would not be expected.

When Michelson performed the experiment in 1881, he found what he least expected--there was no shift in the interference pattern. A review of the procedures by Lorentz resulted in the discovery that Michelson had not fully considered all the motion effects properly. It turns out that the light traveling perpendicular to the earth's motion through the aether would experience a change in path length. Referring again to frame B of figure 5-1, we see that the path followed by the light in this arm of the apparatus is lengthened proportional to the velocity by application of the Pythagorean theorem. Even so, the path length along this arm still differs from the path length along the other arm, though to a lessor extent than initially anticipated. When Michelson analyzed his results with this insight, he determined that within the range of experimental error, no conclusion could be drawn from the results. In 1887, Michelson teamed with Arthur Morley to try again. This time the experiment was set up on a sandstone block floating in a tub of mercury to ensure stability during the test. The equipment could then be set slowly in motion in a circle, and measurements could be made at different orientations as the sandstone block slowly turned in place. Additionally, the two beams of light were caused to reflect between the mirrors several times, so as to effectively increase the path length many fold, to an effective length of a bout ten meters. With this improvement, and the corrected calculations proposed by Lorentz, it was anticipated that the displacement of the fringes would be expected to change by about one-fourth of a wavelength.

The experiment was performed six times at different times of day and on different days, always with the same result--no shift in the fringe pattern developed, so there was no slowing of light in either direction. Various ideas were put forth to explain this, one of which was that the earth actually dragged a part of the aether with it as it moved. There were other ways to test whether this actually occurred, such as the aberration effects which would occur if such were the case. Eventually it was decided that the earth does not drag the aether, and the Lorentz model of length contraction due to motion dominated. Lorentz's model was conceptually simple. In the direction of motion through the aether, molecular forces were effected such that the length of the arm in that direction was shortened by just the right amount to compensate for what would otherwise be the increased path length experienced due to that motion. This concept was explained fully in chapter two. Even though Einstein was apparently not directly aware of the interferometer experiments when he formulated the special theory, he was well aware of Lorentz's analysis concerning length contraction and hinting at a preferred "local time" for moving observers. Thus the Michelson-Morley experiment, though it preceded the theory of relativity by almost twenty years, had a major though indirect influence on its derivation.

All of the above analysis, and even the cause for the experiment itself, rested on the assumption that Maxwell's equations predicted an absolute speed of c for light. This assumption resulted in the aether hypothesis, and, thus, the test for the earth' s motion through it. Since in the radiation continuum model of light, the detected speed of light depends only on the apparatus, no aether is necessary. The results of the experiment would be clearly negative with no further analysis required. In fact, had Maxwell's equations not been saddled with the assignment of measured values to his elegant constants, the Michelson-Morley experiment would never have been performed. Even so, the experiment can be used to demonstrate the effects on the apparatus in different reference frames as far as velocity, time and frequency measurements are concerned in the RCM theory, so some detailed analysis of the experiment is provided below. The point is to demonstrate that, as far as the test apparatus is concerned, the emission, reflection and combining of the light beams is simultaneous no matter what the frame of reference of the laboratory.

In frame A we see the experiment from the rest frame of the apparatus itself. Since the source and observers (mirrors) are all stationary with respect to one another, the required component of velocity along each path is c. Clearly, since each of the interferometer arms is the same length, the total time for the round trip along each path is the same. Thus the two light rays constructively interfere and the fringe pattern obtained is precisely the one we would expect. The time required for the light beam to travel the round trip of either arm is equal to twice the length of the arm divided by c.

In figure B, the apparatus is in motion horizontally along the page with a constant velocity in some frame of reference other than that of the apparatus. The location of the apparatus is shown at three different times, to indicate when and where the light will strike the mirrors and recombine. In this figure, the light travels a path from o to d' and back to o". Since d' is moving away from o at a fixed velocity, the component of light required must leave o at a velocity of c plus v. The time required for this pulse to reach d' is the same as the time required to go from o to d in frame A. If you have to drive a car to meet your friend who is parked one mile away, and you drive at 60 MPH, it will take you one minute to reach him. If your friend begins driving away at 10 MPH at the moment you begin your trip, and you increase your speed to 70 MPH, it will still take you only one minute to reach him. As long as your speed is equal to the initial 60 MPH plus your friends speed, the total time of the trip will remain unchanged, even though the distance covered is longer. In the interferometer experiment, the light component of interest has a velocity of c plus the speed of the mirror, thus the trip time is the same, even though the trip from o to d' is longer than the trip from o to d in frame A. For the return trip, d' to o", the velocity of light which must strike mirror o" is equal to c minus the velocity of the apparatus, since o" is moving toward d' at that velocity. The time required to make this shorter trip at a lesser speed is again equal to the time required to make the trip from d to o in frame A. Thus we see that the total time of the trip along the horizontal arm of the apparatus is the same in the moving and non-moving frames of reference, from the viewpoint of the apparatus itself

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We will now follow the path from o to b' to o''. As we saw in the section on perpendicular incidence and the Doppler shift, the velocity of light required from o to b' is related by the Pythagorean theorem to the sums of the squares of c and the velocity of the equipment. However, the path length from o to b' is related to the length from o to b by exactly the same relation--the ratio of the increased path length to the original is identical to the increase in light velocity required to c. Thus the situation is the same as in the case above. The time required for the light pulse to move from o to b' is identical to the time required to go from o to b in frame A. The situation for the path from b' to o'' is the same. The path length increases proportionally to the increased light velocity required, and thus, the round trip time of the light pulse along the vertical arm is the same in the moving frame of reference as it is in the stationary one. Furthermore, since the travel time along each arm of the apparatus is the same, the interference fringe pattern obtained is the same in the moving and non-moving frames of reference. Similar reasoning will show that the trip time and consistency of the fringe pattern obtained will be the same for any orientation of the apparatus and velocity chosen. This lack of change in the interference effects is the negative result which Michelson and Morley obtained, and the above analysis was performed without the imposition of an aether or an absolute frame of reference. The abolition of the requirement of an aether or absolute reference frame was viewed as one of the more important and inspiring aspects of relativity theory, promoting the acceptance of length contraction and time dilation. As we see, RCM theory does away with the need of both the aether and the concept of absolute frames of reference without invoking length contraction or time dilation.

DOPPLER SHIFT IN THE MICHELSON-MORLEY EXPERIMENT

In the last section, it was noted that different velocities of light are required at the various mirrors and detectors to have a "relative" velocity of c. Since the source of these light pulses was also in motion with the same direction and speed, the motion of the source contributed the necessary additional velocity, and the component of light which was of interest in the experiment was the light which originated with a velocity of c. This fact is important, since if this were not the case, there would have been a Doppler shift involved in the light going from source to mirror and back to the source, and this Doppler shift would be different in each direction. Results of the actual experiments indicate that this is not the case (there is no Doppler shift). We will look at the experiment again, once from the point of view of the apparatus itself as in the previous section, and again from the point of view of an observer in motion relative to the frame of reference of the apparatus. We will be mainly concerned with Doppler frequency shifts and time durations and delays, if any.

In frame B of the Michelson-Morley experiment diagram, the apparatus is moving to the right relative to our stationary reference frame. In this frame, the horizontal and vertical path lengths truly are changed, and the light emitted from the source or reflected from the mirrors must cover this actual physical space. Even so, from the point of view of the equipment, the end result should appear exactly as if the equipment were stationary, thus there should be no Doppler frequency shifts, and, as we have seen, no lengthening of the time required to make either of the round trips.

We look first at the trip along the horizontal arm. The mirror at d' must see light passing it at a relative velocity of c, or a velocity in our frame of reference of c plus the velocity of the apparatus. This light is produced by that component which leaves the source at a speed of c, since the source is also moving. The motion of the source contributes the additional velocity required to that component leaving it at c, in the same manner that a ball thrown from a moving car travels faster than the same ball thrown from a stationary platform. Since the component velocity of light detected by the mirror and that leaving the source are both c, there will be no Doppler shift in the frequency. For the return trip, in our frame of reference, the combining mirror requires a velocity of c minus the speed of the equipment. The light leaving the mirror at d' with a velocity of c will have this speed, since the mirror d' is moving as well, and contributes the additional, negative velocity required. Again, there will be no Doppler shift since the component velocity leaving the mirror is the same as that seen by o''.

In the vertical arm of the apparatus, the same situation again arises. The motion of the mirror in our frame of reference is exactly compensated by the motion of the source. The component velocity leaving the source and that detected by the mirror are both c, and there is no Doppler. The same is true for the return trip. Thus, from the point of view of the apparatus, we saw from the previous section that the time of the light beam's travel through each arm

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of the interferometer is the same, and have just demonstrated that there is no Doppler. This is exactly as we would expect. But what does an observer stationary in our reference frame see?

Again we must rely on the rule that observers in motion relative to each other may see an event at the same location, but at different times. Thus, the observer in our reference frame will not necessarily see the two beams traverse the experiment's arms at equal times and frequencies. This is not a problem as long as the observer is able to determine his motion from measuring the different values of Doppler along each arm. We will assume the source of the light and mirror b are to the left of the observer for the entire experiment (which we will assume takes only a fraction of a second), and that mirror d remains always to the right of the observer. It may be helpful to recall at this point that, despite the following discussion, the observer cannot actually "see" the light beams traveling along each of the interferometer arms, but can see only the backscattered or reflected light.

In the horizontal arm, since the apparatus is moving toward him, our observer will see only that component of light leaving the source with a velocity of c minus the speed of the apparatus. The frequency of this light will be shifted to the blue or higher frequencies by the ratio of c to this initially slower velocity of light. Also, the time required by that component of light to cover this distance will be longer by the same ratio. If a car covers a distance in two minutes at 60 MPH, it will take three minutes to cover the same distance at 40 MPH, the ratio of times being proportional to the ratio of the velocities. As was explained in the section on Doppler shift and simultaneity, the light which the mirror reflects, traveling at c, will reach the mirror before that slower component of light seen by the observer. Thus the observer will see the reflected pulse begin before he sees the light hit the mirror. As the aforementioned section demonstrated, this does not violate causality, as the observer is not actually "seeing" the light at these distant surfaces at all. This aside, the component of light which the observer then "sees" reflected from the mirror has a velocity of c plus the speed of the apparatus, which is now moving away from him. The frequency will thus be shifted to the red or lower frequencies, and the time required to cover the distance to the combining mirror will be reduced by the ratio of c to this initially faster component of light. The observer will see the reflected pulse return to the combining mirror before the apparatus does. Chapter three outlined the means by which the observer can determine his velocity with respect to the apparatus based on the two frequencies he observes. It is the Doppler shift he encounters that allows him to account for the apparent early reflection from the mirror and to calculate the time and frequency at which the light actually traversed the apparatus. From this he can deduce that in the frame of the equipment, there would be no effect in the outcome of the experiment due to the relative motion between him and the interferometer.

In the vertical arm, the observer must "see" the light travel the path from o to b' at a speed of c. According to the Pythagorean theorem then, the required initial velocity component of light along this line must be related to the difference of the squares of c and the observer's velocity toward the apparatus. This initial velocity is less than c, and the frequency seen by the observer is shifted to the blue or higher frequencies. This light also reaches the mirror later than the component which the mirror actually reflects, so the observer is again in a position of seeing the reflected pulse begin before he sees the beam reach the mirror. The analysis for the return trip is identical, as the observer is still moving toward the apparatus. It is interesting to note that the delay between the time at which the apparatus responds to the beam of incident light and the time at which the observer "sees" the light strike either the mirror b or the combining mirror is exactly proportional to the time delay proposed in relativity theory. We will demonstrate more clearly in the section on the effect of motion on light clocks that this is not an actual time dilation, but is simply an expression of the relation between the relevant velocity components of light in each observer's frame of reference.

SIMULTANEITY AND THE GAMMA FACTOR

We have seen that, in general, two observers in motion with respect to each other will not observe the same distant event at the same time or at the same location. They will agree on the location of and time of the event, but will experience the effects of (light from) the event at different times or different locations, or both. In the special theory of relativity, on the other hand, observers in motion will observe the event at the same place and time, but disagree on the distance to, and time since, the event. The relativistic model also states that observers in motion will suffer a contraction in length and a slowing down of clocks relative to the "stationary" observer (in the "proper" rest frame) due to the motion involved. Note that it does not matter which observer considers himself "stationary", the other observer will suffer the time and length contraction. The value of this length contraction and time slowing is given the symbol gamma (γ), and is related to the velocity of the moving object by one over the square root of one minus the square of the velocity, with the velocity expressed as a fraction of the speed of light. It is this time and length contraction which allows the two observers in motion to reconcile the time and location of the event--they simply agree that neither knows how long his rulers are or how fast his clocks run in an absolute sense. The following example will present this idea more fully, and then reconcile it to the radiation continuum model.

In figure 5-2, we have two observers, Alice and Bob. We are going to set things up such that Alice and Bob are at the same location when the light from a distant explosion reaches them. Since we are considering the relativistic model, in which there is only one component of light and that component travels at the universal speed of c, the light from the explosion will reach both observers at the same time. For convenience of notation, we will again define a distance or length of 300,000 km as one light second, denoted 1 ls, since this is the distance light travels in one second at a speed of c. Bob is at the end of a measuring rod which is 10 ls long. Alice is at the end of a measuring rod which is half this length, 5 ls. The far ends (left side of figure) of both Alice's and Bob's rods are at the source of an imminent explosion which will leave marks at the end of their rulers and send a burst of light hurtling towards them. Alice and Bob are aware of their motion with respect to each other, separating at a velocity equal to six tenths of c, though neither observer knows its velocity with respect to the source of the explosion itself. In frame A, Alice presumes herself to be stationary with respect to the event. She observes the mark at the end of her rod, and deduces that the event must have occurred five seconds ago, the time it would take a light signal to travel the length of her rod. Bob, who also presumes himself to be stationary, observes the mark on his rod at 10 ls, and concludes that the event occurred ten seconds ago. This would be fine if both observers actually were stationary with respect to the event, and also observed the flash at different locations, but Alice and Bob observe the light when they are both at the same location, and also know that they are separating at a velocity of .6c. Clearly, one of them is mistaken as to the time of and distance to the event. Alice resolves the apparent paradox as follows. Since Bob is in motion at .6c, lengths contract in his frame of reference by the γ factor, which for this velocity is 1.25. This means that in Alice's frame of reference, Bob can fit a 10 ls measuring rod in a shorter space, one which is 8 ls long. Thus, his initial location is actually 8 ls, not 10 ls, from the event, in Alice's space. Furthermore, since Bob is moving toward the source at .6c, Alice calculates that, at the time they observe the light, five seconds after the event, Bob has moved from 8 ls a distance of his velocity times the time, so that he is now only 5 ls from the event, in agreement with Alice's own findings. Now that Alice has determined to her own satisfaction that Bob is in motion, she proceeds to reconcile the time differences. She explains to Bob that, in his own frame of reference, he must subtract from his measurement of 10 ls the distance he moved in one second, so that he must consider the event to have occurred at a distance of 4 ls from their current location. The time it would take light to travel this distance in Bob's frame is 4 seconds. Since the time in Alice's frame is 5 seconds, Bob's clocks must have slowed down so that they can only fit 4 seconds worth of clock ticks in a "proper" (Alice's frame) time of 5 seconds. Thus, once Alice applies the gamma factor to account for the slowing of Bob's clocks, she arrives at a time of explosion in agreement with her own. {{Notice how these length contractions and time dilations appear only in Alice's view of things, and not to Bob himself. The entire effect arises simply because, in special relativity, the assumption is made that Alice and Bob will each see the light of the flash at the same place and at the same time!!! Alice is assuming that bob sees the same component of light that she sees, namely the on traveling at c in her frame of reference. As we have demonstrated earlier, third party observers cannot actualyy "see" light traveling toward a mirror or another observer, and the light that they are sensitive to is not the same component ….}} Alice is now certain as to the location and time of the event, and she is certain that Bob's rulers have shortened and that his clocks have slowed due to his motion. But what about Bob?

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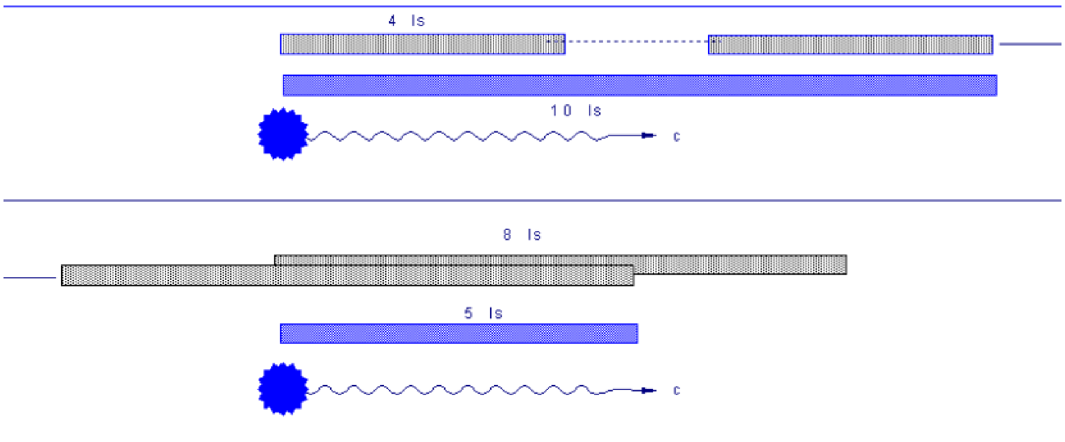

Figure 5-2 Under the rules of special relativity, Alice and Bob can never agree on a specific distance to and time since a remote event.

By looking at frame B of figure 5-2, we can see how Bob views the problem. Bob insists that Alice is moving away from the source at .6c, and that therefore her rod is shortened by the gamma factor to a length of only 4 ls. Thus she was actually only 4 ls from the event when it occurred. Since Bob sees the light after ten seconds, he calculates that Alice would be at a location equal to her initial 4 ls plus the distance she traveled in ten seconds. This would place Alice at 10 ls from the event when they observe the flash, exactly the distance Bob had assumed all along. As to the time since the event, Bob explains to Alice that, in her frame of reference, she must add the distance she moved in the time since the event, 3 ls, to the length she measured on her rod, 5 ls. Thus the correct distance she should be using in her space is 8 ls, and it would take the light 8 seconds to cover this distance in her space. The reason this time is not the ten seconds measured by Bob is that Alice's clocks have slowed by the gamma factor so that she can fit only 8 seconds worth of ticks in the ten seconds since the explosion. Bob is now certain as to the location and time of the event, and he is also certain that Alice's rulers have shortened and that her clocks have slowed.

Alice and Bob are each equally certain, and yet they have each reached different conclusions. They were able to resolve the relative distance to and time since the event in each others reference frames, but, since they don't know which of them was in motion with respect to the event, they cannot agree whether the event is 5 ls or 10 ls away from the supposed mutual observation point (of course, if neither is stationary with respect to the event, then it could have occurred at almost any location in space, depending on the speed at which they are actually approaching or receding from the event). In fact, not only can they not agree as to the exact location and time of the event, but the whole concept of an exact point in space and time has no meaning in the special theory. All concepts of simultaneity, distance and time are relative, and differ from observer to observer. No two observers in motion relative to each other will share the same set of simultaneous events, distances to anyone or anything, or measurements of time. What they are able to agree on is that the square of c times the time since an event minus the square of the distance to that event has the same value in all frames of reference.

Now, consider the same example from the radiation continuum model point of view. We will begin by stressing once again the key difference in the analysis of simultaneous events between relativity theory and RCM theory. In relativity theory, observers in motion with respect to each other will each see the light from a distant event at the same place and at the same time. In RCM theory, these observers may see the light at the same place, but at different times, or at they may see the light at the same time, but at different points in space. They may also see the light at different times and at different points is space, though they will always ultimately be able to agree on the time of and relative distance to the event. As is illustrated in figure 5-2, Alice is carrying a rod which is 5 ls long, while Bob is carrying a rod which is 10 ls long. These lengths correspond respectively to Alice's and Bob's distance from the event at the time of the explosion. Alice and Bob are therefore initially 5 ls apart at the time of the explosion.

Since the mark on Bob's rod is at 10 ls, he knows that the explosion occurred ten seconds before he saw the flash, whether or not he is moving, since in his frame of reference the velocity of light is always c. If he assumes himself to be stationary, he will conclude that the event occurred ten light seconds from his location at the time he

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sees the flash. If he considers himself to be the one in motion, toward the source, he will determine that the explosion occurred 4 ls from his position at the time at which the light from the flash reaches him. In either case, Alice will be 1 ls to Bob's right when he sees the flash, since that is how much their relative separations will change in ten seconds. Alice, on the other hand, knows that the event occurred 5 seconds before she saw the flash, since that time corresponds to the distance to the mark on her rod. If she is stationary with respect to the source of the flash, then the explosion occurred 5 ls from her position. If she is moving, then she must add the distance she moved and conclude that the event occurred 8 ls from the point at which she sees the light. In either case, Alice will still be 2 ls to the left of Bob when she sees the light, since their relative separations will not have changed as much in only 5 seconds. Thus we see that since Alice is moving away from the source with respect to Bob, she is sensitive to a higher velocity component of light, and will see the flash before Bob does. In fact, she will see the light while she is still to the Bob's left, and then proceed to pass him (or he will pass her), and be to his right by the time he sees the flash.

Now, we know from setting up the experiment that the explosion did indeed occur ten seconds before Bob saw the flash and 5 seconds before Alice saw the flash, so each is correct as to the time of the explosion. Alice is correct in assuming the event occurred 5 ls from her initial location, and Bob is correct in deciding the event occurred 10 ls from his initial location, as Alice and Bob were initially 5 ls apart, the difference of these two values. All of this can be determined without knowing which observer was in motion with respect to the source. However, if these two wish to pinpoint the exact location of the explosion compared to their current position, they each have to decide their velocity with respect to the source. If they know the expected frequency of the flash, or of any characteristic part of the flash, then each can determine their velocity toward or away from the event by using the concepts developed in chapters three and four concerning velocity and Doppler shift. Now they will agree not only as to the time of and relative distance to the event, but, using the Doppler shift, will also agree as to the exact distance to the event from their current location. Note that Alice and Bob were able to come to these agreements without the need to challenge each other as to the lengths of their rulers or the ticks of their clocks. The only item which Alice and Bob cannot agree on is their location relative to each other when each sees the light. Alice sees the light when she is to Bob's left, while Bob sees the light when Alice is past him to his right. In the special theory of relativity, their mutual location at the time they observe the light is the only point on which they can agree. In the Gallilean framework of RCM theory, Alice and Bob never can agree on these items, since each observer is seeing a different component of light with a different velocity. It would be like two cars, starting at the same place and time, one at 50 MPH, the other at 20 MPH, trying to agree on the time of their mutual arrival at the 100 mile marker. They cannot agree because the presumed event can never occur.

THE EFFECT OF MOTION ON LIGHT CLOCKS

According to the relativistic model of light, clocks in motion will slow down relative to stationary clocks in proportion to the gamma factor. Actually in this theory, not only do clocks slow down, but time itself is slowed (dilated) so that all objects in the moving reference frame will age more slowly than their counterparts in the non-moving reference frame. The relativistic slowing of clocks can be explained with the aid of a hypothetical light clock, as in figure 5-3. This example is often used in books explaining the special theory of relativity, as it is graphically very simple. However, it must be pointed out that, in this example, as in the theory itself, we are dependent on the movement of a light signal as seen from different frames of reference. This, in itself, poses no problem, but in relativity theory, the light signal must always obey Einstein's second postulate--the speed of light must be c from all frames of reference. Once again we shall see that it is the imposition of this postulate that causes the slowing of the clock in motion, and that this effect is not necessarily related to an actual slowing of time itself. In figure 5-3, the two ground clocks are stationary and synchronized, and separated by a distance equal to that covered by the moving clocks in five units of time. Time in these clocks is established by means of a light pulse reflecting from two parallel mirrors. The time from the start of one round trip of the pulse to the start of the next is defined as one unit of time. In order for a pulse to start, obviously, the light from the previous pulse must reflect off the top mirror and strike the bottom mirror. The reflection from the bottom mirror defines the start of the next pulse, and also the next unit of time. All the clocks are identical, so as far as the stationary clocks go, one time unit in any one

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clock equals one time unit in any of the other clocks. The top figure illustrates a clock obeying the special theory of relativity. The bottom figure illustrates a clock operating under the postulates of RCM theory.

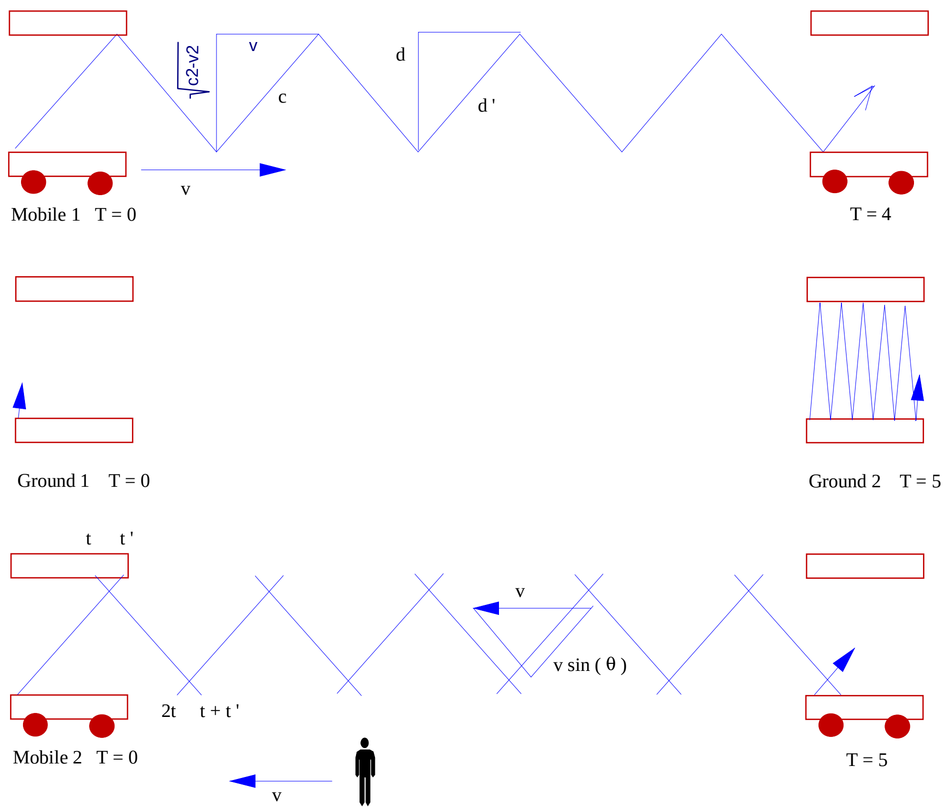

Figure 5-3 *Light clocks in motion relative to a "stationary" clock run more slowly when operating under the laws of the special theory of relativity, but remain unaffected under the conditions of RCM theory. In SRT, a clock in motion will run more slowly than a staionary clock, just be virtue of the relative motion. In RCM, this is not true. Clocks created and calibrated in any IFR will agree with clocks in any other IFR. It is the act of being placed in motion with respect to the rest frame that initiates the slowing.*

In the top figure, since the clock is in motion, the light pulse must trace out the zig-zag pattern indicated, at the invariant speed of c. From the figure, it is clear that the diagonal path length for any one way leg is related to the velocity of the clock by the Pythagorean theorem where one leg of the triangle is the velocity of the clock, and the hypotenuse is c. Thus the distance covered by the light on each upward and downward pulse of the clock is equal to gamma times the separation distance between the two mirrors. If the path length is increased by gamma, and the speed of the light pulse is a constant c, then the time for each pulse must also increase by the same factor. In figure 5-3, we have used a speed of .6c which results in a relativistic gamma factor of 1.25. With this factor, for every five ticks of the stationary or "proper" clocks, we will see only four ticks of the moving clock. It takes five seconds in the stationary reference frame for the moving clock to tick off only four seconds, thus according to the special theory, the moving clock slows down. The reason this happens in the relativistic model is that the light which the stationary observer sees strike the mirror is the same light which the mirror actually reflects--there is only one component of light, and it travels at c from every frame of reference. Thus, the mirror's ability to reflect that light properly in the reference frame of the observer depends on the motion of the observer and the skewing of time and length associated with this motion. The faster the observer is in motion with respect to the mirror, the longer the mirror has to wait for the light (which to it is coming straight up along a path of fixed length) from the mirror below. This delay, of course, supposedly occurs only in the observer's frame of reference, and is thus transparent to the mirror. The contraction of space-time caused by being in motion is what reconciles this paradox.

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But why don't we have to consider length contraction in this example? Shouldn't this provide an additional delay, or perhaps counterbalance the time delay so that the clock doesn't slow at all? The answer is no. We are concerned with the separation distance between the two mirrors, and the relative velocity between the observer and the clock. Since there is no motion in the direction of a line joining the two mirrors, there is also no length contraction in this dimension. Thus the distance between the mirrors does not change, though the distance between the wheels of the clock's platform will become smaller. Furthermore, the velocity of the clock as determined by the observer will be the same as the velocity of the observer determined by the clock. This relative velocity of separation is the same in both frames of reference, so length contraction does not apply in this manner either. We could consider this same example with the clock turned on its side, so that there is length contraction between the mirrors. In this case we have the situation depicted in figure 3-5 and explained in that section. The light will see a receding mirror on the first half of the pulse, and will see an approaching mirror on the second half. If this were the only effect, the math would work out in such a manner that the time unit would increase by the square of gamma. However, the length contraction between the mirrors in this case exactly offsets one factor of gamma, as the light has a shorter distance to cover on each leg of its trip. This leaves us in the relativistic model with a clock which again slows exactly proportionally to gamma.

In the bottom figure, the reflected light is following the radiation continuum model. In this example, the observer again sees light traveling along the diagonal path at a velocity of c. Since this light is made up of the initial component velocity leaving the source and the velocity of the clock, related by the Pythagorean theorem, the initial velocity from the source must be less than c. It is, in fact, less than c by the gamma factor, which is after all derived from the Pythagorean theorem as well. Since the component of light which the observer sees has a lower velocity than that which the mirror detects, the time required to make the trip according to the observer is longer than the time recorded on the moving clock by the factor gamma. Now, if this time dilation were carried on to the return pulse, the observer would see something very similar to the relativistic time dilation of the special theory. Remember, though, that the mirror sees that component of light which is traveling toward it in its frame of reference at a velocity of c. As described in the section on the Michelson-Morley experiment, the time required for that component of light to make the one way trip does not change when the clock is placed in motion. It is this component of light which is actually reflected from the top mirror. It is at the time of the actual reflection from the mirror that the observer sees the reflected pulse begin its journey back toward the lower mirror, even though he has not yet seen the upward moving pulse strike the upper mirror. Once again we must keep in mind that the observer is not actually "seeing" the light pulses traveling between the mirrors. As explained in chapter three, he is capable of seeing only reflected or backscattered light. Despite the fact that we can't actually see the pulses, and this applies in the relativistic model as well, the analysis provided remains valid.

In a manner identical to the above analysis, the observer sees the return pulse strike the mirror after a time delayed according to gamma, but sees the next upward pulse beginning at the same time at which the mirror actually reflects it. Thus, to the observer, the time between upward pulses does not change--it is the same value which the clock itself sees. There is no slowing down of the clock in RCM theory, at least not of a light clock constructed in the fashion described above. Obviously, even if the clock were placed on its side, the start of each reflected pulse from either mirror would begin when the mirror actually reflects that component of light to which it is sensitive, thus there is still no time delay. It is important to note that not many clocks are constructed in the manner described above. A typical clock used for measuring relativistic effects on clocks (or on time itself as the relativists contend), is a cesium time standard. The effect of motion on this type of clock is explained in the next chapter, and there it is shown that clocks of this type do indeed slow down when in motion.* The point of this discussion, using light clocks, was to illustrate that time dilation in relativity theory is directly related to the second postulate. If we are not required to accept the second postulate, then we are not required to accept time dilation as a necessary consequence.

* *ALL clocks slow when PLACED in motion, but not by virtue of simply being in motion. Thus, the fact that an observer is passing by a properly calibrated clock at some arbitrarily high velocity will have no effect on the rate of time recorded by the clock.*

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