Simultaneity

We see then that there is a close interrelationship of the definitions of simultaneity, length and time interval, and the fact that all observers obtain the same measured velocity for light implies that all three of these concepts must be considered not as absolutes but rather as having a meaning only in relationship to a frame of reference.

David Bohm, 1965

What is meant by the idea of simultaneous events? The most straightforward and intuitive definition would be that two events are simultaneous if they occur at the same time. Implied in this definition are the ideas of absolute space and absolute time, dating formally to the writings of Newton and conceptually to even earlier times. Under this definition, all events throughout the entire universe occurring at a specific instant of time would be considered simultaneous. The relative distances to these events are not important. Nor does the amount of time required to send a signal telling of the occurrence of an event affect its simultaneous nature. For example, consider a child born on February 26, 1993 at 2:00 p.m. EST in San Diego, California. The parents are preoccupied with the birth of their new child, and pay no attention to world events for a few days. On February 28th, the father reads that, at the moment his daughter was born, explosions rocked the World Trade Center building in New York. These two events were separated by 3000 miles, and it took two days for the "signal" from one event to reach the location of the other. However, it is clear to any outside observer that the events were simultaneous.

Not so according to the special theory of relativity. Einstein's second postulate leads to the impossibility of assigning common times and distances to widely separated events. Minkowski declared in an address in 1908 that "Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality." The problem in relativity theory lies in the inability to accurately synchronize clocks in different moving frames of reference. While there was no one in motion in the above example, we can imagine a vacationer flying en route to New York at the time of the birth and the explosion. In order for this observer to record the actual time of the birth and explosion, a radio or light signal from each would have to reach the plane signaling their occurrence. It is the propagation of this signal under the rules of the second postulate that causes the problems. To illustrate this explicitly, we will use Einstein's classic example of a passenger on a train that moves at a good fraction of the speed of light, and an embankment on which stationary observers may sit and watch.

Suppose in figure 3-1 that two gunpowder explosions, P and Q, occur simultaneously on the banks of the railroad tracks. That is to say that a stationary observer, Alice, seated on the bank and located midway between the two events observes the two flashes of light from the explosions at the same time. If Alice has a very long rod which stretches in both directions beyond events P and Q, and if the rod is close enough to the events that the explosions will leave marks, then Alice will be able to measure the distance to each event after it has occurred by marking off the distance from her location to each of the marks. We will define a distance of one light second as 300,000 km; the distance light travels in one second at the speed of c. We will also set up the experiment such that the distance Alice measures on her rods is six light seconds. Therefore Alice concludes that the events occurred simultaneously, six seconds before she saw the flashes.

In the same figure, let us look at Bob, who is traveling on a train moving at a velocity of 0.5c. Further, let's schedule his arrival at Alice's location to coincide with the time at which she observes the two flashes. According to the special theory of relativity, Bob will also see both flashes at the same time. However, since Bob has moved three light seconds in the six seconds since the explosions, he was initially three light seconds closer to explosion P and three light seconds further away from explosion Q when they occurred. Since Bob considers himself to be at rest, he does not take his movement into account when recording the distance to each of the explosions. Thus he measures on his rods a distance of three light seconds to explosion P and nine light seconds to explosion Q. From this he calculates that explosion P occurred three seconds ago and that explosion Q occurred nine seconds ago, since the light he sees traveled these distances at a speed of c in his frame of reference. According to Bob, the two events were not simultaneous. As we stated in chapter one, according to the special theory of relativity, Alice and Bob will see the event at the same time *and* at the same place, but will be unable to agree on a common distance to or time since the events, thus rendering the concept of simultaneity meaningless.

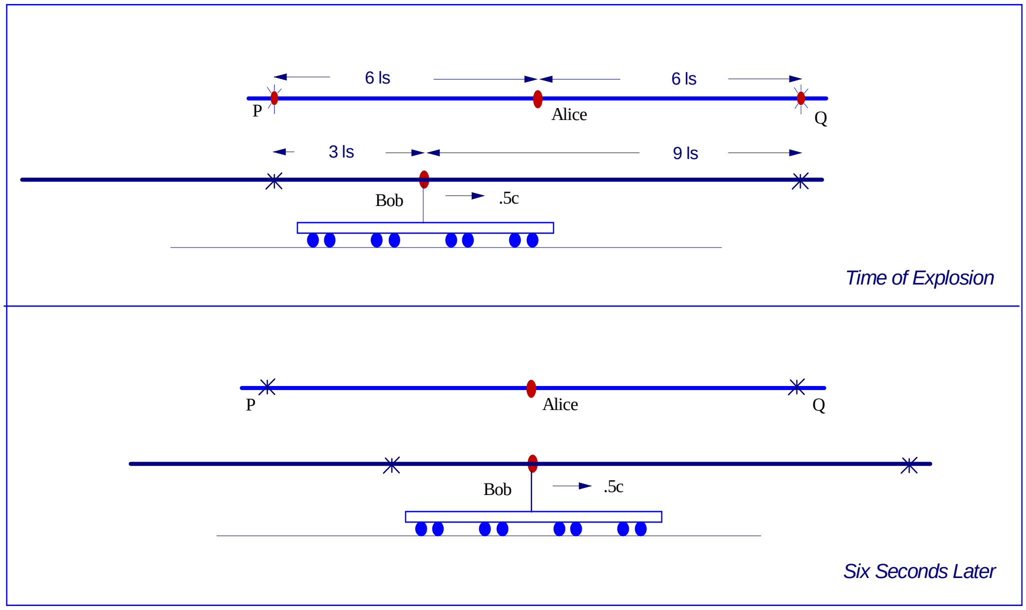

Figure 3-1 Simultaneity in the special theory of relativity: Alice and Bob will each see a flash of light at the same place and at the same time.

Now let us view the same experiment in terms of the RCM theory, as depicted in figure 3-2. The situation for Alice remains unchanged. She will observe the flashes six seconds after the explosions occur, and be left with marks on her rods indicating a distance of six light seconds to each of the events. As for Bob, we will schedule his trip slightly differently than in the previous example. Let us schedule his arrival at Alice's location to be four seconds after the explosions (an odd choice, the reason for which will be clear as the example progresses). Since Bob is traveling at 0.5c, he is sensitive to that component of light which is leaving explosion P at a velocity of 1.5c. This component will cover the six light seconds from point P to Alice in four seconds, and arrive just in time for Bob to see the flash. Since Bob has been traveling at 0.5c for four seconds since the explosion, then he was two light seconds closer to point P when the explosion occurred. Thus the mark on his rod will indicate that the explosion was four light seconds away. Once again, since Bob is unaware of his motion, he assumes that the light which he sees traveled this distance at c, and calculates that the explosion must have occurred four seconds earlier, which, of course, it did. We now see that Alice and Bob agree as to the time of explosion P, something they can't do under special relativity, but they have yet to agree on the distance to the explosion. We will dispense with this shortly. For now though we see graphically that two observers in motion relative to each other may see the light from an event at the same place but at different times. The case of explosion Q is a little different.

We know from the preceding paragraph that at the instant of the explosions, Bob was two light seconds further away from Q than Alice was. Thus the mark on Bob's rod indicates a distance of eight light seconds to Q at the time of the explosion. Since Bob is moving toward Q, the component of light that he can see must be leaving Q with a velocity of 0.5c. With Bob and the light each traveling at 0.5c, the light will only need to travel four light seconds from Q before it and Bob are at the same location and it strikes him at a relative velocity of c. It will take this component of light eight seconds to cover a distance of four light seconds at 0.5c. Thus Bob will see the flash from Q eight seconds after the explosion occurs. Since, from the mark on his rod, he assumes the explosion occurred at a distance of eight light seconds, he concludes that the explosion must have occurred eight seconds before he saw the flash, as of course it did. This time, Alice and Bob see the light at different locations and at different times, but they once again agree as to the time of the explosion. More importantly, they each agree that explosions P and Q occurred *simultaneously*. If we could now get them to agree as to the location of the explosions, then the concept of simultaneity as Newton defined it would be complete.

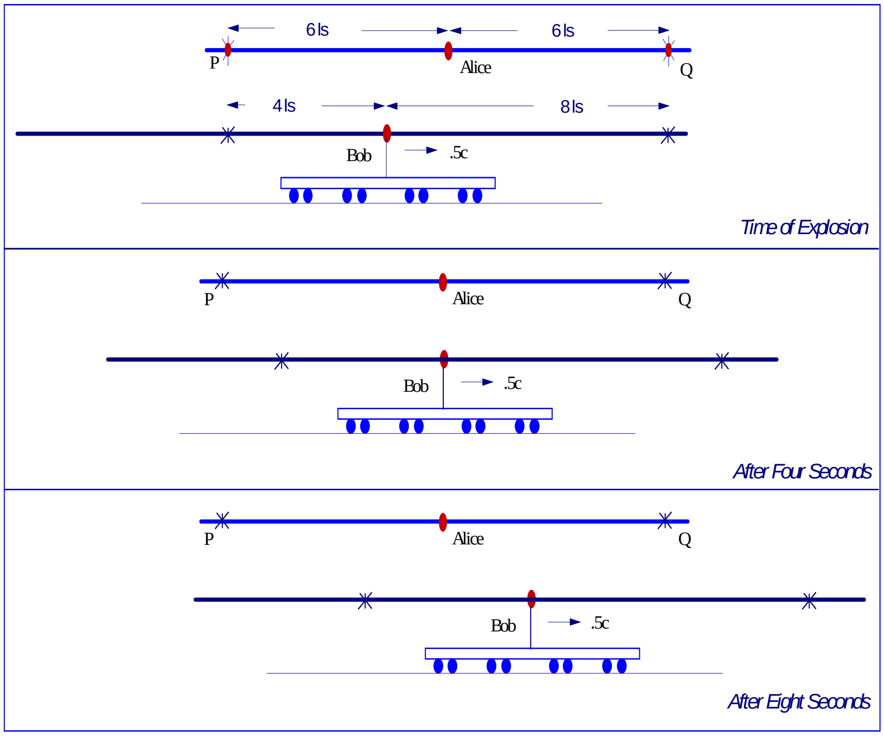

Figure 3-2 Simultaneity in the Radiation Continuum Model: Alice and Bob will see the flashes at different times and locations.

Let's begin by assuming that Bob knows he is moving with respect to Alice and the explosions. In the case of explosion P, then, Bob knows that he has been traveling for four seconds since the explosion and has covered a distance of two light seconds by the time he reaches Alice's position. He must add this to the length of the mark on his rod, four light seconds, to get the actual location of the explosion, which is six light seconds from Alice. So far so good. Regarding explosion Q, Bob has been traveling for eight seconds, or four light seconds at his speed of 0.5c. He must subtract this value from the length of the mark on his rod, since he has been traveling toward the explosion, and concludes that the event occurred a distance of four light seconds from his current location. Since he was initially two light seconds in front of Alice and has traveled four light seconds, he must now be two light seconds past Alice. Therefore, explosion Q must have occurred a distance of six light seconds from Alice. This is, of course, the correct answer.

Thus, in this example, both Alice and Bob deduced that events P and Q occurred at the same time, each at a distance of six light seconds from Alice. The important point in the above example can be seen by considering just the observations of explosion P. In RCM theory, Alice and Bob see the explosion at the same place but at different times, though they are able to agree on the location of and time since the event. In classic problems addressing the question of simultaneity in Lorentz-Einstein relativity, it is assumed that observers in motion relative to each other observe the event at the same place *and* time, thus leading to their inability to agree on the time and location of the event, and to the concept of relative space and time. This effect is a direct result of the second postulate, and exists only in thought experiments such as the one above. There has never been any direct experimental confirmation of this concept. One reason for this is that until very recently, the technology to perform such a test has not existed. Another and more compelling reason is that no one, until now, has ever questioned the validity of the statement. David Bohm, in describing the relativistic train experiment in his book *The Special Theory Of Relativity*, states "*Of course* [Bob] will also see the two flashes at the same time." He also goes on to address the nature of the second postulate being tied to physical measurements, even though it is treated as an absolute condition: "In fact, however, all observers must assign the same speed to light, since as we have seen, experiments show this to be the case. Therefore the train observer can no longer agree that the two flashes are simultaneous, because they cover different distances at the same speed." In his book *Einstein's Theory of Relativity*, Max Born repeats two statements, one from Newton's theories, the other from Einstein's:

1. According to classical mechanics the velocity of any motion has different values for two observers moving relative to each other.

2. Experiment informs us that the velocity of light is independent of the state of motion of the observer and has always the same value c.

He then makes the assertion that "Of the two statements (1) and (2), the first is purely theoretical and conceptual in character whereas the second is founded on fact." This is an interesting conclusion. The first statement is based on hundreds of years of direct experimental verification, albeit for relatively slow moving objects. The second statement is based on absolute conjecture, and has not been tested by experiment. The experiment which resulted in the statement, that of Michelson and Morley, demonstrated that the speed of light is dependent *only* on the observer, as opposed to the source or the background aether. In all experiments of the determination of the velocity of light, the determination has been made by the observer. Yes, the velocity of light has always the same value *c*, but that velocity is *always* dependent on the state of motion of the observer, in complete contradiction to the "fact" of statement (2).

The General Case Of Simultaneity

In the above example it may appear that in order to correctly deduce the locations and velocities of Alice and Bob and explosions P and Q, we would have had to invoke additional knowledge about the locations and relative velocities not privy to the actual observers Alice and Bob. We in fact began with the assumption that we knew Bob was moving relative to the source of the explosion. Since we were using trains and embankments, this was not an unreasonable assumption.   But what if we have no arbitrary "stationary" reference frame. Are we still able to determine the simultaneity of events? It will be sufficient to show that we can consistently agree as to the time of and relative distance to a single event, since this can then be extrapolated to the case of multiple events.

Consider the situation depicted in figure 3-3. Here an explosion is about to occur at some undefined point in space. Bob is in a spaceship some as yet undefined distance from the immanent explosion, traveling with an undetermined velocity relative to the event, in the direction shown. Bob is again carrying an extremely long measuring rod on which the explosion will leave a mark.

The explosion occurs and blackens Bob's ruler at a certain point. Bob is not yet aware of the explosion, as the light has not yet reached him. The light to which Bob is sensitive will have a velocity of c plus his velocity with respect to the source. At the instant the light reaches Bob, he will note the time and begin reeling in his ruler to determine how far away the explosion occurred. Suppose he records a time of one second past noon and measures a distance of 300,000 km (any time and distance will do, it is simply easier to speak of specific examples than in generalities). Bob now knows that the explosion occurred at exactly noon, since it takes light one second to travel 300,000 km. Bob is unaware of his motion relative to the source, and does not need to know it in order to determine the time of the event. He knows that, for him, light travels at c and that it traveled 300,000 km in one second to reach him. If we also allow Bob to know his velocity with respect to the explosion, he will deduce that the event occurred at a distance of 300,000 km plus the additional distance he traveled in the one second it took the light to reach him.

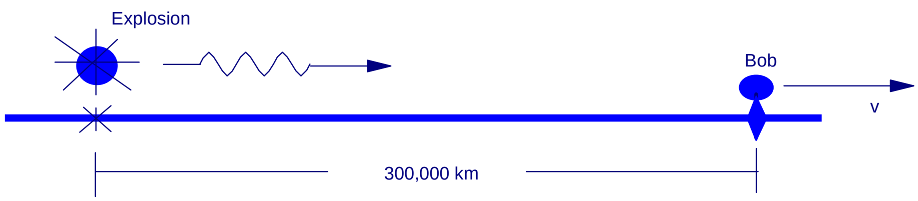

Figure 3-3 Observers at any velocity relative to the event or each other will be able to agree on the time of an explosion by consulting the marks on their measuring rods.

Thus we see that, from any frame of reference, Bob will correctly record that the event occurred at noon, and, if his velocity with respect to the event is known, he will deduce the correct location as well. No matter how many observers we have, traveling at any velocity and starting at any given location from the event, each will agree on the time of the explosion. If they know their velocity with respect to the event, they will also agree on its precise location relative to their current ones. The observers do not need to actually carry long measuring rods with them. If they know their distance from an event at the time of its occurrence, say from New York to San Diego, or if they can determine it from some other means, the effect is the same as carrying a measuring rod. Note that if the observers know their velocity relative to each other, but not relative to the event, they will agree on the relative distance to the event from any observer, but will be unable to pinpoint the exact location since they are unaware of any motion with respect to the event itself. Fortunately, thanks to the Doppler shift, any observer can accurately determine his velocity with respect to the source, as explained in the next section.

Doppler Shift And The Determination Of Velocity

Doppler shift is the name assigned to the shift in frequency experienced when an observer is in motion relative to the source of the frequency. The classic example of this is the change in pitch (frequency observed) of a train whistle as it is approaching an observer and when it is moving away. During the approach, the pitch (frequency) is much higher than when the train is moving away. The explanation for this is straightforward.

Sound travels through the air at roughly 1000 ft/sec (fps). A train whistle has a frequency of about 100 cycles per second, or 100 Hertz. The wavelength of the sound is equal to the velocity of the sound divided by the frequency, or ten feet, and is a measure from the top of one peak to the next, or of one cycle. Wavelength is usually denoted by he symbol lambda, or λ. Another way to look at this is that the frequency is equal to the speed of sound divided by the wavelength. That is to say that 100 peaks (cycles) of the sound wave will pass a fixed point in one second. If the train is moving toward the observer (or the observer moving towards the train) at 100 ft/sec, the observer will detect approximately ten extra cycles of the sound per second. This is because each cycle is ten feet peak-to-peak, and the observer will effectively move across ten of these peaks during one second. This is depicted in the top half of figure 3-4, with the observer moving towards the train at 100 ft/sec for clarity of illustration. The impression that the observer gets (on his ears) is that during that one second, 110 peaks went past his ears to produce a sound with a frequency of 110 Hz.

Another way to look at this example is that, since the train is approaching at 100 ft/sec, the effective speed of the sound passing the observer is 1100 ft/sec (the speed of the train plus the speed of the sound "thrown" from the train towards the stationary observer). The frequency of this sound will be given by the speed divided by the wavelength (1100fps/10ft) or 110 Hz. This is illustrated in the bottom half of figure 3-4. By similar reasoning, as the train is moving away from the observer, the observer will detect approximately ten less peaks during a second, resulting in a perceived frequency of 90 Hz.

The reason the Doppler shifting of sound occurs in the above example is due to the fact that the speed of sound is *not* invariant for all frames of reference. In other words, a stationary observer listening to the gong of a stationary bell at 100 Hz (wavelength of ten feet) will perceive the sound passing him at 1000 ft/sec, while an observer moving towards the bell at 100 ft/sec will perceive the sound passing him at 1100 ft/sec, thus giving rise to the increased pitch described above. If another observer is moving away from the bell faster than 1000 ft/sec, he will never hear the gong of the bell, since he is moving faster than the sound from the bell, and this sound will never reach him. The classic example of this is the case of a jet breaking the sound barrier. In this case, as the jet is moving towards you, and approaching the speed of sound, the noise is being generated closer and closer to you, and the sound waves are beginning to bunch up. As the jet achieves the speed of sound, the jet is generating noise on top of the original noise, which is traveling right along with the jet. The result to you is that you are ultimately hit with a solid wall of noise, the characteristic "sonic boom". Once the jet pushes through the sound barrier, you actually hear the sound of the jet passing overhead before you hear the sound of the jet approaching. You see the jet flying one direction, yet your ears tell you it is traveling in the opposite direction.

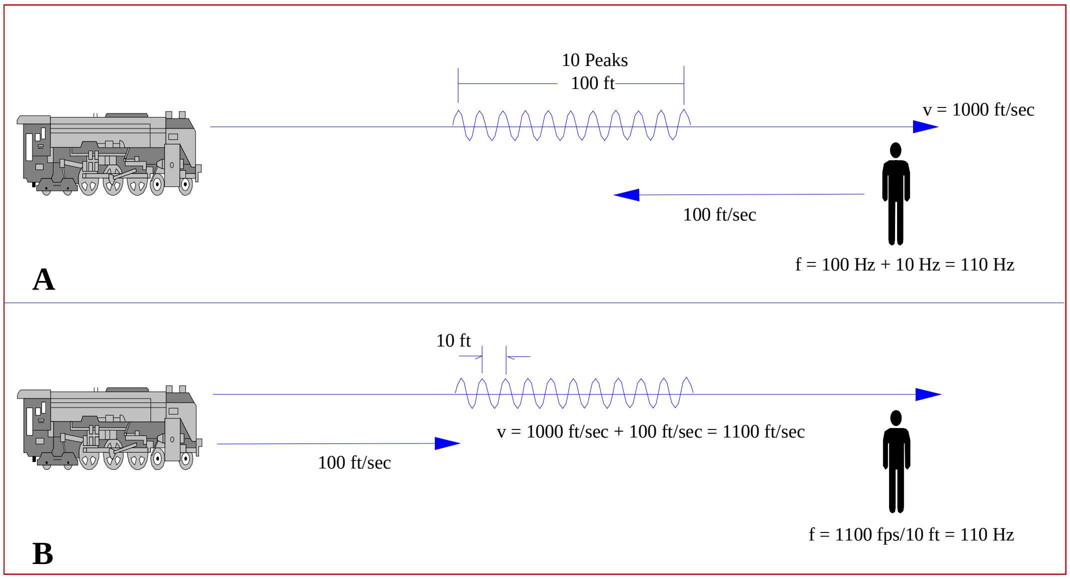

Figure 3-4 The Doppler shift causes the whistle of an oncoming train to be heard at a higher frequency proportional to the relative velocity of the train and the listener.

To view the example of the bell from another perspective, if the speed of sound *were* invariant for all frames of reference, the observer moving towards the bell would perceive the sound as passing him at 1000 ft/sec, as would the stationary observer. The frequency of the sound heard for each observer would be given by the speed divided by the wavelength or 100 Hz. Thus each observer would hear the same pitch from the bell. We know from experience and investigation that this is not the case, and therefore, the speed of sound is not invariant from all frames of reference.

Light or radio waves observed from a point in motion relative to the source experience a shift in frequency due to this relative motion--the Doppler shift. The observed frequency of light is always given by c times one over the wavelength (l^{-1}). Remember that light is emitted from the source at all velocities from zero to C. In order for all light emitted from a source to have the same frequency, the wavelength of the light must therefore be proportional to the component velocity of interest. Slower components will have shorter wavelengths while faster components will have longer ones. This knowledge can be used to determine the frequency of light that an observer will see if he is moving away from the source at some arbitrary velocity. If we call the component velocity of light leaving the source the "initial velocity", then λ^{-1} is equal to the frequency of the source divided by the initial velocity. The shifted frequency of the observer is then given by c times one over the wavelength or c times the frequency divided by the initial velocity. With light, lower frequencies are redder, while higher frequencies are bluer. Thus if the source and observer are moving away from each other, we say the light is red-shifted, while if they are moving toward each other we say it is blue-shifted.

Now if the observer knows the expected frequency of the source (say the absorption spectrum of Hydrogen), he can determine his velocity with respect to the source by solving the above relation for frequency shift in terms of velocity. Thus the relative velocity between the source of light and the observer is equal to c times the ratio of the Doppler shift to the observed frequency. This relation is not the same formula used for determination of velocity in the classic sense involving sound. With sound, the actual velocity of the wave that the listener hears changes, while with light the velocity seen is always strictly c. However, the two formulas are accurate to within the most insignificant decimal places. The formula is also not the same as the formula derived in special relativity, though the differences become significant only when one's speed approaches c. This presents no problem for almost any experiment one can think of. In fact, the formula normally associated with the Doppler shift in sound was successfully applied to light to make one of the most important discoveries of the twentieth century.

Edwin Hubble used the light characteristic of a certain class of stars to demonstrate that they were not a part of the Milky Way galaxy. It was this discovery that led to the realization that there were indeed galaxies other than the Milky Way. By measuring the luminosity of his special stars in several galaxies, he was able to determine how far each was from the Milky Way. In 1914, Vestor Slipher had measured the spectra (characteristic frequencies common to all stars) of thirteen remote galaxies, and found that, according to the Doppler relation, they were all moving away from the Milky Way, with the single exception of the Andromeda galaxy. Hubble armed with several additional measurements, made a graph comparing the distance to the red shift in spectra for a total of twenty-two galaxies. What he found was astonishing. He discovered that the distance was proportional to the redshift--the greater the galaxy's distance, the faster it was moving away. The universe appeared to be expanding. This conclusion was made using the Doppler shift formula for sound, as Hubble wasn't even aware of Einstein's formulas. He was also reluctant to conclude that the universe actually was expanding, or that the shift in frequencies was even due to the Doppler effect. As Dennis Overbye reflects in *Lonely Hearts Of The Cosmos:*

> Einstein, in fact, had already predicted that the galaxies were just like raisins in a rising cake, being pushed apart by the mysterious explosion of space and time themselves. But Hubble had done his work in ignorance of Einstein, and he had been reluctant to draw such a grand conclusion from his own flinty data. He cautioned, in fact, that the redshifts might not be classic Doppler shifts at all, but some new physics, and perhaps should be thought of as "apparent velocities."

The importance of the frequency shift and velocity determination relations becomes clear if we return to the question of simultaneity and compare the relativistic model to the radiation continuum model. This is done in the next section. But first, we must review the nature of Doppler shift and see why it qualitatively prohibits the use of Galilean transformations under the assumption of an invariant velocity for light.

Earlier, it was shown how the Doppler shift arises in sound due to the fixed velocity of the sound wave's propagation through the atmosphere. Any two observers in motion with respect to each other will perceive a net velocity of sound equal to its velocity in the atmosphere plus their velocity toward it. A ball moving through the air at fifty miles per hour will hit your glove at sixty miles per hour if you are running toward it at ten miles per hour. It is precisely this lack of invariance in the speed of sound that results in the Doppler effect. There is another Doppler effect known as aberration. If the train in the previous example is moving toward you, the sound wave will be compressed since each successive peak is released closer to you than the one before. This will have the effect of an increase in frequency for an approaching train, and a decrease in frequency for a receding train. If a pitcher throws balls at you once every second, they will reach you once per second, or with a frequency of one Hertz (one cycle per second). If the pitcher is running toward you as he is throwing the balls, each successive ball will have a shorter distance to travel before reaching you, and the balls will reach you more frequently than once per second. Their frequency will increase due to aberration. The sonic boom of a jet approaching and then exceeding the speed of sound takes the aberration effect to the limit and causes a sonic boom as the speed of sound in the atmosphere in the jet's frame of reference reaches zero. Note that the speed of sound is not an unattainable velocity, even though this odd effect occurs at that speed. In the early ages of flying, it was felt that this was an impenetrable barrier. It was felt that a craft would break to pieces at the speed of sound due to the shock wave and other stresses. This myth was dispelled when Chuck Yeager flew the first aircraft to break the sound barrier.

The important point in the above discussions is again that it is the lack of invariance in the speed of sound (and of baseballs) in a Galilean universe that produces the Doppler effects. If the velocity of sound were invariant, then all sources would observe the sound wave leaving at a velocity of one thousand feet per second with respect to itself and there would be no aberration. The sound leaving the source would have the same frequency as the source. Likewise, all observers would hear the sounds approaching at one thousand feet per second, and there would be no Doppler shift. The frequency heard would be the same as the frequency emitted, for all listeners at all velocities. Additionally, there would be no sonic booms, as jets would not be able to outrace the very sound they were emitting, and they would therefore always travel at less than the speed of sound in their frame of reference.

And yet there is a Doppler shift associated with light. It is such a well documented effect that its uses range from tracking the velocity of aircraft using radar signals, to adjusting the frequency of radio receivers on ships at sea to account for their motion with respect to a satellite, to calculating the velocity of distant galaxies as they stream away from us through space. The aberration effect is invoked to explain the behavior of synchrotron radiation. In a synchrotron a fast moving light-emitting electron moves at close to the speed of the emitted radiation, causing a bunching up of the wave crests in the same manner as a jet approaching the speed of sound. There is even an effect similar to a sonic boom in light called Cerenkov radiation which occurs when the speed of an electron in a certain medium exceeds the speed of light in that medium. The electron does not exceed the speed of c; the medium is one in which the speed of light is less than c, and, also less than the speed of the electron. Since the Lorentz model assumes an invariant speed of light, and also accepts Doppler shifted frequencies, the familiar concept of Galilean transformations must be abandoned in relativity theory.

DOPPLER SHIFT AND SIMULTANEITY

If we return to the general case of simultaneity presented in figure 3-3, that section concludes by illustrating that if the observer knows his velocity with respect to the source, he will be able to deduce the distance to the source. Fortunately, the Doppler shift allows us to determine our velocity with respect to the source as being equal to *c* times the ratio of the Doppler shift to the observed frequency.

This is a major deviation from the relativistic description of simultaneity which states that events at different points of space that are simultaneous for one observer are in general not simultaneous for any other observer moving uniformly relative to the first. To see the difference between these two models of simultaneous events, consider the following example, illustrated in figure 3-5. In the first figure, we see Alice, who is (and remains) at rest with respect to the apparatus during the entire experiment. Two flashes of light at the same frequency are radiated from a point equidistant between two mirrors, by a source stationary with respect to the mirrors. As Alice sees things, the light pulses leave the source, travel to each mirror, strike and reflect off the mirrors simultaneously, and also return to the source simultaneously. This situation is the same in the special theory and in RCM theory.

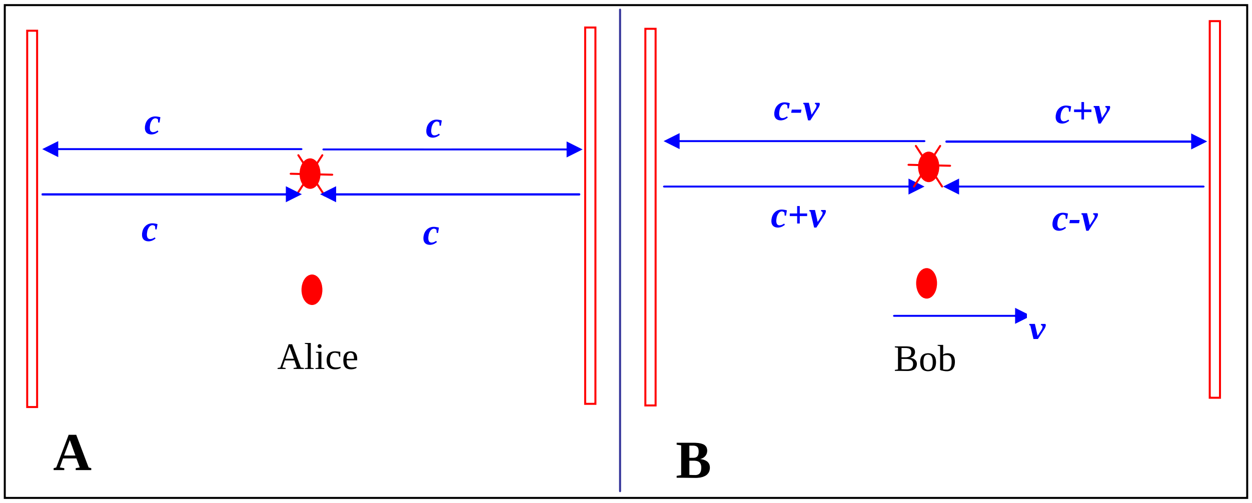

Figure 3-5 Light reflections from mirrors equidistant and stationary with respect to a source will be perceived differently by a stationary observer and another in motion.

In the second figure, Bob is in motion relative to the apparatus in the direction indicated. We will first consider the relativistic viewpoint. Bob sees the right hand mirror approaching the source, while the left hand mirror is moving away from the source. Therefore, since light travels at *c* in all frames of reference under the special theory, the light will reach the right hand mirror earlier than it will reach the left-hand mirror. After being reflected from the right hand mirror, that light will see a receding source while the light from the left-hand mirror will see an approaching source. The effect of this will be that the total distance traveled by the light striking the left mirror equals the total distance traveled by the light striking the right mirror, and the two beams will return to the source at the same time from Bob's point of view. Thus Bob concludes that the light beams struck each mirror at different times, but returned to the source simultaneously. In the relativistic model, therefore, Alice and Bob do not agree on the simultaneity of the event of light striking each mirror, but do agree on the simultaneity of each signal's return to the source. This concept results in a slowing of clocks for observers in motion (relative to Alice), which will be explained in the section on the effect of motion on light clocks.

In the radiation continuum model, Alice sees things exactly as described above. Bob, however, sees things differently. Since he is in motion, that component of light, which he sees traveling towards the right hand mirror, must have a velocity of *c* plus his velocity. He will see this light strike the mirror before the time at which Alice sees it strike the mirror. He will not, however, see this light immediately reflected from the surface of the mirror. This is because the stationary mirror does not "see" the same component of light that Bob sees. The mirror reflects that component of light that strikes it at a velocity of *c*. This component arrives at the mirror later than that component that Bob is observing. Next, the light that Bob sees leaving the mirror does so at the same time in Bob's frame of reference as it does in Alice's. Alice and Bob disagree on the time the light reaches the mirror, but agree on the time at which the reflected return pulse begins. In Bob's frame of reference, however, he can only see that component of the reflected pulse that is traveling at a speed of *c* minus his velocity, thus the light he sees will return to the source at a later time than that light that Alice sees. This is completely consistent with the RCM model of simultaneity presented earlier, which stated that observers in relative motion can see the light from an event at the same place, but at different times. For light traveling to the left-hand mirror, Bob observes only that component of light traveling at a velocity of *c* minus his velocity, slower than the component of the light which the mirror "sees" and reflects. Thus Bob will see the light reflected off the mirror before the source light he is observing reaches the mirror! (It is not actually true that Bob will "see" the reflected pulse before he "sees" the source pulse hit the mirror. It is true that the mirror will reflect that velocity component of light to which it is sensitive before the velocity component to which Bob is sensitive reaches the mirror. This is explained in the next section.). As in the above example, Bob will agree with Alice on the time of the reflected pulse's origin, but he will disagree on the time it took for the light to actually strike the mirror. Now the light component that Bob sees reflected from the left hand mirror must have a velocity of *c* plus his velocity, and will therefore return to the source before the component observed by Alice returns. In the end, Alice and Bob will agree on the simultaneity of the origin of the light pulses, but will disagree on the simultaneity of the light pulses striking the mirrors, and disagree again on the simultaneity of the reflected pulses reaching the source. How can this conflict be resolved? The answer involves looking at the Doppler shift of the light signals.

Recall that for an observer traveling in the same direction as a light pulse, the frequency will be Doppler shifted according to the relative velocities, and that the observer can then use this shift to determine his velocity relative to the source. Bob knows that the frequency of the light, which he sees moving toward the right-hand mirror, is not the same as the source pulse. He can thus determine his velocity with respect to the source and mirror, and conclude that the mirror is sensitive to a slower component of light than that which he observes. Similarly for the reflected pulse, since the frequency Bob sees will be higher than the source pulse, he knows that the light, which Alice sees, is moving faster than that which he sees.

Suppose that Bob did not know either the frequency of the source, or his velocity with respect to the apparatus. Could he still come to the same conclusions regarding Alice's perception of the events? The answer is yes, and we will use the light pulse traveling to the left-hand mirror to analyze this. Since Bob is moving toward the source and away from the mirror, the frequency he sees leaving the source will be higher than the frequency he sees reflecting from the mirror. Knowing these two observed frequencies, the Doppler shift and velocity determination relations can be manipulated to determine the source frequency. Once he knows the unshifted frequency of the source, Bob can determine his velocity with respect to the source as before. Thus both Alice and Bob conclude that *from the view of the apparatus*, the emission of the two pulses was simultaneous, the reflection from each mirror was simultaneous, and the arrival of the two beams back to the source was simultaneous.

The major problem with the relativistic model is that it assumes that the time at which the light strikes the mirror in Bob's frame of reference is the same time at which the mirror itself is struck in its frame of reference. Thus, from the perspective of either Alice or Bob, the mirror reflects the same pulse of light at different times, depending on the observer's frame of reference. This is troublesome for the mirror, which has no knowledge of either observer. As with the radiation continuum model, Bob detects the Doppler shift in his observed frequencies, though he is unable to use these shifts to resolve the timing differences, and instead must use Lorentzian time and length contraction due to motion. Even armed with this information, the concept of simultaneous events in the special theory of relativity has no meaning.

Now it may seem as though we have replaced one confusing theory with a new one which is equally confusing. Light reflecting from a mirror before it arrives? How could this be? The answer lies in the way in which we actually see things, and what we can and cannot see, as the next section will demonstrate.

THE INCIDENCE-REFLECTION TIME GAP

In previous sections, our moving observers "saw" the light pulses hit the mirror at different times than they "saw" the light pulses reflected. Additionally, a moving observer sometimes "saw" a pulse reflected from a mirror before the incident pulse struck the mirror. While we have shown that this is not actually the case, as the mirror is simply sensitive to a different component of light, there is still an apparent violation of causality from the point of view of the observer. How can this incidence-reflection time gap be resolved? First, consider a different means of "seeing," involving long rods and marks, which will support the validity of the time lag.

In previous examples, our observers carried long rods with them to detect the occurrences of explosions in space and other events, so that the times of and distances to the events could be determined in one reference frame or another. In the situations described in the previous section, we will allow our observers Alice and Bob to carry two long rods with them, sufficient to stretch to both mirrors. Since the rods are traveling at the same speed as the respective rod carrying observers, then any light-detecting device on them will detect only that component of light appropriate to its own observer's reference frame. If such a device is located so that it will be opposite the mirror at the instant when light of the appropriate speed reaches the mirror, a mark will be impressed on the plate. Since each observer knows that light travels at a speed of c in his frame of reference, he can simply measure the distance to the effected plate and thus determine the time of impact by dividing by c. We could also use a light sensitive clock which stops when a pulse of light strikes it, and each observer could simply read the time on the clock when it stopped to determine the time of impact. (One must of course consider the effect of motion on the particular type of clock chosen, as discussed in chapter six). In this manner, each observer will determine that the time at which light in his frame of reference reached the mirror is not necessarily the same as the time at which the light was reflected by the mirror. Again this is consistent with the RCM concept of simultaneity which states that observers in motion relative to each other may see the light from an event at the same place, but will see it at different times. In this case the observers would be the stationary mirror and the moving observer's light sensitive clock.

Why go through all this trouble? The problem is, neither observer can actually "see" the light hit the mirror at all. They are able only to see that light which is reflected from the mirror and which returns to their eyes at a velocity of c in their frame of reference. This problem exists for the relativistic model as well as the radiation continuum model, as it is a fact of nature. When you shine a flashlight up into the night sky, you seem to "see" a column of light racing away from the flashlight and into space. Actually, what you are seeing is the reflection of the light from particles in the night air. If you were to shine that same light through a vacuum (say outside the space shuttle), you would not see the column of light at all. You would still be able to illuminate a distant reflector or mirror, and see the reflected light, but you would not see the characteristic "beam" of light connecting the flashlight to the mirror. The familiar trace of the "photon torpedoes" of *Star Trek* fame would never be seen in an actual battle.

Arthur Zajonc in *Catching the Light* speaks of an apparatus he has created for something called "Project Eureka". Basically the apparatus is an empty box into which a bright projector shines. The setup ensures that no part of the box itself is illuminated, and thus there is no reflection from the walls. Though the box is "full of light", one sees nothing but darkness upon looking inside. This is because you can see only that light which is aimed directly at your eye or that which reflects from an object toward your eye. One can pull a handle on Zajonc's Eureka box that moves a wand through the interior of the apparatus. When the light that defied observation before strikes the wand, the wand becomes brilliantly lit on one side.

In previous sections, we talked of Bob "seeing" the light hit the mirror before or after he "saw" the reflected pulse begin. If he uses the rods provided above, he will draw these conclusions. But his eyes, watching the light as it is scattered (reflected) back to him off the night sky on its journey toward the mirror, will see the light hit the mirror at the exact time at which the reflection begins. The reason for this is that each scattering particle can be thought of as a mirror. It is only the light which is reflected from these "dust mirrors" at the velocity of c minus Bob's velocity (if he is moving toward the mirror) that he will see, not the actual light pulse heading toward the mirror. We can imagine a large number of these particles, all equally spaced along the path to the mirror, as in figure 3-6. Light from the source will strike these particles at regular, equal intervals, and be reflected at regular, equal intervals. Each of these reflections will be traveling toward Bob at c minus his velocity, and he will see each reflection at regular, equal intervals. Eventually, the light pulse will reach the mirror, which is one equal interval beyond the last particle. When Bob sees the light reflected from the mirror, it will occur at the same time at which he actually "saw" the beam strike the mirror. The important point here is that Bob never actually saw a beam of light racing toward the mirror. What he actually saw was effectively the reflected light from an infinite set of mirrors along the path to the mirror, each reflecting that component of light to which it was sensitive.

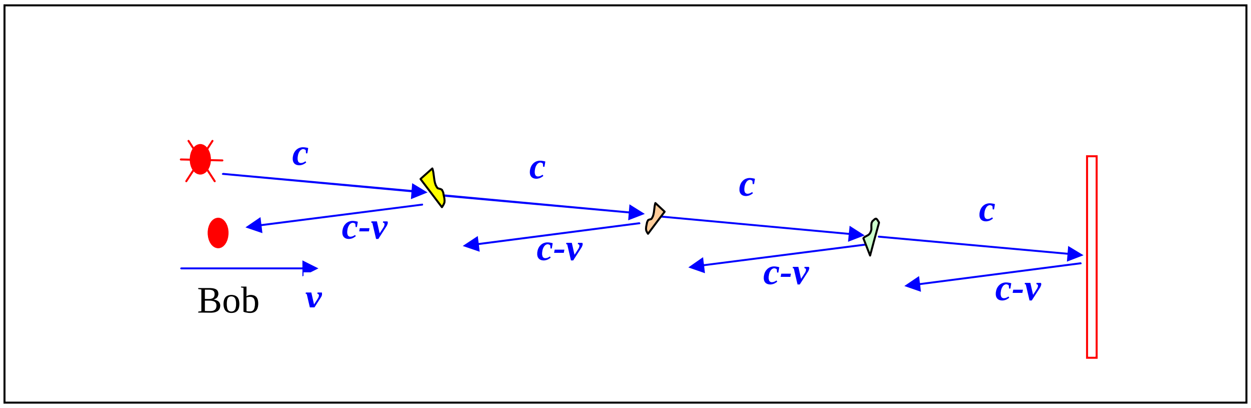

Figure 3-6 The characteristic beam of a flashlight in the night sky is actually due to backscattering from particles in the atmosphere. Without such particles, no beam is seen.

In the above figure, Bob is sensitive to that light with a velocity (with respect to the source and mirrors) of c minus his velocity. The light actually striking the particles is traveling at the much faster speed of c. Since this light covers the distance between the particles faster than Bob would expect it to, he perceives that the distance between particles is shorter than it actually is. Note that this perception of a shorter distance is not due even remotely to the Lorentz length contraction as required in special relativity. The effect here is due to the observer not knowing he is in motion with respect to the reflecting particles. If you throw a ball at a wall with a velocity of ten feet per second and it hits the wall after two seconds, you will conclude the wall is twenty feet away. However, if you are moving toward the wall at ten feet per second when you release the ball, the ball will have a velocity of twenty feet per second with respect to the wall. The ball will strike the wall after only one second and you will perceive the distance to be ten feet instead of the actual twenty. This is the "shorter distance" that Bob is experiencing.

Since the carrying of rods and clocks eliminates the distinction between "seeing" light at a distance and seeing backscattered light, we can leave the wording of the previous sections as it stands. Bear in mind, though, that when we speak of an observer "seeing" light strike a distant object, we actually mean something else. The observer is actually obtaining physical evidence at a distant point on a rod or with a distant clock synchronized to the observer's clock, and that the rod and all clocks are stationary in the observer's frame of reference.