Reference Frames & Simultaneity

The Postulates of Special Relativity

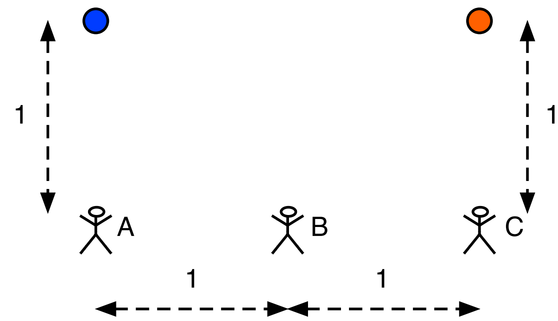
1. The laws of physics are the same in all inertial reference frames.
2. All inertial reference frames measure the speed of light in a vacuum to be 3 x 10^8 m/s.

Defining Inertial Reference Frames

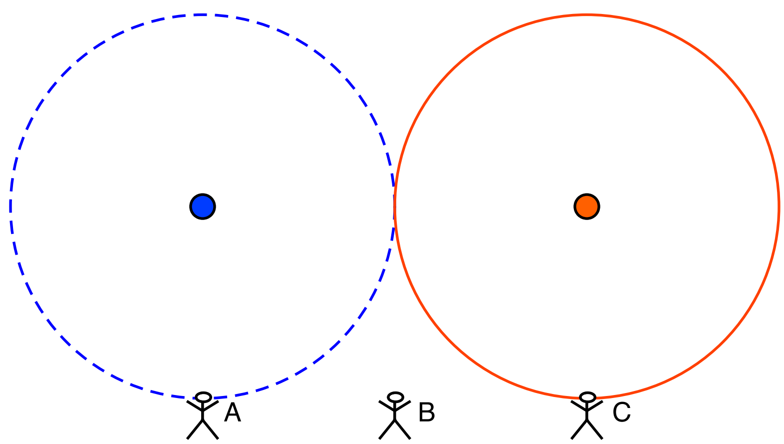
Inertial reference frames are based on relative velocity, not relative position.

You are in the same inertial reference frame as anyone who is at rest with respect to you. Anyone moving with respect to you is in a different inertial reference frame. Imagine you are sitting on a bus going down the highway. You and everybody sitting in your bus is in the same inertial reference frame. Every bus that passes you is in a difference reference frame. However, another bus that has the same speed as your bus in in your inertial reference frame, because that other bus is not moving with respect to your bus. It also doesn't matter where on the bus people are sitting, they are all in the same inertial reference frame.

Before we get into different inertial frames, let's stress a point: different people in the same inertial frame will literally *see* slightly different things depending on their location – but everyone will *calculate* the same things. For example, in the diagram to the right, there is a blue light (on the left) and a red light (on the right.) There are three different people, labeled A, B and C. The distances between everybody is also shown. We will say the distances shown are 1 μls (micro-light-second) – which means the distance light travels in 1 μs (which is 300 m.)



Now let's imagine that both lights flash simultaneously. What would each of the people actually see? When the lights flash, light spreads out in all directions at the speed of light. The diagram below shows the flashes exactly 1 μs after flashing:



Notice how the blue (dashed) light on the left has reached person A, but not B or C, because they are farther from the light than A. Likewise, the red light on the right has just reached person C, but not the other two.

About 1.42 μs after flashing, both lights hit person B, as shown below. (Hopefully, you can figure out why it is about 1.42 μs. Also note that I didn't draw the whole flash as the diagram would get too big.)

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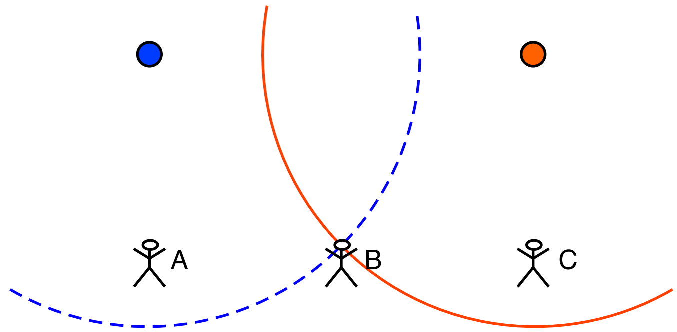


Finally, about 2.24 μs after flashing, the blue light arrives at person C and the red light arrives at person A. (No diagram for that.)

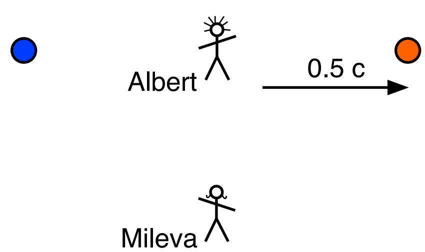
Notice how all three people *saw* different things:

A saw the blue light flash first, followed 1.24 μs later by the red light.
B saw the lights flash at the same time.
C saw the red light flash first, followed 1.24 μs later by the blue light.

However, they would all end up agreeing that the lights flashed at the same time. Person A saw the red light 1.24 μs after they saw the blue light BUT the red light is 1.24 μls farther than the blue light. They only saw the blue light first because they were closer to it, but they can calculate that the lights had to flash at the same time. Person C would have to do a similar analysis, and would also conclude that the lights had to flash at the same time. Person B has it easy; because they are the same distance from each light, they can just say the lights flashed at the same time because that is what they saw, no calculations needed.

So that we can focus on important ideas without having to do calculations, from here on we will always use a convenient location in a reference frame to speak for the reference. Only the people who happen to sitting an equal distance from each light will actually “see” the lights flash at the same time; everybody else will have to do some calculations to conclude that the lights must have flashed at the same time. *That means we will always figure out what happens in a reference frame by placing an observer at the midpoint of the two events.*

Flashing Lights in Two Different Reference Frames
Now let’s begin the fun! We will step through a few situations involving two different reference frames and flashing lights. We will always choose a convenient position in the reference frame to decide what is happening – always equidistant from the two lights.



In the diagram above, Albert is between two lights that are moving past Mileva* at 0.5c. We will go through two situations to see what happens: 1) Mileva sees the lights flash simultaneously and 2) Albert sees the lights flash simultaneously. In both cases, the diagrams will be drawn in Mileva’s reference frame (which means you are in Mileva’s reference frame.)

** Mileva was Einstein’s first wife, who was a fellow physics major in college.*

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1) Mileva sees the lights flash at the same time.

The pictures to the right show the situation at five different times after the flash. The blue (left) and red (right) circles are the expanding light flashes, and the slightly faded circles are the positions of the lights when they flashed, shown for reference. The flashes of light expand at the speed of light while Albert and the light bulbs move to the right at half the speed of light. In A, notice how Albert is just about to run into the expanding red flash of light, while the blue flash is chasing after him.

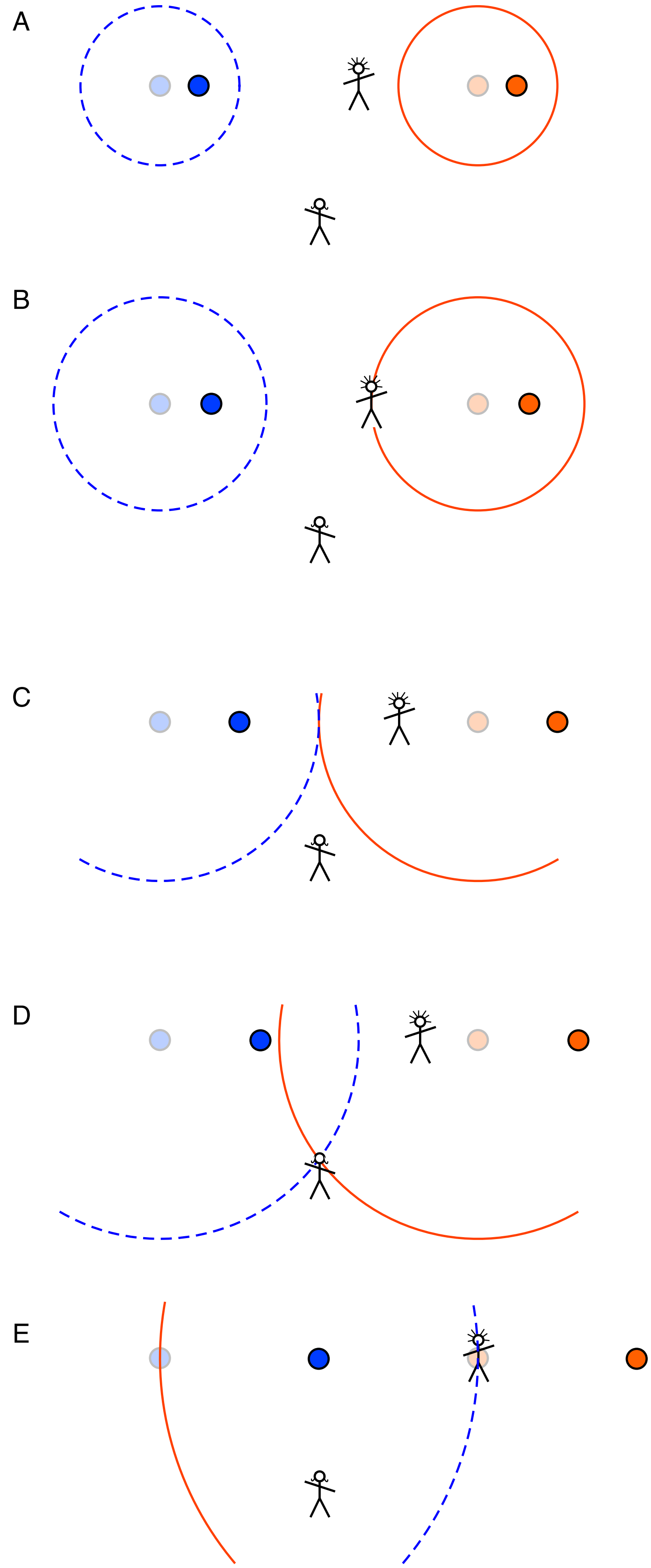
B shows the moment when the red flash hits Albert. Mileva still has not seen either flash, and the blue flash is still chasing after Albert.

The flashes continue to spread out and Albert continues to move to the right. C just shows another moment – but the circles are too big at this point so I am only showing part of the circles. The flashes are getting closer to Mileva..

D is the moment when both flashes finally arrive at Mileva - she sees the flashes simultaneously. Notice how the blue light is still chasing after Albert – he hasn't seen the blue light flash yet.

E is when the blue flash finally catches up to Albert. And here is also the key idea: since Albert is exactly in the middle of the lights, if he sees the red flash first, and then some time later sees the blue flash, he knows the red light had to flash first. What was simultaneous for Mileva was NOT simultaneous for Albert.

Let's take the time to restate that: In Mileva's frame of reference, the two lights flashed at the same time, while in Albert's they flashed at different times. This turns out to be fundamental to relativity. **Events at different locations can only be simultaneous in <u>one</u> reference frame.** If Mileva sees the light flashes as simultaneous, then Albert <u>must</u> see them as occurring at different times. What was simultaneous in one reference is not simultaneous in another!



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2) Albert sees the lights flash at the same time.

What happens if Albert sees the lights flash at the same time? In order for Albert to observe the lights flash at the same time, flashes from each light have to reach him simultaneously. Recall that in the previous example we saw the blue flash chasing after Albert; in order for the red and blue flash to arrive at Albert at the same time, the blue flash needs a head start. A shows a little time after the blue light has flashed, but not the red light.

B shows the moment when the blue flash arrives at Mileva. So Mileva sees the blue light flash first, just as we said.

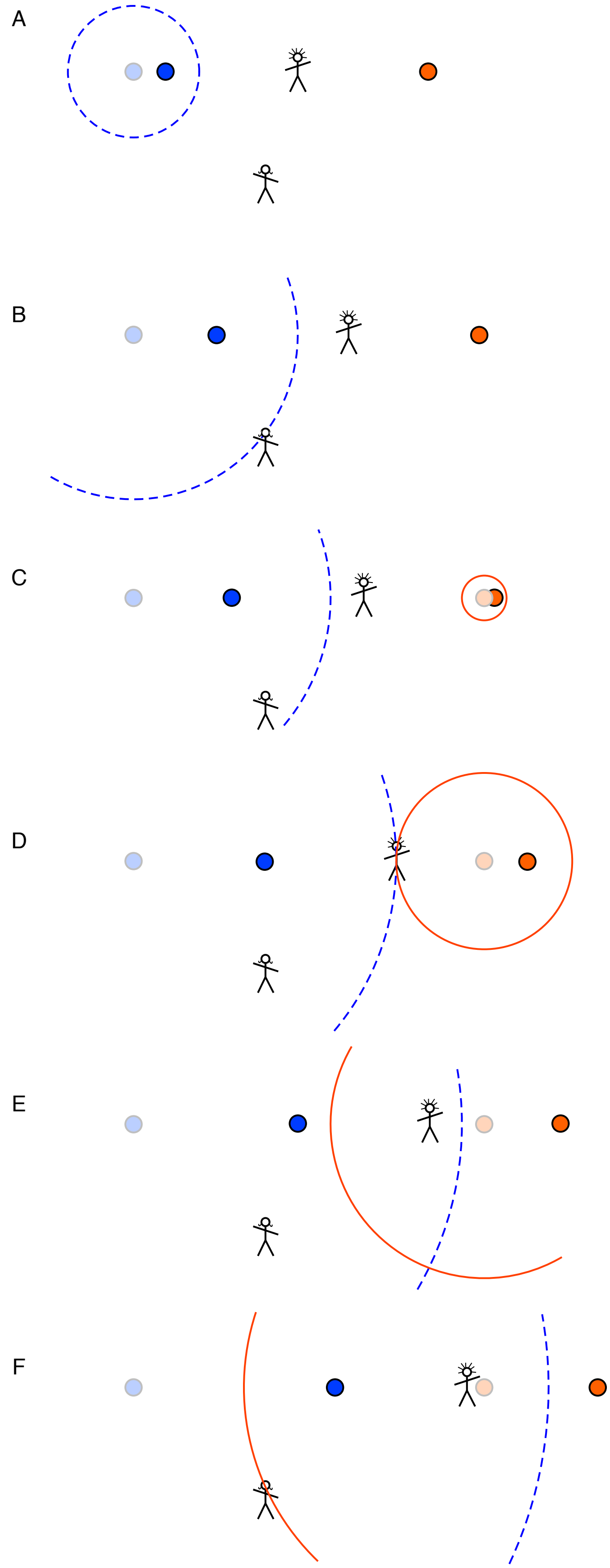
C shows a time just after the red light has flashed. Notice the blue flash still hasn't reach Albert.

D soon after the red light flashes, it arrives at Alberts location just as the blue flash arrives. So Albert sees the flashes simultaneously, and therefor concludes that the light flashed at the same time. Mileva, however, still has not seen the red flash.

E just shows the growing light flashes. The red flash still has not reached Mileva.

F shows the moment when Mileva finally sees the red flash. Both flashes are well past Albert at this time. Clearly, Mileva saw the blue light flash first, and then some time later saw the red light.

In Albert's reference frame the two flashes were simultaneous, while in Mileva's they were not.



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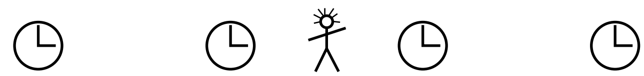
Other Implications: Spacetime

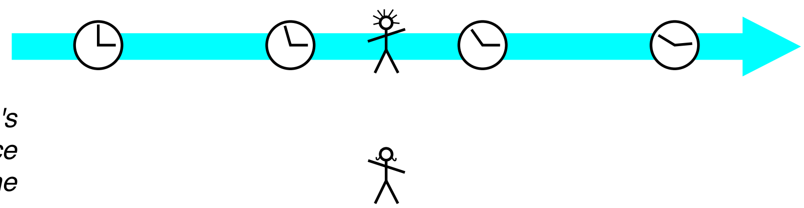
It is easy to think that the above arguments are somehow only a minor issue that affects flashing lights – but it is deeper than that. Think about how you would set up distant lights to all flash simultaneously. You don't want to worry about the time it takes an electrical signal to go from you to the distant lights, so you set them up on timers: e.g. the lights all flash at exactly 3:00.

Albert's reference frame



The picture above shows a few of the clocks attached to lights in Albert's reference frame. They are all spaced very far apart and have lights that will flash at 3:00. In Albert's frame, they all flash simultaneously. (Again, note that Albert does not actually *see* all the flashes arrive at him simultaneously – he would have to do some calculations because there are many lights at many different distances from him. But he would calculate that they all flashed simultaneously.)

What happens if he is moving past Mileva like earlier?



Mileva's reference frame

Recall that earlier the light that was at the end of line had to flash first so that the two flashes arrived at Albert simultaneously. That means the clock at the end of the line has to be at 3:00 first! According to Mileva, Albert's clocks are not synchronized: the further to the right the clock is, the earlier it is. The picture attempts to show the clocks getting a few minutes earlier as you move to the right.

What this all really means is that TIME is wrapped up in SPACE and one actually shouldn't think about space and time as being independent things (like we usually do unfortunately.) Space and time are just the four coordinates that tell us where things are in SPACETIME.

Other Implications: Length Contraction

But wait! There's more! (Sorry to be an infomercial.)

Let's imagine that instead of blinking lights, it is actually some space ships flying by us. According to the ships they are all synchronized and as they go by you, instead of flashing lights, they accelerate at the same time. According to the ships, they all accelerate simultaneously, so they are always the same distance apart. According to us, however, the ship at the back starts accelerating first – so the ships get closer together! It turns out that if something goes by you close to the speed of light, the object will be shorter in the direction of travel. Space actually contracts when it is moving by you. This is known as *length contraction*.