“Moving Clocks Run Slowly”

We’ll make a clock that keeps time using pulses of light that leave an emitter, bounce off a mirror, and return to a detector next to the receiver.

The mirror is 3 m from the receiver/detector.

If the clock is at rest in your reference frame how far does the light travel in its round trip from the emitter to the detector? How long does this take, according to you?

Isabelle has an identical clock, mounted with its axis perpendicular to the direction her rocket is traveling. According to Isabelle, how far does the light travel in its round trip from the emitter to the detector?

If Event 1 is the light pulse leaving the emitter in Isabelle’s clock and Event 2 is the light pulse arriving back at the detector, what is the interval? Remember that the interval is invariant, so we can work this out from Isabelle’s perspective.

From our perspective the light in Isabelle’s clock follows the hypotenuse of a 3-4-5 triangle to the mirror, and then comes back along the hypotenuse of a second 3-4-5 triangle back to the detector. Verify that this is the case.

From our reference frame, what is the time taken by the light in Isabelle’s clock to make the round trip? What is the spatial separation between the two events according to us? What is the interval?

What does the invariant quantity represent? Why is it the same for all observers moving parallel to Isabelle?

Let’s return to the Isabelle situation we looked at in session 1.

Here’s a typical relativity question. In the reference frame of the Earth a particular star is 20 light-years away. Isabelle is passing by the Earth in her rocket ship traveling toward the star at a constant velocity of 0.8 c. At the instant she passes by you send a light pulse toward the star.

According to you, on Earth, how long does the light pulse take to reach the star? How long does Isabelle take?

Your friend Yan is in your reference frame, but located at the star. According to you, the two of you have synchronized clocks that both read 0 at the instant you send the light pulse. Isabelle happens to be passing by Earth when you send the light pulse, and sets her clock to read zero at the same instant you set your clock to zero.

What does Isabelle’s clock read when she sees the star pass by outside her rocket ship window?

What does Isabelle measure for the distance between Earth and the star?

According to you, what does Yan’s clock read when Isabelle passes the star? According to you, what does your clock read?

Based on the above, what do you and Yan think about Isabelle’s clock?

According to Isabelle, what is the reading on her clock when the light pulse reaches Yan? In other words, according to Isabelle, how long does it take the light to reach Yan?

How much more time passes from that event (the light reaching Yan) until the event of Isabelle passing Yan at the star? It depends who you ask. What is this time according to Isabelle? According to Yan?

Based on this, what does Isabelle say about your clock and Yan's clock?

How much time does Isabelle see elapsing on Yan's clock (and your clock) between the events of Earth passing by her rocket-ship window and the star passing by her rocket-ship window?

What is the reading on Yan's clock, according to all three observers, when the worldlines of Yan and Isabelle intersect?

According to Isabelle, what was the reading on Yan's clock when your clock (and her clock) was set to zero?

We can make some sense out of the above by considering a clock-synchronization process agreed to by you and Yan some years ago. A beacon was placed at the midpoint between you and Yan, and a light pulse was sent out in all directions from that beacon. You and Yan agreed to set your clocks to zero at the instant you observed the light pulse from the beacon. The light pulse you then sent out to Yan was confirmation that you had received the pulse from the beacon.

According to you and Yan, how far is the beacon from you and from Yan?

According to Isabelle, what is the distance between the beacon and you, and between the beacon and Yan?

Before the light pulse reaches you, you and Isabelle are getting closer together. In Isabelle's reference frame, you are approaching her at 0.8*c*, and the light pulse traveling from the beacon to you is coming toward her at *c*. According to Isabelle, then, what is the relative speed between you and the light pulse from the beacon?

As measured by a clock in Isabelle's reference frame, how much time passes between the events of the synchronization pulse leaving the beacon, and the synchronization pulse arriving at you?

In Isabelle's reference frame, Yan is approaching her at 0.8*c*, and the light pulse traveling from the beacon to Yan is traveling away from her at *c*. According to Isabelle, then, what is the relative speed between Yan and the light pulse from the beacon?

As measured by a clock in Isabelle's reference frame, how much time passes between the events of the synchronization pulse leaving the beacon, and the synchronization pulse arriving at Yan?

As measured by a clock in Isabelle's reference frame, how much time passes between the event of the synchronization pulse arriving at Yan and the event of the synchronization pulse arriving at you? Remember that in the reference frame of you and Yan, these events are simultaneous!

According to Isabelle, how much time passes by on Yan's clock between the event of the synchronization pulse arriving at Yan and the event of the synchronization pulse arriving at you?