SPH4U UNIVERSITY PHYSICS

REVOLUTIONS IN MODERN PHYSICS: ...

- ☞ Simultaneity & The Twin Paradox (P.591-594)

Simultaneity

Suppose you are at a Canada Day celebration and you see two sets of fireworks explode at exactly the same time – one off to your left and one off to your right. This is an example of ***simultaneity*** *– the occurrence of two or more events at the same time.*

Simultaneity

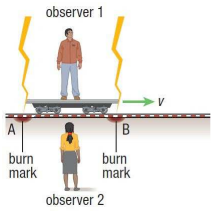
PRACTICE

1. Suppose a car was speeding by at 80 km/h when the fireworks exploded. Would the passengers in the car say they also saw the fireworks explode at the same time?

   no – special relativity and the constancy of the speed of light creates problems with the simultaneity of events

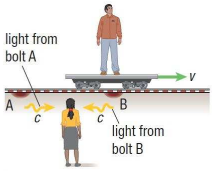
Relativity of Simultaneity

For example, consider the following scenario. Observer 1 is standing in the middle of his railway car, moving with a speed v relative to observer 2, when two lightning bolts strike the ends of the car and leave two burn marks on the ground (points A and B). We now ask the question, "Did the two lightning bolts strike simultaneously?"



Relativity of Simultaneity

Since observer 2 is midway between the burn marks and the light pulses travel at the speed of light, they reach her at the same time. Thus observer 2 concludes that the lightning bolts are simultaneous. However, because observer 1 is moving, the light pulse from B will reach him before the light pulse from A. Thus observer 1 will conclude that the bolts are not simultaneous. So now the question becomes, "Who is correct?"



Relativity of Simultaneity

Both observers are correct in their own reference frames, even if their observations are different – the observation of simultaneity can be different in different reference frames.

NOTE!

*The **relativity of simultaneity** is necessary to make sense of time dilation and length contraction. Together, these concepts ensure that no reference frame is preferred and that special relativity makes sense.*

Relativity of Simultaneity

SIMULTANEITY

- the occurrence of two or more events at the same time

RELATIVITY OF SIMULTANEITY

- events that are simultaneous for observers in one inertial FOR are not necessarily simultaneous for observers in a different inertial FOR

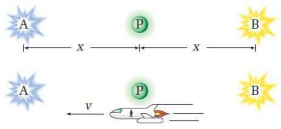
NOTE!

The whole concept of simultaneity, of past, present, and future, is fuzzy in relativity. What is a future event in one frame of reference becomes a past event in another. This is due entirely to the fact that the speed of light is the same in all inertial frames of reference, regardless of their relative velocities.

Relativity of Simultaneity

PRACTICE

2. In the diagram, two stars (A and B) are equidistant from a planet (P) and are at rest relative to that planet. They both explode into novas at the same time, according to an observer on the planet. From the point of view of passengers in a rocket ship travelling past at relativistic speeds, however, which star went nova first? Give reasons for your answer.

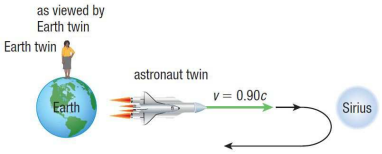


Twin Paradox

With this understanding of space and time as properties that are both affected by motion comes the challenge of keeping track of what happens in each reference frame. One of the most famous examples of this type of problem is the ***twin paradox****.*

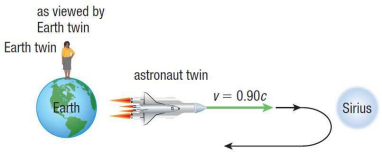
Twin Paradox

Consider an astronaut who travels to the Sirius star system, which is 8.6 light years from Earth. His spacecraft is capable of a speed of 0.90c, which means that he can reach the Sirius system in ~ 9.6 years (or ~ 19 years for a round trip). Back on Earth a crew of scientists, one of whom is the astronaut's twin sister, tracks the astronaut's health. The scientists' observations indicate that he is aging more slowly than he would have on Earth (although he is unaware of any change in the flow of time).



Twin Paradox

During the 19 year round trip, the crew notes that he ages only 8.3 years. However, from the astronaut's frame of reference, Earth recedes from him at a rate of 0.90c. He therefore expects everyone on Earth, including his sister, to age only 8.3 years, while he ages 19 years. However, upon his return, his sister's analysis is correct and his is wrong – she has aged 19 years compared to his 8.3 years. What happened? Did the special theory of relativity fail, or is the error in the interpretation of relativistic effects?



Twin Paradox

To understand the situation correctly, you need to consider that the astronaut moved in a frame of reference that was not truly inertial. In his case, he had to accelerate to change direction during the trip so the situation is, therefore, not symmetrical between the astronaut and his non-accelerating sister. As a result he cannot draw the same conclusions as his sister since his frame of reference is not the same as his sister.

NOTE!

There is a relativistic observation that the astronaut can use that completely reconciles the imagined paradox. Recall the interpretation of muon decay in the atmosphere.

Twin Paradox

From the astronaut's frame of reference, the universe undergoes length contraction. The distance that he must travel each way is, from his point of view, not 8.6 ly but 3.7 ly. With a total distance of 7.4 ly and a speed that is 0.90c most of the time, the astronaut sees the mission take only 8.3 years – the same amount by which his twin has determined he will age during the voyage. So he returns to find that his sister has aged 19 years while he has aged only 8.3 years.

Twin Paradox

TWIN PARADOX

- thought experiment in which a moving observer ages more slowly than his/her "twin" despite the reciprocity of time dilation
- reference frame of moving observer is not inertial and thus they cannot draw the same conclusion as the stationary twin
- resolved using relativistic motion (recall muon decay)

Space-Time

NOTE!

Time is often thought of as a fourth dimension. An object or event may be specified by four quantities; three to describe where it is in space, and a fourth to describe when it is there, in time. Strangely, when objects move at speeds near c, space and time become interchangeable. A loss in space (length contraction) is accompanied by a gain in time (time dilation). Events look smaller but last longer. Time cannot be thought of as independent of space, or vice versa.

Space-Time

PRACTICE

3. Imagine you were on a spaceship moving away from Earth at 0.80c.
   (a) Would you notice any change in your pulse or shoe size?

(a) no

Space-Time

PRACTICE

3. Imagine you were on a spaceship moving away from Earth at 0.80c.
   (b) Would an observer watching from Earth note any changes in these quantities?

(b) your pulse slows down (time dilation) and your shoe size decreases (length contraction)

✔ Check Your Learning

TEXTBOOK

P.597 Q.7,8

INTERNET

✎.... Google/Complete the following: "Al's Relativistic Journey"