

The Two Postulates in the Theory of Special Relativity

To understand special relativity, we must accept two postulates:

1. The laws of physics are the same in all inertial reference frames.
2. The speed of light is constant in all reference frames, regardless of any relative motion between an observer and the light source.

There are two postulates in the theory of special relativity.

The first postulate is not difficult to accept. An inertial reference frame is one that is at rest or moving with a constant velocity (constant speed in a straight line). If you throw a ball straight up in the air while you are in a car that is at rest, it comes back down and lands in your hand again. If your car is moving at a constant velocity and you throw the ball straight up, it still comes back down in your hand, since the car, you, and the ball all have the same horizontal velocity. This can be extended to any physics experiment that you can think of. In other words, there is not one special inertial reference frame that is better than or different from any other when it comes to making physical measurements. This leads us to the second postulate, which is a little more difficult for us to accept.

An inertial reference frame is one that has a constant velocity, including a velocity of zero.

The second postulate of special relativity states that everyone in any reference frame will measure the same value for the speed of light regardless of how fast he or she is moving relative to the light source. If I am at rest relative to your flashlight and you turn it on, I measure the speed of the light as being $c = 3 \times 10^8$ m/s, and so do you. But if you remain at rest, and I begin moving at 100 miles per hour, Newtonian physics says that we would not agree on the speed of the light beam since I am moving and you are not. However, Einstein's second postulate states that we will both still measure the speed of the light beam as $c = 3 \times 10^8$ m/s. Even if I move at half the speed of light ($0.5c$), the second postulate still holds true; that is, you and I will still agree on the speed of the light beam, $c = 3 \times 10^8$ m/s. This can be difficult for us to accept, since we are used to taking into account the relative motion between reference frames when calculating velocities. This leads us to some interesting effects on length and time.

The speed of light is constant for all observers.

The basic equation for the speed of an object is

$$v = \frac{\text{distance}}{\text{time}} .$$

The speed of light is written no differently. Substituting the speed of light into the equation, we have

$$c = \frac{\text{distance}}{\text{time}} .$$

We've seen that all observers must agree on the value of the speed of light c , regardless of their frame of reference. This means that all observers must agree on the ratio of the two, but they do not have to agree on the value of distance or the value of time. In other words, if you remain still while I accelerate away from you, the closer I get to the speed of light relative to your position, the more we will disagree on measurements of distance and time. And since we disagree on measurements of distance, we will also disagree on the lengths of objects. This gives rise to the *relativistic effects* on length and time:

An observer who measures the length of an object moving relative to the observer will measure the length of the object as being shorter (contracted) in the direction of motion compared to the measurement of its length when it is at rest relative to the observer.

Length contracts in the direction of motion for a moving object.

In other words, a moving object is shorter than when it is at rest. In order to keep the ratio of length to time constant (equal to c), time must also change:

A moving clock will run more slowly than a clock that is at rest.

This is called *time dilation*, and has been verified experimentally many times. This means that the ticks of a moving clock are farther apart than the ticks of a clock that is at rest.

Moving clocks run more slowly than clocks at rest.

Time is simply the duration between two events, and since any two observers must agree on the speed of light, they may not agree on the length of a moving object or how much time has passed between two events. Relativistic effects occur at all speeds, but they only become measurable at speeds above about ten percent the speed of light.

There is one other relativistic effect we should discuss. In his 1905 paper, Einstein suggested that energy and mass are actually different aspects of the same phenomenon. The famous equation that links energy to mass is

$$E = mc^2.$$

This equation tells us that energy and mass can be converted into one another, and that their value is connected by a constant, the speed of light squared. Since the speed of light is a huge number, a little mass can be converted into a lot of energy, as history has witnessed with the release of nuclear binding energy when the nuclei of atoms are split and that energy is released. But not only can mass be converted into energy, energy can be converted into mass.

Mass and energy can be converted into one another.

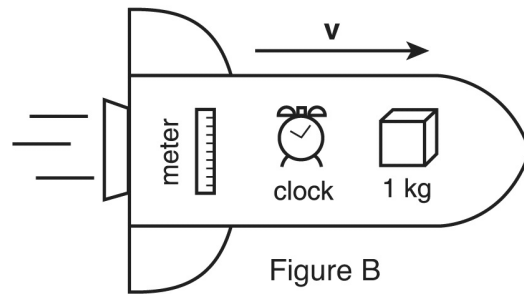
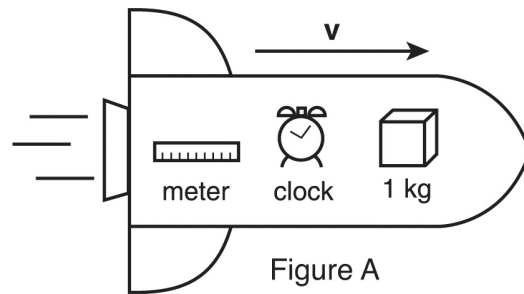
A moving object has kinetic energy, and experiments have shown that at high velocities, the kinetic energy of a moving object such as a proton begins turning into mass. As a proton approaches a speed near the speed of light, its mass becomes larger and larger, as verified by momentum measurements. This puts an ultimate speed limit on moving objects, the speed of light. The equations of relativity tell us that if it were possible for an object to achieve a speed equal to the speed of light, it would have zero length, its clock would stop, and it would have infinite mass. Since none of these are possible in our universe as far as we know, achieving the speed of light is impossible.

Mass increases as speed increases.

Our discussion of special relativity can be summarized as follows:

- *All inertial reference frames are equivalent.*
- *The speed of light is constant for all observers.*
- *An observer watching a moving object will see its length contract in the direction of motion, its clock slow down, and its mass increase by the equation $E = mc^2$.*

Example: Two spaceships pass you at a speed near the speed of light, each containing a meter stick, a clock, and a 1 kg block. For each of the following diagrams, describe the changes in the length of the meter stick, the ticks of the clock, and the mass of the 1 kg block.



Solution: In Figure A, the meter stick is aligned in the direction of motion of the ship. Thus, you would measure the meter stick as being shorter than one meter. You would also measure the clock as running slower, that is, more time between ticks, and the mass as larger than one kilogram.

In Figure B, you would still measure the clock as running slower and the mass as larger than one kilogram, but since the meter stick is aligned perpendicular to the motion of the ship, you would still measure it as being one meter long, although a little thinner, since length contraction occurs only in the direction of motion.

If an astronaut in the ship Figure A looked at your reference frame as he was passing you, he would see your meter stick as being shorter than one meter, your clock running slower, and your mass as larger. Since his reference frame is as good as yours in which to make measurements, he should measure the same effects in your reference frame as you measured in his. However, if the astronaut looked at the ship in Figure B, he would see that the length, mass, and time on the other ship would be the same as on his. This is because the two ships are moving at the same speed relative to an outside observer and thus are in the

same frame of reference; additionally, their speed relative to one another would be zero.

THINGS TO REMEMBER

- The two postulates in the theory of special relativity
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