Section 2.1

Einstein’s Postulates of Special Relativity

Einstein’s Postulates of Special Relativity

Postulate 1) All the laws of physics are the same in any inertial reference frame.

That is, the laws of physics hold equally well in a system moving at constant velocity as they do in a system at rest.

What is an inertial reference frame?

An inertial reference frame is one in which Newton’s 1st law holds.

How do you know if you are in an inertial reference frame?

Take some objects and toss them in various directions. If they move in straight lines with constant speed, then you are in an inertial reference frame.

Postulate 2) The speed of light is a universal constant.

Light travels (in vacuum) at same speed ($c = 3.0 \times 10^8$ m/s), in all inertial reference frames. That is, all observers measure the same speed of light regardless of their state of motion.

Postulate 1: The Principle of Relativity

Example using “Conservation of Momentum”

A 3-kg cart rolling at 4 m/s to the right on a frictionless horizontal track collides and sticks to a 1-kg cart initially at rest. Calculate the speed of the two-cart system after the collision.

Before   After

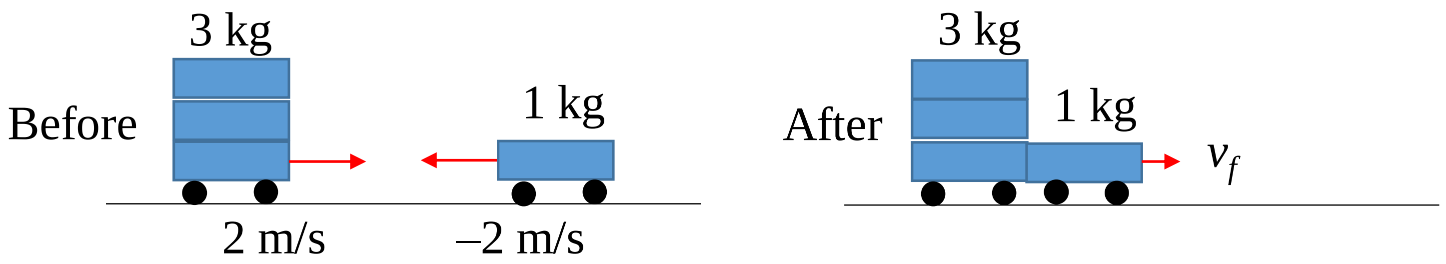
$$p_i = p_f.$$

$$(3\text{ kg})(4\text{ m/s}) + (1\text{ kg})(0\text{ m/s}) = (3\text{ kg} + 1\text{ kg})(v_f).$$

Solve for $v_f = 3$ m/s.

The Principle of Relativity (con’d)

Now suppose the collision took place on a bus moving to the right at 2 m/s. (This is an inertial reference frame.) The numbers given above were from the observer standing on the ground. To an observer on the bus, the process looks like a 3-kg cart rolling at 2 m/s on a frictionless horizontal track collides and sticks to a 1-kg cart initially moving to the left at 2 m/s. The final speed of the two-cart system is v_f = 1 m/s. (Notice that the speeds relative to an observer on the bus are found by subtracting 2 m/s from the ground observer’s measured speeds.)



Is momentum still conserved in the “bus frame?”

Check: $p_i = p_f$. Does (3 kg)(2 m/s) + (1 kg)(–2 m/s) = (3 kg + 1 kg)(1 m/s)?

$$4\ \text{kg}\cdot\text{m/s} = 4\ \text{kg}\cdot\text{m/s}$$

Yes! Although the numbers are different, the law of conservation of momentum still holds.

Velocity Addition (Galileo)

Suppose a you on a slow bus that is moving forward at 8 m/s, and you started walking toward the front of the bus at 2 m/s, how fast would you appear to be moving as seen by an observer standing on the ground watching the bus go by?

10 m/s (obviously). You just add the two velocities. This is Galileo's velocity addition rule.

$$v_{AC} = v_{AB} + v_{BC}$$

In this example, A = "you," B = "bus," and C = "ground." That is, 10 m/s = 2 m/s + 8 m/s

Now suppose that you are sitting on a (very fast) train traveling at 0.4*c*. And you switched on a flashlight toward the front of the train. You would see the light travel forward at speed *c*. What speed would an observer standing on the ground (watching the train go by) measure for the speed of light?

According to Galileo, $v_{AC} = v_{AB} + v_{BC}$. Letting A = "light," B = "train," and C = "ground," then the speed of the light beam relative to the ground would be:

$$v_{Light,Ground} = v_{Light,Train} + v_{Train,Ground} = c + 0.4c = 1.4c \text{ (according to Galileo)}$$

Postulate 2: Velocity Addition (Einstein)

But the result on the previous slide cannot be true according to Einstein's second postulate of relativity! Both observers (you and the ground observer) must measure the same speed, c.

To resolve the conflict, Einstein came up with a correction to Galileo's velocity addition rule:

$$v_{AC} = \frac{v_{AB} + v_{BC}}{1 + \frac{v_{AB} v_{BC}}{c^2}}$$

This is Einstein's velocity addition rule. Notice how this fixes the problem:

$$v_{Light,Ground} = \frac{v_{Lght,Train} + v_{Train,Ground}}{1 + \frac{v_{Light,Train} v_{Train,Ground}}{c^2}} = \frac{c + v}{1 + \frac{(c)(v)}{c^2}} = \frac{c + v}{1 + \frac{v}{c}} = \frac{c(c + v)}{c + v} = c$$

Why was this not noticed before? For "ordinary" speeds, the correction term is negligibly small!