C1.2.2.

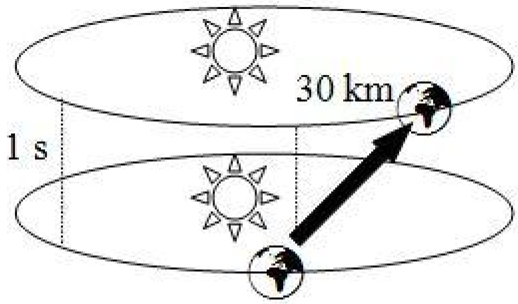


Figura 1.9

Galileo Galilei´s scientific career was closely linked to the dispute between geocentrism and heliocentrism (in relation to Galileo, see Annex 1: A1.2).

An essential aspect of this controversy lays in the difficulty of being able to accept that the Earth can be moving around the Sun, due to the absence of visible effects of this movement.

Figure 1.9 represents heliocentrism in spacetime. The black arrow indicates the displacement of our planet after a second. As the figures above show, the actual movement of the Earth is not tilted, but remains in the plane of the circular orbit. The slope, as before, indicates the speed at which it moves. A simple calculation allows to conclude that our planet, in the heliocentric model, should be traveling through space at a speed of 30 km per second, which far exceeds any of the speeds of the phenomena that occur on the terrestrial surface. And despite this, no effects of this movement are observed.

To explain why there are not observed effects due to Earth´s translation around the Sun, Galileo established the *principle of relativity*,according to which the laws of physics are the same for all reference systems that are uniformly moving between them. Like when the cabin of a ship drags everything it contains, so that no one can appreciate the uniform motion of the boat on the water from what happens inside the cockpit, it is not possible to check the movement of the Earth from what happens in Earth itself.

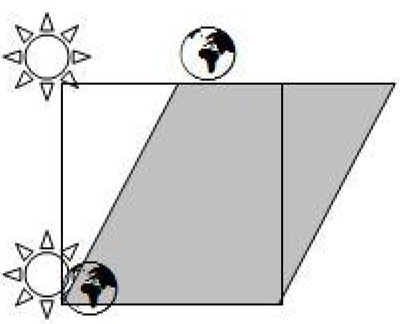


Figura 1.10

In Figure 1.10 we can see the representation of this principle in a geometric way in a spacetime diagram: a unit cell for the reference system from outer space, which is situated in the motionless sun, and it has the shape of a square, which is transformed (for a moving Earth) in a parallelogram with a horizontal base (gray figure). When we turn a geometric figure, it continues to retain all the properties and geometrical relationships, in the same way we see now that by turning spacetime in this way it retains all the physical relationships that we saw previously (in relation to the Galilean transformation, see Annex 1: A1.2.1).

To do this, simply observe in Figure 1.11 the scales that represent time and space in the original reference system (Sun, white square) and in the transformed reference system (Earth, gray parallelogram)

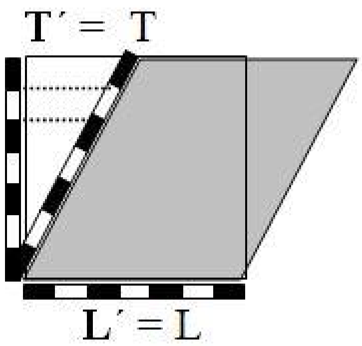


Figura 1.11

We see that the measure of time (vertical height) does not change when moving from one system to the other (dotted line). This is consistent with the intuition of time as a measure of universal changes happening at all times and at all points of the universe alike, regardless of the state of motion of observers. You can also check at the horizontal scale that the base of the parallelogram is equal to the measure of the side of the square, and that as time passes this measure remains constant in the parallelogram, although moving to the right. Also here you get a common-sense property: The length of the objects is not altered by the movement of those who observe them.

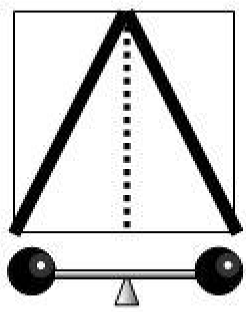


Figura 1.12

In Figure 1.12 we now see the representation of an inelastic symmetrical collision that was presented in the previous section: Two equal masses move against each other at the same speed, colliding at one point. By the symmetry of the situation, it is clear that the center of mass (CDM) must at all times be located in the center of the figure (dotted line).

As we saw in the previous section, from this figure it is possible to compare the two masses, and reach the conclusion that they are equal. A lever represented at the bottom is just to remember the physical content of this situation. One should not forget that, in fact, the two masses are separated and moving freely before the crash, and we can locate the MDC from the movement of the set after the collision (which in this case would be vertical, ie, they would be at rest) .

Then we apply the Galilean transformation to this figure, to see what physical consequences we can get of it.

To do this, first we transform the square in a spacetime parallelogram with a horizontal base (Galilean transformation), and then we draw the remaining lines from corresponding points of the figure (lower corners and midpoints of the horizontal sides in both cases.

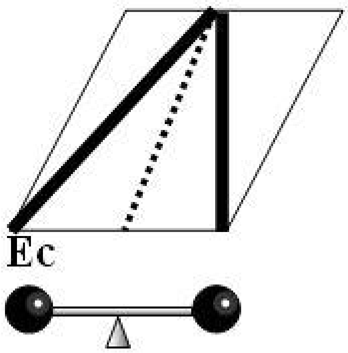


Figura 1.13

In the resulting diagram (Figure 1.13), we note the following:

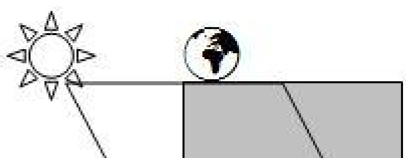
The right line is now vertical. We already know what that means: the mass at the right is at rest in the new reference system. How can we understand that? We can realize that something similar happens when we travel on a train that goes parallel to another train and at the same speed: it seems that neither we nor the other train are moving. What happened is that we move to the left with the mass of the right and its same speed, so that, for us, it is at rest. What happens with the mass of the left? We are going now to meet her, so for us it has a higher speed than before. The CDM, which was previously at rest, moves (for us) to the right with the same speed with which we move (for him) to the left.

The result of interest is the following: that the CDM remains at all times at the midpoint between the two masses.

At the bottom of Figure 1.13 we show that now the symmetry of the previous case disappeared: the mass of the left (black sphere) has also kinetic energy, **Ec,** as it is in motion, while the mass of the right has no kinetic energy (as it is at rest). However, the position of the MDC in the center of the base indicates that it continues to be an equality between both masses. As a result, the kinetic energy is not influencing the balance between the masses. This also was expected, since in classical physics mass and energy are different magnitudes, so it makes no sense to add them (in relation to measures of physical quantities in the Galilean transformation, see Annex 1: A1.2.2).

Figure 1.14 serves to explain a couple of technical aspects (inverse transformation and conservation of spacetime surface) that are not essential in a first reading, so if you want, you can ignore it without problems.

According to the principle of relativity, we can consider that the Sun system is at rest and Earth is moving (as we did above), or that is in the Earth which is at rest and the



Sun in motion (provided it is done in such a short time that the curvature of the orbit was not taken into account). Thus, we would have Figure 1.14, in which it is the referential system (SR) of the Earth which is at rest (gray square) while the sun and outer space are moving to the opposite side to the advancing Earth (white parallelogram). This transformation is called *inverse transformation* of the previously seen (Figure 1.10), since the application of one after the other returns to the initial system. To understand it better, we can consider that the sun is on the platform of a railway station, in which a train is passing to the right (the Earth system). If we get into the train told (ie, we stand on the Earth), we will be making the first of these transformations. Once on the train (Earth), the platform (Sun) appears to be moving toward the left with the same speed. If we get into that second *train* (Sun) which now (for us) goes backwards (ie we jump from the train (Terra) in progress), we will be again on the platform of the principle (Sun), the same as if we didn´t make any transformation all.

The fact that by reversing the direction of the movement we obtain the inverse transformation, along with the fact that all directions of space have the same properties (spatial isotropy), has as a consequence a general property of these transformations: the fact that the surface of the unit cell does not change. In the Galilean transformation this can easily be checked if we consider that the surface of a parallelogram is equal to the base by the height, which in this case are both equal to unity, so that their product is also the unit, like the surface of the original square (in relation to the conservation of the spacetime surface, see Annex 1: A1.2.3).

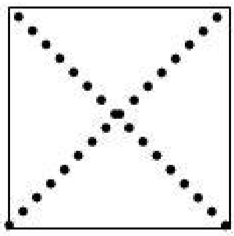
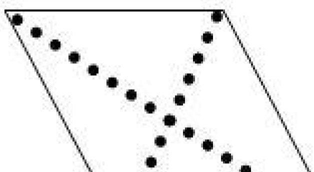


Figura 1.15

Taking into account the above, we do an analysis of what will be the movement of the light from the reference system of the Earth. We start from the basis that light moves through empty space (because otherwise the stars would be not visible), and that its speed is the same in all directions (again from spatial isotropy). We represent this with Figure 1.15, in which we see two diagonal lines that indicate the speed of light through space. It is equal to unity, both to the left and to the right.

Now let us take into account what would happen if we look at the speed of light from the reference system of the moving Earth. To do this, we apply the Galilean transformation to Figure 1.15, taking into account that we stand on the Earth, so that it



is the space (and the Sun) which moves back (to the left in the representation being used).

In the resulting Figure 1.16 now we can see that the two light signals no longer carry the same speed.

The light which goes to the right has a lower speed, since it is *dragged* through space on its movement to the left. In fact, if the Earth would be moving at the speed of light to the right, it would be moving just like the said light pulse, so this would be at rest, as seen from the Earth (the figure would be so inclined that the signal of the right would be vertical).

The signal which travels to the left will have a higher speed instead, for the same reason as before.

Thus, if we are able to measure the speed of the two light signals, we know what is the speed with which the Earth is moving in relation to the empty space outside.

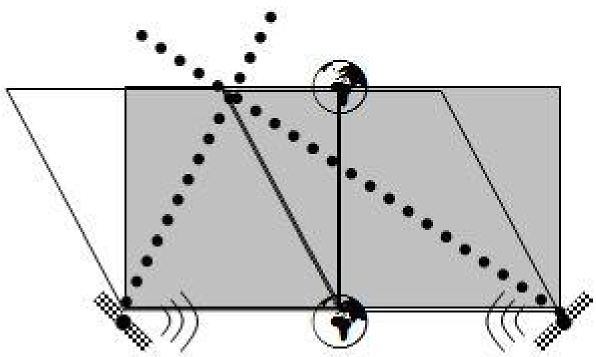


Figura 1.17

All these considerations led Michelson and Morley to conduct an experiment in which they compared the speed of light in different directions, in this way to establish the speed with which the Earth moves through the absolute space.

To their surprise they did not obtain any difference in speeds.

At present, the system of satellite navigation (GPS) is playing continuously an experiment like Michelson did, as we see in Figure 1.17.

We apply the Galilean transformation from the reference system of the Earth (gray squares) to the figure explaining the operation of the GPS. As this is based on signals sent from satellites which are placed in orbit around the Earth high above the atmosphere, these signals travel mostly through the empty space, so their speed should be affected by the transformation of Galileo, as we have seen before.

So due to the different speeds of the signs, they now do not come together at the same point as before. There will be a space shift equal to the space that the Earth runs in the time it takes for the signals to arrive, which was 0.1 s. But we already know that the

Earth in that time runs 3 km. If the Earth were always moving in the same direction, there would be no problem, because it would suffice to adjust the calculations to take into account such displacement, which would be the same at all times. But because the Earth goes around the Sun in a year, after six months it will be moving in the opposite direction, so that the displacement is continuously varying a radius of 3 km over a year and it will not be possible to achieve greater precision than 3 km with GPS.

The fact that the GPS accuracy is several meters, and it is not necessary to make any adjustments or corrections due to the displacement of the Earth, confirms the null result obtained by Michelson.

If the Earth is not moving through space, as the geocentric theory says, this result would be expected. But when Michelson made his experience, geocentrism had already been discredited.

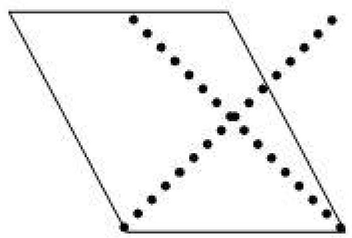


Figura 1.18

If there were a medium in which the light displaced (called the "ether"), we could explain the null result of Michelson if the Earth drags it on his movement through space (as it does with the atmosphere), but such "ether" should fill the entire space of the universe, which does not conciliate with the proposal that the Earth can drag it.

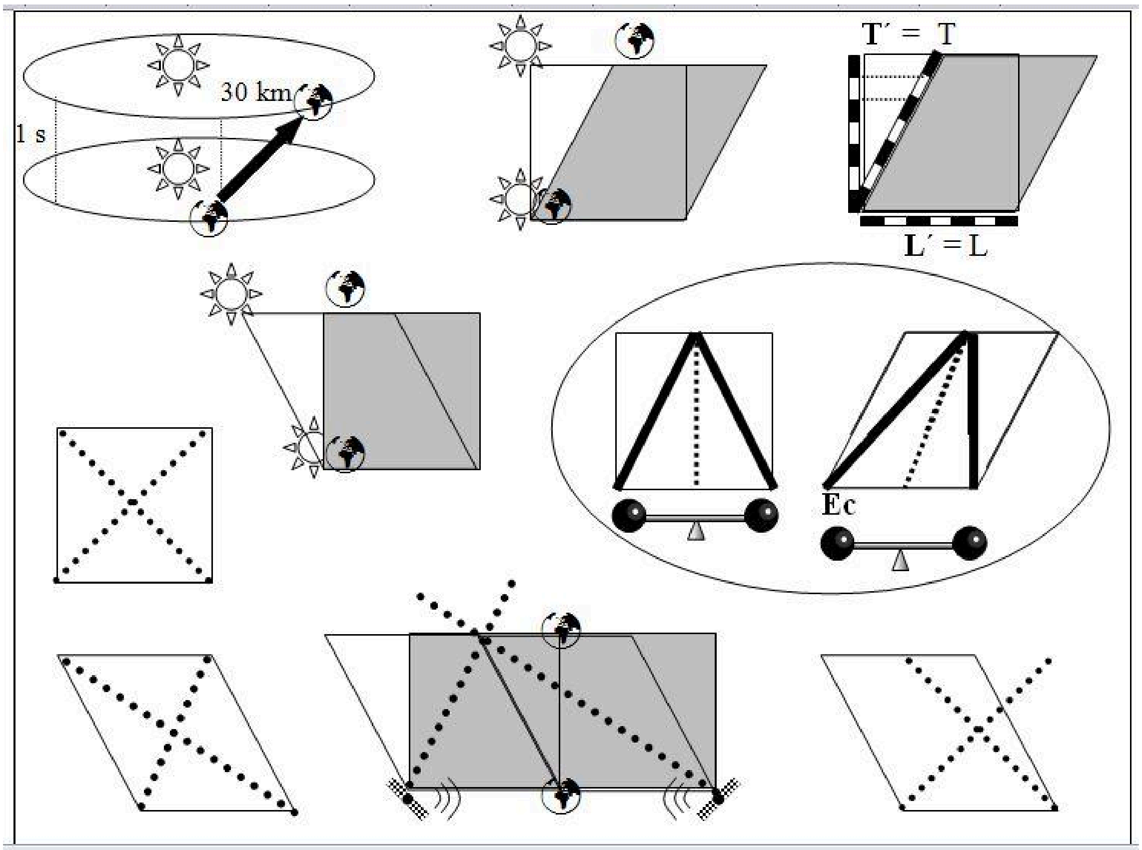
In connection with Michelson, see Annex 1 : A1.3.

As a result of the above, we can see in Figure 1.18 that there is an insurmountable contradiction between the Galilean transformation and propagation of light.

If we consider that the Galilean transformation is the basis of all Newtonian mechanics, and that the speed of light (and all electromagnetic waves) is an intrinsic part of the electrpmagnetic theory, we see that these results contrast in a radical way the two most fruitful theories of classical physics, which reveal seemingly irreconcilable.

This was the state of affairs in the early twentieth century.

Then, in Table 1.2, we meet the figures seen so far, this way to have a synthetic representation of classical relativity by spacetime charts.



Michelson

Table 1.2: visualization of Galilean spacetime

At top left of the picture we observed the representation of Earth´s translation around the Sun, which is at the root of the establishment of classic relativity.

The two figures that accompany it represent the view of this translation from two RS: equivalent: the Sun RS (white) and the RS of the Earth (in gray).

At the bottom left you can see two figures representing the movement of the light from the solar RS (square), in which the speed is equal to 1, and from the terrestrial RS (parallelogram) in which the speed of light would no longer be unity.

In the top right corner you see the figure that explains the conservation of space and time in classic relativity .

We also note that on the right side that the figures of levers and collisions are collected in the same "balloon", as in the Aristotelian Table . One can see that the mass balance is not affected by the presence of kinetic energy.

At the bottom center we represent the oscillations in the positioning by GPS that would be due to variation in the speed of light because of the Earth translation.

The fact that these oscillations are not observed, together with the result of Michelson (mentioned in the lower right corner of the picture), demonstrate the contradiction of classic relativity with experimental facts, reflected in the figure of the lower right corner.

This set of figures is titled with the name of *Galileo* to underline the fact that this wise Italian was the architect of the classical theory of relativity, which underlies the whole theoretical building known as Classical physics.