# 3.3: What Is the Same in Different Frames

## the same: physical laws, physical constants in those laws

***Laws of physics the same in different frames***

Different values of some physical quantities between the two frames? Yes, but identical physical *laws*! For example, the relation between the force acting on a particle and the change in velocity per unit time of that particle follows the same law in the laboratory frame as in the rocket frame.[1] The force is not the same in the two frames. Neither is the change in velocity per unit time the same. But the law that relates force and change of velocity per unit time is the same in each of the two frames. All the laws of motion are the same in the one free-float frame as in the other.

Not only the laws of motion but also the laws of electromagnetism and all other laws of physics hold as true in one free-float frame as in any other such frame. This is what it means to say, "No test of the laws of physics provides any way whatsoever to distinguish one free-float frame from another."

***Fundamental constants the same***

Deep in the laws of physics are numerical values of fundamental physical constants, such as the elementary charge on the electron and the speed of light.[2] The values of these constants must be the same as measured in overlapping free-float frames in relative motion; otherwise these frames could be distinguished from one another and the Principle of Relativity violated.

***Speed of light the same***

One basic physical constant appears in the laws of electromagnetism: the speed of light in a vacuum, $c = 299,792,458$meters per second. According to the Principle of Relativity, this value must be the same in all free-float frames in uniform relative motion.[3] Has observation checked this conclusion? Yes, many experiments demonstrate it daily and hourly in every particle-accelerating facility on Earth. Nevertheless, it has taken a long time for people to become accustomed to the apparently absurd idea that there can be one special speed, the speed of light, that has the same value measured in each of two overlapping free-float frames in relative motion.

Values of the speed of light as measured by laboratory and by rocket observer turn out identical. This agreement has cast a new light on light. Its speed rates no longer as a constant of nature. Instead, today the speed of light ranks as mere conversion factor between the meter and the second, like the factor of conversion from the centimeter to the meter. The value of this conversion factor has now been set by decree and the meter defined in terms of it (Box 3-2 in Section 3.2). This decree *assumes* the invariance of the speed of light. No experimental result contradicts this assumption.

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### ✔ Example 3.3.1: Examples of the Principle of Relativity

Examples of the Principle of Relativity relative motion. According to the Principle of Relativity, which of the quantities on the following list must *necessarily* be the same as measured in the two frames? Which quantities are *not* necessarily the same as measured in the two frames?

a. numerical value of the speed of light in a vacuum
b. speed of an electron
c. value of the charge on the electron
d. kinetic energy of a proton (the nucleus of a hydrogen atom)
e. value of the electric field at a given point
f. time between two events
g. order of elements in the periodic table
h. Newton's First Law of Motion ("A particle initially at rest remains at rest, and . . . ")

**Solution**

a. The speed of light IS necessarily the same in the two frames. This is one of the central tenets of the Principle of Relativity and a basis of the theory of relativity.
b. The speed of an electron IS NOT necessarily the same in the two frames. Determining the speed of a particle depends on space and time measurements between events — such as flashes emitted by the particle. Space and time separations between events, respectively, can be measured to be different for observers in relative motion. So the speed—ratio of distance covered to time elapsed — can be different.
c. The value of the charge on the electron IS necessarily the same in the two frames. Suppose that the charge had one value for the laboratory frame and progressively smaller values for rocket frames moving faster and faster relative to the laboratory frame. Then we could detect the "absolute velocity'' of the frame we are in by measuring the charge on the electron. But this violates the Principle of Relativity. Therefore the charge on the electron must have the same value in all free-float frames.
d. The kinetic energy of a proton IS NOT necessarily the same in the two frames. The value of its kinetic energy depends on the speed of the proton. But speed is not necessarily the same as measured in the two frames (b).
e. The value of the electric field at a given point IS NOT necessarily the same in the two frames. The argument is indirect but inescapable: The electric field is measured by determining the force on a test charge. Force can be measured by change in velocity that the force imparts to a particle of known mass. But the velocity—and the change in velocity — of a particle can be *different* for observers in relative motion (b). Therefore the electric field may be different for observers in relative motion.
f. The time between two events IS NOT necessarily the same in the two frames. This is a direct result of the invariance of the interval (Chapter 1 and Section 3.7).
g. The order of elements in the periodic table by atomic number IS necessarily the same in the two frames. For suppose that the atomic number (the number of protons in the nucleus) were smaller for helium than for uranium in the laboratory frame but greater for helium than for uranium in the rocket frame. Then we could tell which frame we were in by comparing the atomic numbers of helium and uranium.
h. Newton's First Law of Motion IS necessarily the same in the two frames. Newton's First Law is really a definition of the inertial (free-float) frame. We assume that all laboratory and rocket frames are inertial.

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1 Laws of physics the same in different frames

2 Fundamental constants the same

3 Speed of light the same

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