3.2: What Is Not the Same in Different Frames

not the same: space separations, time separations, velocities, accelerations, forces, fields

Notice what the Principle of Relativity does say. It does *not* say that the time between two events is the same when measured from two different free-float frames.[1] Neither does it say that space separation between the two events is the same in the two frames. Ordinarily neither time nor space separations are the same in the two frames.

The catalog of differences between readings in the two frames does not end with laboratory and rocket records of pairs of events. Physics to the Greeks meant the science of change and so it does to us today. Motion gives us a stream of events, for example the blinks of a firefly or the pulses of a sparkplug flashing as it moves. These flashes trace out the sparkplug's trajectory. Record the positions of two sequential spark emissions in the laboratory frame. Record also the laboratory time between these sparks. Divide the change in position by the increase in time, yielding the laboratory- measured velocity of the sparkplug.

Velocity not the same

Spark events have identities that rise above all differences between reference frames. These events are recorded not only in the laboratory but also by recording devices and clocks in the rocket latticework. From the printouts of the recorders in the rocket frame we read off rocket space and time separations between sequential sparks. We divide. The quotient gives the rocket-measured velocity of the sparkplug. But both the space separation and the time separation between events, respectively, are ordinarily different for the rocket frame than for the laboratory frame. Therefore the rocket-measured velocity of the sparkplug is different from the laboratory-measured velocity of that sparkplug.[2] Same world. Same motion. Different records of that motion. Figures for velocity that differ between rocket and laboratory.

Acceleration not the same

Apply force to a moving object: Its velocity changes; it accelerates.[3] Acceleration is the signal that force is being applied. Two events are enough to reveal velocity; three reveal change in velocity, therefore acceleration, therefore force. The laboratory observer reckons velocity between the first and second events, then he reckons velocity between the second and third events. Subtracting, he obtains the change in velocity. From this change he figures the force applied to the object.

The rocket observer also measures the motion; velocity between the first and second events, velocity between second and third events; from these the change in velocity; from this the force acting on the object. But the rocket-observed velocities are not equal to the corresponding laboratory-observed velocities. The *change* in velocity also differs in the two frames; therefore the computed *force* on the object is different for rocket observer and laboratory observer.[4] The Principle of Relativity does not deny that the force acting on an object is different as reckoned in two frames in relative motion.

An electric field or a magnetic field or some combination of the two, acting on the electron, is the secret of action of many a device doing its quiet duty day after day in home, factory, or car. An electromagnetic force acting on an electron changes its velocity as it moves from event P to event Q and from Q to R.[5] Laboratory and rocket observers do not agree on this change in velocity. Therefore they do not agree on the value of the force that changes that velocity. Nor, finally, do they agree on the magnitudes of the electric and magnetic fields from which the force derives.

In brief, figures for electric and magnetic field strengths, for forces, and for accelerations agree no better between rocket and laboratory observers than do figures for velocity. The Principle of Relativity does not deny these differences. It celebrates them. It explains them. It systematizes them.

Box 3-2

The Speed of Light:
A "fundamental constant of nature"?
Or a mere factor of conversion between two units of measurement?

METERS AND MILES IN THE PARABLE OF THE SURVEYORS	SECONDS AND METERS IN SPACETIME

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Meter? Originally (adopted France, 1799) one ten-millionth of the distance along the surface of Earth from its equator to its pole (in a curved line of latitude passing through the center of Paris).	**Second?** Originally 1/24 of 1/60 of 1/60 of the time from high noon one day to high noon the next day. Since 1967, "The second is the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the fundamental state of the atom cesium 133."
Mile? Originally one thousand paces — double step: right to left to right—of the Roman soldier.	**Meter?** Definition evolved from geographic to platinum meter rod to today's "One meter is the distance traveled by light, in vacuum, in the fraction 1/299,792,458 of a second."
Modern conversion factor? 1609.344 meters per mile.	**Modern conversion factor?** 299,792,458 meters per second.
Authority for this number? Measures of equator-to-pole distance eventually (1799 to today) lagged in accuracy compared to laboratory measurement of distance. So the platinum meter rod at Sevres, Paris, approximating one ten-millionth of that distance, for awhile became — in and by itself — the standard of distance. During that time the British Parliament and the United States Congress redefined the inch to be exactly 2.54 centimeters. This decree made the conversion factor (5280 feet/mile) times (12 inches/foot) times (2.54 centimeters/inch) times (1/100 of a meter per centimeter) equal to 1609.344 meters per mile — exactly!	**Authority for this number?** Meeting of General Conference on Weights and Measures, 1983. In the accepted definition of the meter important changes took place over the years, and likewise in the definition of the second. With the 1983 definition of the meter these two streams of development have merged. What used to be understood as a measurement of the speed of light is understood today as two ways to measure separation in spacetime.
A fundamental constant of nature? Hardly! Rather, the work of two centuries of committees.	**A fundamental constant of nature?** Hardly! Rather, the work of two centuries of committees.

Commentary

Is the distance from Earth's equator to its pole a fundamental constant of nature? No. Earth is plastic and ever changing. Is the distance between the two scratches on the standard meter bar constant? No. Oxidation from decade to decade slowly changes it. Experts in the art and science of measurement move to ever-better techniques. They search out an ever-better object to serve as benchmark. Via experiment after experiment they move from old standards of measurement to new. The goals? Accuracy. Availability. Dependability. Reproducibility.

Make a better measurement of the speed of light. Gain in that way better knowledge about light? No. Win instead an improved value of the ratio between one measure of spacetime interval, the meter, and another such measure, the second — both of accidental and historical origin? Before 1983, yes. Since 1983, no. Today the meter is defined as the distance light travels in a vacuum in the fraction 1/299,792,458 of a cesium-defined second. The two great streams of theory, definition, and experiment concerning the meter and the second have finally been unified.

What will be the consequence of a future, still better, measuring technique? Possibly it will shift us from the cesium-atom-based second to a pulsar-based second or to a still more useful standard for the second. But will that improvement in precision change the speed of light? No. Every past International Committee on Weights and Measures has operated on the principle of minimum dislocation of standards; we have to expect that the speed of light will remain at the decreed figure of 299,792,458 meters per second, just as the number of meters in the mile will remain at 1609.344. Through the fixity of this conversion factor c, any substantial improvement in the accuracy of defining the second will bring with it an identical improvement in the accuracy of defining the meter.

Is 299,792,458 a fundamental constant of nature? Might as well ask if 5280 is a fundamental constant of nature!

1 Space and time separations not the same in different frames

2 Velocity not the some

3 Acceleration not the some

4 Force not the some

5 Electric and magnetic fields not the same