14. Final evaluation of Special Relativity

At the end of the presented investigations, the various presentations of special relativity (SRT) available in the literature are discussed and evaluated in brief form. For this purpose, first the two central preconditions "principle of relativity" and "constancy of the speed of light" are examined. To represent the occurring range used in the literature, the possible representations were divided into "objective observation criterion" and "axiom". In recent publications very often the axiomatic approach is chosen. The earlier presentations, e.g. of Einstein, were mostly using the objective observation concept.

The common interpretation of the SRT today includes the aspect that there can be no system of absolute rest. The chains of reasoning used in the literature concerning this matter are quoted and evaluated. It is shown that none of these approaches can deliver a generally valid proof.

Einstein has chosen a top-down approach for the formulation of the SRT. For this purpose, the principle of relativity and the constant speed of light were defined as basics and the Lorentz transformation and later also the relativistic mass increase were derived from them. Now, with an "Extended Lorentz theory", a bottom-up concept is presented where the relativity principle is the result. The validity was proved by a multitude of examples.

With free choice of the base system, both approaches are completely equivalent. However, the Theory of Special Relativity has the disadvantage that it excludes the existence of a system of absolute rest in principle, but this can be integrated without problems into the extended Lorentz concept by a simple choice of the base system. From today's point of view, it seems reasonable to use for it the system which is the basis for the uniform cosmic background radiation in the universe. However, since up to now no experimental proof has succeeded, a decision cannot be made at present. In the context of this elaboration a proposal was made, how an experiment could be arranged, which makes a clear decision possible concerning the different approaches (chapter 13.1).

14.1 Principles of SRT and their presentation in the literature

It is quite surprising that until today there is no uniform formulation of the two central conditions "principle of relativity" and "constancy of the speed of light". Every author of a publication about the SRT chooses his own approach for this (only in individual cases, no presentation is made at all and without comment the Lorentz equations are used [89]). In order to represent the occurring bandwidth, the possible formulations were divided into "objective observation criterion" and "axiom" (Tab. 14.1). In more recent publications, the axiomatic approach is rather (but not exclusively) chosen.

Objective observation criterion	**Axiom of Special Relativity**
1. The execution of any physical experiment leads to the same result in all inertial systems.	1. Principle of Relativity: All inertial systems are equivalent.
2. Measurements of the speed of light in different spatial directions lead to the same result in all inertial systems.	2. Constant speed of light: The speed of light in different spatial directions are the same in all inertial systems.

Tab. 14.1: Currently common representations of the basics of Special Relativity

To show the differences, individual examples are presented in the following. The principle of relativity is defined in its original form by Einstein as follows [12]:

> “Principle of Relativity: The laws by which the states of physical systems undergo change are not affected, whether these changes of state be referred to the one or the other of two systems in uniform translatory motion relative to each other.”

This is therefore a formulation that can be assigned to an objective observation criterion. Some other authors also use the reference to measurements, although the representation can be completely different [27]:

> “Postulate I: It is impossible to measure, or detect, the unaccelerated translatory motion of a system through free space or through any ether-like medium which might be assumed to pervade it.”

This is different with the constancy of the speed of light. For this exist only few cases with the reference to measurements, e.g. M. Born with the following formulation [26a]:

> “The principle of the constancy of the speed of light: In all inertial systems, the speed of light, measured with physically identical rods and clocks, has the same value.”

In almost all other cases, the reference to measurement methods is not mentioned and the form as an axiom is used. Einstein himself used a more complicated form of representation which describes a measuring method but makes a clear assignment difficult:

> “Principle of constancy of the speed of light: Every light ray moves in the "resting" coordinate system with a certain speed V, independent of whether this light ray is emitted by a resting or a moving body. Here is
>
> $$\text{velocity} = \frac{\text{lightpath}}{\text{time period}}$$
>
> where "time period" is to be understood in the sense of the definition of § 1.”

The overall situation can be simplified as follows:

- Objective observation: No difference can be determined. The facts are verified by experiments.
- Axiom: In principle, there is no difference.

The interpretations associated with these representations are significant in the following and will therefore be evaluated in detail. The discussion starts with the constancy of the speed of light.

14.2 Constant Speed of light in every inertial system

First the possibilities to measure the speed of light shall be presented and discussed on a principal basis. The options for measurements can be characterized first by direct and indirect procedures (Tab. 14.2). Whereas direct measurements create quantifiable values, the indirect approach only allows the comparison between values measured in different spatial directions.

1. **Direct** **Use of time measurements**	2. **Indirect** **Comparison of oscillations**
1a) Measurements using light pulses Measurement of time differences at sender/receiver between emitting and receiving a signal after reflection at a mirror.	**2a) Measurement of frequency** Comparison of frequency at sender/receiver between emitting and receiving a signal after reflection at a mirror.
1b) Measurements using moved clocks Two or more identical clocks shall be synchronized. After the transport to reference objects light signals are exchanged and time is measured.	**2b) Oscillation measurements** Analysis of light signals between sender/receiver and mirror as reference (Number of oscillations referring to travelling distance going and coming after reflection).

Tab. 14.2: Possibilities for measurements of the speed of light

In case when direct measurements are chosen, it is essential that the distance between emitter and reference object must be known exactly. It makes no difference, whether the reference object is at rest relative to the sender or moving. First the possibility exists that the time difference between emitting and receiving a light signal after reflection at a mirror is measured (1a). In addition, identical clocks can be synchronized and transported to defined reference points, then signals can be exchanged followed by time measurements (1b). The disadvantage of this procedure is, however, that for test evaluation it must be recognized that moving clocks are subject to time dilatation and that this effect must be considered during test evaluation.

With the indirect methods, only possibly existing differences between the light velocities in different spatial directions can be determined. The distance to a reference object might be unknown but must remain constant during the measurement. First, the comparison of frequencies between outgoing and incoming signals is possible (2a). Furthermore, oscillation measurements have often been performed in the past, comparing the number of oscillations on the way to and from a mirror (2b). Here, the use of measurement providing interference patterns is particularly suitable, such as it is the case in the Michelson-Morley experiment.

The methods were all examined in the context of this elaboration, namely 1a) in chap. 2, then 1b) in chap. 5 as well as 2a) and 2b) in chap. 8. It is important for the interpretation of experiments of the type 2b) that here the phase velocity of light must be used for the evaluation. In the past, this was not done in a sufficient way, so that new and consistent results became visible in a new interpretation of the Michelson-Morley and Kennedy Thorndike experiments, taking this effect into account. If this effect is not respected, false conclusions are drawn.

In the following, another important aspect about the speed of light will be dealt with. The statement: "The speed of light is the same in all inertial systems" must be considered and interpreted carefully. Equal speed of light means:

In every inertial system the speed of light can be chosen in such a way that the own system serves as basis. All conditions of the theory of special relativity are then valid without restrictions. The following relation was defined by Einstein for a base system called "resting" by him, related to another arbitrarily moved system [12a]:

$$\frac{1}{2}(\tau_0 + \tau_2) = \tau_1 \tag{3.60}$$

This condition, today also called “Einstein synchronization”, means that the times for a signal exchange between two points are divided exactly in half for the way there and back (for details see chapter 3.4 and 12.2). This statement is independent of whether the reference object is at rest with respect to the origin or is in motion. Together with the statement that the speed of light is constant in all directions, the distances must also be the same.

The situation is different when the system emitting the signal itself is moving. Let's consider the simple case that the origin of the signal and the reference object have the same velocity. Also, here it is possible that the light velocity of the origin is taken as resting and the same conditions apply as already derived. The same procedure is possible for a signal exchange likewise for any other system from its subjective view.

However, if several test participants from different inertial systems moving against each other observe the *same* event, e.g. the signal exchange between different spatially separated points, different observations must occur. If the speed of light of the own system is taken as a basis for measurements and if the times and distances necessary for the signal exchange are determined for the way there and back, different results appear. Distance and time are *not* divided symmetrically. This effect is caused by the "relativity of simultaneity".

This fact has already been presented in detail in chapter 12.2. At this point it shall be shown additionally that the data taken from this diagram correspond exactly to the results of the Lorentz transformation. For this purpose, first in Fig. 14.1 the left side of Fig. 12.3 is shown again, which represents the correct signal course from the point of view of the moving system S.

The determination of the Einstein synchronization for the outgoing and returning path for the signal exchange between two points (e.g. the ends of a laboratory A and E), which means time and path are in each case divided to the half, is valid only subjectively for the system L which is at rest to the laboratory. If from another moving inertial system S this determination would also apply and the times $t_1 = t_2$ would be equal, the situation would arise as shown in the right part of the diagram 12.3 with signal velocities larger or smaller than c as well as measurable synchronization differences. Moreover, according to these considerations, a situation where the path is constant in both directions cannot even theoretically occur because the lab end moves away from the original point immediately after the signal is emitted and is at a different location on the return path. Instead, the situation as shown in the left part of the diagram applies. This means that the determination of a reference system can always only be subjective.

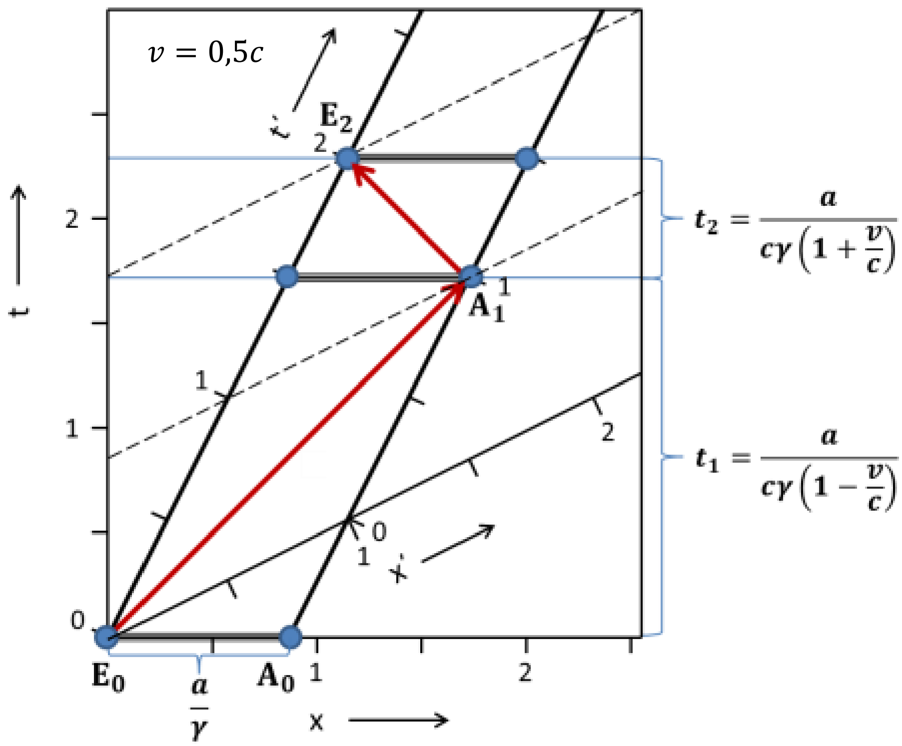

Fig. 14.1: Schematic presentation of a signal in a laboratory L between E and A from the point of view of an inertial system S moving relative to it ($v = 0{,}5c$).

Table 14.3 shows the coordinates for displacement and time taken from Fig. 14.1. The values subjectively valid for the moving system were calculated by using the Lorentz equations. It is immediately recognizable that in this normalized representation the value of the speed of light is c in all cases; for the reference system this results immediately from the position of the signal course in the diagram (45° to x and t), for x' and t' from the relations between path and time.

	x	t	x'	t'
E_0	0	0	0	0
A_1	1,73205081	1,73205081	1	1
E_2	1,15470054	2,30940108	0	2

Tab. 14.3: Determination of the coordinates of E_0, A_1 and E_2 from Fig. 13.1
The values of x' and t' were calculated using the Lorentz-Transformation.

In summary, the following is valid: If the same event is considered from different inertial systems, this leads subjectively to the situation that in all cases the definition of the own speed of light is possible as a basis. The connection between the systems is given by the Lorentz equations, furthermore the principle of the relativity of simultaneity is valid.

14.3 Principle of relativity

For a better understanding of the specifics of this point, it is useful to consider the historical development first. As a main issue to mention here is the conviction, which lasted until the 20th century, that light, because of the wave properties attributed to it, requires a carrier medium for propagation, which was called "ether". This was a general consensus for centuries, although there were great differences in the understanding of the structure of this ether.

Until the Michelson-Morley experiment was carried out in 1887, the idea existed that this ether penetrates everything and shows similarities in its properties with air and sound waves transported in it. Derived from various experimental results, however, there were different opinions about whether ether is influenced by matter and is carried with it completely, partially, or not at all. (Further details of these experiments and subsequent discussions are presented in chapter 1.3).

However, there was a general understanding that when passing through ether, there must be an effect caused by an occurring "ether wind". On the basis of these considerations, the Michelson-Morley experiment was carried out, which, however, gave a null result. This result led to a multiplicity of considerations, which brought however over nearly two decades no breakthrough. It is reported that Lord Kelvin spoke on the subject of "ether" during the international physics congress in Paris in 1900. He said at that time: "The only cloud in the clear sky of the theory was the null result of the Michelson-Morley experiment" [49h]. He as well as many other physicists of his time shared the opinion that the experiment should be repeated with higher accuracy and then would bring the expected positive result; however, none of these attempts were successful.

A first solution appeared when Hendrik A. Lorentz developed the equations later named after him, which allowed a contradiction-free calculation of the correlations. The key point was the introduction of different local times and an effect which was later called "relativity of simultaneity" by Einstein. It was essential in the development that these relations had a similar structure as the previously developed Maxwell equations for electromagnetism. Lorentz was convinced that the ether, which he still considered necessary, must have these properties.

Einstein revolutionized the view on this problem. In 1905, he first showed that light propagation does not need a medium but can be understood as emission of "discontinuous energy quanta" [48]. Until then, the idea of their existence had not existed, but only the nature of light as a wave and the existence of a transport medium connected with it was in the focus. With this approach, Einstein was able to reduce the fundamentals of the theory he presented to the two principles already discussed. The dualism between corpuscle and wave, which is evident for physics today, was not yet known at that time; it was formulated for the first time in 1924 by Louis de Broglie.

The principle of relativity formulated by Einstein also requires a precise interpretation. First, this can be divided into the following detailed statements:

a) If identical experiments are carried out by different observers in reference systems moving uniformly relative to each other, the results will be the same.
b) An observer can describe results of any experiment in another inertial system that shows a constant relative movement using only the Lorentz transformation equations and the relativistic increase of mass. In particular, the observation of the time sequence of events is the same in all cases.
c) All systems moving uniformly relative to each other are equivalent and there is no absolute "system at rest".

The statement a) will now be defined as "principle of identity", b) as "principle of equivalent observations" and c) as "principle of complete equivalence of all inertial systems". While points a) and b) are today backed up by multiple test results, this must be considered in a differentiated manner for point c). This will be done in the following. From the literature, several argumentations are known to support the statement of point c), namely:

1. The results of the Michelson-Morley experiment show that there can be no system of absolute rest.

This becomes clear e.g. in the formulation of Kneubühl [46c] with the evaluation of the Michelson-Morley experiment:

> "The Galilei transformation is not valid for the light! The concept of a "resting" universe is not tenable."

While the first sentence is correct without doubt (the Lorentz transformations are valid as known) the conclusion in the second sentence cannot be derived from it. If the principle of constancy of the phase velocity of light is taken as a basis, the integration of a system of absolute rest is possible without contradictions, which has already been presented in detail in chapter 8. Therefore, contrary to the author's opinion, the Michelson-Morley experiment does not provide evidence for this thesis.

Furthermore, there exists another argument:

2. What is not measurable does not exist.

This view is held, for example, by Born [26b]. The formulation he uses is:

> "If two observers moving relative to each other have the same right to say that they are resting in the ether, there can be no ether."

The term "ether" is to be understood here as a synonym for a system of absolute rest, whose existence is completely rejected based on the available knowledge. Einstein himself has said the following about the topic ether and Theory of Relativity in his inaugural speech as visiting professor in Leiden in 1920 (for explanation: the systems K and K1 are inertial systems moving relatively to each other) [86]:

> "Now the anxious question arises: Why should I distinguish the system K, to which the systems K1 are physically completely equivalent, in the theory in favor to the latter by

> the assumption that ether rests relative to it? Such an asymmetry of the theoretical building, to which no asymmetry of the system of experiences corresponds, is unbearable for the theoretical physicist. It seems to me that the physical equivalence of K and K1 with the assumption that ether is resting relative to K, but is moving relative to K1, is not exactly incorrect from the logical point of view, but nevertheless unacceptable."

The ether concept was not completely rejected by him. In the following explanations he even pointed out that it is necessary for General Relativity; however, he contradicts the idea that it is a system of absolute rest and was of the opinion that ether must exist for every inertial system.

From this representation another argument becomes recognizable, which can be formulated as follows:

3. The Theory of Relativity is preferable to the ether theory according to "Ockham's principle".

"Ockham's principle" is the basic approach to a problem and is named after William of Ockham (1287-1347) and concerns the "law of parsimony". In short, it describes a problem-solving procedure according to which, when several possible explanations are available, the simplest theory is always to be preferred to all others. The simplest theory has the fewest variables and hypotheses. The application of this principle is also called "Occam's razor" because it cuts off everything superfluous and allows only one sufficient explanation.

If the theories on this fundamental basis are compared with each other, then the Theory of Relativity contains 2 basic assumptions, the ether theory on the other hand needs, with the condition of a state of absolute rest (which cannot be proved experimentally at present) a further one. According to the general concept that a theory should be based on as few assumptions as possible, the Theory of Special Relativity is therefore preferable.

The topic ether versus relativity principle was subject of long and controversial discussions at the beginning of the 20th century. Especially because of the considerations presented here, the controversy was clearly decided in favor of Special Relativity and there were no serious objections against it for many decades.

This did not change before the beginning of the second half of the 20th century with the discovery of the uniform cosmic background radiation. Latest measurements with extreme precision showed, that our sun is moving relative to it with a velocity of 369.1 km/s. The maximum deviation of the measurements is actually 0.9 km/s, i.e. 0.25% [23]. Various approaches have been developed to reconcile this measurement result with SRT. However, these were all connected with the consideration to cancel the "relativity of simultaneity" and to introduce a state of absolute rest on this basis. None of these theories were able to show results without severe discrepancies to experimental findings. Major characteristic for all formulated theories was that the simple concept of the invariant phase velocity of light had found no entrance into the considerations and consequently the following interpretations could not be useful.

The Theory of Special Relativity says so far nothing about the cosmic background radiation. But if this phenomenon is also considered, the fact would have to be added that an unspecified coincidence has led to the uniform alignment of this radiation. Here the view of a coincidental givenness is possible; this theory is represented e.g. by Johann Rafelski in "Relativity Matters" (2017). Thereby the cosmic background radiation is ascribed the status of an appearing "beacon" to which one can refer [93].

If now the two competing theories are compared again, it becomes clear that Ockham's principle cannot be effective here because of the same number of fundamental assumptions, since Special Relativity needs an additional hypothesis by the appearance of the cosmic background radiation. This is not necessary for the ether theory. So, based on these considerations it is not possible to decide which of the theories is preferable. Only an unambiguous experiment could provide clarity.

As already mentioned, in this compilation the basic approach was applied that all phenomena are considered from the point of view of a stationary and a moving observer. However, none of the calculations performed showed any difference. These are the following topics, for which the relevant chapter is given in this elaboration:

- → Exchange of signals between point-shaped observers (2.1)
- → Exchange of signals inside moving bodies (2.2)
- → Exchange of signals and correlation of angles (2.3)
- → Signal exchange in any spatial direction (2.4)
- → Experiments with transparent media in motion (4.2)
- → Triggering of engines after synchronization (4.3)
- → Exchange of signals between observers with spatial geometry (4.4)
- → Clock transport t (5.1)
- → Twin paradox (5.2)
- → Relativistic mass increase and energy (6.1)
- → Spring paradox (6.2)
- → Relativistic elastic collision (6.3)
- → Exchange of signals in systems with constant acceleration (6.4.1)
- → Relativistic rocket equation (6.4.2)
- → Relativistic non-elastic collisions (7.1)
- → Analysis of disintegration into 2 particles (7.2.1)
- → Disintegration into 2 photons (7.2.2)
- → Invariance of phase velocity during transition between different inertial systems (8.)

In summary, there is only one reason to prefer the Theory of Special Relativity to the approach of Lorentz. This is the fact that SRT generally covers all conceivable physical experiments, while the Lorentz transformation only describes the signal exchange between different inertial systems. To guarantee a general validity, therefore, an addition must be made, which is given by the solution of the Einstein equation regarding kinetic energy. This will be shown in the following chapter.

14.4 Alternative presentation: Extended Lorentz-Theory

As already explained in chapter 1.6, Einstein had chosen a top-down approach for the Theory of Special Relativity. For this purpose, the principle of relativity and the constant speed of light were defined as basics and the Lorentz transformation and later also the relativistic mass increase were derived from them. For the formulation of the principle of relativity, a similar variant must be chosen as by Einstein himself, namely the representation as objective observation criterion. Also, the statement about the velocity of light can be made in this way, but here it is better to use the constancy of the phase velocity of light. The proposal for a contradiction-free and unambiguous formulation of the principles of the SRT reads accordingly:

1. The execution of any physical experiments leads to the same results in all inertial systems.
2. The phase velocity of the light is invariant in all inertial systems and its speed is equal to the value of the velocity of light measurable in every inertial frame.

However, the investigations presented here have also shown that a bottom-up approach with an extended Lorentz theory is also possible. In this case, the necessary physical basic laws are defined, and the relativity principle can then be derived from them. This approach reads as follows:

1. From the unlimited number of existing inertial systems, one is selected as base system and marked with index 0.
2. In this basic system, measurements of the speed of light show the same value c in all directions.
3. The properties of all other inertial systems are defined by their relative velocity v to the base system, and the following relations are valid for time t, displacement x and mass m

   a) $t = \gamma\left(t_0 - \frac{v}{c^2}x_0\right), \qquad x = \gamma(x_0 - vt_0)$

   b) $m = \gamma m_0$

   with: $\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$

First some formal remarks: The equations under a) are the Lorentz transformation (related to the basic system with index 0). In order to unify the formulas, the traditional representation with t' and x' was not used here (see. chapter 1.6). Equation b) describes the relativistic mass increase and contains the Einstein equation for the kinetic energy (see also chapters 1.6 and 6.1)

$$E_{kin} = m_0 c^2(\gamma - 1) \tag{6.14}$$

In this representation, special relativity and the extended Lorentz approach are mathematically completely equivalent. However, the Theory of Special Relativity excludes with usual interpretation the existence of a system of absolute rest, which can be integrated in the extended Lorentz approach by simple choice of the basic system without further assumptions or restrictions. From today's point of view, it seems to be reasonable to use for this the system which is the basis for the uniform cosmic background radiation. However, since up to now no experimental proof has succeeded, a decision cannot be made at present.

From today's point of view, the only possibility for an experimental proof of a system of absolute rest is the realization of experiments with superluminal velocities. Today there are investigations within quantum mechanics, e.g. in tunneling experiments, where superluminal effects have been detected. Regarding the interpretation of the results, however, there are still big differences. On the one hand it is assumed that despite superluminal effects were detected, no information is transmitted faster than light and therefore the validity of Special Relativity need not be questioned, on the other hand it is assumed that a simple signal transmission, e.g. by a pulse, can indeed be faster than light. In the context of this elaboration a proposal was made, how an experiment could be arranged, which allows a clear decision concerning the different approaches (chapter 13.1).

Further experiments were also presented, which should experimentally confirm other interesting aspects such as the "relativity of simultaneity" and "mass increase after a non-elastic impact".

If these experiments would be carried out, important fundamental questions of physics could be investigated and possibly finally decided. There is certainly some effort involved, but compared to today's costs for experiments, this should be bearable. It is hoped that teams of researchers will be found to undertake the experiments.

In conclusion, it is remarkable that even more than a century after the formulation of the Theory of Special Relativity, new aspects still become apparent when intensively examined.