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THE SENSE OF SPECIAL RELATIVITY: BETWEEN PHYSICS AND PHILOSOPHY [1]

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Abstract. *In this paper I deal with the sense of mechanics in general, because it studies the values of the physical law as the regulation of nature, as the determination of the sense and evidence of gnoseological and ontological implications to make up the physical theory.*

Key words: *special theory of relativity, mechanics, physics, quantum mechanics*

INTRODUCTION

The basic assumptions in Newtonian mechanics have been that the mass of body, being one of its inherent characteristics, is independent of its state of motion with respect to the observer.

Thus equal forces applied upon a body would produce equal accelerations, whatever the instantaneous velocity of the body. Hence if we continue to apply a force indefinitely, the velocity of the given body would go on increasing at a "constant" rate and finally it could exceed any pre-assigned value. This, however, negates our earlier result that there exists an obvious limit, given by the velocity of light in free space, by the velocities that material objects can have.

Thus a given force acting on a body should produce an effectively constant acceleration in the initial stages, but its influence should gradually decrease as the velocity the body increases until the influence of the force should tend to vanish finally, as the velocity approaches its limiting value – c .[2]

Meanwhile, the quantity mg [$mg = m_0 f(v)$] denotes the rest mass of the body, and mg, on the other hand, is referred to as the relativistic mass of the body, that it is a new expression from the new mechanics from Einstein's special theory of relativity as a very important extension of mechanics with implications for the philosophical foundations.[3]

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[1] To celebrate the memory of A. Einstein (1955), and the special theory of relativity (1905)
[2] Cf. A. Einstein – *The Meaning of Relativity*, Chapman and Hall, London, 1-4
[3] Cf. J. L. Mccauley – *Classical Mechanics*, University Press, Cambridge, 1998, 12-14.

In this article I am explaining the sense and foundations of the classical mechanics and the critical implications for Newton's mechanics in relation to the relativistic mechanics or from Newton's to Einstein's thinking. The relativistic mechanics is a creation of physical theories that came from Newton's mechanical sense.

1. THE RELATIVISTIC SENSE

A. Einstein initiated an epistemological revolution in 1905 by elaborating the special theory of relativity. Moreover, he did this for logical reasons, since he had recognized that Maxwell's electromagnetism and Newtonian mechanics were incompatible with one another.

Meanwhile, one theory implied that the velocity of light in vacuum should have the same value "c" for all directions and all inertial frames, independently of their relative motions, but this was forbidden by the other theory.

Einstein, however, removed this paradox in a simple way by changing the previous concepts of space and time. He considered space and time as being defined by the possible results of measurements. These are subjected to a very precise and completely unexpected condition. The outcome of any measurements of space and time intervals in inertial reference frames has to be such that when we measure the distance travelled by a high pulse in vacuum during a measured time interval, this has always to yield the same value.[4]

We will also stress the fact that Einstein's concept of physical laws did influence the development of quantum mechanics; moreover, Einstein did not accept this theory. Naturally, we can say that this theory of relativity takes into account another restriction that Nature imposes on certain measurements, and that these restrictions are also related to the existence of a universal constant of Planck.

But Einstein saw that it led to a very important question. The principle of special relativity would require that the velocity "c" is a universal constant for all inertial reference frames, while Newton's mechanics did not allow for such a velocity.

However, Einstein showed that this problem could be solved, by abandoning the concept of absolute space and time.[5]

We shouldn't consider space and time any more as some kind of physical determination, but define space and time by possible results of measurements by the event. They allow us to explain the space-times coordinates (x, y, z, t) of any given event in a given reference frame. When these measurements are performed in another reference frame for the same event, we get other results (x', y', z', t'). Einstein aimed that for inertial reference frames; these results are related to one another in such a way that a measurement of the velocity of light in vacuum yields always the same value c.[6]

This position changed physics in a very profound way, since it indicated for the time that physical laws should only be considered as sentences concerning the knowledge we

[4] Cf. R. A. Mould – *Basic Relativity*, Springer-Verlag, Berlin, 2002, 20-35.
[5] Cf. R. K. Pathria – *The Theory of Relativity*, Pergamon Press, Oxford, 1974, 10-25.
[6] Cf. A. Einstein – "Relativity, and the problem of Space", in: *The Collected Papers of Albert Einstein*, Volume 6, Princeton University Press, New Jersey, 1997, 394-399.

can get about reality. As we mentioned in the introduction, quantum mechanics did confirm this rule, but even today, this is not always emphasized.[7]

When there exists a finite limit for the smallest measurable distance

$$ds^2 = \sum_{i=1,2,3} dx_i^2 - c^2 dt^2$$

it is meaningless to formulate a physical law that would tell us what happens at a smaller scale, since physical laws should be verifiable, at least in principle. Our usual theories imply: however, that nature laws can be expressed by means of differential equations, assumed to be valid for infinitely small intervals of space and time. They are only approximations that cease to be valid at an extremely small scale.

The laws of classical physics were very good for a certain domain, but they had to be replaced by those of relativistic mechanics and quantum mechanics for larger domains.

To create more general laws of physics that take into account the existence of a finite limit for the smallest measurable distance, we have to proceed very carefully, since we enter the unknown territory. The past experience tells us that it has to be a universal constant like c and h. Distance measurements could then he performed by successive juxtapositions of the same smallest measurable length.[8]

When we perform ideally precise measurements of the x, y, z, ct spacetime coordinates by starting at the origin of this chosen inertial reference frame, we can only get integer multiples of "a" for everyone of these coordinates. This yields a space-time lattice that depends on the chosen origin and the directions of the reference axes, but this lattice constant "a" is always the same.

Einstein showed that the laws of classical mechanics have to be modified in such a way that the energy ($E = m \cdot c^2$), and the momentum $\vec{p} = m \cdot \vec{v}$ of a freely moving particle are related to one another by means of:

$$(E/c)^2 = p^2 + (m \cdot c)^2$$

Since a free particle is unperturbed by external forces, neither its direction of motion nor the values of p and E can change in the course of time.[9]

In classical or relativistic mechanics, we describe the motion of its particle, by assuming that it has a well-defined position at any particular instant t, whether we know this position or not. The rate of variation of this position during a very small time (*de*/*dt*) defines then the instantaneous velocity v.

Meanwhile, it may be difficult to abandon the familiar concept of a space-time continuum, the basic assumptions are in line with the trend of the evolution of classical and relativistic mechanics. Einstein insisted on the essentially constructive nature of thought and more especially of scientific thought. For relativistic theories, the naturalness or logical simplicity of the premises is very important, as well as the inner perfection of all these classical or relativistic theories.

[7] Cf. A. Einstein; B. Podolsky; N. Rosen – "Can Quantum Mechanical Description of Physical Relativity be considered complete?", in: *Physical Review*, 47, 1935, New York, 777-780.
[8] Cf. R. Hill – *Principles of Dynamics*, Pergamon Press, Oxford, 1964, 15-20.
[9] Cf. O. Costa De Beauregard – *La Théorie de la Relativité Restreinte*, Masson et C^{ie}, Éditeurs, Paris, 1949, 87-96.

The theory of relativity leads to a concept of time that contradicts intuition in many ways. Only the theory of special relativity shall be taken into account here. The main point of importance is the fusion of space and time into the four-dimensional space-time by Minkowski. The meaning of space-time can be demonstrated considering the simplest equation of the Lorentz transformations as an example, which are the coordinate transformations of special relativity for inertial uniformly moving systems.[10]

The relations which, when equated, define the Lorentz transformations, show, further, a difference in the role of the time coordinate from that of the space coordinates; for the term Δt^2 as the opposite sign to the space terms dx_1^2, dx_2^2, dx_3^3.

Then the Lorentz transformation, as a coordinate's dictionary, is defined in such a way that, first, it makes the equation $dx_1^2 + dx_2^2 + dx_3^3 - dl^2 = 0$ a co-variant equation, that is, an equation which is satisfied with respect to every inertial system if it is satisfied in the inertial system to which we refer the two given events as emission, and the reception of the ray of light.[11]

The fusion of time and space leads to the concept of space-time in the theory of relativity.

This concept leads to important simplifications. Many cases of this can be found in physics, especially where relativistic effects enter the game.

Accordingly, the world is considered as a space-time-block. The points in this block correspond to events. But the flow of time is a purely psychological phenomenon. Seen from a higher perspective, all events of all times and spaces simply exist.

Consciousness at one time can reach only one dimensional plane of this four-dimensional space-time. This plane corresponds to the present moment. But the presence is an arbitrary point of reference, arbitrary in the same way as a certain point in space.[12]

In accordance with the special theory of relativity, as a new mechanics different from Newton's theory of physics, certain co-ordinate systems are given preference for the description of the four-dimensional space-time continuum. We called these Galilean co-ordinate systems.

For these systems, the four co-ordinates *x*, *y*, *z*, *t*, which determine an event or – in other words – a point of the four-dimensional continuum, are defined physically.

For the transition, from one Galilean system to another, which is moving uniformly with reference to the first, the equations of the Lorentz transformation are valid.

The latter form the basis for the derivation of deductions from the special theory of relativity, and in themselves they are nothing more than the expression of the universal validity of the law of transmission of light for all, Galilean systems of reference (Newton's mechanics).[13]

Minkowski found that the Lorentz transformations satisfied the following simple conditions. Let us consider two neighbouring events, the relative position of which in the four-dimensional continuum is given with respect to Galilean body reference K by the space co-ordinate differences *dx*, *dy*, *dz* and the time-difference *dt*.

[10] Cf. G. L. Maber – *The Geometry of Minkowski Spacetime*, Springer-Verlag, Berlin, 1991, 7-30.
[11] Cf. A. S. Eddington – *The Mathematical Theory of Relativity*, University Press, Cambridge, 1957, 13-15.
[12] Cf. R. d'Inverno – *Introducing Einstein's Relativity*, Clarendon Press, Oxford, 116.
[13] Cf. J. Nielsen – *Vorlesungen über Elementare Mechanik*, Verlag von J. Springer, Berlin, 1933, 10-26.

With reference to a second Galilean system we shall suppose that the corresponding differences for these two events are *dx*', *dy*', *dz*', *dt*'. Then these magnitudes always fulfill the condition

$$dx^2 + dy^2 + dz^2 - c^2dt^2 = dx'^2 + dy'^2 + dz'^2 - c^2dt^2 .$$

This validity of the Lorentz transformation follows from this condition. We can express this as follows. The magnitude

$$dS^2 = dx^2 + dy^2 + dz^2 - c^2dt^2 ,$$

which belongs to two adjacent points of the four-dimensional space-time continuum, has the same value for all selected reference-bodies.[14]

If we replace $x, y, z, \sqrt{-1}\,ct$, by x_1, x_2, x_3, x_4 , we also obtain the result that

$$ds^2 = dx_1^2 + dx_2^2 + dx_3^2 + dx_4^2$$

is independent of the choice of the body of reference we call the magnitude "ds" the distance apart of the two events or four-dimensional points. However, we can regard the space-time continuum, in accordance with special theory of relativity, as a Euclidean four-dimensional continuum.

The description of the space-time continuum by means of Gauss co-ordinates completely replaces the description with the aid of a body of reference, without suffering from the defects of the latter mode of description, it is not tied down to the Euclidean character of the continuum.

It was Lorentz who gave, in his monumental work of 1904, the formula:

$$m_c = m_0 / (1 - v^2/c^2)^{1/2}$$

for the mass of an electron as a function of its velocity. This formula was obtained on the assumption that electrons in motion underwent Fitzgerald contraction.[15] In this paper of 1905, the reason for the century celebration in the international Year of Physics, Einstein also touched upon this question but did not deceive the formula: $m_c = m_0 / (1 - v^2/c^2)^{1/2}$; of course, he did obtain correct expression for the so-called longitudinal mass of the electron and its kinetic energy; see the following section. Critically it was Planck who in 1906 carried out the systematic study of relativistic dynamics and discovered equations which were to replace the Newtonian equations of motion of the material particle.

However, Planck obtained correct relativistic expressions for momentum and kinetic energy, and hence, for the function $f(v)$. Nowadays, relativistic formulae are taken for granted in all considerations, theoretical or experimental, within high-energy particles, cosmic rays or man-made machines.[16]

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[14] Cf. R. Luis Gomes – *A Teoria da Relatividade, Espaço-tempo-gravitação*, Edições Monsanto, Lisboa, 1954, 39-41.

[15] Cf. J. W. Kane; M. M. Sternheim – *Physics*, J. Wiley and Sons, New York, 1988, 25-27.

[16] Cf. A. L. Miller – *Albert Einstein's Special Theory of Relativity*, Springer-Verlag, 1988, 312-316.

The relativistic formulae of mass and momentum are employed towards this end, therefore, and the resulting design is found to work exceedingly well. This may, therefore, be regarded as an indirect, but convincing evidence for the relativistic expression. According to a gnoseological critic, Einstein's mechanics is one generalization from Newton's mechanics. There is a new perspective of the laws of nature by Einstein's opportunity. Now there is a new mechanics that comes from Newton's mechanics.

2. THE CRITICAL STATEMENTS

Although it may be difficult to abandon the familiar concept of a space-time continuum, the basic assumptions are in line with the trend of the evolution of physics.

Einstein insisted on the essentially constructive and speculative nature of thought and more especially of scientific thought. For physical theories, the naturalness or "logical simplicity" of the premises is very important, as well as the "inner perfection" of all these theories.

We applied these rules to establish the foundations of space-time and to test its logical consistency and to show that it has the advantage of removing a severe contradiction that subsisted between relativity and quantum mechanics.[17]

The external confirmation is essential to special Relativity, since the others physical theories should not only be correct, but also true. This means that they have to be in conformity with observed facts. Their objective is to describe what actually happens or could happen in Nature. Regarding the creation of a new theory, Einstein, however, warned against the prejudice that facts by themselves can and should yield scientific knowledge without a free conceptual construction.[18]

The evolution of space-time quantization was mainly motivated by a search of greater harmony between various ideas and facts that carries out the basic tissue of relativistic physics.[19]

The name theory of relativity has greatly contributed to all sorts of misunderstandings. This name contained a clear reference to an epistemological relativism.

But there were also serious thinkers who saw some links between relativity theory and the Kantian transcendental philosophy. Kant opted for the kinetic relativism, the doctrine claiming that one can meaningfully speak only about motion relative to other bodies. All this happened in Kant's pre-critical period; in his mature period he asserted that space and time are categories inherent in our cognitive equipment which are necessary conditions for our perceptions. But thanks to the space category our perceptions can be ordered as coexistent with each other; and, thanks to the time category, they can be ordered as succeeding each other.[20]

The special theory of relativity seemed to satisfy positivistic postulates yet in another respect. In this original work of 1905 Einstein started with formulating measurement pro-

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[17] Cf. A. Pais – *A vida e o pensamento de A. Einstein*, tradução do inglês, Círculo de Leitores, Lisboa, 1992, 318-320.

[18] Cf. A. Meessenn – "Space-time Quantization", in: *Revista Portuguesa de Filosofia*, 61, Braga, 2005, 39-45.

[19] Cf. A. Einstein – *La Théorie de la Relativité Restreinte et Générale, exposé élémentaire*, Gaulthier-Villars, Paris, 1954, 47-49.

[20] Cf. A. Rosales – "Zur teleologischen Grundlage der transzendentalen Deduktion der Kategorien", in: *Kant-Studien*, 4, Berlin, 1989, 377-386.

cedures of such magnitudes precisely as the length of body at rest and in motion, or the length of time intervals.

Einstein's views had a great influence not only on physicists, but also on philosophers. There are, for instance, many striking similarities between Popper's philosophy of science and Einstein's methodology. What Popper called hypothetical deductive method does not differ much from Einstein's teaching on the nature of physical theory. I do not claim that Popper really borrowed from Einstein some of his theses. I want only to say that our present philosophy or science owes many of its features to Einstein, and to his theory of relativity. And because of its exceptional inner perfection, and its rich physical content, this theory was so many times analyzed by various philosophers that we could truly say that without the theory of relativity our present philosophy of science would be different from what it is now.

However, I would state a corroboration of this idea in Einstein's special theory of relativity. For instance, in the fact that in this theory every observer connected with the inertial reference frame decomposes space-time into its own space and its own time. In the theory of relativity, every observer can be identified with the system of devices measuring time intervals and space distances.[21]

CONCLUSION

The special theory of Relativity defines a new methodology for the physical science, because there are, however, determinations for the measurements.

Much later Einstein clearly formulated his methodological views. Physical theory cannot be reduced to a set of measurement results. By mathematical deduction from them one constructs the body of a given theory; but this is by no means a mechanical process, one should invent ways to overcome difficulties, one ponders various possibilities, sometimes one goes back and modifies initial assumptions and so on.[22]

Only when the theory of relativity is ready, one derives from it empirical predictions which should be compared with the results of real experiments.

In Einstein's view, there exist two criteria of the correctness of any physical theory: its agreement with experimental results.

The new relativistic theory means learning a sense of space-time, as relative events, and according to the "metric". However, the spacetime is a holistic perspective of measurements.[23]

The special Relativity is an event theory, because it explains the sense of invariance of the physical laws according to inertial systems of references.

The theory of relativity is intimately connected with the theory of space and time. I shall therefore begin with a brief investigation of the origin of our ideas of space and time, although in doing so I know that I introduce a controversial subject. The object of all science, whether natural science or not, is to co-ordinate our experiences and to bring them into a logical system.[24]

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[21] Cf. W. Pauli – *Theory of Relativity*, translated from the german, Pergamon Press, London, 1958, 1-4.
[22] Cf. E. Schrödinger – *Space-time Structure*, University Press, Cambridge, 1954, 74-76.
[23] Cf. P. T. Landsberg – *The Enigma of Time*, Adam Hilger, Bristol, 1982, 35-40.
[24] Cf. W. Heisenberg – *Physics and Philosophy, the revolution in modern science*, George Allen and Unwin Ltd., London, 1958, 99-105.

But, normally, the theory of relativity is often criticized for giving, without justification, a central theoretical role to the propagation of light, in that the concept of time is founded upon the law of the propagation of light. And there are so many other critical judgments, from natural law to experience, to the new relativity of space and time.

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POJAM SPECIJALNOG RELATIVITETA: IZMEĐU FIZIKE I FILOZOFIJE

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Ovaj rad se bavi opstim pojmom mehanike i vrednostima fizičkog zakona kao regulacije prirode i odrednica i zakona gnoseoloških i ontoloških implikacija na teoriju fizike.

Ključne reči: *specijalna teorija relativiteta, mehanika, fizika, kvantna mehanika*