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The Dynamic Image of Physical Action. Contribution of the Special Theory of Relativity to the Epistemological and Metaphysical Reflection on Cause and Time

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Sommario: *1. The Conceptual Image of the World and Its Transformations. 2. Causal and Temporal Dynamism in Pre-relativistic Thought. 3. The Rationalization of the Image of the World and the Lack of a Physical Dynamism. 4. The New Articulation of Cause and Time in the Special Theory of Relativity. 4.1. The Einsteinian Critique of Classical Time. 4.2. The New Conceptual Elements of Relativistic Time. 4.3. The Causal Structure of Relativistic Space-Time. 5. Two Images of Physical Dynamism.*

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It is often stated that science has transformed the way that we see the world[1]. In many discussions, arguments taken from science frequently emerge; for example, the continuous evolution to which every reality must necessarily be subject, the relative character of all physical magnitude, or the subjective value of every human knowledge, conditioned by interaction with the instruments of measure and with the observer himself. It is true, however, that the excessive nonchalantness with which the arguments come to be adopted in various contexts, at times far removed from those in which they were originally formulated, makes us wonder whether we are not encountering simple "commonplaces" that have been adopted for reasons of convenience or for a reason of relativistic prejudice that has invaded even the realm of scientific objectivity and practice. A further reflection seems necessary on the importance and sense of this transformation.

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[1] See for example P. JOHNSON, *Modern Times. A History of the World from the 1920's to the 1990's*, George Weidenfeld & Nicolson Ltd., London 1983, pp. 1-5.

1. The Conceptual Image of the World and Its Transformations

Is it true that science has transformed our vision of reality? The answer cannot be other than affirmative. The conception that we have today of the reality of the physical world and of its meaning is very different from that which was common only a hundred years ago. However, the challenge is in determining, without falling into easy generalizations, what the fundamental modifications have been and what has been the cause of them. This proves to be not so simple. The changes have been of different types. Science has discovered for us "new worlds," enlarging our view of reality to include the world of the microscopic, the subject-matter of the physics of high energy, and even the immensity of space and time, such that the cosmological order allows us to inquire into its most distant origins. Even more astonishing is the emergence of the last of the "worlds" of discovery: the world of the complex, brought into the spotlight by the multi-disciplinary research of the few last decades.

Nevertheless, this enlargement of horizons has not constituted the main transformation. If our conception of the world has changed it is owing first to the fact that the world first known by us, the "everyday world," has also been the object of a profound transformation. It should not be as surprising for a traveler to land on a new, unexplored world as to notice that that from which he comes proves to be different from what he had always believed[2]. For that reason the transformations of the basic concepts of our image of the world will reveal to us, in a manner more radical, the sense of the conceptual revolution that has occurred. Yet, this task necessarily demands the development of a concrete philosophical reflection, operating not only on the methodological level but also on the epistemological and metaphysical levels. Unfortunately, this type of reflection seems mostly absent from many of the current reflections on science, which are often reduced to a superficial repetition of commonplace ideas.

What is the cause of such an absence? The current philosophy of science, despite the unquestionable success reached in the clarification of the methods of science and of its progress, seems to meet great difficulty in establishing a bridge or a dialogue between scientific constructions and the metaphysical meaning of the fundamental concepts that are at the base of both scientific and philosophical discourse. This difficulty cannot be attributed solely to a prejudice deriving from the Neo-positivist origin of a great part of the current philosophy of science. Even when the transformation of theories is seen in the Kuhnian perspective as a change of paradigm, it is clearly difficult to admit that on one level, which we can call pre-physical (perhaps it would be more adequate to say meta-physical), different from that which is formal and proper to science, a set of fundamental conceptual contents is given. These fundamental concepts are not necessarily

[2] An experience of this type, in the moral sphere, is described by C.S. Lewis, *The Pilgrim's Regress*, W. M. Eerdmans Publ. Co., Grand Rapids, Mich.1992.

stable and definitive, and yet they are essential any attempt to establish a bridge, on both the theoretical and practical levels, between two theories that otherwise should prove to be incommensurable.

The basic conceptual content of the theory, in the Kuhnian perspective, forms part of the accepted paradigm in a particular historical moment, and consequently it must change radically when this paradigm is replaced by the emergence of a new theory. However, changes so radical do not occur in the history of science. The rival theories generally enjoy a common, semantic base constructed from elements of different sources –metaphysical, mathematical and operative concepts; mathematical methods and experimental procedures– that in scientific practice allow for dialogue and comparison among the theories. Even in the more radical revolutions, as in the Copernican revolution, it is possible to find such a common base. This proves to be more ample in the revolutions of the last century, where a large part of outmoded science still remains in use, even if to a limited extent in a context of more precise application[3].

Recently, some interpretations of science have been presented that can contribute to a clarification of the new role of the basic concepts in scientific constructions, by means of a more attentive consideration of the meaning of scientific objectivity and of the connection between the theoretical and experimental elements in science[4]. In this perspective what is decisive is the recognition of the existence of different levels of comprehension in our knowledge of the world and, consequently, in the meaning of the concepts that in such a task we must use. The philosophy of science considers generally two types of concepts: those which proceed directly from sensible experience, that express our observations, and those of theoretical character, created by the mind with the goal of elaborating a scientific construction. The inherent difficulty in the relationship between the two orders has not been resolved in a satisfactory manner. Considering the necessity of recognizing, for example, the theoretical content of the concepts of observation, the only solution seems at times to be that of admitting that they are in reality theoretical constructions[5]. The dilemma in such a conclusion is that it seems difficult to avoid an instrumentalist view of science.

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3 On this point see R. MARTÍNEZ, "Congetture, certezze e verità: la natura fallibile della conoscenza scientifica," in ID. (ed.), *La verità scientifica*, Armando, Rome 1995, pp. 73-97.

4 See E. AGAZZI, "Eine Deutung der wissenschaftlichen Objektivität," *Allgemeine Zeitschrift für Philosophie* 3 (1978): 20-47; IDEM, "Les critères sémantiques pour la constitution de l'objet scientifique," in *La sémantique dans les sciences* (Archives de l'Institut International des Sciences Théoriques, 21), Office International de Librairie, Brussels 1978, pp. 13-29; IDEM, "L'objectivité scientifique," in IDEM (ed.), *L'objectivité dans les différentes sciences*, Editions Universitaires, Fribourg (Swiss) 1988, pp. 13-25; M. ARTIGAS, "Objectivity and Reliability in Science," *Epistemologia* 11 (1988): 101-16.

5 This is that which is known by the slogan "There is no theory/observation distinction." Cfr. N. CARTWRIGHT, "How We Relate Theory to Observation," in P. HORWICH (ed.), *World Changes: Thomas Kuhn and the Nature of Science*, MIT Press, Bradford Books, Cambridge 1993, p. 259.

Only in a perspective open to the metaphysical meaning of reality and of our knowledge is it possible to admit a multivalent semantic of concepts that can allow a harmony between the theoretical and the observational dimensions of science. Many of the concepts we use in the elaboration of physical theories are not only elements of a formal construction, but even before that they form part of a more basic comprehension of reality, of which we make use on a level of ordinary and spontaneous knowledge and on the level of practical action. We can definitively recognize the existence, on a conceptual level, of an *image of the world* that is present prior to theoretical and scientific reflection and that, in addition to being an expression of our spontaneous knowledge of the real, constitutes a conceptual scheme within which one can develop scientific reflection.

This prior conceptual scheme, sometimes called a "pre-scientific understanding" is not prior in the temporal sense, as though it should later be replaced by a scientific understanding of reality. This can at times happen, particularly on the propositional level, when a causal pre-scientific explanation is later replaced by a law of the experimental type. On the level of concepts, however, the understanding that we call here *conceptual image* is in every moment necessary and cannot be later abandoned. It helps to give to the more fundamental notions of the theory –those which put it in correspondence with the observations– a meaning and a concrete denotation. Certainly the development of scientific theories, with their greater precision, and as a result of the encounter between theoretical concepts and experimental observations, delimits, clarifies, and corrects this set of concepts. Science will not be limited, in its process of theoretical construction, to the concepts of this basic conceptual image. Rather, it will modify some of the concepts and it will add new specifically constructed concepts[6].

Even a philosophical reflection, on its various levels, can contribute to a more profound clarification of the context and the meaning of these basic concepts. Many of them are born in a spontaneous and immediate manner in our confrontation with experience, and only later are adopted –with an appropriate precision or modification of their semantic content– by science or by metaphysics. Since both the scientist and the metaphysician, like ordinary people, must in every case refer to their basic conceptual understanding, the changes introduced into these concepts will influence and change their initial image of the world[7]. Consequently, the image of the world is not static nor stationary but appears to be subject to a constant evolution, above all in the periods of great innovation in the fields of science and metaphysics.

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[6] For example, we think of the concepts of mass, force, or impulse, in Newtonian mechanics, or that of charge, spin or color in particle physics.

2. Causal and Temporal Dynamism in Pre-relativistic Thought

Among the concepts which constitute our image of the world those which embrace its dynamic behaviour are of fundamental importance. They enable us to have an image of *material* or *physical dynamism*: they are a collection of conceptual elements that determine the possibility of understanding the dynamic action among the different elements that constitute physical reality; whether that reality be considered as substances, events or processes. The question of physical dynamism, strongly linked to the more fundamental philosophical categories such as being and becoming, proves to be fundamental in every attempt to understand reality. Is dynamism an intrinsic characteristic of the physical world? Is reality essentially dynamic and processual, or must it be conceived in the final analysis as something fixed and stable, like a "given" which is completely determined? What is, in the first instance, the root of such dynamism?

We wish to consider two elements. The first is *causal dynamism*. Even if material reality has often been considered as "inert matter," the current knowledge of the processes of matter, from the level of elementary interactions to the phenomena of self-organization that we observe in different spheres of the physical world, obliges us to recognize physical action as a characteristic intrinsically rooted in every level of material reality[8]. What are its characteristics? Does causal action constitute an illusion owing to our subjective processes, or is it truly independent of our minds, a characteristic proper to every physical system? Is our world only a show of "Chinese shadows" –that remind us in some way of the cave of Plato– in which every relation is pure fiction, or does it represent a real and live drama whose actions are decisive and determine in some way the reality of this world? Certainly, the second alternative seems necessary when the question is put on a human and personal level. Paradoxically, however, the dynamism of physical reality is often presented as an illusion.

There is a second concept that appears necessarily linked to that of causal action in the elaboration of an image of the physical world: *temporal dynamism*. The possibility of achieving a dynamic image of the world seems connected to the role and meaning that has come to be attributed to time. In a world truly dynamic, temporality must necessarily occupy a central role in the understanding of reality. However, the difficulties in achieving an adequate understanding of time are a constant in the history of thought; not only because the obstacles that seem to ap-

[7] The concepts of force and energy, for example, received in the Newtonian revolution a new meaning which later was assimilated into the image of the world characteristic of modern thought. This is true even outside the field of mechanics, the context in which they first arose. See M. JAMMER, *Concepts of Force. A Study in the Foundations of Dynamics*, Harvard University Press, Cambridge 1957.

[8] Cfr. M. ARTIGAS, "Three Levels of Interaction between Science and Philosophy," in C. DILWORTH (ed.), *Idealization IV: Intelligibility in Science* (Poznan Studies in the Philosophy of the Sciences and Humanities, 26), Rodopi, Amsterdam 1992, pp. 123-44.

pear in the understanding of the logical and physical structure of temporality, but also because recognizing the reality of time entails committing oneself with regard to the profound metaphysical questions regarding being and its value. Is time only an illusion that results from the subjective experience of a reality that is fixed and determined, in which there is really no place for the authentic emergence of novelty? Can one affirm the value of a reality that *is not* already fully real?

These are questions that we can qualify as properly metaphysical, and that have always occupied a place in philosophical reflection. Throughout history the answers contrasted sharply, and it seems that a clear image of physical dynamism has still not been achieved. However, some of the elements introduced by recent scientific theories seem to make feasible a more profound understanding of physical dynamism[9]. Einstein's theory of relativity, in particular, seems to offer for the first time an interpretative framework of the fundamental physical structure of the world in which dynamism, temporal and causal, play a role of the first order. This does not mean that the Einsteinian theory has given a complete and definitive answer to the questions about physical becoming. It constitutes only a partial theory within a complex vision of the world that current science seeks to elaborate but from which we are always distant[10]. Yet, the examination of the conceptual modifications introduced by this theory can contribute to a greater understanding of our actual image of the world and its epistemological and metaphysical meaning.

We must in the first place outline the discussion from the historical point of view. It seems correct to recognize that until now a fully dynamic image of reality has not been achieved[11]. If we consider the period preceding the birth of classical science, the reason for this absence can easily be attributed to the scarcity of precise knowledge of the physical world from the scientific-experimental point of view. For this reason the physical images proposed were inadequate, even in the presence of a valid metaphysical perspective regarding the problem of being and becoming. Aristotelian metaphysics, in particular, establishes a solid base to allow an adequate understanding of the connection between being and becoming, a base whose fruitfulness is yet to be fully explored. The conception

[9] Cfr R. MARTÍNEZ, *Immagini del dinamismo fisico. Causa e tempo nella storia della scienza*, Armando, Roma 1996.

[10] Today there is no lack of promises of a soon to come "theory of everything" or a "final theory." See J.D. BARROW, *Theories of Everything. The Quest for Ultimate Explanation*, Clarendon Press, Oxford 1991; S. WEINBERG, *Dreams of a Final Theory*, Pantheon Books, New York 1992. However, this is not a new claim. When Max Planck began his study, there were some who describes physics as a science "that would soon assume a stable and definitive form": it appeared in general to be a secure and nearly definitively acquired science. The facts had soon confuted that claim. Cfr. M. PLANCK, *La conoscenza del mondo fisico*, Einaudi, Turin 1942, p. 139.

[11] This also appears as one of the motivations of a great part of the philosophy of this century, from Bergson and Whitehead, in a field more physical, to Heideggerian existentialism, in the more metaphysical sphere.

of material being as having a fundamental "non-physical" composition[12] between the "subject" itself and its "perfections" or "formalities", together with the recognition of its authentic propensities and dynamisms (not only mechanical but teleological)[13], gave to Aristotelian thought the capacity to present a vision of physical becoming of great penetration and value even today.

However, the Aristotelian reflection was not successful in constructing, in addition to such a lucid metaphysical elaboration, a proportionate image of the physical kind. Aristotelian physics, particularly as it was transmitted to the modern world, constituted at many times an "essentialist" construction, in which the formal predominance of essence rationally considered nullified, at least in great part, the fruitfulness of the dynamic perspective. This is so not only by reason of the predominate role occupied by form and quality, as it is often stated, but also by reason of an inadequate articulation of the quantitative dimension with the formal dimension that rendered impossible the examination of the individual physical processes[14].

If we consider instead the metaphysical image of reality that Aristotelian philosophy offers us, particularly in its highest elaboration by Thomas Aquinas and other philosophers of the thirteenth century, we can do no less than recognize the profound capacity that it has shown in illuminating for example, biological, anthropological and ethical dimensions of human existence as well as its role in the development of theology. For these reasons, the fruitfulness of this prospective can overcome its apparent sterility in the physical field and provide insights into some of the features of reality which are consistent with our own more precise knowledge of nature.

The formulation of Newtonian mechanics in the last part of the seventeenth century marked the culmination of a long process lasting almost one hundred and fifty years that gave rise to that which we call today classical science. Without forgetting that the thirteenth and fourteenth centuries had anticipated many of the elements of modern science, as it was brought to light first at all by Pierre Duhem[15] and successively by other historians of science[16], it is necessary to rec-

[12] Cfr. Aristotle, *Physics* I.7 190b11-12.

[13] Cfr. Aristotle, *Physics* II.8.

[14] A manifestation of such a difficulty appears in one of the more conflicting problems of Aristotelian physics: the question of the elementary composition of material reality. See A. Maier, "Die Struktur der materiellen Substanz," in *An der Grenze von Scholastik und Naturwissenschaft*, vol. 3 of *Studien zur Naturphilosophie der Spätscholastik*, 2d ed., Edizioni di Storia e Letteratura, Rome 1952, pp. 1-140.

[15] P. Duhem, *Le système du monde. Histoire des doctrines cosmologiques de Platon à Copernic*, 10 vols., Hermann, Paris 1913-1959.

[16] A. Maier, *Studien zur Naturphilosophie der Spätscholastik*, 5 vols., Edizioni di Storia e Letteratura, Rome 1949-1958; M. Clagett, *The Science of Mechanics in the Middle Ages*, University of Wisconsin Press, Madison 1958; A.C. Crombie, *Augustine to Galileo: Science in the Middle Ages and Early Modern Times*, 2d rev. and enl. ed., 2 vol., Harvard University Press, Cambridge 1979.

ognize that the new science presents very many specific characteristics, difficult to adapt to the medieval vision of the world, that begin to manifest themselves in the work of Copernicus and later to mature in that of Galileo and Newton. Rejecting the attempt to elaborate a deductive knowledge of the physical world beginning with certain and universal principles reached by means of abstraction and essential induction –a knowledge often articulated in terms of formal characteristics– modern science sought an apparently more limited type of knowledge that seeks to know only "some affections" of nature[17] on the basis of systematic observation, measurement and mathematical reasoning.

In this new methodological and epistemological position basic concepts adopted by science, in particular those of cause and time, underwent an early transformation, the result of the necessity of putting forward, on a methodological level, concepts accurately defined and operative in a context now fully formalized. In the development of the notion of cause it is possible to observe the consolidation of some conceptual elements, like necessity, lawfulness, mathematical regularity and mechanical dependence, that result in transforming completely the notion of cause. Among these elements necessity was the fundamental and more characteristic concern, already announced in the evolution of the concept of cause in the late medieval times[18]. At the beginning of the modern age necessity becomes almost coextensive with the notion of causality: since a cause must act necessarily and an effect must necessarily follow the cause. We have a particularly significant example in Galileo Galilei[19]. In his definition of cause, Galileo uses causality and necessity, or causality and determinism, interchangeably[20]. Cause appears as the condition or set of conditions that are sufficient for determining the effective occurrence of a phenomenon and without which it is not given: the necessary and sufficient condition for the factual occurrence of a phenomenon.

This definition is not astonishing today, even if a superficial examination is enough to notice its insufficiency. Not all the conditions, even the necessary and sufficient ones, are that which we call cause, nor do all causes enjoy such a logical position[21]. However, since the beginning of the modern age there have been

[17] G. Galilei, *Istoria e dimostrazioni intorno alle macchie solari e loro accidenti*, in *Le Opere di Galileo Galilei*, Edizione Nazionale, ed. Antonio Favaro, 20 vols., G. Barbèra, Florence 1890-1909, vol. V, pp. 187-88.

[18] Cfr. A. Maier, "Notwendigkeit, Kontingenz und Zufall," in *Die Vorläufer Galileis im 14. Jahrhundert*, vol. 1 of *Studien zur Naturphilosophie der Spätscholastik*, Edizioni di Storia e Letteratura, Rome 1949, pp. 219-50.

[19] See R. Martínez, "La filosofía de Galileo y la conceptualización de la causalidad física," in J. Arana (ed.), *La filosofía de los científicos*, *Thémata* 14 (1995): 37-59.

[20] Cfr. G. Galilei, *Discorso intorno alle cose che stanno in su l'acqua*, in *Le Opere di Galileo Galilei*, vol. 4, p. 112; *Il Saggiatore*, in *Le Opere di Galileo Galilei*, vol. VI, p. 265.

[21] Following the classical example, one can state that a short-circuit is the cause of a fire, even if it is neither a necessary condition (the fire could have been produced by other factors) nor a sufficient condition (not every short-circuit causes a fire). On the other hand, the nec-

attempts to translate causal relations into relations of "conditionship." The comparison of this notion with the scholastic definition of cause as "the principle which affects the being or becoming of something" reveals an important difference. A change in perspective has been produced: causality is no longer formulated in terms of metaphysical categories such as being, action, or dependence, but rather in terms of straightforward logical terms or in relation to the data of experience.

It seems possible to see in this fact a sign of the predominance of the rationalist current that made its way through the European intellectual panorama of the modern age. Many of the characteristics assumed in the concept of cause in mechanics demonstrate a strict correspondence to the ideals of rationalism. Causality conceived as the determined result of a transmission of movement, for example, guarantees an absolute adherence of the representation of nature according to the principles of reason. Furthermore, causal necessity outlined in a scheme of pure logical deduction (*if* a cause is given, *then* the effect is produced) guarantees the fully analytical nature of the operation of human knowledge, conceived as a result of logical inference. A determinism in which nothing contingent finds a place appears to be the radical consequence of the rationalist doctrine on the physical level.

The conceptualization of time, elaborated by means of the Newtonian notion of absolute time[22], presents similar characteristics. Time is increasingly seen in logical and rational teerms. In classical physics time becomes an independent variable, basis of reference in the measurement of physical phenomena, a "logical space" in which phenomena develop. So, the image of time as a receptacle was a success[23], even if it had been repeatedly rejected by ancient and medieval philosophy as too naive[24]. In this way of thinking time runs the risk of ceasing to be a significant characteristic of physical description. The "atemporality" of classical mechanics, derived from the reversible nature of mechanical formulations,

essary and sufficient condition for two triangle to be equal, as is having two angles and a side equal, is not habitually considered as the "cause" of the equivalence among triangles. These point have been made often. See for example J.L. MACKIE, "Causes and Conditions," *American Philosophical Quarterly* 2 (1965): 245-64; E. AGAZZI, "Time and causality," *Epistemologia* 1 (1978): 397-424.

[22] I. NEWTON, *Mathematical Principles of Natural Philosophy*, trans. rev. F. Cajori, University of California Press, Berkeley 1946, p. 6: "Absolute, true, and mathematical time, of itself, and from its own nature, flows equably without relation to anything external, and by another name is called duration; relative, apparent, and common time, is some sensible and external (whether accurate or unequable) measure of duration by the means of motion, which is commonly used instead of true time; such as an hour, a day, a month, a year."

[23] *Ibidem*, p. 8: "For times and spaces are, as it were, the places as well of themselves as of all other things. All things are placed in time as to order of succession; and in space as to order of situation."

[24] Cfr. P. JANICH, *Protophysics of Time. Constructive Foundation and History of Time Measurement* (Boston Studies in the Philosophy of Science, 30), D. Reidel Publishing Co., Dordrecht, Boston and Lancaster 1985, pp. 210-11.

constitutes a clear manifestation of the fully rational, and for that reason static and definitive, nature that the vision of the world had to take on[25].

3. The Rationalization of the Image of the World and the Lack of a Physical Dynamism

In this two-fold conceptual outline, the connection between causal dynamism and temporal dynamism is certainly conditioned, as appears in a particular way in the philosophy of David Hume. The humean critique of the causal notions proper to rationalist philosophy is well-known. Many of the elements of this critique continue to be source of debate today[26]. Hume will deny the existence of any type of causal "connection," if by that one means a quality or force inherent in the objects that we call causes and effects. The causal relation is reduced to an association between the lively impression of a cause and the idea of an effect, arising by *custom*, as a consequence of the constant conjunction observed among them in the past.[27] However, this does not mean to deny the necessity of the causal relation, in particular in the methodological realm. Causal necessity comes to be a kind of logical necessity[28]. The cause-effect relationship will no longer represent an intrinsic relationship between two entities (a genetic or mechanical dependence but in any case real). Rather, it will only represent an extrinsic relationship, and for that reason is characterized by an absolute logical necessity derived from the same regularity that forms it.

In this perspective time acquires a particular meaning: it is a necessary factor for distinguishing cause and effect in the regular succession that constitutes, in every case, the unique aspect of the causal relationship accessible to human

[25] The so-called "intemporal formula" of Laplace constitutes the greatest expression of this attempt: "An intelligence which for a given moment knew all the forces controlling nature, and in addition, the relative situations of all the entities of which nature is composed –if it were great enough to carry out the mathematical analysis of these data– would hold, in the same formula, the motions of the largest bodies of the universe and those of the lightest atom: nothing would be uncertain for this intelligence, and the future as well as the past would be present to its eyes." *Pierre Simon de Laplace*, *Essai philosophique sur les probabilités* (Paris 1814). English translation from Hans Reichenbach, *The Direction of Time*, University of California Press, Berkeley 1956, p. 10.

[26] In a particular way the exact meaning is discussed that would have had for Hume *causal necessity*. At times it seems to be reduced to pure regularity, while at other times Hume seems inclined to a more metaphysical theory of the associationistic type. Among the recent studies see above all J.L. MACKIE, *The Cement of the Universe. A Study of Causation,* Oxford University Press, Oxford 1980; T.L. BEAUCHAMP and A. ROSENBERG, *Hume and the Problem of Causation*, Oxford University Press, New York and Oxford 1981.

[27] See D. HUME, *A Treatise of Human Nature*, book I, part III, ed. L.A. Selby-Bigge, Clarendon Press, Oxford 1973.

[28] Cfr. G.E. ANSCOMBE, "Causality and Determination," in E. SOSA and M. TOOLEY (eds.), *Causation*, Oxford University Press, Oxford 1993, pp. 88-104.

knowledge[29]. The causal priority, that in Aristotelian metaphysics was always a priority of act and perfection, is transformed into a temporal priority with time being the only element that can introduce a distinction between to the two extremes of the causal relationship. Time becomes a constitutive element of causality: it arises in one's imagination and presents to the mind the expectations produced by remembering a completely uniform and past regularity.

The role that time has in Hume's theory of causality is not surprising. In common experience the causal relationship is profoundly asymmetrical: cause and effect are not interchangeable. In a metaphysical theory of the classical type this need was clearly conceptualized in the active and productive meaning of cause and in the passive and receptive meaning of effect. Causality constituted an asymmetrical relationship, or at least a non-symmetrical relationship[30]. It seems logical to demand that every attempt to conceptualize the causal relationship account for this asymmetrical nature. However, once the concepts of production and of act, which account for this asymmetry in classical metaphysics, and those of force or causal power, which served a similar function in mechanistic and rationalist science, are eliminated, Humean causality must turn to an element extrinsic to cause: temporal asymmetry. In Hume's analysis of cause we find one of the interpretative keys of modern science: the union of the normative aspect of the causal relationship with the notion of temporal succession. Causal dynamism becomes for Hume a simple "regular succession" –as it will be also for Kant, at least in the more accepted part of his philosophy[31]– according to a law known by us either in an aprioristic way, as in Kant, or else by means of a purely empirical procedure, as in the tradition of Hume and John Stuart Mill.

We can now attempt an assessment of the meaning of this situation. What has been the reason for this conceptual transformation? What influence has it had on the image of physical dynamism? The way in which theses questions are articulated depends on the meaning given to the basic conceptual dimension of our image of the world in the elaboration of scientific theories. On the methodological level one can recognize that the new notions of cause and time, like other physical notions, constitute a requirement for the new type of science, analytical and mathematical. However, on a more general level, it is possible to see in the epistemological and metaphysical attitudes that have accompanied the birth and evolution of science the source of the new understanding these notions acquired.

In fact, on the basis of the methodological change worked by classical me-

[29] Hume does not give excessive attention to this fact. Only once he presents a proof in favor of the temporal priority of the cause to the effect. Cfr. HUME, *Treatise*, I, III, II, 75-76.

[30] In an asymmetric relation ($xRy \Rightarrow \neg yRx$), while in one non-symmetric it is possible that ($xRy \cdot yRx$). In this way it would be able to render account of the relations of "reciprocal causation" Cfr. M. BUNGE, *Causality. The Place of the Causal Principle in Modern Science*, Meridian Books, New York 1963.

[31] We do not consider here the further developments of Kantian philosophy, in particular his *Opus Postumum*, where it is possible trace a more profound metaphysical preoccupation.

chanics, we are also able to identify an altered conception of that which knowledge of the physical world requires. The medieval epistemological perspective proved to be largely synthetic. It aimed for the intrinsic unity demanded by knowledge, understood as the search for the meaning and value of reality, but it neglected the particulars. The new, analytical perspective emphasize the determination of the partial aspects as the only way to achieve knowledge of a physical system, whose full description is in terms of a mechanical model. However, in the absence of an adequate and deeper perspective which would take into account the different levels of knowledge of reality and the inherent limits of every conceptualization, this different epistemological conception recalled a different ontological conception that had repercussions on the very image of the world which it was proposing.

We may summarize this transformation as a *process of rationalization* in the epistemological and conceptual approach to nature. The new intellectual commitment had fundamental epistemological and metaphysical aims: both scientific and philosophical processes and the *contents* of our knowledge of the world must become *fully rational*[32].

One can see in this tendency a transposition of the analytical methodology of the new science in the ontological sphere. If the understanding of a system is contained simply in the understanding of the parts, they must in the end constitute a set of elements that present themselves as a-problematic or evident. One of the consequences is what we might call the postulate of "substantiality" or radical autonomy of the basic elements of our knowledge of the world. The philosophy of the modern age abandoned the classical attempt to understand reality in terms of substance and accident. Even if the classical attempt was imperfect, and perhaps it is of little use of the problems of modern science, it provided a scheme in which it was possible to articulate the different "levels of reality" of the physical world: bodies, properties, actions, etc. Its loss brought in some way the "substantializing" of every reality; that is, considering each element as absolutely independent and subsistent, as a condition for achieving an understanding of all of them. Such a substantialization rendered the ontological relationships among different entities difficult to comprehend, and afterwards a recursive process brought about the isolation of every element in its own reality. It was thus possible to arrive at a rationalism, like that of Leibniz, in which each individual entity innately contains not only its own reality but even, in some way, the entire history of the universe[33].

[32] In fact, the more systematic elaboration of mechanics which comes on the nineteenth century through the work of Lagrange, Hamilton, Laplace and others often received the name "rational mechanics."

[33] In the introduction to New Essays, Leibniz states: "On peut même dire qu'en consequence de ces petites perceptions le present est plein de l'avenir, et chargé du passé, que tout est conspirant (sumptonia panta, come disoit Hippocrate), et que dans la moindre des substances, des yeux aussi perçans de Dieu puorroient lire toute la suite des choses de l'u-

How does one conceive of causal action in this scheme? Among entities that are so radically autonomous one can not discover a true active and productive relationship. Causal action could only be considered as "transference" of some element (quantity of motion, energy, etc.) as occurs in the purely mechanistic scheme, or else it would have to be reduced to the only characteristic of the causal relationship that is left reinforced by the whole process described: logical necessity. Causality then becomes simply the effect of a law, purely normative. However, only the lawfulness that is reflected by pure regularity is dealt with. The content of the law is no longer nature (that is, the essential characteristics of things), but only universality, the result of generalization. The temporal dimension then constitutes the only characteristic that allows one to identify the sense of such a causal relationship, and so permits one to attribute particular causes to particular effects. Consequently, it becomes the only guarantee of the distinction among the phenomena.

However, this new, apparently fundamental role of time in the scheme of causal dynamism contrasts with the meaning that this same image has attributed to it. In physics time appeared only as an "independent variable" in the mechanical equations, as a variable necessary in the calculations and analyses of material reality, but which vanishes once these analyses have been completed. Not even the role it performs within the notion of cause allows one to attribute to it a greater reality: it constitutes a substratum that is necessary for the development of causal dynamism, and particularly for the difference between cause and effect, but only a substratum of the purely logical type, such that it does not succeed in being a real feature of the world.

The world of classical science did not appear as a temporal and dynamic world. Some authors even speak of the elimination of time in the classical image of physical nature[34]. In such a view, temporal notions are not relevant for the physical understanding of phenomena. But time taken as such seems unable to be eliminated from our image of nature, if that means the denial of its reality. The problem is not so much that of recognizing the necessity of temporal categories as that of determining to what extent the temporal dimension affects the other basic aspects of reality.

From the speculative point of view the situation is profoundly unsatisfactory. The reality of dynamism of the world rests upon time. Yet, temporality does not seem to have much foundation other than constituting a need of the mind. This implies the impossibility of a true understanding of the material world. If time becomes only an abstract dimension, which ignores the true novelty of the past,

nivers. *Quae sint, quae fuerint, quae mox futura trahantur*," which calls to mind the formula of Laplace already cited. G.W. LEIBNIZ, *Nouveaux Essais sur l'entendement humain*, preface, in *Sämtliche Schriften und Briefe*, ed. Deutschen Akademie der Wissenschaften, series VI, vol. VI, Akademie-Verlag, Berlin 1990, p. 55.

[34] We can recall in particular G.J. WHITROW, *The Natural Philosophy of Time*, 2d. ed., Clarendon Press, Oxford 1980, pp. 1-4.

reality itself becomes purely static. The dynamism that scientific elaboration can describe will not be an intrinsic dynamism. Rather, reality will appear as a juxtaposition of states or events which turn out to be almost completely independent of one another. Temporal, successive juxtaposition is not a proper and internal dynamism that demands, in addition to a succession of states, an underlying unity from which such a dynamism proceeds.

The metaphysical extent of this situation is evident. It is reflected in the attitude, common to all modern thought, that passes from a consideration of real modality to a consideration of a merely gnoseological or even logical modality[35]. A metaphysics that lacks, in its ultimate expression, the temporal dimension becomes purely mathematical and logical: a science of purely formal contents without any reference to the dynamics and existing reality of things.

4. The New Articulation of Cause and Time in the Special Theory of Relativity

The situation presented thus far changes profoundly in the historical period of science that opens at the beginning of the twentieth century. Many of the fundamental concepts of classical science immediately undergo profound changes in the new scientific theories of that century, and as a result there has been a transformation in our image of the world. The first of these revisions, from the historical point of view, was that which gave rise to the special theory of relativity in 1905, altering the meaning of many of the basic notions of mechanics: space, time, matter, and energy. Causality and temporality occupy a particular place among these.

It is therefore necessary to reflect on the epistemological significance of this transformation. The theory of relativity is not put forward as an attempt to explain completely the world, not even on the physical level. Just like every other scientific theory, Einsteinian relativity constructs a formalism the precise application of which occurs only in the theoretical-experimental context in which it was formulated. Consequently, such a formalism is considered as an abstraction or an idealization, and its application to problems of the practical order requires a rigorous assessment of the factors that contribute to the system description. For this reason it would not be correct to attempt simply to "transfer" the theoretical elements that we find in relativity to other reflections about nature that operate on a different level. Every physical theory presents only one aspect of reality.

However, it is possible and useful to consider the contributions of this theory to our general image of the world. Relativity theory brings to our attention features of reality that are necessary for a fuller comprehension of the world. Whereas classical physics, based on mechanics, set up an idealization of the

[35] Cfr. A. Llano, *Metafísica y lenguaje*, Eunsa, Pamplona 1984, pp. 25-26.

physical systems that were its subject-matter. Notions essential to the formalism and theoretical meaning of classical mechanics, like those of "a point endowed with mass" or "absolutely inertial movement," do not have a true reference in the physical world. They were, rather, theoretical constructions designed to grasp important aspects of reality like the dynamic individuality of a system and the relative isolatablity of its kinematic components, aspects that are necessary to formulate a coherent image of reality. The concepts central to relativity theory also permit us to grasp something about the physical world and to construct a more adequate image from it.

4.1. The Einsteinian Critique of Classical Time

Albert Einstein[36] presented the complete formulation of the special theory of relativity in 1905 in an article published in *Annalen der Physik* under the title "Zur Elektrodynamik bewegter Körper"[37]. The essay contains all the fundamental elements of the theory. The later work done by Einstein and by other physicists and mathematicians served to perfect the mathematical formalism of the theory of relativity without introducing any changes or corrections to it[38]. For this reason the article of 1905 still constitutes the principal guide for examining the conceptual novelties introduced by the theory into our physical concepts. Following Einstein's central points we can present briefly the principal innovation of this theory: the relativity of temporal measurements.

The Einsteinian revision of time has as its historical origin some of the paradoxes of classical electromagnetism[39], which up until the nineteenth century were explained by means of different theories of ether. The different proposals, unable to resolve these paradoxes, admitted as an undisputed basis the kinematics of classical physics; that is, that developed by Galileo, Descartes, and Newton. This meant the acceptance of the meaning attributed to the basic concepts of the image of the world in classical mechanics, in particular those of space and

[36] Ulm (Württemberg) 14 March 1879 – Princeton (New Jersey) 18 April 1955. The more complete "intellectual biography" of Einstein is that by A. Pais, *'Subtle is the Lord...' The Life and the Science of Albert Einstein*, Oxford University Press, Oxford and New York 1982.

[37] A. Einstein, "On the Electrodynamics of Moving Bodies," in Einstein *et al.*, *The Principle of Relativity. A Collection of Original Memoirs on the Special and General Theory of Relativity*, ed. and trans. by W. Perrett, G.B. Jeffery, Dover, New York 1952, pp. 35-71. The original text, *Annalen der Physik* 17 (1905): 891-921, is now reprinted in *The Collected Papers of Albert Einstein*, vol. II: *The Swiss Years: Writings, 1900-1909*, ed. by J. Stachel, Princeton University Press, Princeton 1989, doc. 23, pp. 276-306.

[38] Of particular importance would be the formalism introduced by Minkowski in 1908, which was immediately adopted by Einstein himself. Cfr. H. Minkowski, "Space and Time," in *The Principle of Relativity*, 73-91.

[39] A. Einstein, "On the Electrodynamics of Moving Bodies," 37 (*Collected Papers*, p. 276).

time. For this reason Einstein directed his reflections, first of all, towards these fundamental kinematic concepts[40], re-examining the proposed connect between the reality of a physical system and the formal description that we could obtain from it by means of the magnitudes defined by scientists.

The Einsteinian revolution does not consist, as is sometimes thought, in the substitution of relative time for the absolute time of Newton. That was only a consequence of and not the root of his innovation. The first novelty is the recognition that time, rather than constituting a presupposed dimension, must be adequately defined on the basis of specific experimental procedures[41], as one does with space or any other physical magnitude. Consequently, the definition of time demands the selection of a clock, that is, of a specific physical process that is adopted by agreement. Even if this definition poses some problems in the theoretical order, for example, in guaranteeing the equivalence of temporal successive periods, from the practical point of view it is necessary to adopt a temporal definition of this type: it is, however, not possible to *justify* the validity of the definition adopted. Hans Reichenbach later showed the necessity of prescinding, in the coordinative definitions, from the possible "universal forces," whose effects are by no means experimentally knowable[42].

Once the clock is defined, one must examine the operative processes by means of which an observer can attribute "time" to the physical events of the universe. However, the real possibility of arriving at such an attribution requires that one take into account the process of communication between the object and the observer, which brings with it the need to consider the different spheres of temporal definition. The observer can, in the first place, assign with the help of the clock a temporal value only to those events of his immediate experience, that is, those that take place in his immediate neighborhood. This time will constitute that which we can call *local time*[43].

Next, the observer will attempt to apply his clock to "distant" events with the

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[40] So it was expressed by Einstein in the final words of the introduction to the article of 1905: "The theory to be developed is based –like all electrodynamics– on the kinematics of the rigid body, since the assertions of any such theory have to do with the relationships between rigid bodies (systems of co-ordinates), clocks, and electromagnetic processes. Insufficient consideration of this circumstance lies at the root of the difficulties which the electrodynamics of moving bodies at present encounters." EINSTEIN, "On the Electrodynamics of Moving Bodies," 38 (*Collected Papers*, p. 277).

[41] A. EINSTEIN, "On the Electrodynamics of Moving Bodies," 38-39 (*Collected Papers*, p. 277): "If we wish to describe the motion of a material point, we give the values of its co-ordinates as functions of the time. Now we must bear carefully in mind that the mathematical description of this kind has no physical meaning unless we are quite clear as to what we understand by 'time.'"

[42] H. REICHENBACH, *The Philosophy of Space and Time*, trans. Maria Reichenbach and J. Freund, Dover, New York 1958.

[43] The structure of the different spheres of the temporal definition has been developed by Whitrow, *The Natural Philosophy of Time*, with a different terminology.

aim of establishing a definition of time valid for every point in space. We must speak then of *time at a distance*. It proves to be possible to select different methods, for example, establishing a synchronization method between identical clocks belonging to different observers, or else attempting to determine a set of distant events that are simultaneous with a given instant of the local time of a single observer[44]. The two prove to be equivalent. Yet, in any case we run into a difficulty never before considered by classical physics. This is a central point of the Einsteinian analysis. Classical mechanics presupposed in practice that the determination of the simultaneity between two events always was possible and that this gave rise to a definition of time that was universally valid and coherent, but this is not the case. Measuring a distant event always entails some elaboration in which complex methods arise that entail different theoretical elements. The definition of time at a distance entails an arbitrariness that cannot be experimentally eliminated. This is because of the impossibility of determining, before defining time, the temporal contributions of the processes of physical communication between events, which are necessary in establishing the definition of time itself.

Nevertheless, it is true that one deals with an arbitrariness that is more theoretical than practical. The assumption made by Einstein, that is, that the velocity of the signal of communication (a beam of light) is the same in two senses, going and returning, permits an observer to define a valid and coherent time for every event in the universe by means of times defined by other observers in a state of rest in respect to the first. Nevertheless, this arbitrariness or conventionality in the definition of time at a distance will have important consequences for an ultimate temporal definition.

In fact, once time at a distance is defined there still remains a third step: establishing the correlation between time defined by different observers. If these belong to the same inertial frame of reference as the first, that is, are at relative rest, the relative definitions prove to be equivalent. Yet, when one takes into consideration the relative motion between the observers one finds that, as a consequence of the theory of relativity, the relative definitions will no longer be equivalent. It is not possible to define in an absolute manner a simultaneity valid for all possible observers independent from their state of movement. Only within each inertial frame of reference is it possible to have unambiguous temporal measurements. It is not possible to establish a common temporal scale that permits the observers in different frames of reference to attribute common temporal measurements to physical processes and events. Time must independently defined in each frame of reference, and, in general, different times must be attributed to events in different frames of reference.

[44] In the 1905 article Einstein adopted the first system. However, the second is that which is more frequent in many later treatments of relativity, particularly of the popularized type.

4.2. The New Conceptual Elements of Relativistic Time

The results of the Einsteinian critique are well-known: time and space lose the absolute nature that had been conferred on them by Newtonian mechanics; the formal structure of the two magnitudes are profoundly changed, and the uniqueness of their determination vanishes. What is the significance of this transformation? It is essential to consider this changes on the epistemological and metaphysical levels to grasp the consequences that they can have on our image of the world.

The first question is what is the precise meaning of the so-called *relativization* of time? At times there is a confusion between the two characteristics of the temporal notions that relativity has eliminated: the *absolute* nature of time, on the one hand, and the *uniqueness* of temporal determinations, on the other. The two are often identified with each other or considered as direct consequences of each other, when instead they concern different (but related) levels of reflection about time. Denying that time possesses an absolute character, which constitutes a reality in itself, independent of every other physical reality, means taking a position on the *metaphysical nature* of time; that is, on its intrinsic and fundamental characteristics and on the role that temporality plays in our conceptual image of the world. However, the uniqueness of time, namely the view that each event has a unique and definite value, is a characteristic of the *metrical definition* of time that is relevant in the analysis of particular physical questions.

Theses two levels are certainly connected. A metaphysical absolute time will be, as in the case of Newton, a time unambiguously determined. However, the reverse sense does not necessarily yield a similar dependence. The non-uniqueness of temporal determinations attributed to physical events in the special theory of relativity cannot be seen simply as a direct consequence of the elimination of the Newtonian notion of absolute time. If this were so, we would not find ourselves confronted with a properly scientific theory, but rather with a construction of the philosophical type. The theory of relativity would then be presented as a "paradigm" without possible rational justification, adopted simply by a kind of faith. Such a view does not correspond to the meaning that the scientific community attributes to the special theory of relativity. We ought not to reduce the meaning of the absolute nature of time to that of the concrete uniqueness of the temporal determinations. Such an identification would mean ceasing to attribute to the concepts of our image of the world any value other than that which is purely phenomenal. This is the position more frequent in the positivist interpretations of the Einsteinian relativity, which wish to ignore the opening of the physical theory to a more profound level of understanding: the metaphysical order[45].

[45] We find traces of this interpretation of a positivist sign in H. Reichenbach, *The Philosophy of Space and Time*, and in A. Grünbaum, *Philosophical Problems of Space and Time*, 2d enl. ed. (Boston Studies in the Philosophy of Science, 12), D. Reidel Publishing Co., Dordrecht and Boston 1973.

It is possible to show, by examining the methodological order followed by Einstein in the initial section of the article of 1905 and the use which he makes of temporal concepts, that Einstein's theory of relativity, and particularly the notion of time developed in it, is not the consequence of the elimination of the Newtonian notion of absolute time. Einstein did reject the Newtonian idea of absolute time. However, the physical formulation of Einstein's theory does not begin from such a "metaphysical" presupposition, but rather from presuppositions of the physical type, concerning the role of the concepts and of the magnitudes in a physical theory, from which Einstein was able to eliminate unjustified presuppositions, even of the metaphysical type, present in classical kinematics.

The formulation of special relativity, with its particular critique of classical time, begins in fact, as we have schematically presented earlier, with a specific epistemological conception about the place which metrical concepts must occupy in a physical theory. They must be defined "operatively"; that is, in such a way as to explicitly include a procedure which assigns to concepts (which in themselves constitute theoretical constructs) a precise value in relation to experience[46]. The use of such a method means the existence of a new concept of time on the level of the physical theory that in its turn contains, on a more general level, a new understanding of the nature of temporality itself, an understanding which gives rise to a new concept of time in our image of the world. What emerges is a *conventional* element in the definition of time.

The non-uniqueness of temporal determinations arises from that conventional element instead with another feature of the physical world, the non-existence of a privileged frame of reference (conjectured by theory and confirmed provisionally by experience), when we consider different frames of reference with relative velocity comparable to that of light[47].

Consequently, we notice that a new element has been added to the two characteristics, absoluteness and uniqueness, discussed earlier: the relative conventionality of temporal determinations. This conventionality is a properly epistemological characteristic, but it determines, as has been seen, the characteristics of time on the physical-experimental level, and will have a specific meaning at the level of our basic conceptual image of time. In fact, by means of the conventionality of the definitions of time, the negation of the absolute nature of time acquires a greater force. Time is not a reality in itself, independent from the objects and events to which we apply temporal concepts, but is connected to the precise relations of temporal measurements performed by physical observers (real or hypothetical). This allows for the overcoming of another of the philosophical positions on time that had been developed in reaction to Newtonian absolute time:

[46] Cfr. E. AGAZZI, *Temi e problemi di filosofia della fisica*, 2d ed., Abete, Rome 1974, pp. 125-53.

[47] I have briefly presented this analysis in "Congetture, certezze e verità…," pp. 87-90.

that which reduced time to the ideality of a mental content[48]. In fact, the notion of time that includes a conventional aspect, but that guarantees, nonetheless, a precise knowledge of physical phenomenon, makes sense only within the conception of nature as objective reality, even if is only partially known by human being; in other words, such a view of times requires a realist vision of nature.

The relativistic concept of time is at variance with many characteristically modern concepts in physics and philosophy. Yet, what is it relationship to premodern conceptualizations, like those of Aristotle and Aquinas? There is an obstacle in confronting this question: it is not clear to what degree it is possible to speak properly of the existence of a *physical* concept of time in the elaborations prior to Newtonian science. The time-number of ancient and medieval thought is very different from the time-variable of Galilean and Newtonian science. Aristotelian time belongs, in a natural and inseparable way, to the concrete movement of bodies and to the unity of the cosmos. It does not seem possible to attribute to it a determined "structure." Perhaps for this reason medieval physics did not formulate a temporal science of material phenomena; nor did medieval metaphysical reflection achieve a notable understanding of the temporality of the physical world. Only towards the end of the medieval period is the way opened for a notion that prefigures Newtonian time: a uniform variable[49].

However, if we attempt to reconstruct the "physical component" of Aristotelian-Thomistic time, we find a certain closeness with the Newtonian conception, at least regarding one of the elements that we have examined: uniqueness. Aristotelian physics seems to attribute a fully unambiguous structure to time: each event possesses a time well defined and identical for every possible observer, without giving any relevance to the different physical conditions of the observer, like his state of movement[50]. However, this apparent closeness deserves closer attention. In the Aristotelian perspective the uniqueness of time was not due, like in the case of the Newtonian perspective, to Aristotle's having admitted an absolute nature of time that almost constituted, as an independent variable, a logical dimension in which uniqueness proves to be necessary. For Aristotle the uniqueness of time depends on a cosmological presupposition that attributed to the cosmos in its totality a determinant meaning from the spatial-temporal point of view[51]. Such a meaning manifests itself both in the Aristotelian doctrine of "natural places" and in the attribution of a privileged place, from the dynamic

[48] One can see an example in the well-known "unrealistic" position of J.E. McTaggart, "The Unreality of Time," *Mind* 17 (1908): 457-74.

[49] See A. Maier, "Das Zeitproblem," in *Metaphysische Hintergründe der spätscholastischen Naturphilosophie,* vol. IV of *Studien zur Naturphilosophie der Spätscholastik*, Edizioni di Storia e Letteratura, Rome 1955, p. 133.

[50] Aristotle, *Physics* IV.14 223b2 - 4: "Is there then another time, and will there be two equal times together? Perhaps not, for the time which is equal and together is one and he same (and ever those which are not together are the same in kind)."

[51] Aristotle, *Physics* IV.14 223b12 - 23.

point of view, to the movement of the entire cosmos, or of the first sphere. Thus, the uniqueness of medieval time does not represent a proper characteristic of its image of temporality, but rather a need derived from other presuppositions. The Aristotelian notion of time as a "number" of movement, even if different from the new relativist concept, remains open to a physical conceptualization of temporality that keeps in mind operational needs[52].

Even if classical science evidently achieved a greater understanding of the world on the physical level than that obtained by Aristotelian and medieval thought, things are different when it comes to the notion of time and its relation to the dynamic nature of the physical world. Relativistic time presents a more radical novelty in relation to Newtonian time, whereas it finds some point of contact, even if not on the physical (scientific) but on the "pre-physical" level, with the conception of time in ancient and medieval thought.

4.3. The Causal Structure of Relativistic Space-Time

The causal content of relativistic physics, which is closely connected to the "spatial-temporal" structure that derives from the theory, still remains be to considered. Einsteinian relativity presents on this point an important novelty. In classical physics the "geometric" structure of space-time had very small consequences for the dynamic possibilities of a system (or of the universe in its totality). Space and time simply constituted a space of possibility, a logical space in which phenomena acquire their concrete realization from further dynamic conditions, "superimposed" so to speak on the geometric and temporal structure of the world.

In the special theory of relativity the influence of the kinematic structure on the dynamic will prove to be much more relevant. Space and time are no longer merely a "formless" field of possibility, but they represent a certain condition for the very dynamic activity of the physical system. We can say, perhaps, that the topology of relativistic space and time is not "purely geometrical"; it has some consequences for physical entities, on their possibility of their action and their communication, and consequently on their causal relationship.

Certainly this affirmation constitutes an interpretation of the relativistic formalism that must be appropriately evaluated. However, it is advisable to present first the fundamental points from the physical point of view. One of the main consequences of special relativity is the interdependence between spatial coordinates and temporal coordinates which the observers must attribute to every phys-

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[52] ARISTOTLE, *Physics* IV.12 220b32 - 221a4: "Since time is a measure of change and of being-in-change, and since it measures change by defining some change which will measure out the whole change (just as the cubit measures length by defining some magnitude which will measure off the whole magnitude)..."

ical event. In Newtonian mechanics, as a consequence of the assumption of an absolute simultaneity, two events must always maintain a unique and identical spatial and temporal relation, with total independence from the conditions in which the observations of the event have occurred. Two simultaneous events in a given system of reference must necessarily be simultaneous for any other system. The distance and time elapsed (the *spatial interval* and the *temporal interval*) are invariant with respect to the transformations of the coordinates characteristic of classical mechanics (the group of Galilean transformations).

In relativistic mechanics the situation is different. The spatial and temporal relations between events are no longer invariant; they depend on the frame of reference assumed. There exists, however, a new invariant magnitude in relativistic space-time: the *space-time interval*, defined as:

$$ds^2 = dx^2 + dy^2 + dz^2 - c^2dt^2$$

In the application of the Lorentz transformations, the space-time interval remains unchanged. This implies a considerable restriction of the "relative" nature of the space temporal magnitudes that describe physical events[53]. As a consequence, the possible variations in spatial measurements on the one hand, and temporal measurements on the other, also prove to be strictly limited.

The invariance of the space-temporal interval has an important consequence on the causal structure of physical events, as it is described by relativity[54]. In fact, two events for which $ds^2 < 0$ satisfy that

$$dx^2 + dy^2 + dz^2 < c^2dt^2$$

means that their spatial distance is less than that traveled by light in the time that separates them. This has an obvious physical interpretation: it is possible to establish a process of material communication between these two events by means of a physical signal (electromagnetic waves, material transport, etc.). On the contrary, if the events are such that $ds^2 > 0$, there is no possible material communication between them since there is no signal whose propagation happens more quickly than that of light[55]. Such events are completely isolated.

[53] The importance of this result within the theory of relativity has been taken to mean that this theory cannot in reality be considered as a "relativistic" theory. Instead, it reinforces the absolute meaning of the possible description of a physical system.

[54] Hans Reichenbach was among the first to highlight this. Cfr. H. REICHENBACH, "The Causal Structure of the World and the Difference between Past and Future" (1925), in *Selected Writings, 1909-1953*, eds. Maria Reichenbach and Robert S. Cohen (Vienna Circle Collection, 4), D. Reidel Publishing Co., Dordrecht, Boston and London 1978, vol. II, pp. 81-119.

[55] Such an affirmation has at times been called the Principle of Limitation, and is one consequence of the theory established for reasons of the dynamic order: the energy necessary to accelerate a body of non-zero mass to the velocity of light would be infinite.

In relativistic space-time there are, for every event, two separate regions: that of events causally connectable with the first (the events whose interval is *time-like*, that is, such that $ds^2 < 0$) and that of events not causally connectable (*space-like* interval, $ds^2 > 0$). In Minkowski's space-time diagram these two regions correspond respectively inside and outside of the light-cone whose origin is the event considered. The hyper-surface of the light-cone, constituted by events whose interval is *light-like* ($ds^2 = 0$), represents the physical horizon of such an event.

In classical physics the whole universe (even considered as space-time) was causally connectable. However, for exactly this reason the causal relationships did not seem to offer any element that was able to increase our knowledge of the structure of physical reality. Causality appeared as a notion "indifferent" to every concrete explanation of physical phenomena. In the special theory of relativity it seems to present itself instead as a constitutive element of physical reality, which delimits not only the effective relationships among phenomena but also their space-time topological structure. Causality seems to have a central role in the development of the image of the world presented by relativity.

5. Two Images of Physical Dynamism

What are the philosophical consequences of this situation? It opens for us the perspective of a radical change in the understanding of the physical dynamism of the world since the space-time structure of physical events itself appears connected to the possibility of physical action among them. It seems necessary, as a consequence, to examine the significance which such a structure possesses in the more general image of the world. Classical science, as it has been shown, reduced causality to a kind of logical space without an effective relationship with physical action. On the basis of the new reflections on causality and time it seems possible to grasp a different image, in which casual action represents a basic and radical characteristic of reality. In this scheme the temporal dimension has its foundations in causal dynamism. It seems possible thus to present a world view in which the dynamic dimensions of physical action among bodies possesses a genuine reality.

Nevertheless, it is necessary to set this claim in the proper context. In fact, it would be incorrect to state that the theory of relativity demonstrates this dynamic image of the world. It is necessary to remember that we are facing a multiplicity of levels of consideration. The content of the concepts used by relativity has its rigorous application only on the level of the formal elaboration of the theory. On the level that we have called conceptual image, as well as on the metaphysical level, it is possible to have different interpretations based on these same concepts. In fact, various interpretations of special relativity present radically opposed claims concerning the question of physical dynamism. In addition to the dynamic interpretations there are interpretations, that on the basis of the same facts, attempt to restore a static and a-causal image of the world. The more radical of these offer a spatialized and static image of space-time, as is the case with Minkowski, Weyl or Costa de Beauregard[56]. In their interpretation becoming is eliminated as a characteristic of the real world.

The foundation of these interpretations is still found in the non-uniqueness of the temporal determinations assigned to physical events by special relativity. If two observers, even in the same place and instant, can assign different times to an event, the distinction between past and future seems to lose its meaning[57]. The only way to recover the logical understanding of the world seems, for many, to claim that the events are not really past or future: they "simply are" in a spatialized "space-time" in which there is no real physical becoming. The relationship among physical events would only have the appearance of true dynamic action, but they would in reality be only a network of timeless logical relations.

It is possible to show the insufficiency of these interpretations. Many critiques have been directed against them, especially by Meyerson[58], Reichenbach[59], and other authors[60]. We will not concern ourselves with these critiques that seek principally to highlight the reductionist character of the timeless and spatialized interpretations of relativity. We are interested instead in noting that when one takes into consideration the fact that in the special theory of relativity causal concepts play a fundamental role, it seems to open the way for a very different image of the world. One of the main attempts along these lines, even if not

[56] Cfr. H. Minkowski, "Space and Time," in *The Principle of Relativity*, pp. 73-91; H. Weyl, *Philosophy of Mathematics and Natural Science*, Princeton University Press, Princeton 1949, p. 116: "The objective world simply *is*, it does not *happen*. Only to the gaze of my consciousness, crawling upward along the life line of my body, does a section of this world come to life as a fleeting image in space which continuously changes in time," and O. Costa de Beauregard, *La notion de temps. Équivalence avec l'espace*, 2d ed., J. Vrin, Paris 1983; Id., *Time, the physical magnitude* (Boston Studies in the Philosophy of Science, 99), D. Reidel Publishing Co., Dordrecht, Boston, Lancaster and Tokyo 1987.

[57] H. Putnam, "Time and Physical Geometry," *The Journal of Philosophy* 64 (1967): 240-47. Reprinted in *Mathematics, Matter and Method*, 2d ed., Philosophical Papers, vol. 2, Cambridge University Press, Cambridge 1979, pp. 198-205.

[58] É. Meyerson, *La déduction relativiste*, Payot, Paris 1925.

[59] H. Reichenbach, "The Causal Structure of the World," 87; Id., "The Logical Foundations of Quantum Mechanics" (1952), in *Selected Writings*, 2:276.

[60] See for example S. McCall, "Objective Time Flow," *Philosophy of Science* 43 (1976): 337-62; Idem., *A Model of the Universe. Space-Time, Probability, and Decision*, Clarendon Press, Oxford 1994, pp. 1-47; P. Kroes, "Objective versus Minddependent Theories of Time Flow," *Synthese* 61 (1984): 423-46; Idem, *Time. Its Structure and Role in the Physical Theories* (Synthese Library, 179), D. Reidel Publishing Co., Dordrecht, Boston and Lancaster 1985; R. Martínez, "Determination and Becoming in the Special Theory of Relativity," in G.V. Coyne, K. Schmitz-Moorman and C. Wassermann (eds.), *Origins, Time & Complexity*, vol. II, (Studies in Science and Theology, 2) Labor et Fides, Ginevra 1994, pp. 96-104.

fully successful, has been that of the *causal theory of time*, according to which that ancient problem *Quid est ergo tempus?*[61] has a straightforward answer: *time is causality*; it is only the development of the causal relations of the world. The structure and properties of time derive completely from the casual structure of the universe.

The causal theory of time is a recent philosophical proposal. Even if it is possible to find historical precedents that go back even to Leibniz[62], it does not appear in a systematic manner until this century, after the consolidation of Einsteinian relativity. Hans Reichenbach is, without doubt, its principal exponent[63]. After his death his efforts were continued by different authors, principally in the American philosophy of science[64]. In the last few decades interest in this theory seems to have faded markedly. Nevertheless, it remains as one of the more interesting and suggestive attempts of the philosophy of science in the last century. Even if this philosophical "program" presents some limitations, not the least of which being the absence of a metaphysical consideration, its reflections on the causal and temporal content of relativity demonstrate with clarity the necessity of overcoming the rationalistic classical image of the world. From the philosophical point of view, and not just on the methodological level, one encounters a series of problems regarding the role that causality and time play in the perspective of modern thought. From the time of Hume and Kant causality, having lost its metaphysical productive content, had to turn to time as a epistemological-transcendental foundation of the cause-effect distinction. Thus cause becomes a regular succession in time. Now the roles seem newly inverted, turning back in some way to classical metaphysics, where time seemed, in a sense, to be reduced to movement[65], which obviously requires a connection to causal action.

In special relativity causal concepts do not simply carry out the role of logical connections among events, independent of the evolution undergone by physical systems. Rather, they seem to structure the very spatial-temporal conditions of the physical world that become dependent, on the existence or non existence of

[61] AUGUSTINE, *Confessions*, XI, 14.

[62] In particular his brief work *Initia rerum matematicarum metaphysica*. Cfr. H. MEHLBERG, *Essay on the Causal Theory of Time*, vol. I of *Time, Causality, and the Quantum Theory*, ed. Robert S. Cohen (Boston Studies in the Philosophy of Science, 19), D. Reidel Publishing Co., Dordrecht, Boston and London 1980, pp. 42-50.

[63] Different formulations of his causal theory of time were presented in H. REICHENBACH, *Axiomatization of the Theory of Relativity* (1924), trans. Maria Reichenbach,, University of California Press, Berkeley and Los Angeles 1969; IDEM, *The Philosophy of Space and Time* (1928), trans. Maria Reichenbach and J. Freund, Dover, New York 1958, and in the posthumous work, IDEM, *The Direction of Time*, ed. Maria Reichenbach, University of California Press, Berkeley 1956.

[64] We can note mainly A. GRÜNBAUM, *Philosophical Problems of Space and Time*, and some of his disciples, as B.C. VAN FRAASSEN, "Foundations of the Causal Theory of Time" Ph. D. diss., University of Pittsburg, 1966.

[65] Cfr. ARISTOTLE, *Physics* IV.10 218b9 - 11 219b 2.

the causal connection among events. In this way the image of the physical world recovers its dynamism as an essential and inalienable characteristic. The space-temporal conditions of physical reality, far from constituting a "scheme" independent of physical reality, appear specifically as manifestations of the "unfolding" of the physical action itself of real beings. That is, they do not constitute an *a priori* "condition" of physical reality, neither in the absolute, objective sense as in Newtonian space-time, nor subjectively as in Kantian transcendentalism. Rather, they can be considered as its "outstretching": it is the active physical being itself that, in its interaction with other entities, *gives* itself and *manifests* itself throughout a concrete space-time structure. Consequently such a structure is not the ultimate subject of reality, as it became in the rationalistic positions. The problem of achieving a rational, simple and coherent image, that is universally valid, of such a structure loses the significance that it possessed in Newtonian mechanics and in forms of "spatialized" relativity. In fact, that which human knowledge primarily attempts to achieve is not space-time determinations but material physical beings. The fact that in certain situations it is impossible to achieve a complete and exhaustive description of their space-temporal conditions does not constitute much of a difficulty nor a failure, but rather it is a sign of the more profound, never fully objectifiable dimension of the real being of things[66].

We find ourselves faced with two alternative images of the physical world, whose manifestations one discovers not only around the debate about special relativity but also in other moments in the history of thought. The first is the logical-rational image, proper to the mechanistic determinism of modern science and also some of the spatialized interpretations of relativity. The second is the metaphysical or naturalist image that has found expression in the reflections of Aristotle and Thomas Aquinas, in different attempts to express in physical categories causal action by means of the notion of force, cause, action or energy, and in the causalist vision of Einsteinian relativity.

This does not mean that the two images are radically opposed to each other. A certain compatibility between the two seems possible, and even necessary, both from the physical-formal point of view and from the metaphysical point of view. Each one presents a partial aspect of reality. However, neither of the two can be absolutized with out running the risk of hindering a more profound understanding of reality. Classical physics, and with it the thought dominant in modernity, having formulated the logical-rational static and deterministic image, eliminated from the image of the world the possibility of a metaphysical dimension. The special theory of relativity, if assessed correctly, highlights the importance and necessity of a dynamic image of the world and consequently demands a reflec-

[66] We find here a perspective that gets back to some of the intuitions more characteristic of the classical metaphysics of Aristotle and Thomas Aquinas: the analogy of being, together with the profound richness united to the act of being of every reality, even every physical reality.

tion of another order (metaphysical) about the meaning of natural entities, of their actions, and of their potentialities.

The image that results will certainly no longer be that "fully rational" image to which modern thought aspired, not because the world is in some way irrational, but rather because reason manifests the insurmountable limits in its objectifying capacity. In achieving a more profound understanding of dynamic reality we must turn to an understanding that is not purely formal. Here then, special relativity reopens the possibility of examining metaphysical concepts, like those of *act* and *potency*, which in Aristotelian metaphysics served to express the profound content of reality and to grasp the richness of being and becoming of our real world.

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Abstract: *La teoria speciale della relatività è stata la prima teoria della fisica contemporanea a suggerire una profonda revisione dei concetti fondamentali della nostra immagine del mondo, in particolare quelli di causalità, dinamicità e temporalità. In questo studio si considera il significato di tale trasformazione, attraverso l'esame della struttura epistemologica soggiacente alla formulazione einsteiniana del problema della determinazione temporale. La distinzione fra i livelli concettuali in cui operano gli elementi della teoria, consente di inquadrare i nuovi concetti in un'immagine della realtà in grado di superare uno schema puramente razionalistico e di comprendere il suo carattere dinamico; tale immagine si apre ad una comprensione di tipo metafisico.*