Phänomenologie in der Naturwissenschaft

Lutz-Helmut Schön, Johannes Grebe-Ellis [Hrsg.]

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Georges Ibongu

Cassirer's Structural Realism

λογος

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Phänomenologie in der Naturwissenschaft

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Humboldt-Universität zu Berlin

Mit der Reihe «Phänomenologie in der Naturwissenschaft» soll ein Forum für Arbeitsansätze in den Naturwissenschaften und ihren Didaktiken geschaffen sein, denen der Verzicht auf reduktionistische Konzeptionen von Natur und anstelle dessen das «Geltenlassen der Erscheinungen» gemeinsam ist.

Berücksichtigt werden sollen insbesondere

- phänomenologische Erschließungen einzelner Fachgebiete in den Naturwissenschaften
- didaktische Entwürfe von naturwissenschaftlichem Unterricht mit phänomenologischem Ansatz
- historische und erkenntniskritische Darstellungen phänomenologischer Naturzugänge

Band 7
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To Prof. Dr. John M. Krois

Geleitwort

Der vorliegende Band der Reihe *Phänomenologie in der Naturwissenschaft* ist mit Ernst Cassirer einem der bedeutendsten deutschen Philosophen des 20. Jahrhunderts gewidmet, dessen umfangreiches philosophisches Werk sehr eng sowohl mit der Phänomenologie als auch den Naturwissenschaften verbunden ist. Ursprünglich der Marburger Schule des Neukantianismus entstammend gilt Cassirer, den 1907 an der Berliner Universität Habilitierten und hier bis 1918/19 als a.o. Professor Lehrenden, von Anfang an die Beziehung zwischen Philosophie und den Naturwissenschaften als ein zentrales Feld seiner Interessen, die konzeptionell das Ziel verfolgen, die Ablösung des Substanz- durch das Funktionsdenken nicht nur in der neueren Geschichte der Wissenschaften, sondern auch in der Philosophie nachzuzeichnen. Das erste große, am Ende auf vier Bände anwachsende Werk trägt deshalb auch völlig zu Recht den Titel *Das Erkenntnisproblem in der Philosophie und Wissenschaft der neueren Zeit*, zeugt es doch nicht nur von der intimen Kenntnis der naturwissenschaftlichen Theorien eines Kopernikus, Kepler, Galilei, Newton, Darwin, von Uexkül und vieler anderer, sondern auch von dem Bemühen, neue Denkstile korrelativ in der Philosophie- und Wissenschaftsgeschichte aufzuweisen. Die Aufmerksamkeit für die Naturwissenschaften, ihre Methoden und deren erkenntnistheoretische Implikationen wird auch nicht geringer, als Cassirer während seiner Zeit als ordentlicher Philosophieprofessor an der 1919 neugegründeten Hamburgischen Universität sein zweites großes Werk, die *Philosophie der symbolischen Formen* als eine Kulturphilosophie ausarbeitet, bildet doch in systematischem Sinne die [Natur-]Wissenschaft neben Sprache und Mythos eine der drei zentralen Formen bzw. Typen von Objektivation: realisiert sich in der mythischen Ordnungsform die Ausdrucksfunktion, in der Sprachform die Darstellungsfunktion, so in der naturwissenschaftlich-theoretischen Form die reine Bedeutungsfunktion menschlichen Welterkennens. Folgerichtig trägt der dritte Teil des dritten Bandes dieses Werkes den Titel »Die Bedeutungsfunktion und der Aufbau der [natur-]wissenschaftlichen Erkenntnis«.

Bevor ich auf Cassirers Stellung zur Phänomenologie zu sprechen komme, wofür dieser dritte Band der *Philosophie der symbolischen Formen* eine gute Gelegenheit bietet, da er den Bandtitel *Phänomenologie der Erkenntnis* trägt, ist noch kurz darauf hinzuweisen, daß Cassirer Zeit seines Lebens zwei Probleme bewegen, denen er nicht nur viel Zeit und Energie, sondern auch zwei berühmt gewordene Buchveröffentlichungen widmet. Das ist zum einen die Frage, inwieweit die Einsteinsche Relativitätstheorie die Grundpositionen kritischer Erkenntnistheorie und Logik berührt, d.h. diese in Frage stellt oder bekräftigt. Aus der Beschäftigung mit dieser Frage geht 1921 die Schrift *Zur Einsteinschen Relativitätstheorie* hervor,[1] die Cassirer nicht nur dem befreundeten Einstein zuvor im Ms. vorgelegt hatte, sondern die auch auf das Buch *Einführung in das Verständnis der allgemeinen Relativitätstheorie* (1917) von Moritz Schlick, des Physikers, der sich der Philosophie zugewandt hatte, reagiert. Bekanntlich interpretiert Cassirer die Relativitätstheorie als Triumph des kritischen Funktionsbegriffes; eine Interpretation, gegen die Einstein, der die „Abhandlung mit sehr viel Interesse gründlich studiert [hat] und vor allem bewundert, mit welcher Sicherheit [Cassirer] die Relativitäts-Theorie dem Geiste nach beherrscht“,[2] selbst nichts einzuwenden hat. Das zweite Problem, das Cassirer unaufhörlich beschäftigt, ist die philosophisch-erkenntnistheoretische Frage, inwieweit die Quantenmechanik das Kausalprinzip und damit den Determinismus als Grundlagen naturwissenschaftlicher Erkenntnis als obsolet erscheinen lasse. Als Frucht dieses Nachdenkens legt Cassirer 1936 in der schwedischen Emigration die Schrift *Determinismus und Indeterminismus in der modernen Physik* vor, die das Gelten des Kausalitätsprinzips auch in der Quantenmechanik verteidigt. In dieser Schrift geht er u.a. auf diejenige Form der Naturbetrachtung ein, die Ludwig Boltzmann die »phänomenologische« nennt und deren Erklärungsanspruch in Abgrenzung zur Atomistik als zweiter Form der Naturbetrachtung er kritisiert und als Selbsttäuschung zurückweist.[3]

Das Verhältnis Cassirers zur und seine Stellung in der Phänomenologie stellt in der Cassirerforschung einen eigenen Gegenstand dar, da er sich

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[1] Ernst Cassirer: Gesammelte Werke. Hrsg. von Birgit Recki. Bd. 10. Hamburg 2001.

[2] Albert Einstein an Ernst Cassirer, 5. Juni 1920. In: Ernst Cassirer: Ausgewählter wissenschaftlicher Briefwechsel. Hrsg. von John M. Krois. (Nachgelassene Manuskripte und Texte. Hrsg. von Klaus Christian Köhnke, John M. Krois und Oswald Schwemmer. Bd. 18.) Hamburg 2009, 45f.

[3] Ernst Cassirer: Gesammelte Werke. Hrsg. von Birgit Recki. Bd. 19. Hamburg 2004, 210.

nicht nur zur zeitgenössischen Phänomenologie Edmund Husserls, sondern auch zur Hegelschen Phänomenologie des Geistes sowohl kritisch-distanzierend als auch in vielen Fragen zustimmend verhält. Wobei ihm letztere sogar als Vorbild für sein dreibändiges Hauptwerk *Philosophie der symbolischen Formen* dient, erklärt er doch im Vorwort des drittes Bandes, er „knüpfe [...] hierin nicht an den modernen Sprachgebrauch [bei Husserl - C.M.] an, sondern [...] gehe auf jene Grundbedeutung der »Phänomenologie« zurück, wie Hegel sie festgestellt und wie er sie systematisch begründet und gerechtfertigt hat“.[4] Die große Bedeutung, die Hegels Phänomenologie für Cassirer besitzt, wird auch durch das Faktum unterstrichen, daß ursprünglich nicht nur der dritte sondern alle drei Bände (Sprache, Mythos, Wissenschaft) *Phänomenologie der Erkenntnis* heißen sollten.[5] Die Tatsache, daß sich Cassirer selbst als Phänomenologe versteht, daß er mit seiner *Philosophie der symbolischen Formen* neben einer »Phänomenologie der Erkenntnis« eine »Phänomenologie der sprachlich Form« und eine »Phänomenologie des mythischen Denkens« zu entwerfen beansprucht, macht eine klare und fundierte Beantwortung der soeben formulierten Frage natürlich nicht einfacher; eine solche Antwort kann und soll hier auch gar nicht versucht werden. Wir haben uns auf den Hinweis zu beschränken, daß Cassirer den Ausdruck »phänomenologisch« in unterschiedlichen Kontexten auch unterschiedlich verstanden wissen will: so nennt er gelegentlich den Gesichtspunkt, den Geist mit Hilfe der dialektischen Methode (Hegels) als ein strukturiertes Ganzes „in seinen notwendigen gedanklichen Vermittlungen“ zu entwickeln und darzustellen, »phänomenologisch«.[6] In anderen Zusammenhängen meint »phänomenologisch« jedoch das zeitlose ideelle Moment gegenüber psychologischen Momenten in der wissenschaftlichen Begriffsbildung. Außerdem steht »phänomenologisch« bei Cassirer für phänomenal, für sich an den sich gebenden Erscheinungen und folglich an der Erfahrung orientierend, weist er doch z.B. eine systematische Deduzierbarkeit seiner symbolischen Formen grundsätzlich ab. Es ist die Analyse der Empirie, die auf immer neue Formen des

[4] Ernst Cassirer: Phänomenologie der Erkenntnis. In: Philosophie der symbolischen Formen. Dritter Band. In: Gesammelte Werke. Hrsg. von Birgit Recki. Bd. 13. Hamburg 2002, VIII.

[5] Editorische Hinweise des Herausgebers John M. Krois. In: Ernst Cassirer: Zur Metaphysik der symbolischen Formen. (Nachgelassene Manuskripte und Texte. Hrsg. von John M. Krois und Oswald Schwemmer. Bd. 1), Hamburg 1995, 299f.

[6] Ernst Cassirer: Das Erkenntnisproblem in der Philosophie und Wissenschaft der neueren Zeit. 3. Bd. (1920) In: Gesammelte Werke. Hrsg. von Birgit Recki. Bd. 4. Hamburg 2000, 313.

Geistes bzw. der Kultur führt. Cassirer teilt die Überzeugung Goethes, wonach die Natur eine Welt der Erscheinungen, der Phänomene ist, denen keine eigene transzendente Welt korreliert, die folglich auch nicht durch ein unmittelbar zugängliches Wahres fundiert sind. Aus diesem Grunde unterlegt er seiner Philosophie im Spätwerk ein tieferes Fundament – eine Theorie von Ur- bzw. Basisphänomenen, wobei er diese, ganz in Goethes Sinne, als dasjenige versteht, das „nicht mehr aus etwas anderem abgeleitet oder bewiesen werden [kann]", sondern sich als ein „Phänomen [...] nur sich selbst beglaubigen und sich selbst erklären kann".[7]

Georges Ibongu hat die vier Studien, die seine sachkundigen Recherchen und Überlegungen zu unterschiedlichen Themen von Cassirers langjähriger philosophischer Beschäftigung mit erkenntnistheoretischen Fragen in den modernen Naturwissenschaften, wie der Reformulierung des physikalischen Objektes, Raum und Zeit als strukturell-dynamischer Kategorien, des wissenschaftlichen Experimentes und des Zusammenhanges von Kausalität und Objektivität, unter dem Titel *Cassirer's Structural Realism* zusammengefaßt. Sie bereichern auf nachdrückliche Weise die internationale Cassirerforschung, indem sie auf neue Aspekte im Cassirerschen Werk aufmerksam machen, Anregungen für weitere Untersuchungen formulieren und immer wieder auf das – heutigen Philosophen in dieser Weise nicht mehr zur Verfügung stehende – Vermögen Cassirers aufmerksam machen, sich dermaßen souverän nicht nur innerhalb der philosophischen Erkenntnistheorie samt ihrer Geschichte, sondern auch innerhalb der zeitgenössischen naturwissenschaftlichen Theorien samt der Wissenschaftsgeschichte zu bewegen, daß ihm führende Naturwissenschaftler seiner Zeit ihren Respekt nicht versagen. Die Verortung des Werkes von Ernst Cassirer in einem phänomenologischem Blick auf Philosophie und Naturwissenschaft, auf die philosophische Durchdringung von Philosophie und Wissenschaft, prädestinieren die von Georges Ibongu als Resultat seiner zweijährigen Recherchen an der Humboldt-Universität zu Berlin vorgelegten Studien, in der Reihe *Phänomenologie in der Naturwissenschaft* zu erscheinen. Den beiden Herausgebern, Lutz-Helmut Schön und Johannes Grebe-Ellis, die dies erkannt und ermöglicht haben, gilt deshalb mein herzlicher Dank.

Berlin im Juli 2011
Christian Möckel

[7] Ernst Cassirer: Phänomenologie der Erkenntnis. A.a.O., 189.

Foreword by the author

Frege's semantics distinguishes between the sense and denotation of singular and complex terms in relation to the notion of truth. He refers to some illustrations from physics and geometry – for example to *Pythagoras' Theorem* – in order to explain the objective not anthropomorphic and timeless character of truth. He asserts that the thought expressed in this theorem is true timelessly and independently of the fact that somebody considers it as true or not. It means that Frege adheres to a form of realism about knowledge which, far from being naïve, claims that the truth of a thought expressed by a proposition is independent of its discovery. By focusing his semantic analysis on concepts within the framework of a theory of sense and denotation, Frege does not study the formation of concepts in the sciences of nature as such, but only takes an interest in their apprehension as functions, whose value is always a value of truth. He clarifies what a concept is, namely: the meaning of predicate, by rejecting a psychologist analysis of it: concept is neither a mental image nor a psychic process.

Cassirer is interesting to the work of modern logicians (Leibniz, Frege and Russell), in order to illustrate the nature of the logical concept insofar as it can be applied to the language of mathematical modern physics. From an epistemological perspective, he shows how Aristotle's logic becomes limited. This Aristotelian logic is in accordance with the substantialist analysis of the scientific concept of reality and can no longer meet the needs of the conceptualization of mathematical modern physics. He systematically examines the way physics constitutes its language and highlights the sense of concept essentially as *function*.

In the context of the extreme antipathy of logical empiricism directed at Kantian idealism, Cassirer defends – from a conciliatory and interferential point of view – a transcendental interpretation of Einstein's theory of relativity. Thus, the exclusively empiricist position becomes a controversial topic in the current epistemological debate. Currently, most epistemologists (T. Ryckman, M. Friedman, C. Schmitz-Rigal, M. Paty, etc) take an interest in Cassirer's interpretation of Einstein's theories of relativity, although this interpretation has long been underestimated because of its attachment to Kant. Cassirer always asks the question of the conditions that constitute the objectivity of physical knowledge. This question underpins his study of Einstein's theories of relativity and that of quantum mechanics. What I intend to emphasize, here, is that Cassirer's sense of the transcendental concept is not merely reducible to the Kantian meaning of it.

Cassirer pleads for collaboration between philosophers and physicists, beyond the dialog he establishes among the epistemological schools, by aiming at relating, for instance, Einstein's theories of relativity with the critical theory of knowledge. He is concerned, even in purely epistemological matters, to remain in close contact with physics. That is why he declares that the purpose of his writing dealing with Einstein's theories of relativity "will be attained if it succeeds in preparing for a mutual understanding between the philosopher and the physicist on questions, concerning which they are still widely separated"[8]. Cassirer does not pretend to provide a complete account of the philosophical problems raised by the theory of relativity; and he is aware of the fact that no epistemological school could alone vindicate the authority of the philosophical interpretation of relativity. Strictly speaking, he does not anywhere reject the interpretation of logical empiricism.

The one of main purposes of this book is to contend that the influence of Kant on the philosophical ideas of Cassirer on physics has decreased more and more. That means that Cassirer also underscores the limits of Kant's transcendental system, on which some logical empiricists (Moritz Schlick, Philipp Frank, etc.) and physicists (Max Born, Albert Einstein, etc.) have insisted. Since his first volume of *Erkenntnisproblem*, Cassirer has sharply distanced himself from Kant. The most important fact is the dynamic conception of categories connected with his comprehension of the history of science.

In the third volume of *The Philosophy of Symbolic Forms,* Cassirer explicitly reveals the originality of his thought and defends the conception of physics as symbolic form. He clearly adopts Leibniz' Conception of pure signification, by breaking more decisively with the Kantian conception of the transcendental schematism of the understanding. And "by sharply distinguishing between intuitive or representative meaning and the purely formal or significative meaning characteristic of modern abstract mathemat-

[8] E. Cassirer, [1921] 1953, Engl. Trans., 349.

ics, in the tradition of Leibniz's 'universal characteristic,' Helmholtz's theory of signs, and Hilbert's axiomatic conception of geometry, Cassirer has clearly moved out of the Kantian camp and has come extremely close, in fact, to the position of Carnap […] ."[9] It would be remiss, in the line of Friedman's emphasis, not to mention the influence of Heinrich Hertz for whom Cassirer acknowledges as "the first modern scientist to have effected a decisive turn from the copy theory of physical knowledge to a purely symbolic theory."[10] Furthermore, the most decisive influence, in my opinion, is Klein's group theory, whereby Cassirer manages to grasp the nature of space-time of physics and to elaborate his theory of objectivity as invariance.

In *Determinism and Indeterminism in Modern Physics,* Cassirer more precisely underlines the difference between his and Kant's perspective on the notion of causality. Here, the most decisive influence comes from Helmholtz's conception of causality which permits Cassirer to deal with the considerations of physics as such. The role of scientific experiment in his thought, his correspondences with the modern physicists and the philosophers of logical empiricism as well as the importance which he grants to Leibniz, to Russell, to Felix Klein and the non-Euclidian geometries etc., are the proofs whereby Cassirer distances himself from the ideas of the transcendental philosophy of Kant. Thus, this book – constituted of four essays or articles – only intends to serve as an introduction to Cassirer's structural realism, which my future research will more thoroughly examine[11].

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[9] M. Friedman, 2000, 110.

[10] E. Cassirer, [1929] 1957, Engl. Trans., 20; E. Cassirer, [1950 English first edition] 1957, *Erkenntnisproblem,* IV, S. 111–13; etc.

[11] Nowadays, a diversity of perspectives in the current debate opposes several trends of scientific and structural realisms (M. Ghins, J. Worrall, B. Gower, H. Stein, J. Ladyman; etc.). Within scientific realism Ghins, for instance, criticizes Van Fraassen's constructive empiricism also called structural empiricism or instrumental structuralism. Ghins defends a selective or moderate scientific realism which considers sciences as mathematical structures or models capable of describing partially or approximately physical entities independent of our desires, our language, our mind etc. (*cf.* for instance M. Ghins, "Laws of nature: do we need a metaphysics?," *Principia,* 11 (2) (2007), 136–37). My investigation does not here deal with this very complex debate. My purpose here is to examine the grounds of the existence of structural realism in Cassirer's philosophy of physics. My future project aims, as did Gower, at drawing an historical survey of structural realism and at discussing how structuralism figures in the thought of Ernst Cassirer, Moritz Schlick, Rudolf Carnap and Bertrand Russell (*cf.* B. Gower, "Cassirer, Schlick and 'structural realism': The philosophy of the exact sciences in the background to early logical empiricism," *British Journal for the History of Philosophy,* 8: 71–106).

The first essay defends the argument that the reformulation of physical object is one of the main topics of Cassirer's epistemology of science and does not deal with Kant's Copernican revolution in epistemology. The new basic viewpoint of modern physics puts, according to Cassirer, the concept of law ahead of the concept of object. In agreement with Weyl, Cassirer thinks that the Aristotelian idea of rigid individual substances as the basis of physics cannot be sustained in the context of field theory. He offers a structural and realist conception of the field. The electron does not exist before the field but is first constituted by its relation to the field.

The second essay concerns Cassirer's conception of the space-time of physics. For Cassirer, the nature of space and time is fundamentally expressed in the concepts of order, of relation, and of field structure. They deal with invariant properties according to a specific group of transformations.

The third essay shows that Cassirer is one of the founders of structuralism who shares an appreciation of the significance of group theory in the ontology of physics. Experiment constitutes the sphere of necessity and universality within and by which the reality concept of physics has to be established. The concepts of space-time, of invariance and dynamism, of causality and interaction constitute the true and *ultimate invariants* of experiment itself. And Cassirer's conception of objectivity as *invariance* is also connected with his conception of experience as well as to his interpretation of the principle of causality.

The fourth essay presents Cassirer's interpretation of the principle of causality which, according to him, does not deal with the causal problem as such but with the causal problem of physics. He considers its epistemological significance and he understands it as a question of the methodology of physics.

This book is dedicated to Professor John Michael Krois. After examining my research plan he did not hesitate to recommend me for the Alexander von Humboldt Foundation Fellowship and to accept being my host professor in Humboldt Universität zu Berlin. Sadly, he is no longer with us; but I mention him here to record debts that I shall find other ways to pay. God rest his soul. I also thank professors Akenda, Dimandja, Okolo and Ghins for their recommendations.

My heartfelt thanks are due the Alexander von Humboldt Foundation for granting me the postdoctoral fellowship in order to carry out this research.

I am very grateful to Professor Christian Möckel, who agreed to become my host after Professor Krois's death. He was very involved in finding an English native speaker to correct the draft of this book; and he recommended to the administration of the Institute of Philosophy of Humboldt University of Berlin that it receives financial support for its publication. I also wish to thank Shanna Römisch, Paul Markus (from *Studentische Hilfskraft* of "Ernst-Cassirer-Nachlassedition"), and Fatin Ward.

I also received encouragement, advice, constructive criticism, and assistance from Bernardo Mota, Rouin Farshchi, Franz Engel, Sascha Freyberg, and Maike Werner.

My warmest thanks go to Professors Jean Seidengart, Heinz Wismann, Christiane Schimtz-Rigal, Massimo Ferrari and Fabien Capeillères for providing me with helpful information about the philosophy of Cassirer. This book owes its existence to many others whose names cannot here receive detailed mention. I extend my deepest thanks to all.

Georges Ibongu,
Berlin, March 2011

Table of contents

Cassirer and the Reformulation of Physical Object

Keywords: physical system/motion/object/law/rigidity/flexibility/substantialism/ functional relations/logical task/unobservable entity/ field/structure

Abstract

A central concern of Cassirer's *systematic philosophy* is the structure and articulation of *a theoretical world view*, the *form of knowledge of exact science*[12], which constitutes, as he claimed, "problems from which his philosophical work began."[13] In 1910, this concern started "from the assumption that the basic and constitutive law of knowledge can most clearly be demonstrated where knowledge has reached its highest level of necessity and universality."[14] In 1937, Cassirer was convinced that with "the new developments in theoretical physics, the displacement of its epistemological center of gravity became increasingly evident."[15] That is, due to the development of quantum mechanics and Einstein's general Relativity, Cassirer manages to better justify and to formulate more precisely the concept of scientific object without essentially altering the fundamental viewpoint of his previous analyses[16].

[12] Cf. E. Cassirer, [1929] 1957, Engl. Trans, xiii. P. xiii. I do not aim to discuss here the question of the hierarchy of symbolic forms in Cassirer's thought. I simply want to stress the following point: it is true that in the third volume of *Philosophy of Symbolic Forms* the theme of the fundamental form of knowledge is raised in a broader and more universal sense than in *Substance and Function* (whose content concerns only the exact sciences): "It has broadened the concept of theory itself by striving to show that there are formative factors of a truly theoretical kind which govern the shaping not only of the scientific world view but also of the natural world view implicit in perception and intuition." (*cf.* E. Cassirer, [1929] 1957, Engl. Trans, xiii. P. xiii) Nevertheless, Cassirer clarifies that a *central concern* of this third volume is again "the problem of knowledge, the structure and articulation of a theoretical world view." (*cf.* E. Cassirer, [1929] 1957, Engl. Trans, xiii. P. xiii).

[13] E. Cassirer, [1936] 1956, Engl. Trans, xxi.

[14] E. Cassirer, [1929] 1957, Engl. Trans, xiii.

[15] E. Cassirer, [1936] 1956, Engl. Trans, xxi.

[16] *Cf.* E. Cassirer, [1936] 1956, Engl. Trans, 130–31.

First of all, I want to show that there is, according to Cassirer, continuity between classical and modern physics: in both periods of physics we always deal with the epistemological primacy of law over things or objects. That is why naïve realism cannot be found even in Galilean-Newtonian mechanics. Nevertheless classical mechanics establishes dualism between space and matter; hence, it rests upon a substantialist presupposition: physical laws have to be based upon space and ether as privileged physical objects. General Relativity overcomes this dualism. For Cassirer, both quantum mechanics and General Relativity clarify this epistemological primacy of law over physical object. Second, since Kant's thinking on physics rests upon Newtonian mechanics, Cassirer maintains that Kant does not really abandon a rigid and substantialist point of view. Furthermore, Kant's analysis is limited to the world of perceptions and does not speak of physical objects as such. Kant's comprehension of the relation between knowledge and object is only static, and his transcendental logic doesn't go beyond Aristotelian substantialist logic. Cassirer's enterprise is not merely to mount a criticism of pure reason, but also analyses physical experimental procedure based upon measurement.

I defend the thesis that the reformulation of the physical object is one of the main topics of Cassirer's epistemology of science and does not deal with Kant's Copernican revolution in epistemology. The new basic viewpoint of modern physics places, according to Cassirer, the concept of law ahead of the concept of object. The concept of law represents the true nucleus of object. Cassirer thinks that the Aristotelian idea of rigid individual substances on the basis of physics cannot be defended in the context of field theory. He offers a structuralist and realist conception of the field. For him, the possibility of speaking of objects in this context is the possibility of individuating invariants.

1. The state of a physical system

Cassirer affirms that what a physical object or a thing is can only be described by referring to the laws governing it[17]. For him "the unity and determinateness of measurement can be immediately understood and expressed as the unity and determinateness of the object, precisely because

[17] E. Cassirer, [1936] 1956, Engl. Trans, 133.

the empirical object means nothing but a totality of relations according to law."[18] What a physical object means is to be understood relatively to what is called the state of a physical system. In a physical theory a system is typically described in terms of its state. The relevant physical quantities or variables are specified and then dynamical laws govern the time evolution of these variables in order to determine their values in the future. For example, in classical particle mechanics, the state of a system is specified by the positions and velocities (or the momenta) of all of particles in the system (that is, *r(t)* and *v(t)* for each particle).[19] Newton's second law $m\frac{d^2x}{dt^2}$ then determines the time evolution of the state (variables) of the system. For electrodynamics, the state variables are the electric and magnetic fields, ***E*** and ***B***, and Maxwell's equations govern the time evolution of these. In classical physics (including Einstein's Relativity here), the state variables that are the central entities of the dynamical equations (typically the positions and momenta of particles) are also the directly observable physical quantities.

In classical mechanics, the description of the position of a physical event consists of the indication of the point of a rigid body (reference body) with which this event coincides. In fact, it is by means of measurements that we determine the distance of two points on a rigid body. The fact that there are material objects to which, within the limits of a certain field of perception, we can only ascribe changes of position and not changes of state, is of great importance for the formation of the concept of space (and even, to a certain extent, for the justification of the concept of the material object). These objects are considered as *practically rigid*. The concept of space, such as it was used in classical mechanics, is thus connected to the existence of rigid bodies. Hence, physics improved its measurement of the physical events by using the Cartesian system of coordinates (which replace here the rigid bodies). The physical description becomes independent vis-à-vis the points provided with names which exist on the rigid body to which the indication of positions relates.

Newton's mechanics is a dynamics of the material point. Newton considers a celestial body as a geometrical point. A particle has all the physical properties of a real body but occupies only a single point in space. There is

[18] E. Cassirer, [1921] 1953, Engl. Trans., 386.
[19] J. T. Cushing, 1998, 290.

no confusion between the mechanics of the material point, the mechanics of system of material points and the mechanics of the rigid bodies. Thus, the concept of the material point is constitutive of mechanics. A material object (i.e. any object perceptible to the senses) cannot be treated, with any rigor, as a material point in itself.[20] Newton's mechanics does not intend to give a complete description of objects. It naturally tends to suppose these material points as well as the laws governing their interaction as unchanging, because it cannot supply temporal modifications with theoretical explanations.

In opposition to the classical mechanics, the state (or state vector or wave function ψ) of a quantum-mechanical system is a more abstract object and is not itself directly observable. The fundamental dynamical equation of quantum mechanics, the Schrödinger equation (the quantum analogue of Newton's second law) $\left|\psi(x,y,z,t)\right|^2$, governs the time evolution of the state vector for the system, but this does not itself yield definite values for the positions and momenta of the parts of the system. Rather, the state vector or wave function ψ, which is the central entity in the theory, permits us to compute only probabilities of various allowed outcomes (the so-called *eigenvalues*) of an experiment or of an observation. Thus, Cassirer thinks that "the 'causal law of quantum mechanics' is valid – that is, the thesis that if at any time certain physical quantities are measured as exactly as possible in principle, quantities will also exist at any other time whose magnitude on being measured can be predicted with precision."[21] Whereas in the classical view a physical object always exists in a completely determined state and changes its state in a strictly determinable manner, quantum mechanics considers the aggregates of processes, to each of which is ascribed a definite wave function. In this way exact statements are also obtained, "but they are statistical only."[22] Quantum mechanics, unlike classical mechanics, does not lead to the determination of the position of an individual mass point at a

[20] Harvey Brown clarifies that "Even Newton realized that his absolute space and time – those entities distinct from material bodies but whose existence is necessary in Newton's eyes to *situate* the bodies so that their motions can be defined – 'by no means come under the observation of our senses'. Newton was keenly aware of the need to arrest the backsliding into pure metaphysics: but how to make the theoretical edifice touch solid empirical ground?" (cf. H. Brown, 2005, 23).

[21] E. Cassirer, [1936] 1956, Engl. Trans, 127–28, 188

[22] E. Cassirer, [1936] 1956, Engl. Trans, 192.

given instant; it only provides the probability, for the totality of electrons, that the individuals particles are found in a certain position at a given time.

We understand here that in both classical mechanics and modern physics, scientific laws cannot be designated as natural laws in the customary sense; for they do not refer to physical things and phenomena but rather to measurements – that is, to particular forms of obtaining scientific knowledge. They are, as Cassirer says of uncertainty relations, statements "about the empirically possible, about the physically observable."[23]

2. The substantialism of the mechanistic point of view and the reformulation of the physical concept of object

2.1. The substantialism of the mechanistic point of view

Aristotle was, according to Cassirer, the first to provide a true analysis of the phenomenon of motion. This analysis "explains change by reducing it to the ultimate and universal concepts of Aristotle's metaphysics, to substance and form."[24] Paradoxically, the Aristotelian theory of elements essentially does not go beyond the region of an immediate *given*, because the metaphysical supreme categories of substance and form are everywhere connected with observations taken from the sensory sphere, in order to make them applicable to concrete natural phenomena and – therefore explicable. Aristotle's view considered place as "a certain physical property that produced definite physical effects. The 'here' and 'there,' the 'above' and 'below,' were for it no mere relations; but the particular point of space was taken as an independent real, which consequently was provided with particular forces. In the striving of bodies to [assume] their 'natural places,' in the pressure of air and fire upwards and in the sinking of heavy masses downwards, these forces seemed given as immediate empirical realities."[25] The logic and physics of Aristotle, which are grounded in his metaphysics, presuppose things given in the immediate world, giving rise to Aristotle's substantialism.

[23] E. Cassirer, [1936] 1956, Engl. Trans, 193.
[24] E. Cassirer, [1929] 1957, Engl. Trans, 453.
[25] E. Cassirer, [1921] 1953, Engl. Trans., 361.

Since motion is just as certainly the fundamental fact in Aristotle's physics as it is the focus of Galileo's thought and of his physical theories, Cassirer believes that Aristotle's physics seems to be at first sight in full agreement with the new science of dynamics[26]. Galileo "had removed the barrier Plato had erected between mathematical and natural science; for this new science proved nature itself a realm of necessity rather than of chance. Nature is governed by universal and inviolable laws."[27] According to Plato, the constitution of physical nature is not to be found in fire or earth, in water or air, considered by natural philosophers as the true elements. These sensible elements have to be replaced by mathematical elements; that is, by triangles, by retraeders, hexaeders, octaeders, dodecaeders, icosaeders. Thus, we shall come to a better insight into natural phenomena by at least describing them in an intelligible language. Cassirer underscores that we find in Galileo's work "very little of these intellectual conflicts. His position [on] Platonic theory is clear and unmistakable from the [...] beginning. For he had to build up a general Dynamics, a deductive theory of the movements of bodies. For this task he could find no immediate help in Plato's work. Plato's view of the physical universe was a static, not a dynamic view. He thought in [terms of] numbers and geometrical forms. But according to Galileo we cannot hope to understand and to master the fundamental fact of nature, the phenomenon of motion, by the mere study of these constant, invariable, eternal forms."[28] Galileo introduces the language of our modern analysis that deals with "variable quantities and the relations, the mutual interdependence of these quantities."[29]

Cassirer says that Galileo's work initiates the new science of dynamics, which also does not completely agree with Aristotle's physics but aims at overcoming Aristotle's substantialism and at destroying Aristotle's concept of a radical heterogeneity of matter. There is, continues Cassirer, a decisive difference between Galileo and Aristotle about the explanation or reasons for motion: "According to Aristotle we must seek these reasons in the essence and nature of things, in their 'substantial forms'. Every particular substance has a motion of its own corresponding to its peculiar nature, to its ontological character. […] Whereas all earthly elements move in straight

[26] E. Cassirer, "Galileo: a New Science and a New Spirit", [1942] 2007, 58.
[27] E. Cassirer, "Galileo: a New Science and a New Spirit", [1942] 2007, 57
[28] E. Cassirer, "Galileo's Platonism", [1944/1946] 2007, 340.
[29] E. Cassirer, "Galileo's Platonism", [1944/1946] 2007, 340–41.

lines – a movement that after a certain time must necessarily come to a standstill – the motion of celestial bodies is eternal because their substance is eternal and indestructible. The substance of the heavens is incorruptible whereas the substance of our elements, of the world below the moon, is liable to change and decay."[30]

Galileo's theory of motion is rooted "in the choice of a new standpoint from which to estimate and measure the phenomena of motion in the universe."[31] This choice allows him to formulate the law of inertia and to find the real foundation of the new view of nature. For this, "place is a nothing; it does not exist and exerts no force, but all natural power is contained and grounded in bodies themselves."[32] Thus, what is called the true place is never given to us as an immediate sensuous property, but must be discovered on the basis of calculation and of the arithmetic of forces in the universe. The true physical place is of a geometrical nature. Motion has to possess a being, that is, from the standpoint of the physicist, numerical constancy. This is what the law of inertia expresses and realizes. In its measure of motion, in the differential quotient of space by time, Galileo's physics claims to have reached the kernel of all physical being, to have defined the intensive reality of motion. The concept of the 'state of motion' now becomes "the real mark and characteristic of physical reality."[33]

Newton has provided the precise mathematical formulation of the Law of Inertia, discovered by Galileo and the fundamental law of dynamics. With him, the epistemological primacy of law over things is clearly established[34]: "physics no longer deals directly with the existent as the materially real; it deals with its structure, its formal context. The tendency toward unification has triumphed over the tendency toward representation: the synthesis guided by the pure concepts of law has shown itself superior to summation in thing-concepts."[35] Accordingly, Cassirer cites Sir Arthur

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[30] E. Cassirer, "Galileo: a New Science and a New Spirit", [1942] 2007, 58–9.

[31] Cassirer, [1921] 1953, Engl. Trans., 361.

[32] E. CASSIRER, [1906 (1911)] 1991, *Das Erkenntnisproblem.* I, S. 360; quoted by E. Cassirer, [1921] 1953, Engl. Trans., 362.

[33] E. Cassirer, [1921] 1953, Engl. Trans., 363.

[34] E. Cassirer, [1929] 1957, Engl. Trans, xv.

[35] E. Cassirer, [1929] 1957, Engl. Trans, 467.

Stanley Eddington who states that “the world itself is represented no longer as a coexistence of thing unities but as an order of “events.”[36]

It is true that Newton’s mechanics rests upon a kind of substantialism, which is logically, according to Cassirer, justified in Newton’s system. Nevertheless, Cassirer is very close to Worrall's position claiming that “what Newton really discovered are the relationships between phenomena expressed in the mathematical equations of his theory.”[37] Cassirer is convinced that “Newton imposed a different task upon science. As a physicist he was not investigating these substantial forms (the pure forms of things) – the form of heat or the ‘essence’ of gravity. He wished to reduce the phenomena of nature to general laws and to derive these laws from mathematical principles.”[38] This is one of the main reasons for claiming that Newton’s substantialism does not deal with naïve realism; this substantialism is presupposed as relative to absolute space and time, in order to underpin the coherence of his physical system.

Moreover when classical physics spoke of ‘individual’ mass points, Cassirer explains that “this expression was always to be taken with a grain of salt – with definite reservations in principle. In no case can we simply assume this ‘individuality’ of the given – that is, of direct sense perception; it must be “defined” in some way – that is, represented in the exact conceptual means of physics, before we can admit it into its system of knowledge.”[39] Cassirer insists that in classical physics, there is always a logical task to define an individual. He is guided by the “idea of the epistemological primacy of law over things,”[40] by means of which continuity is established between classical physics and modern physics. For him, the very transformations of content occasioned by both Einstein’s Relativity and quantum mechanics have reconfirmed and clarified this continuity.”[41] Henceforth, the substantialism of classical mechanics is not that of Aristotle’s physics and this substantialism is no longer overcome even by Einstein’s Special Relativity.

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[36] A. S. Eddington, 1923, pp. 12 ff., p. 184 ff.; quoted by E. Cassirer, [1929] 1957, Engl. Trans, 467.
[37] J. Worral, 1989, 122.
[38] E. Cassirer, “Newton and Leibniz”, [1943] 2007, 139–40.
[39] E. Cassirer, [1936] 1956, Engl. Trans., 186.
[40] E. Cassirer, [1929] 1957, Engl. Trans, xv.
[41] E. Cassirer, [1929] 1957, Engl. Trans, xv.

Before General Relativity, space played a completely independent role towards matter. As a vase can exist and preserve its shape without being filled, so space should preserve its properties, whether or not it is filled of matter. Cassirer thinks that the supposed dualism between space and matter (or physical events) lies in the substantialism of classical mechanics. The concept of reality of classical mechanics rests on two basic presuppositions, the concept of substance and that of space. This latter is developed, shows Cassirer, with great precision by Descartes.[42] Matter is *substantia extensa* and absolutely nothing other. All its observable predicates or attributes have to be reduced to this determination: "'Descartes' analysis of the concept of space is very closely bound up with his analysis of the concept of substance. […] For according to the basic presuppositions of the Cartesian metaphysics, the thing, the empirical object, can be clearly and distinctly defined only through its purely spatial determinations."[43] To ascribe to a physical object an objective existence does not mean that we think of it as the union of diverse qualities, each describable through the senses, because the mere aggregate of these qualities does not constitute the existence of the object.

For example, if we look at a piece of wax (as an individual thing), it cannot be characterized by means of certain observable attributes, such as its size, its form, its color, its hardness, etc. Wax is rather "something other than the mere aggregate of individual properties. For suppose it is now brought close to the fire and melts – we find the properties entirely changed: the color and hardness have disappeared; […]. Is it nevertheless still the same wax? Nobody doubts it; everybody is convinced that the 'being' of the wax survives all these changes. It follows that this "being" can only "be grasped in thought," and cannot be apprehended by the senses: *superset ut concedam, me ne quidem imaginary quid sit haec cera, sed sola mente perpicere.* Accordingly it is only the logically definable characteristic of persistence that constitutes the wax as a physical object."[44]

Cassirer concludes that a "general condition is established on which all objectivity rests in the mechanical view of nature. 'Objective' denotes a being which can be recognized as the same in spite of all changes in its

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[42] *Cf.* E. Cassirer, [1936] 1956, Engl. Trans, 177. –

[43] E. Cassirer, [1929] 1957, Engl. Trans, 144. This idea can be also found in E. Cassirer, [1950 English first edition] 1957, *Erkenntnisproblem,* IV, S. 34–5, 105.

[44] R. Descartes, *Meditationes de prima philosophica* Pt. II, Meditation 2; quoted by E. Cassirer, [1936] 1956, Engl. Trans, 177.

individual determinations, and this recognition is possible only if we posit a spatial substratum."[45] It is this presupposition upon which rests the entire axiomatic system of classical mechanics. And in his principles of mechanics, Heinrich Hertz employs it as a virtual definition of the concept of mass when he declares: "A mass particle is an indicator (*Merkmal*) by means of which we can unambiguously correlate a definite point in space at a given time with a definite point in space at every other time."[46] He insists that in determining the concept in this way the immutability and indestructibility of mass particles need no longer to be deduced, because they are already contained in the definition.

2.2. The concept of field.

It is not possible, according to the heritage of a mechanistic point of view, to grasp physical phenomena without the assumption of some material 'carrier'. The latter represents "a rigid, self-existent nucleus, which our knowledge encounters and before which it must come to a halt."[47] Hermann Weyl's conviction is that the role of substance in physics today is over: "The claim of this idea, metaphysically conceived by Aristotle, to express the essence of real matter – the claim of matter to be substance incarnate – is unjustified."[48] This is obvious when we consider field theory. The field denotes "a complex of pure effects of, or pure relations between, 'lines of force' which are no longer necessarily tied to a material substratum but which determine physical events, as it were, by their free mutual interaction."[49] That means that the field concept is not a thing; and that individual electron does not possess any substantiality in the sense of a thing, since it "exists only in its relation to the field, as a 'singular location' in it."[50] The electron does not exist before the field but is first produced or constituted by

[45] E. Cassirer, [1936] 1956, Engl. Trans, 177.

[46] H. Hertz, *Prinzipien der Mechanik*, S. 54; quoted by E. Cassirer, [1936]1956, Engl. Trans, 178.

[47] E. Cassirer, [1936] 1956, Engl. Trans, 130.

[48] H. Weil, *Was ist Materie?*, S. 17; quoted by E. Cassirer, [1936] 1956, Engl. Trans., 131.

[49] E. Cassirer, [1936] 1956, Engl. Trans., 131; similar ideas can be found in E. Cassirer, [1936] 1956, Engl. Trans, 178 and E. Cassirer, [1929] 1957, Engl. Trans, 465.

[50] E. Cassirer, [1936] 1956, Engl. Trans, 178 ; and E. Cassirer, [1929] 1957, Engl. Trans., 474–75.

its relation to the field[51]. Physicists know, together with Faraday, that the concept of ‘lines of force’ has replaced and pushed aside the concept of the persisting thing on which classical mechanics was constructed[52]. Thus, the concept of mass, particularly according to the results of the theory of general relativity, “no longer appears as a self-sufficient entity but merges into the concept of electric charge.”[53] It is the concept of law that constitutes the true nucleus of the object[54].

Henceforth, matter no longer is, as a physical entity, opposed to the field; but it is reduced to the field and becomes a product of the field[55]. Consequently, the way or method of defining a physical object “by mode of ‘indication,’ a το δε τι, however subtle, is precluded from the very first.”[56] This form of demonstration becomes untenable. We can continue to speak of an individual object, but this object is not established as a substantial background for relations but only as the expression and aggregate of these relations.

Before the theory of relativity, physics always admitted tacitly that the indication of time had an absolute value; that is, it was independent of the state of motion of the reference body. It is true that Special Relativity does not overcome the dualism between space-time and physical events and cannot allow us to decide in favor of substantialism or not. Nevertheless, Einstein established the relativity of simultaneity: every reference body has its own time; an indication of time has sense only if we indicate the reference body to which it relates. Einstein recognized the equivalence between inertial systems. He submitted the presuppositions which are the base of our measurements of space and of time to critical examination, and rejected the hypothesis of absolute ether. For him, the privilege of immobility granted by Lorentz to the ether with regard to all other inertial systems is not empirically acceptable. In his Leyden lecture “Ether and the Theory of Relativity”, as Cassirer cites, Einstein declared that the general theory of

[51] E. Cassirer, [1929] 1957, Engl. Trans., 475.

[52] E. Cassirer, [1936] 1956, Engl. Trans, 178; E. Cassirer, [1921] 1953, Engl. Trans., 396–397; and E. Cassirer, [1929] 1957, Engl. Trans., 466.

[53] H. Weil, *Was ist Materie?*, S. 41; quoted by E. Cassirer, [1936] 1956, Engl. Trans., 131.

[54] E. Cassirer, [1929] 1957, Engl. Trans., 476.

[55] H. Weyl, *Raum, Zeit, Materie,* 4th ed., S. 181; quoted by E. Cassirer, [1929] 1957, Engl. Trans., 466.

[56] E. Cassirer, [1929] 1957, Engl. Trans, 465.

relativity has to "cease to attribute any definite state of motion to the ether, since the ether may be said to be at rest in any system, however moved."[57]

With General Relativity, the electromagnetic field must not be conceived of as being of a material support. This theory arrives at the sublimation of the concepts of space and of time in the form of a continuum with a metric structure. Here, Cassirer is in complete agreement with Einstein. In his speech to *the International Congress of Surgeons* in Cleveland (Ohio) in 1950, Einstein criticized the tendency of physicists to naively look "upon the objects in space as directly given by our sense perceptions."[58] For him, the introduction of immutable mass points "represented a step in the direction of a more sophisticated realism. For it was obvious from the beginning that the introduction of these atomistic elements was not induced by direct observation. With Faraday-Maxwell's theory of the electromagnetic field, a further refinement of the realistic conception was unavoidable"[59]. Field becomes an irreducible element of the physical description; that is, the same irreducible reality has to be ascribed to the electromagnetic field as it had formerly been attributed to perceptible matter; but sense experiences certainly do not lead inevitably to the field concept. "There was a trend to represent physical reality entirely by the continuous field, without introducing mass points as independent entities into the theory. […] There exists a physical reality independent of substantiation and perception."[60] The physical reality can be completely grasped by "a theoretical construction whose justification, however, lies in its empirical confirmation. The laws of nature are mathematical laws connecting the mathematically describable elements of this construction. They imply complete reality in the sense mentioned before."[61]

Cassirer shows that the *field* concept becomes a new mediating concept between matter and empty space[62]. General Relativity cancelled dualism between space and time which characterized all the previous physical theories.[63] It is based upon an entirely new comprehension of the propagation of electromagnetic effects in empty space. These electromagnetic

[57] E. Cassirer, [1929] 1957, Engl. Trans, 467.
[58] A. Einstein, "Physics, philosophy, and Scientific Progress", [1950] 2005, 46.
[59] A. Einstein, "Physics, philosophy, and Scientific Progress", [1950] 2005, 46.
[60] A. Einstein, "Physics, philosophy, and Scientific Progress", [1950] 2005, 46.
[61] A. Einstein, "Physics, philosophy, and Scientific Progress", [1950] 2005, 46–7.
[62] *Cf.* E. Cassirer, [1921] 1953, Engl. Trans., 396.
[63] *Cf.* E. Cassirer, [1921] 1953, Engl. Trans., 394–397.

effects are not transmitted through a medium. They do not take place through immediate action at a distance. But the electromagnetic field in empty space is a thing possessing self-existent physical reality independently of all substance: "the 'independent physical reality' of the electromagnetic field can mean nothing but the reality of the relations holding within it which are expressed in the equations of Maxwell and Hertz. Since they are for us the ultimate attainable object of physical knowledge, they are set up as the ultimate attainable reality for us."[64] Thus, "physics, instead of imagining some sort of hypothetical substratum of phenomena and losing itself in consideration of the nature of this substratum, is satisfied, as it becomes a pure 'state of motion,' with the body of field-equations themselves and their experimentally verifiable validity."[65]

In this context, space-time continuum has in a sense taken over the role of substance[66]. Cassirer explains that "the ten functions $g_{\mu\nu}$, which occur in the determination of the linear elements of the general theory of relativity $ds^2 = \overset{4}{\underset{1}{\Sigma}} g_{\mu\nu} d_{x\mu} d_{x\upsilon} (\mu, \nu = 1,2,3,4)$, represent also the ten components of the gravitation potential of Einstein's theory. It is thus the same determinations, which, on the one hand, designate and express the metrical properties of the four-dimensional space and, on the other hand, the physical properties of the field of gravitation."[67] And the spatio-temporal variability of those magnitudes $g_{\mu\nu}$ and the occurrence of such *a field* are equivalent assumptions which differ only in their expression. In this respect, the new physical view no longer proceeds from the assumption that space, matter and force are separate entities. There is only the unity of *certain relations* differently designated according to the reference system in which these fundamental concepts are expressed. Cassirer cites Weyl to underscore that "the 'metric field' provides a unitary and supreme concept which links together the

[64] E. Cassirer, [1921] 1953, Engl. Trans., 406. It is important to know that nowhere does the notion of ether intervene in the equations of Maxwell, which refer to electric and magnetic fields, to charges, to currents, etc. Thus, we are free to postulate the reality of field instead of taking some ether as material support of the electromagnetic vibrations: "nothing in the equations of Maxwell imposes us an ontology of ether, no more than the equations of classical mechanics as such implied the existence of absolute space, contrary to what Newton thought." (Cf. M. Ghins, *L'inertie et l'espace-temps absolu de Newton à Einstein*, p. 108).

[65] Cassirer, [1921] 1953, Engl. Trans., 405.

[66] *Cf.* E. Cassirer, [1936] 1956, Engl. Trans, 131.

[67] E. Cassirer, [1921] 1953, Engl. Trans., 397–98.

special viewpoints of space, time, and matter in an entirely new way. The world is defined with systematic unity as a (3+1) dimensional metric manifold; all physical field phenomena are expressions of world metrics.[68]

2.3. The reformulation of the physical concept of object

2.3.1. Cassirer's approach is not Kantian

According to Cassirer, Kant saved knowledge from the dogmatism that teaches us nothing and from the peril of skeptical disintegration that does not even promise anything. But Cassirer shows that this Kantian salvation and liberation "proved to be possible only through a shift in the aim of knowledge."[69] Instead of a static relation between knowledge and object established by Kant, as might be designated by the geometrical notion of congruence between the two, Cassirer opts for a dynamic relation between them.

It is true that the object of science cannot – for Kant – be immediately grasped. To apprehend this object is only possible through certain mediation that constitute functions and judgments. The reality of the theoretical knowledge does not appear as a datum or as a finished product that the nature of things would impose on us in a particular way. Rather it denotes the result of an activity, independent of any arbitrary power, which entirely conforms to the a priori laws or rules of the understanding. By emphasizing this process of the construction of the object, Cassirer thinks that Kant instigated a revolution in the method which, in spite of its weaknesses, has had a major importance in epistemology: the object is not taken as if it were immediately known to us, but only the laws of knowledge are really accessible to us, and contain from the beginning some guarantee.

Cassirer reminds us that Kant rejected the naïve point of view of the truth of knowledge. This latter was explained by the fact that in knowledge the essence of things was correctly and adequately copied. Kant produced a revolution, which he himself compared to the work of Copernicus, consisting "in the fact that he does not begin with any dogmatic description of being in order to determine on this basis the concept and nature of knowl-

[68] H. Weyl, *Raum, Zeit, Materie,* secs. 12, S. 35; quoted by E. Cassirer, [1929] 1957, Engl. Trans., 472; and E. Cassirer, [1921] 1953, Engl. Trans., 398.
[69] E. Cassirer, [1929] 1957, Engl. Trans., 4.

edge but rather, starts with an inquiry into knowledge in order that in the end he may advance to being, to firmly grounded propositions about the reality of things."[70]

Thus, the key to the problem of knowledge lies for Kant in the fact that knowledge has not to be regulated by things, but that things as empirical objects must be regulated by the fundamental condition of the faculty of knowledge, because as objects of experience (as phenomena) they can be offered to us as only in the form of experience and on its a priori basic functions. It is obvious that the spontaneity of the pure understanding, the free lawmaking power of the theoretical faculty, represents a condition for every judgment concerning the being of objects, a condition for objective truth. Kant declared that "we can know of things a priori what we ourselves put into them: "daß wir nämlich von den Dingen nur das a priori erkennen, was wir selbst in sie legen."[71] An order has to be found in nature, in the appearances of space and time; for these appearances in order to be known by us have to assume the form of knowledge, i.e. "must be determined in accordance with the general and necessary rules of perception and pure thought."[72]

But the problem with Kant's thinking is that he does not leave this sphere of perception and immediate experience to which he only seeks how to apply the categories of the understanding. Cassirer no longer follows Kant's way. He is convinced that Kant does not examine the problem of the dynamism of this reality, and the scientific tools or means as such of grasping it. What constitutes the definitive purpose and the product of Kant's critical doctrine, as Cassirer underscores, is the reduction of the *given* in the pure functions of knowledge.[73] The object presented by Kant's transcendental system is determined, as correlative to the synthetic unit of the understanding, only in a purely logical way. The specificity of Cassirer's thought is to have exactly considered this dynamism[74] as one of the core issues of all its work.

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[70] E. Cassirer, *Kant* [1932] 2004, 444.

[71] I. Kant, *Kritik der reinen Vernunft* (Werke, Bd. III, hrsg. v. Albert Görland), S. 19 (BXVIII); quoted by Ernst Cassirer, *Kant* [1932] 2004, 444.

[72] E. Cassirer, *Kant* [1932] 2004, 444.

[73] *Cf.* E. Cassirer, [1907 (1911)] 1991, *Das Erkenntnisproblem.* II, S. 762.

[74] I discuss this question in the third essay, by showing that Cassirer's theory of scientific experiment clearly constitutes the point of his departure from Kant's transcendental system.

According to Cassirer, the knowledge of objects in physics consists in nothing save knowledge of objective relations.[75] Kant declared that "'whatever we know of matter is purely relations,' that it is a *substantia phaenomenon* and thus an aggregate of relations."[76] It is true that this Kantian principle was, for Cassirer, by no means overthrown but rather strengthened by modern physics. But, what is important for him is not the concept of *substance* but only this idea of the aggregate of permanent relations by which a scientific object is established. And permanence is of a mathematical nature, that is; the empirical manifold is expressed by a mathematical manifold, which issues from certain fundamental elements according to rules held as unchangeable. The general theory of relativity has, for instance, "shifted these 'independent and permanent relations' to another place by breaking up both the concept of matter of classical mechanics and the concept of ether of electrodynamics; but it has not contested them as such, but has rather most explicitly affirmed them in its *own invariants*, which are independent of every change in the system of reference."[77] Thus, the theory of relativity criticizes the physical concepts of objects by springing from the same method of scientific thought, which led to the establishment of these concepts, and only carries this method a step further by freeing it still more from the presuppositions of the naively sensuous and 'substantialistic' view of the world.

Krois refers to the following Kant' text: "the substratum of all that is real, that is, of all that belongs to the existence of things, is *substance*; and all that belongs to existence can be thought only as a determination of substance."[78] He points out that the notion of substance expresses that to which all predicates are ascribed. For Kant this category, namely *substantia et accidens,* characterizes the nature of the object of cognition. Cassirer

[75] *Cf.* E. Cassirer, [1921] 1953, Engl. Trans., 386.

[76] E. Cassirer, [1937] 1956, Engl. Trans, 183 [I. Kant, *Kritik der reinen Vernunft* (cited from Ed. 2, [1787]) S. 341; cf. Müller's Trans., p. 232]; E. Cassirer, [1921] 1953, Engl. Trans., 386; E. Cassirer, [1910] 1953, Engl. Trans., 261; and E. Cassirer, [1950English first edition] 1957/1991 *Das Erkenntnisproblem.* IV, 108: „Daß der gegenstand der Physik nichts Absolutes sei, sondern ganz und gar ‚aus den Verhältnissen bestehe', war keine neue Einsicht. Die „Kritik der reinen Vernunft" hatte diesen Satz immer wieder und mit dem stärksten Nachdruck eingeschärft".

[77] E. Cassirer, [1921] 1953, Engl. Trans., 386.

[78] I. Kant, *Critique of Pure Reason,* 213, B 225; quoted by J. M. Krois, 1987, 115.

clarifies that Kant regards the concept of reality to "be interchangeable with that of '*complete determination,*' '*durchgängige Bestimmung.*"[79]

Kant declared that nature is "the existence of things; in so far as it is determined in accordance with universal laws."[80] For Cassirer, the construing of the concept of nature follows for Kant from his conception and definition of the understanding. This latter is for him the faculty of rules; and the empirical rules of nature are only particular instances and applications of the a priori rules of the understanding.[81] Cassirer cites this passage from Kant: "We must […] distinguish empirical laws of nature, which always presuppose particular perceptions, from the pure or universal laws of nature, which, without being based on particular perceptions, merely contain the conditions of their necessary union in experience; and in respect of these universal laws nature and possible experience are one and the same […] the understanding does not derive its laws (a priori) from nature, but prescribes them to nature."[82]

Such an absolute ruling and legislative understanding cannot be found in Cassirer's approach to physical knowledge. Cassirer and Goethe do not think, like Kant, in terms of mere relations. They see in Kant the culmination of an abstract theoretical reflection[83]; and Kant did not really leave a rigid and substantialist way of thinking: "The armor of the 'rigid way of thinking,' which in Goethe's words had quite befogged the century, Kant penetrated at two points. He accepted the Newtonian theory of nature and its explanation of phenomena in terms of forces acting at a distance. But he wanted not only to describe the being of matter, he wanted to understand its genesis. And so he was one of the first to offer a theory of the evolution of the material world from the original nebulae to its present form. He was the author of the theory we today call the Kant-Laplacian hypothesis."[84] Cassirer particularly begins by immersing himself in the fullness and fruitfulness of physical measurements, in the word of physical facts.

[79] E. Cassirer, [1936] 1956, Engl. Trans., 189; cf. I. Kant, *Critique of Pure Reason,* 488; A571/B599; quoted by J. M. Krois, 1987, 115.

[80] I. Kant, *Prolegomena* (§ 14), p. 44; quoted by E. Cassirer, "Goethe and the Kantian Philosophy", 570.

[81] *Cf.* E. Cassirer, "Goethe and the Kantian Philosophy" [1941–1946] 2007, 569.

[82] E. Cassirer, "Goethe and the Kantian Philosophy" [1941–1946] 2007, 570.

[83] *Cf.* E. Cassirer, "Goethe and the Kantian Philosophy" [1941–1946] 2007, 559.

[84] E. Cassirer, "Goethe and the Kantian Philosophy" [1941–1946] 2007, 551.

2.3.2. The relative determination of physical knowledge and the epistemological primacy of law over object

Cassirer upholds here that the constitution of a physical object or entity depends on the choice of a theoretical perspective and that of the conditions under which observation takes place.[85] He acknowledged that physics and epistemology cannot in principle continue to establish an object with the complete realization which "contradicts the conditions of physical knowledge."[86] Thus, it is always necessary to recognize, in what physics presents to us as its objects and *things*, "the specific logical conditions on the ground[s] of which they were established."[87] The scientific object is first "determined by some standpoint of knowledge."[88] The universal functions of rational and empirical knowledge constitute a system of conditions, relative to which the assertions concerning the object gain an intelligible meaning.

The concepts of physics, such as those of position, speed, or mass of an individual electron have to be filled with defined empirical contents; otherwise they have to be excluded from the theoretical system of physics, although their function may have been important and efficient. These concepts are nothing other than predicates of possible judgments; and only experiment can determine, according to Cassirer, the truth value and objective contents of these judgments. Nevertheless, physical concepts such as atoms or electrons completely share the logical character of geometrical concepts: basically they can only be defined implicitly. The concepts of 'point', 'curve', 'straight line' have no definite existence or no defined meaning attributed independently of their mutual relations. "All these structures," insists Cassirer, "do not exist in order, subsequently, to enter into certain relationships; rather it is these relations themselves which determine and completely exhaust the being expressed in mathematical concepts."[89]

Thus, modern physics does not start by positing definite realities, which are subsequently brought into relation with each other, but rather by establishing "certain symbols expressing the *state and the dynamic vari-*

[85] *Cf.* E. Cassirer, [1936] 1956, Engl. Trans., 179, 191
[86] E. Cassirer, [1936] 1956, Engl. Trans, 195.
[87] E. Cassirer, [1921] 1953, Engl. Trans., 356.
[88] E. Cassirer, [1921] 1953, Engl. Trans., 356.
[89] E. Cassirer, [1936] 1956, Engl. Trans, 195.

ables of a physical system. From these, on the basis of definite axiomatic presuppositions, other equations are derived, and physical consequences drawn from them."[90] And only "things and attributes are examined which satisfy the rules valid for the interrelationship of the symbols."[91] The difference between the mathematical and physical concepts consists only in the way they are constituted: "mathematical concepts can be obtained by construction; we 'create' these concepts by means of the conditions which we impose on them, by means of the systems of axioms which they have to satisfy. In physics the place of these logical axioms is taken by the hypothetical formulation of the basic concepts, and by hypothetical deductions."[92]

2.3.2.1. About the theory of general relativity

Cassirer sees, in principle, no difference between the material point and the ideal mathematical point. To such a point, as space-time, "no being in itself can be ascribed; it is constituted by a definite aggregate of relations, and consists in this aggregate."[93] In the context of the theory of space-time, the metric tensor or the general concept of the linear element *ds* is, according to Cassirer, the a priori invariant as the condition of physical knowledge.[94] This invariant is expressed in the equation:

$$ds^2 = \sum_1^4 g_{\mu\upsilon} dx_\mu dx_\upsilon \, (\mu,\upsilon = 1,2,3,4) \, .$$

When Einstein declares that "*physical objectivity is denied to space and time*"[95] by the theory of general relativity, it has to mean, maintains Cassirer, "something else and something deeper than the knowledge that the two are not things in the sense of 'naïve realism.'[96] General relativity remained attached, as to the ultimate datum, to the various relations of measurement within the physical manifold, within that inseparable correlation of space, time, and the physically real object. These relations of

[90] E. Cassirer, [1936] 1956, Engl. Trans, 195.
[91] E. Cassirer, [1936] 1956, Engl. Trans, 195.
[92] E. Cassirer, [1936] 1956, Engl. Trans, 196.
[93] E. Cassirer, [1936] 1956, Engl. Trans, 195.
[94] *Cf.* E. Cassirer, [1921] 1953, Engl. Trans, 433, 418.
[95] E. Cassirer, [1921] 1953, Engl. Trans., 412, 432,
[96] *Cf.* E. Cassirer, [1921] 1953, Engl. Trans., 357.

measurement are expressed in the language of non-Euclidean geometry. And the reality which alone this language "can express is not that of things, but that of laws and relations."[97]

Cassirer is one of the founders of structuralism who shared an appreciation of the importance of group theory in the ontology of physics. He established that the possibility of speaking about objects in a context is the possibility of individuating invariants.[98] He cites Paul Dirac to underscore that the formulation of scientific laws requires the use of the mathematics of transformations. The more significant things "in the world appear as the invariants of these transformations. The growth of the use of transformation theory, as applied first to relativity and later to the quantum theory, is the essence of the new method in theoretical physics."[99]

Considering General Relativity, the objective determinations are indifferent to every change in the system of reference taken as a basis. Object possesses the form of laws of nature, "whose form is independent of the particularity of our empirical measurements of the special choice of the four variables x_1, x_2, x_3, x_4, which express the space and time parameters."[100] Thus, the empirical object of physics denotes a structure of the invariant functional relations and has become the concept of what remains invariant under such arbitrary transformation; it "means nothing but a totality of relations according to law."[101] Thus, this object is not so much a sign of something objective as but rather an objective sign that satisfies certain conceptual conditions and demands.

[97] E. Cassirer, [1921] 1953, Engl. Trans., 432.

[98] Cassirer treats the question of invariance in several of his publications (1910, 1929, 1944, etc.). On this subject, Max Born asserts that "Invariants are the concepts of which science speaks in the same way as ordinary language speaks of 'things', and which it provides with names as if they were ordinary things. […] The feature which suggests reality is always some kind of invariance of a structure independent of the aspect, the projection" (*cf.* M. Born, "Physical Reality," *Philosophical Quarterly,* 3, 1953, 149). Born goes on to state: "I think the idea of invariant is the clue to a relational concept of reality, not only in physics but in every aspect of the world." (*cf.* M. Born, 1953, 144). Eddington also affirms that: "What sort of thing is it that I know? The answer is *structure*. To be quite precise it is structure of the kind defined and investigated in the mathematical theory of groups" (A. S. Eddington, "Lorentz-Invariance in Quantum Theory," *Proceedings of the Cambridge Philosophical* Society 35, 1939, 147).

[99] P.A.M. Dirac, 1930, v; quoted by E. Cassirer, [1936] 1956, Engl. Trans, 138.

[100] E. Cassirer, [1921] 1953, Engl. Trans., 383–384.

[101] E. Cassirer, [1921] 1953, Engl. Trans., 385 ; E. Cassirer, [1910] 1953, Engl. Trans., 305.

Cassirer thinks that the theory of general relativity “abandons the attempt to characterize the ‘object’ of physics by any sort of pictorial properties, such as can be revealed in presentation, and characterizes it exclusively by the unity of the laws of nature.”[102] The objects of physics are the result of *a logical work, in which we progressively transform experience* according to the theoretical demands;[103] that is, a kind of transcendence is ascribed to them, because they differ from the flowing and changing objects of perception. A physical object marks “the logical possession of knowledge, and not a dark beyond forever removed from knowledge. The ‘thing’ is thus no longer something unknown, lying before us as bare material, but is an expression of the form and manner of conceiving.”[104]

According to Cassirer, the critical concept of object requires nothing more: object is no absolute model and does not correspond, as copies, to our sensuous presentations. But it is a concept by which presentations acquire *synthetic unity*. That is exactly, as Cassirer insists, what the theory of relativity shows: it no longer represents this concept “in the form of a picture but as a physical theory, in the form of equations and systems of equations, which are covariant with reference to arbitrary substitutions.”[105] Thus, a *relativization* of a purely logical and mathematical nature is accomplished; by which “the object of physics is indeed determined as the ‘object in the phenomenal world;’ but this phenomenal world no longer possesses any subjective arbitrariness and contingency. For the ideality of the forms and conditions of knowledge, on which physics rests as a science, both assures and grounds the empirical reality of all that is established by it as a ‘fact’ and in the name of objective validity”[106]. General covariance is indeed the one of these *ideal forms and conditions*, a *norm*, a *methodological maxim* or *regulative principle* for the intellectual treatment of nature.[107]

Cassirer clarifies that this ideality does not deal with subjective presentation. It merely denotes the objective validity of certain conditions or axioms and norms of scientific knowledge. These latter determine the truth, the invariant and relative characteristics of the object. He specifies that “this

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[102] E. Cassirer, [1921] 1953, Engl. Trans., 393.

[103] Cf. E. Cassirer, [1910] 1953, Engl. Trans., 299.

[104] E. Cassirer, [1910] 1953, Engl. Trans., 303 ; and E. Cassirer, [1936] 1956, Engl. Trans, 137.

[105] E. Cassirer, [1921] 1953, Engl. Trans., 393.

[106] E. Cassirer, [1921] 1953, Engl. Trans., 393.

[107] *Cf.* E. Cassirer, “*Ziele und Wege der Wirklichkeitserkenntnis,*” [1936–37] Bd. 2. 1999, S. 118; T. Ryckman, 2005, 44–5.

relativity obviously does not mean physical dependency on particular thinking subjects, but logical dependency on the content of certain universal principles of all knowledge."[108]

Defending Cassirer's interpretation of General Relativity, Ryckman thinks that the general covariance is "the most thoroughgoing refinement yet of the *normative* methodological principle of 'unity of determination'. […] the significance of general covariance as the regulative idea of a 'radical elimination' from physical description of the 'anthropomorphic slag' contributed by the senses and intuition."[109] Ryckman's conviction is that Cassirer grasped what is arguably the most philosophically significant aspect of general relativity, namely "the principle of general covariance, as a 'regulative principle' and constituent part of an ideal of physical objectivity from which all traces of 'anthropomorphic' subjectivity have been removed."[110] This requirement clearly means that dynamical laws must be formulated without a *background* space and time. The scientific object is completely expressed by pure measure relations (*reine Maßbeziehungen*) of a fully relational dynamics.[111] It is true that Cassirer confused the principle of general covariance and that of principle of general relativity, corrected by Erich Kretschmann[112]. The important fact here is that Cassirer recognized the statement that "the universal laws of nature are not changed in form by arbitrary changes of the space-time variables"[113] not only as an analytic assertion, which explains what a universal law of nature means, but in addition, due to the fact that in general there exist such ultimate invariants,

[108] E. Cassirer, [1910] 1953, Engl. Trans., 298.

[109] Cf. T. Ryckman, *The Reign of Relativity...*, 2005, 45–6.

[110] T. Ryckman, 2005, 7.

[111] Cf. E. Cassirer, [1921] 1953, Engl. Trans., 420–21. Cassirer's emphasis here cannot be defended in a Kantian way. This point, it seems to me, renders Ryckman 's interpretation a little problematic.

[112] Cassirer remained in this confusion, because he failed to take proper account of the evolution of Einstein's thinking on the principle of general covariance. H. Brown clarifies Einstein's position concerning the principle of general covariance. By the time Einstein addressed Kretschmann's famous challenge regarding the principle of general covariance in 1918, his thinking had changed (cf. H. Brown, 2005, p. 178–181). Thomas Ryckman also indicates Einstein's error (confusion) concerning this principle and also mentions that Einstein's belief that the principle of general covariance expressed the relativity of all motions was erroneous (cf. T. Ryckman, *The Reign of Relativity...*, 2005, 17, 18). See also M. Friedman, 1983, 212 ; M. Ghins, 1990, p. 135 ; M. Ghins and T. Budden, 2001, 33–51.

[113] E. Cassirer, [1921] 1953, Engl. Trans., 384.

that this statement is also a synthetic requirement. Here, Cassirer explicitly recognizes Einstein's point of view that the principle of general covariance is not physically empty but "has 'considerable heuristic force' in the construction of physical theories"[114].

Furthermore Ryckman emphasizes that "the fundamental intent of general covariance is to forbid any principled separation of the metrical and underlying topological structure of space-time itself"[115] Ryckman adds that obviously in locating the physically real in point-coincidences, Einstein gave rhetorical force to the fact that, in general relativity unlike special relativity, space-time coordinate is deprived of chronogeometrical-meaning. This is the reason why Cassirer points out the following: "That the equations governing larger or smaller fields are to be regarded as what is truly permanent and substantial, since they make possible the gaining of a stable picture of the world, that they thus constitute the kernel of physical objectivity: this is the fundamental view in which the two theories combine."[116] Therefore, Ryckman concludes that "Such a conception of general covariance as an 'idea of reason' constraining fundamental physical theory is no longer constitutively *a priori* in Kant's sense. That *regulative* ideals can play a heuristic but still *constitutive* role in physical cognition is then not Kantian orthodoxy."[117]

2.3.2.2. About quantum theory

According to the substantialistic conception, there is in physics a definitely determined entity, which possesses certain properties or attributes and enters, with other entities, into definite relations expressible by laws of nature. But Cassirer defends the functional viewpoint, which stipulates that this "entity constitutes no longer the self-evident starting point but the final goal and end of the considerations: the *terminus a quo* has become a *terminus ad quem*."[118]

Thus, Cassirer thinks that "the entities of physics, its empirical objects, are of course never completely given, because they are never completely determined; but on the other hand they no longer threaten us as a mysterious

[114] T. Ryckman, 2005, 15.
[115] T. Ryckman, 2005, 19.
[116] E. Cassirer, [1921], 1953, Engl. Trans., 427.
[117] T. Ryckman, 2005, 46.
[118] E. Cassirer, [1936] 1956, Engl. Trans., 131.

impenetrable absolute to whose last roots we cannot reach."[119] In quantum theory, for instance, the atom invariably no longer constitutes a mere entity but a most complex system of forces. Physics first establishes certain basic presuppositions necessary for the relative equilibrium of this system in order to grasp it as a stable whole. These assumptions do not rest upon "the rigidity or the absolute hardness of the atom but are derived by presupposing the quantum postulate."[120]

For Cassirer, one of the essential results of physics developments consists in the reversal, in a sense, of the relationship between the concepts of object and law: "the concept of law is now regarded as prior to that of object, whereas it used to be subordinate to it."[121] The new fundamental conception in physics puts the concept of law ahead of the concept of thing or substance[122]; what a thing or an object is can only be described by referring to the laws governing it. Here, Cassirer agrees with Schrödinger to claim that "no physical reality exists for us except the one that is mediated to us by physical measurements and by the determination of laws based on them, which are objective because of this relation."[123] He thinks as Howard Stein that "science comes closest to comprehending 'the real', not in its account of 'substances' and their kinds, but in its account of the 'Forms' which

[119] E. Cassirer, [1936] 1956, Engl. Trans., 132.
[120] E. Cassirer, [1936] 1956, Engl. Trans, 133.
[121] E. Cassirer, [1936] 1956, Engl. Trans., 131.
[122] In *Cassirer. Symbolic Forms and History*, Krois shows that Cassirer considers Schlick's work (*Allgemeine Erkenntnislehre* 1918*: General theory of knowledge*) as the vindication of a thesis that he had to develop and prove nearly two decades ago in his book *Substance and Function*; namely that: the concept of law replaces the concept of substance in modern physics (E. Cassirer, "Erkenntnistheorie nebst den Grenzfragen der Logik und der Denkpsychologie," 1927, 75). He adds that "Schlick uses the same conceptual means to make this point, emphasizing, as Cassirer did, the conceptual role in science of implicit definitions" (cf. J. M. Krois, 1987, 117, 118). I find that Schick also develops this question in his paper entitled "The Philosophical Significance of Relativity". He declares that "the principle of relativity has yet another consequence of great philosophical importance. It concerns the *concept of substance*." The revision of this concept consists of rejecting the idea of substances as bearers of properties hidden behind things. "Once it has been recognized that the concept of substance is only a special form of the concept of law, and is reducible to the latter, this great truth can never again be lost to science" (cf. M. Schlick, "The philosophical significance of relativity" in *Philosophical Papers* Vol. 1 [1909–1922] Engl. Trans. By Peter Heath, London: 1979), 184, 185, 187.
[123] E. Cassirer, [1936] 1956, Engl. Trans, 135.

phenomena 'imitate' (for 'Forms' read 'theoretical structures', for 'imitate', 'are represented by')."[124]

For Cassirer, to claim that an electron, at a given time, is at a certain location, and that it has a sharply defined velocity, is only possible when we take account of the means of physical knowledge. This means that a status (*Bestand*) which exceeds what can be constituted or established by the means of physical knowledge cannot be claimed; since this function of positing only implies a logical basis[125]. The way we can talk about the individuality of single particles is possible only indirectly. They are not themselves given as individuals; but they are only "describable as 'points of intersection' of certain relations."[126] Cassirer illustrates this as following. When we consider de Broglie's wave theory of matter and Schrödinger's wave mechanics, it is obvious that "the concepts of proton and electron are maintained, but they are defined no longer as 'material points' in the sense of classical mechanics, but instead as centers of energy."[127] Electron is a definite object but it does not possess the individuation that could be designated by a simple *here* and *now*; that is, the electron position cannot be circumscribed within intuitive space. For "waves are not tied to a single spatiotemporal point; they enjoy a kind of omnipresence. Each extends through the entire space – which, however, is no longer to be considered as an empirical space but as a configurational space."[128]

That is why, according to Cassirer, "it became necessary to carry out a dual description for every phenomenon of radiation. The 'particle picture' had to be complemented with the 'wave picture,' and vice versa. The absolute significance of the former was thus sacrificed."[129] Nevertheless, the fact that the charge of electrons and protons remains constant by no means demands a substantialistic interpretation. For the constancy of a certain relation is not at all sufficient to support the inference of a constant carrier. The indivisibility of charge is just such a self-subsistent and permanent relation, which justifies our speaking of the electron as being a determinate object; but it is not sufficient for a substantialization and hypostasis of the electron. Accordingly Einstein holds, in relation to a unified field theory,

[124] H. Stein, 1989, 57.
[125] *Cf.* E. Cassirer, [1936] 1956, Engl. Trans, 179.
[126] E. Cassirer, [1936] 1956, Engl. Trans, 180.
[127] E. Cassirer, [1936] 1956, Engl. Trans, 180.
[128] E. Cassirer, [1936] 1956, Engl. Trans, 180–81.
[129] E. Cassirer, [1936] 1956, Engl. Trans, 182.

that the very notion of a particle does not exist in the strict sense of the word.[130]

This situation with which Cassirer deals is not far from Einstein's conviction that "what appears untenable to physicists of our time is not only the requirement of complete causality but also the postulate of a reality which is independent of *any measurement* or *observation*."[131] Einstein illustrates this idea by considering a beam of a certain color which strikes a reflecting and transparent plate. The beam will be decomposed into one transmitted and one reflected beam. A *single* photon is responsible for the ability of the two beams to interfere with each other, as well as for the absorption of light from one of the beams. It is evident that Maxell's theory cannot account for this complex of properties of the photon. It does not provide us with any means to understand the atomistic character of the absorbed energy of radiation. But if one tries to picture the photon as point-like structure moving in space, it must either be transmitted or reflected by the plate, since its energy is indivisible. One of the difficulties this interpretation leads to is that "the interpretation of the photon as a point-like structure does not admit of an explanation for the interference which is only produced if both parts of the beam interact."[132]

The face of an object depends on the conditions under which the observation takes place. The choice of measuring instruments and the particular use made of them determines the outcome of different pictures of the event. Both particle and wave pictures of the events cannot be revealed at one time by a single observation. Thus, Cassirer claims that the "answer given to us by nature is thus determined not only by nature itself but at the same time by the manner of questioning, and by the chosen instruments of observation. […] The abandonment of absolute determination restores the highest degree of relative determination of which physical knowledge is capable."[133] It is physically correct to continue here talking about objects or things in the sense of classical mechanics and of macroscopic experience, but they cannot be merely considered as rigid.

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[130] *Cf.* A. Einstein's Letter to Besso, 15 April 1950, in Speziali 1972, 438–39, as cited in Stachel 1992a, 25; see T. Ryckman, 2005, 23.

[131] A. Einstein, "Physics, philosophy, and Scientific Progress", 47.

[132] A. Einstein, "Physics, philosophy, and Scientific Progress", 47.

[133] E. Cassirer, [1936] 1956, Engl. Trans, 191.

3. Conclusion

Epistemology cannot keep itself immune from the developments that have occurred in modern physics. Cassirer sees this situation made evident in the reversal of the relationship between the concepts of law and object; that is, the concept of law is now regarded as prior to that of object, whereas it used to be subordinate to it. Cassirer is convinced that the new physics has not destroyed the bases on which physical knowledge rests; rather it has made them known more clearly than ever before, in their characteristic individuality and conditional nature.

Physical reality is only mediated to us by physical measurements and by the determination of laws based on them. We can continue to speak of individual objects as electrons, protons, etc., but these concepts are no longer merely rigid. The object is not established as a substantial background for relations but only as the expression and aggregate of these relations. The electron does not exist before the field but is first produced or constituted by its relation to the field.

I assert that Cassirer always wants to underscore what for him is epistemologically very significant; that is, what he calls 'the logical task' which characterizes not only the scientific investigation of Einstein's relativity and quantum mechanics but also the beginning of modern physics with Galileo and Newton. I think that this 'logical task' also concerns what remains as Kantian influence in Cassirer's philosophy of science; that is, in a scientific theory there is always an aspect which cannot be delivered merely from experience, but which nonetheless at the same time renders this latter comprehensible. I would try to express this a little more clearly. It is true that Cassirer aims at showing in a transcendental manner how physics elaborates some logical conditions in order to grasp its object. But Cassirer's way or approach of establishing and explaining this logical task cannot be Kantian in any way. Cassirer's enterprise is not that of a mere critic of pure reason. This logical task cannot be undertaken without interweaving it with scientific experiment. It is a symbolic task. Cassirer essentially begins to analyze the actual procedure of physics (the facts of physics), by integrating both inductive and deductive perspectives.

Cassirer's conception of space and time as structural dynamical categories

A survey of the historical dimension of physics

Keywords: category/*a priori*/relation/structure/order/relative/dynamical/invariant/plasticist

Abstract

Cassirer's approach to science essentially concerns the historical dimension of physics, whereby we can grasp for instance the dynamical change of space-time structure depending on its various theories. He defends a conception of the dynamism and flexibility of categories, as well as the principles of physics with regard to the dynamism of physical experiment. Each physical theory is associated with a definite group of transformations as expressed in geometry[134]. His conception waives the substantialist point of view about the nature of space-time and lies in the ideality of the space-time of Leibniz and in Felix Klein's group concept. No amorphous background reality or field can define the concepts of space and time. Their nature is fundamentally expressed in the concepts of order, of relation, and of field structure. They deal with invariant properties according to a specific group of transformations. For him, dynamism and transformation do not entail absence of invariance and permanence; rather, he always shows the dialectical connection between them.

I will argue that physical investigation is, according to Cassirer, marked by a sort of complex dynamism in the formation of physical objects. Thus, space and time are for him categories which intervene in the dynamical process by which the reality concept of physics is constituted. They are *a priori* elements but at the same time dynamical and relativised. Hence, this space-time conception of Cassirer is not at all Kantian.

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[134] Cassirer is not interested in the classical definition of geometry as a science of figures and magnitudes (as a science of triangles and squares, circles and conic sections, parallel lines and obtuse angles). He adopts Leibniz's *Analysis Situs* and Felix Klein's group theory. Geometry, for him, is essentially a science which studies the invariant properties of space itself.

1. Kant and Cassirer follow two different approaches

For Kant, space and time are conditions of the possibility that objects be given in sensation. They are *a priori* forms of sensibility; and these sensible (apprehensible/palpable) phenomena form only the field where they have some value, as conditions of the possibility by virtue of which objects are given to us. Beyond these limits they represent nothing more, because they exist only in the senses and have no reality beyond the senses. According to Kant, Cassirer reminds us, "space is the form of our 'outer experience,' time the form of our 'inner experience.' In the interpretation of his inner experience man had new problems to confront."[135] Strictly speaking, for Kant, the judgments concerning space and time are not constitutive of physical objects as such. They have nothing to do with the way phenomenal diversity is unified by means of the categories.

Kant considers sensible experience as deprived of universality and necessity, which are "*Lettres de noblesse* of categories."[136] Ghins clarified that the objects of perception are, for Kant, hylemorphic entities constituted of a phenomenal content, given in our sensibility, and a form, provided by our understanding. The physical object is the unified product of an empirical content and a form. A moving body, for instance, is an object of physical knowledge, which constitutes a product of the unifying application of a pure concept of the understanding to a phenomenal diversity received by us in space and time. Some principles of understanding (true and a priori: constitutive of physical objects) govern the possible application of pure concepts to phenomena. Newton's laws are special cases of the a priori principles of the understanding. Therefore, the Kantian approach establishes the primacy of the pure activity of understanding above all. The knowing subject is finally both the source and the actor of the constitution of objects. And space and time are thought of as related not to the scientific objects as such but only to the objects given in immediate experience.

The Kantian statement of the second postulate of empirical thought generally seems to underline well, according to Cassirer, the link with the world of direct experience or perception: "'whatever *coheres* with the

[135] E. Cassirer, 1944, 49.

[136] Ghins uses this expression in Ghins, M., Rynasiewicz, R. and Bas van Fraassen, "*Review of Thomas Ryckman, The Reign of Relativity. Philosophy in Physics 1915–1925*." With replies by Thomas Ryckman. *Metascience* 16, 2007, 397–407.

material conditions of experience (sensation)' […] 'is actual.'"[137] However, this coherence is, according to Cassirer, produced by the general laws of the understanding which determine its particularity and formal character. In this sense, all particular laws of nature are merely specifications of these laws of the understanding. Thus, Cassirer affirms that, according to Kant, both the object of empirical intuition and the object of the exact sciences are determined by the same purely intellectual synthesis[138]. In this case, the "categories on which the system of mathematical and physical cognition is founded are accordingly the same as those on which our concept of the natural world rests."[139]

It is true that for Kant experience is no aggregate of sense impressions but a system resting on objectively valid and necessary principles. This experience is possible only through the representation of a necessary connection or combination between perceptions.[140] But Kant did not go beyond this level of perceptions.[141] Scientific experience or experiment does not, according to Cassirer, only deal with mere relations.

For Cassirer, the faculties of sensibility and understanding are coordinated and are considered as the expression of a more fundamental unifying faculty of reason. The object of knowledge is not a product of the simple application of formal concepts to sensible experience; but it is an expression of the form and the mode of conceiving itself. Space and time are, as categories, logical invariants or functional relations, whereby reason constitutes the physical object. They are present in every object of experi-

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[137] E. Cassirer, [1929] 1957 Engl. Trans., 11.

[138] See also M. Friedman, *A Parting of the Ways: Carnap, Cassirer, and Heidegger*. Chicago, Open Court, 2000, 109 (*cf.* Cassirer, 1929, 535–36, 459) : "From Kant's original point of view, that of classical Newtonian physics, the theoretical and perceptual worlds fuse quite naturally together, and it is just this circumstance, in fact, that lies behind all the difficulties following from the original Kantian doctrine of pure sensibility."

[139] E. Cassirer, [1929] 1957, Engl. Trans., 1957, 11.

[140] *Cf.* E. Cassirer, [1929] 1957, Engl. Trans., 11; and E. Cassirer, "Goethe and the Kantian Philosophy", 569; Cassirer refers to I. Kant, *Kritik der reinen Vernunft,* 166 (B218);

[141] Cassirer reminds us, for instance, that Kant rightly insists that the *category* of causality has to be specified in a definite sense, in order to be usable and empirically applicable. However, Cassirer no longer seeks this specification in the same way that Kant did: "we cannot be satisfied with the mere reference of concepts to the purely sensuous schemata, to the 'perceptual forms of space and time'. For it is precisely these schemata which have lost their universal significance through the discovery of non-Euclidean geometry on the one hand, and the results of special and general relativity theories on the other." (*cf.* E. Cassirer, [1936] 1956, Engl. Trans., 166).

ence and are valid for all observers. No background space-time of metrical structure is a condition of possibility for the constitution of physical objects. Cassirer sees no possible separation between the purely mathematical and the purely empirical, but always underscores an intimate symbiosis between the two.[142]

The formation of physical knowledge has, according to Cassirer, an essential dynamism between several levels of statement: facts, laws, and principles, which expresses an organization in empirical knowledge. These levels always possess a mutual interconnection. In this organization "the statements of the results of measurements may indeed be designated as the *alpha* and *omega* of physics, its beginning and end. From them all its judgments take their departure and to them they must all lead back again."[143] Only through the mediation of the statements which result from *measurements* can the concepts and judgments of physics refer to an object and thus attain to objective significance and validity[144]. There is, for Cassirer, not only a dynamical process of the constitution of scientific objects within a particular physical theory; but also various theories express a sort of progress or dynamism about the structure of fundamental categories and the principles of physics.[145]

Cassirer refers to physical experiment as such, within which measurements have to be made. He accepts "Planck's neat formulation of the physical criterion of objectivity, that *everything that can be measured exits*"[146] Nevertheless, the process of measurement is more and more regarded by him as a logical and epistemic problem. It is the question of explaining strictly the underlying presuppositions to the act of measurement. Space and time are necessary premises in every valid judgment concerning facts. They are not measurable in themselves, but in relation to

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142 Michel Ghins sharply presents Cassirer's point of view in his review of 2005 Ryckman's book: Ghins, M., Rynasiewicz, R. and Bas van Fraassen, 2007, 397–407.

143 E. Cassirer, [1936] 1956, Engl. Trans., 36.

144 *Cf.* E. Cassirer, [1936] 1956, Engl. Trans., 36.

145 Kuhn acknowledges that not only was Cassirer's work "important for scientific development;" (*cf.* T. Kuhn, 1977, 108) but also "had a great and fructifying influence on the subsequent treatment of ideas in history."(T. Kuhn, 1977, 149). I do not develop here Cassirer's ideas on the history of the sciences. I presented this question in my publication of 2008 and I am working again on this question, in order to examine the last development of Cassirer's thought.

146 E. Cassirer, [1921] 1953, Engl. Trans., 357.

physical events: “Space and time are the framework in which all reality is concerned.”[147]

2. What are space and time?

2.1. Space-time: ideal concepts of relation and of order

For Cassirer, the concepts of relation and order represent the true nature of space and time: “relations or orders, not absolute existence or entities. Space is the ‘order of coexistence’; time the ‘order of successions’.”[148] Cassirer points out that “it is not Kant but Leibniz who was first to explain that space was a pure ‘form’.”[149] In this respect, “the world is not defined as an entity of bodies in space nor as an occurrence in time, but it is viewed as a ‘system of events’.”[150] The ideality of space and time determines their objectivity. Cassirer learns from Klein that this purely ideal unity, that is the systematic unity of space, unifying different geometries, by no means is given up, but is on the contrary established even more solidly than previously: “the general form of space, the form of ‘possible coexistences’ is used and presupposed by different geometries as a non-deductible fundamental concept.”[151]

It is true that Kant had denied absolute space of Newtonian physics. To the conception of space as a self-subsisting, absolute entity he opposed his own critical theory. For Kant, space is not thing; it is neither an empirical nor a metaphysical object. It is an *a priori* condition of all experience, a form of pure intuition. But Cassirer remarks that “even in this case it seemed to be obvious that such an *a priori* form must have a definite structure. If this structure – as Kant took for granted – is expressed in the axioms and postulates of Euclidean geometry – then this geometry is the

[147] E. Cassirer, 1944, 42.

[148] E. Cassirer, “Newton and Leibniz”, [1943] 2007, 154.

[149] E. Cassirer, *Erkenntnisproblem,* t. IV, 1957, 43: „Nicht erst Kant, sondern bereits Leibniz hat erklärt, daß der Raum eine reine ‘Form’sei. Er ist nach ihm die ‚Ordnungsform des Beisammen‘, wie die Zeit die ‚Ordnungsform des Nacheinander‘ ist.“ See also E. Cassirer, *Leibniz’ System in seinen wissenschaftlichen Grundlagen,* Marburg, 1902, 245.

[150] E. Cassirer, „Mythic, aesthetic and theoretical space”, [1931] 1969, Engl. Trans., 6–7.

[151] E. Cassirer, *Erkenntnisproblem,* t. IV, 1957, 59, 43: „Denn die allgemeine Raumform, die Form des ‘möglichen Beisammenseins’, wird von jeder Geometrie als ein unableitbarer Grundbegriff benutzt und voraussgesetzt.“

only one to which we can ascribe an objective reality. If there are many and different systems of geometry one of them must be true, the others must be false, or at least devoid of any empirical meaning – of any applicability to the problems of our empirical world."[152] After having studied Klein's *Erlanger Program,* which introduced the concept of group, Cassirer declared that he began to see "the problem in an entirely new light."[153] And the Kantian puzzle was thus solved.

Geometry is distinguished from topography and, from the point of view of its general concept as well as its universal task, represents a theory of invariants concerning a definite group; the particular nature of this geometry depends on the choice of these groups.[154] Cassirer is interested in the approach of Klein, who "limits himself strictly to the formal and analytical explanation of the problem and disregards any ontological considerations on the effective reality of space."[155] Geometry deals neither with things and the character of things nor with substances or the properties of these substances but rather with pure determinations of order. The observations of a spatial object or the observations relating to it do not possess, as such, the character of a geometrical statement: "only are called geometrical the invariant properties with regard to definite transformations."[156] Thus, the invariance is not opposed to transformation and dynamism. This permanence does not denote the duration of things or given objects and their properties, but is valid only relative to a certain intellectual operation, chosen as a system of reference.

Thus for Cassirer, the non-Euclidian geometries "reduced to nothingness the fundamental postulate of the *Criticism*, resting on the concept of *a priori* space. For the Criticism, the space has to be one."[157] The objection of the criticism is justified, in fact, and irrefutable if we are held in a substantialist

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[152] E. Cassirer, "The concept of group", [1944] 2010, 186.

[153] E. Cassirer, "The concept of group", [1944] 2010, 187.

[154] *Cf.* E. Cassirer, [1950 English first edition] 1957, *Erkenntnisproblem,* 38; E. Cassirer, "The concept of group", [1944] 2010, 192; E. Cassirer, [1910] 1953, Engl. Trans., 90, 249; E. Cassirer, [1929] 1957, Engl. Trans., 157.

[155] E. Cassirer, [1950 English first edition] 1957, *Erkenntnisproblem,* 36.

[156] E. Cassirer, [1950 English first edition] 1957, *Erkenntnisproblem,* 39.

[157] E. Cassirer, *Erkenntnisproblem,* t. IV, 1957, 42: „Den schwersten Anstoß für diese Kritik bildete der Umstand, daß hier ein fundamentales Postulat verletzt wurde, das a priori im Begriffe des Raumes selbst liege. Der Raum muß Einheit sein, während er durch die Anerkennung der Nicht-Euklidischen Geometrie in eine bunte Vielfalt verwandelt würde."

view (einer substantialistischen Ansicht) of space. Space seems to be something self-subsisting, which geometry must recognize and faithfully reproduce in its entirety. But when the various geometries provide different reproductions, when the one asserts that 'the measure of curvature' of space is equal to zero, other one that it is positive, the last one finally that it is negative, then the fact to determine the original image is lost forever. To try to determine this original image is, inevitably, a contradictory enterprise[158].

2.2. Space and time: *a priori* elements

For Cassirer, space and time are not *a priori forms* of sensibility but categories belonging to the invariant structure of scientific experiment as such. This latter represents a sphere of necessity and universality. The sensibility constitutes by no means a clause of the empirical characteristic of physics. He also speaks of space and time as "forms of *intuition*."[159] But he "treats 'pure intuition' functionally."[160] *A priori* does not mean either 'innate' or 'given'. Cassirer unifies space and time with the pure categories of the understanding. He never accepted the original Kantian distinction between the mental faculties of sensibility and understanding. On these grounds Cassirer reinterprets (from Leibniz and Klein, but not from Kant) "the doctrine of pure intuition in *conceptual terms* as belonging only to 'the order in general of coexistence and succession'."[161]

Moreover, Friedman clearly specifies that for Cassirer "space and time count as 'pure intuitions,' therefore, not because they are expressions of a distinctive non-discursive faculty of the mind, but simply because they are the very first products of constructive empirical thought."[162] That means that space and time are the first and fundamental orders in which the empirical

[158] For Cassirer, it is easy to show that these contradictions do not arise from geometrical conceptualization, but much rather from the erroneous positioning of the problem, which is imposed on geometry from the outside. Geometry is a pure 'doctrine of relation' [Die Geometrie ist eine reine 'Beziehungslehre']. (See E. Cassirer, *Erkenntnisproblem,* t. IV, 1957, 42).

[159] E. Cassirer, [1921] 1953 Engl. Trans., 417.

[160] J. M. Krois, *Cassirer: symbolic forms and history,* New Haven, Yale University Press, 1987, 120.

[161] T. Ryckman, 2005, *The Reign of Relativity: Philosophy in Physics 1915–1925*. Oxford, Oxford University Press, 7, 44; *cf.* E. Cassirer, [1921] 1953, Engl. Trans., 418.

[162] M. Friedman, 2000, 91; see Cassirer, [1907] 1922, 699.

content has to be grasped. Cassirer rejects, for example, the definition of time in relation to the form of the inner sense. Speaking of the absolute world of Minkowski, he claims that "the world of physics changes from a *process* in a three-dimensional world into a *being* in this four-dimensional world, in which time is replaced as a variable magnitude by the imaginary 'ray of light' (*Lichtweg*) $\left(x_4 = \sqrt{-1}ct\right)^2$(1). This transformation of the time-value into an imaginary numerical value seems to annihilate all the 'reality' and qualitative determinateness, which time possesses as the 'form of the inner sense,' as the form of immediate experience."[163]

Even Newton himself never defines space and time in relation to the inner sense or external experience: "Absolute, true, and mathematical time, of itself, and from its own nature, flows equally without relation to anything external. […] Absolute space, in its own nature, without relation to anything external, remains always similar and immovable."[164] For him, it is obvious that space and time are not intuitive. They are entities distinct from material bodies which by no means come under the observation of our senses; but their existence is necessary in Newton's eyes to situate the bodies so that their motions can be defined.[165] This means that Kant's analysis needs to be considered more restrictively.[166]

Klein defended intuition as a particular form of knowledge. However, this defense necessarily required, according to Cassirer, that we give up the traditional and excessively naive reference to intuition, and we replace it by a purified critical conception.[167] Here, there is absolutely no place for imagination. The group concept is manifestly characteristic of purely intellectual mathematics freed from any intuition[168], characteristic of a pure

[163] E. Cassirer, [1921] 1953, Engl. Trans., 449.

[164] I. Newton, *Principia,* ed. Cajon, Scholium following the Definitions I, II, and IV, 6–7; quoted in H. Weyl, [1927] 1949, *Philosophy of mathematics and natural science.* Trans. by Olaf Helmer. Princeton, Princeton University Press, 99.

[165] *Cf.* H. Brown, Physical Relativity. Space-time Structure from a Dynamical Perspective. New York – Oxford, Oxford University Press, 2005, 23.

[166] See also M. Friedman, *Reconsidering logical positivism.* New York, Camgridge: Cambridge University Press, 1999, 61.

[167] *Cf.* E. Cassirer, [1950 English first edition] 1957, *Erkenntnisproblem,* 32.

[168] Cassirer was fascinated by Klein's group theory and Hilbert's axiomatic. In accordance with Klein, he claims that there are "'postulates by means of which we raise ourselves above the imprecision or limited precision of intuition to an unlimited precision.' This character of postulates is not borrowed from intuition; rather, it forms an original determina-

doctrine of forms, in which the intellectual objects, the thought-things are placed in relation to each other.[169] Klein clarifies that intuition as such is insufficient, because it is something essentially indistinct. This indistinctness must be removed by an idealization which allows us to reach statements of absolute precision and universality.[170] The space of pure intuition is, according to Cassirer, always only ideal and formal, and physics deals with the relations of measurement of the empirical and the physical.[171]

The link with intuition is to be understood in the sense of what relates to the foundation of physical knowledge. Space, as *form of intuition* (a form given in the intuitive realm), denotes the general form of spatiality, the coexistence and externality of the particular elements, which "is no mediated result, but is a fundamental relation posited with the elements themselves. It cannot be asked how this form arises in and for itself; it can merely be enquired how the form is more closely determined and specialized in empirical knowledge."[172] But scientific knowledge never remains at this intuitive or foundational level. Cassirer's analysis rests upon Klein's group theory, highlighting the link between physics and intuition, in order to overcome the unfounded and obscure relationship established by Kant.

2.3. Space-time: categories of plasticity and flexibility

Proceeding from classical logic, Euclidean geometry and Newtonian mechanics, Kant fixed, according to Cassirer, the dynamism which

tion of thought, which is held up to intuition as norm." (*cf.* E. Cassirer, [1929] 1957 Engl. Trans., 428). Thus, physical theory reaches this confirmation, "this enrichment and fertilization of intuition, only because it does not confine itself a priori to intuition but learns to know and assert its own peculiar autarchy with ever increasing depth and purity." (*cf.* E. Cassirer, [1929] 1957 Engl. Trans., 464).

[169] *Cf.* E. Cassirer, [1950 English first edition] 1957, *Erkenntnisproblem,* 38.

[170] *Cf.* E. Cassirer, [1950 English first edition] 1957, *Erkenntnisproblem,* 43–44; *cf.* F. Klein, « Zur nicht-euklidischen Geometrie », in *Mathematische Annalen,* t. XXXVII, 1890 ; et *Gesammelte mathematische Abhandlungen,* 1921, t. I, p. 381, 386.

[171] For Cassirer these relations of measurement can only be gained on the basis of natural laws, whereas for Kant it is the rules of the understanding which alone give phenomena synthetic unity and enable them to be collected into a definite concept of experience. Cassirer clearly rejects the intuitive simplicity in this view of the world and this rejection guarantees its greater intellectual and systematic completeness (*Cf.* E. Cassirer, [1921] 1953, Engl. Trans., 439–40).

[172] E. Cassirer, [1910] 1953, Engl. Trans., 288.

represents the kernel of scientific investigation. Kant believed he could completely draw up the system of principles and that of categories[173]. For Cassirer, it obvious that nowadays this pure part could not fulfill the task that Kant set for it: "It was too closely bound to a specific form of science, which classical rationalism held to be the plainly rational form. Kant was certain that all rationality was enclosed within a definite area which was determined on the one side by the axioms of Euclidean geometry and on the other by those of Newtonian physics."[174] Cassirer underscores the dynamical and different sense of *a priori* connected with the historical dimension of the progress of science which is not featured in Kant's system of the philosophy of nature.

Cassirer thinks that Kant's analysis is concerned only with the pure possibility and not with the reality of physics as such, which rests upon physical measurements. In his *Metaphysische Anfangsgründe der Naturwissenschaft,* Kant tried, taking an *a priori* approach, to deduce and to construct the concept of matter as a necessary concept of physics. He was convinced that "he possessed in these deductions a philosophical grounding of the presuppositions of the science of Newton; today we recognize to an

[173] Einstein's general theory of relativity proves the usefulness of non-Euclidean geometries. Thus, the relationship established by Kant between mathematics and the science of nature clearly becomes very problematic. Kant places space and time, which are not thought of as scientific concepts as such, at the level of 'intuition'; and mathematics is, in this context, considered to be an already constituted science. The categories of understanding are definitively fixed and absolutely universal. They explain the sense in which Newton's mechanics represents a model of knowledge, true for humanity at all times and in all places.

[174] E. Cassirer, [1936] 1956, Engl. Trans., 74. Cassirer also shows Kant's limits in his *Einstein's Theory of Relativity*. For instance, he declares that "Kant believed that he possessed in Newton's fundamental work, in the *Philosophiae Naturalis Principia Mathematica*, a fixed code of physical 'truth' and believed that he could definitively ground philosophical knowledge on the '*factum*' of mathematical natural science as he here found it; but the relation between philosophy and exact science has since changed fundamentally. Ever more clearly, ever more compellingly do we realize today that the Archimedean point on which Kant supported himself and from which he undertook to raise the whole system of knowledge, as if by a lever, no longer offers an unconditionally fixed basis. […] The laws, which Newton and Euler regarded as the wholly assured and impregnable possession of physical knowledge, those laws in which they believed to be defined the concept of the corporeal world, of matter and motion, in short, of nature itself, appear to us today to be only abstractions by which, at most, we can master a certain region, a definitely limited part of being, and describe it theoretically in a first approximation." (cf. E. Cassirer, [1921] 1953, Engl. Trans., 352–53).

increasing extent that what he so regarded was in fact nothing but a philosophical circumlocution for precisely these presuppositions. As a fundamental definition of the physical concept of object, the classical system of mechanics is only one structure, by the side of which there are others."[175]

With the publication of his first and second volume of *Erkenntnisproblem* in 1906 and 1907, Cassirer sharply distanced himself from Kant. The most important fact is the dynamic conception of the categories connected to the idea he is going to develop of the history of science. He thinks that Kant did not recognize the historical dimension of the *fact* of science remaining a fact which develops historically. The categories still seem to remain, to Kant, the already constituted fundamental concepts of the understanding.[176] Cassirer essentially considers categories as conditions of comprehension (*Bedingungen des Verstehens*), having a necessary validity and possessing, inside the limits of the experiment and its objects, the unlimited truth (*uneingeschränkte Wahrheit*).[177] Categories depend upon the form and the dynamism of scientific experiment. They no longer have stability and represent the concepts by means of which thought organizes the chaos of the phenomena.[178]

When physics faces up to the new factual material and to the new theoretical tasks, physics always extends and transforms its *conceptual apparatus*. Its theoretical structure is "to be thought of not as rigid but as dynamic, that its significance and efficacy do not rest upon its substantial rigidity established once and for all but precisely upon its plasticity and flexibility."[179] Kant's analysis rests upon a static and rigid point of view, while that of Cassirer postulates the flexible and dynamical perspective. Cassirer

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[175] E. Cassirer, [1921] 1953, Engl. Trans., 394.

[176] See E. Cassirer, [1906 (1911)] 1991, *Das Erkenntnisproblem.* I, 18: „Denn das ‚Faktum' der Wissenschaft ist und bleibt freilich seiner Natur nach ein geschichtlich sich entwickelndes Faktum. Wenn bei Kant diese Einsicht noch nicht unzweideutig zutage tritt, wenn die Kategorien bei ihm noch als der Zahl und dem Inhalte nach fertige ‚Stammbegriffe des Verstandes' erscheinen können, so hat die moderne Fortbildung der kritischen und idealistischen Logik über diesen Punkt volle Klarheit geschaffen."

[177] *Cf.* E. Cassirer, [1907 (1911)] 1991, *Das Erkenntnisproblem.* II, 645.

[178] See E. Cassirer, [1906 (1911)] 1991, *Das Erkenntnisproblem.* I, 4: „Die gedanklichen Einheiten, vermittels deren wir das Gewirr der Erscheinungen zu gliedern suchen, halten selbst, wie es scheint, nirgends stand; in buntem Wechselspiel verdrängen sie sich und lösen unablässig einander ab".

[179] E. Cassirer, [1936] 1956, Engl. Trans., 74.

contends that the "*a priori* that can still be sought and that alone can be adhered to must do justice to this flexibility."[180] This *a priori* has to be understood in a purely methodological sense. It is not fixed and founded on the content of any particular system of axioms, but denotes the process whereby theoretical systems develop each from another. This process possesses "its rules, and these rules provide the presuppositions and foundation for what we may call the 'form of experience'."[181]

Cassirer illustrates, for instance, the idea of flexibility in the following way. In

$ds^2 = \sum_1^4 g_{\mu\nu} d_{x\mu} d_{x\nu} \, (\mu, \nu = 1,2,3,4)$ (2), the magnitudes

$$g_{11}dx_1^2 + g_{22}dx_2^2 + g_{33}dx_3^2 + g_{44}dx_4^2 + 2g_{12}dx_1dx_2 + 2g_{13}dx_1dx_3 + ...(3)$$

are the ten components of the potential of Einstein's general theory of relativity[182] In place of the rigid rod which is assumed to retain the same unchanging length for all times and places and under all particular conditions of measurement there now appear the curved coordinates of Gauss. If any point P of the space-time continuum is determined by the four parameters x_1, x_2, x_3, x_4, then for it and an infinitely close point P' there is a certain 'distance' *ds*, which is expressed by the formula (3), where the magnitudes g_{11}, $g_{22} \cdots g_{44}$ have values varying with the place in the continuum. Each point refers not to a rigid and fixed system of reference outside of it, but to a certain extent only to itself and to infinitely close points. In this fact, all measurements become infinitely *fluid* as compared with the rigid straight lines of Euclidean geometry, which are freely movable in space without undergoing a change of form. Here only *reference mollusks,* according to Einstein, have to be applied, instead of given and finite reference bodies.

3. The function of space-time

Instead of considering space as a self-existent reality, which must be explained and deduced from *binding forces* like other realities, Cassirer retains the *a priori* function of space, the universal ideal relation, involving "possible formulations and among them such as are proper to offer an exact

[180] E. Cassirer, [1936] 1956, Engl. Trans., 74.
[181] E. Cassirer, [1936] 1956, Engl. Trans., 74.
[182] E. Cassirer, [1921], 1953, Engl. Trans., 397.

and exhaustive account of certain physical relations, of certain fields of force."[183]. The pure space-time manifold is conceived "as the logical *prius;* not as if it existed and were given in some sense outside of and before the empirical and physical, but because it constitutes a principle and a fundamental condition of all knowledge of empirical and physical relations."[184] For instance, the general theory of relativity has shown that Riemann' geometrical hypothesis, as a mere possibility of thought, becomes an organ for the knowledge of reality.

Cassirer adds that it is not the concern of the physicist as such; for he is dealing with making the concrete measurements, in which "the spatio-temporal and the empirical manifold is given always only in the unitary operation of measurement itself, not in the abstract isolation of its particular conceptual elements and conditions."[185] Thus, the purely conceptual thought expressed in the concept of manifold and order is connected to physical empiricism (*Empirie*). As a member of the Marburg School, Cassirer highlights the complete interpenetration of form and content; and in this sense, space and time coincidences are also formal for him.

3.1. The space-time of Einstein's Special Relativity

Cassirer recalls Einstein's reformulation of the Relativity Principle (RP), namely: "laws, according to which the states of physical systems change, are independent of whether they are referred to one or the other of two systems of coordinates in uniform translatory motion relative to each other."[186] This means that two coordinate systems K and K', in rectilinear, uniform[187] and non-rotary (in uniform parallel translational)[188] motion relative to each other, are equally permissible for the formulation of the laws of nature. On this basis, the law of the propagation of light in a vacuum and Maxwell's fundamental equations of electrodynamics, for instance, "do

[183] E. Cassirer, [1921] 1953, Engl. Trans., 441.
[184] E. Cassirer, [1921] 1953, Engl. Trans., 442.
[185] E. Cassirer, [1921] 1953, Engl. Trans., 442.
[186] A. Einstein, *Zur Elektrodynamik bewegter Systeme. Annalen der Physik,* 4 F., XVII, p. 29; quoted in E. Cassirer, [1921] 1953 Engl. Trans., 372.
[187] Brown clarifies that when "Newton talks of uniform speeds, he means equal distances being traversed in equal times, and these distances are meant in the sense of Euclid" (*cf.* H. Brown, 2005, 18).
[188] See also H. Brown, 2005, 74.

not change their form when the formulae of the Lorentz-transformation(s) rather than those of the Galileo-transformation(s) are applied to them."[189]

For Cassirer, the RP constitutes a general maxim established for the investigation of nature, "which is to serve as a 'heuristic aid in the search for general laws of nature.'"[190] Nevertheless, as Brown notes, the formulations of the RP make no reference to the form of the coordinate transformations between the two frames in question. Einstein used the combination of the RP and the light postulate to infer the invariance of the velocity of light *c*, and from this he derived the Lorentz transformations. He showed these to be consistent with the claim that a spherical light-wave front centered at the origin and seen in relation to the rest system *K* will also be visible as spherical from the point of view of the moving frame *K*'.[191]

Indeed, in the relative orientation of the coordinates systems, the axes of both frames coincide in a permanent way; that is, at time t = t', K and K' coincide. Einstein supposes a light signal – as a spherical wave – which moves along the positive axis of x. This beam of light propagates according to the following equation which can be visualized in *Figure 1*:

$r = ct$ or $r - ct = 0$ in *K* and $r' = ct'$ or $r' - ct' = 0$. (4)

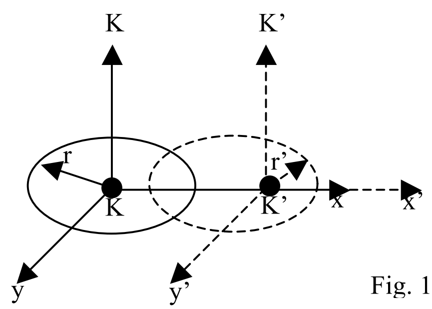

Fig. 1

The important thing here is that, since there is compatibility between the RP and the light postulate, the equation describing the point-events in K and K' takes the same form; that is, the point-event is the same in the two frames.

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189 E. Cassirer, [1921] 1953, Engl. Trans., 372.
190 E. Cassirer, [1921] 1953, Engl. Trans., 377.
191 See also H. Brown, 2005, 78.

$$\left.\begin{array}{l} x^2 + y^2 + z^2 - c^2 t^2 = 0 \\ x'^2 + y'^2 + z'^2 - c^2 t'^2 = 0 \end{array}\right\} (5)$$

Thus:

$$x'^2 + y'^2 + z'^2 - c^2 t'^2 = 0 \Leftrightarrow x^2 + y^2 + z^2 - c^2 t^2 = 0 \quad (6)$$

Therefore, Einstein bases his special theory of relativity upon two presuppositions, namely the RP and the principle of the constancy of the velocity of light in vacuum. These presuppositions stand inseparably connected with each other, according to Cassirer, in the empirical structure of the special theory of relativity. The role of the relativity principle is to guarantee the reproducibility of measurements at different space-time locations.

The validity of Lorentz-transformations is the exact consequence of this condition expressed in Equation (6). In other words, in the standard form of Lorentz transformations the equation (6) is the condition required to obtain the transformations of space and time when we go from K to K'. In fact, the experiment teaches us, through the method of measuring time and the fundamental role that the velocity of light plays in all our physical time measurements, the *relativity of the simultaneity*, namely: every reference body has its own time; an indication of time has sense only if we indicate the reference body to which it relates. On the ground of this relativity of simultaneity, Lorentz-Transformations show us exactly how space and time magnitudes change in passing from one inertial system K to another K', which is in uniform translatory motion with regard to the first:

$$x' = \gamma(x - vt) \quad y' = y \quad z' = z \quad t' = \gamma\left(t - \frac{vx}{c^2}\right) \text{ ; where } \gamma = 1/\sqrt{1 - \frac{v^2}{c^2}}\,.$$[192] (7)

But Cassirer clarifies that these relativizations of space-time magnitudes "are not in contradiction with the doctrine of the constancy and unity of nature; they are rather demanded and worked out in the name of this very unity."[193] Since the above two presuppositions of the theory are compatible there must exist, according to Einstein, a functional relation, a one-to-one correspondence between K and K'. So, the description of the relative

[192] *Cf.* E. Cassirer, [1921] 1953, Engl. Trans., 372.
[193] E. Cassirer, [1921] 1953, Engl. Trans., 374.

position of two neighboring points-events in K and K' is given, in relation to (6), by an equation (of differences of spatial coordinates) having the same form, namely: $dx'^2 + dy'^2 + dz'^2 - c^2 dt'^2 = dx^2 + dy^2 + dz^2 - c^2 dt^2$ (8), where the coordinate of common time *t* is substituted, in the four-dimensional world, by a variable magnitude, the imaginary *ray of light* (*cf.* 1) which is proportional to it.

From (8) we deduce

$ds^2 = dx^2 + dy^2 + dz^2 - c^2 dt^2$ or $ds^2 = dx_1^2 + dx_2^2 + dx_3^2 - dx_4^2$ (9), which expresses the magnitude of two neighboring points of spatial continuum (the distance of two world-points). Thus, the equation (9) constitutes the fundamental invariant, the postulate on which the independence of the equations of physics vis-à-vis the choice of a particular reference system rests. In this direction, Cassirer asserts that "Only those relations can we call laws of nature, i.e., ascribe to them objective universality, whose form is independent of the particularity of our empirical measurements of the special choice of the four variables x_1, x_2, x_3, x_4, which express the space and time parameters."[194] More clearly, Schlick explains that this distance, representing the line-element of the world-line and connecting the two points, is not in general a space-distance (length), but has the physical significance of a motional event, because it denotes a combination of space-

[194] E. Cassirer, [1921] 1953, Engl. Trans., 383–84. Harvey Brown remarks that "In their influential 1973 article on Newton's first law of motion, John Earman and Michael Friedman claimed that no rigorous formulation of the law is possible except in the language of 4-dimensional geometric objects. But the appearance of systematic studies of the 4-dimensional geometry of Newtonian space-time is relatively recent; the first I am aware of is a 1909 paper by F. Frank immediately following the work of Minkowski on the geometrization of special relativity. It is curious that so much success had been achieved by the astronomers in applying Newton's theory of universal gravity to the solar system (including recognizing its anomalous prediction for the perihelion of Mercury) well before this date. How could this be if the astronomers were unable to fully articulate the first law of motion, and hence the meaning of inertial frames? How tempting it is in physics to think that precise abstract definitions are if not the whole story, then at least the royal road to enlightenment. Yet consider the practical problem faced by astronomers in attempting to fix the true motions of the celestial bodies. The astronomers who know their Newton are not helped by the further knowledge that Newtonian space-time comes equipped with an absolute flat affine connection." (*cf.* H. Brown, *Space-time Structure from a Dynamical Perspective,* Oxford New York, Oxford University Press, 2005, 23)

and time-quantities. And the "numerical value of *ds* is always the same, whatever orientation the chosen local coordinate system may have."[195]

Before Einstein, space was considered as a continuum of three dimensions; which means that it is possible to determine the position of any point by means of three coordinates x, y, z and that there is for every point a number of neighboring points, whose position can be determined by coordinates x_1, y_1, z_1. These latter are also neighboring coordinates of the first points x, y, z. This property permits physicists to speak of a continuum. This 3-dimensional metric of space and that of time are respectively invariant. The 3-dimensional Euclidean space is regarded as a physical object, as a vase in which the play of physical processes is enacted. Metrical space is an invariant background.

In a similar way the world of physical events, which Minkowski calls '*world*' tout court, is naturally of four dimensions in this spatiotemporal sense (*cf.*9); since it consists of individual events each of which is determined by four numbers, namely the three coordinates of space x, y, z and the coordinate of time *t*. In this case, the world is also a continuum because there is for every event a number of neighboring events (realized or imagined), whose coordinates x_1, y_1, z_1, t_1 differ from the x, y, z and t coordinates event of the initially considered event. The four dimensional space-time continuum of Special Relativity presents, in its fundamental properties, the greatest relationship (analogy) with the continuum in three dimensions of Euclid's geometrical space. The laws of nature, which satisfy the requirements of Special Relativity, assume mathematical forms where the coordinate of time plays exactly the same role as the three spatial coordinates. These four coordinates correspond exactly to the three coordinates of space of Euclid's geometry on which Newton's mechanics rests; that is, the fundamental Newtonian laws presuppose the Euclidean metrical structure of space.

But Minkowski's space and time are unified; that is, they are not separately invariant. The important thing for Cassirer, here, is that they are neither absolute nor considered as privileged physical objects. They are ideal unified forms of a structural character and *a priori* components of the constitution of physical objects. Nevertheless, Cassirer remarks that it is the space-time of the general theory of relativity which is sufficient in itself to

[195] M. Schlick, [1917 first edition] 1979, 245.

support the scientific character of objectivity as such, because Minkowskian space-time concerns only formal unification.

3.2. The space-time of Einstein's General Relativity

Cassirer understood, with an eye towards Kretschmann's correction, the importance of the general covariance principle as constitutive of physical objects. This principle stipulates that "the universal laws of nature are not changed in form by arbitrary changes of the space-time variables"[196]. It also possesses, according to Cassirer, a regulative or heuristic role, by securing the reproducibility of measurements at different space-time locations. Cassirer had taken credit for emphasizing it, even if he did not overcome the confusion between the principle of general relativity and the principle of general covariance, which he called principle of general invariance. Brown is also convinced that "the connection between the general covariance requirement and the conservation laws also becomes clearer."[197] Space-time measurements depend on different reference systems; that is, they are relative, but it does not entail the absence of invariant and covariant quantities.

In the space of the x_1, x_2, x_3, the point moves curvilinearly and non-uniformly. Its law of motion, expressed in the new space-time coordinates, is given in the above equation (2). This equation also determines the motion of a point in the gravitational field. Here, space-time continuum has, in a sense, taken over the role of substance[198]. Cassirer explains that the ten factors $g_{\mu\nu}$ (certain functions of coordinates), which are contained in the determination of the linear elements of the general theory of relativity [*cf.* Equations (2) and (3)], are also the quantities determining the field, which do not depend on the particular choice of the local system, as ds^2 is invariant or independent of this choice. In other words, the same determinations

[196] E. Cassirer, [1921] 1953, Engl. Trans., p. 384. Brown notes that a theory "may be formulated generally covariantly, but it doesn't follow that the equations are equally simple in all coordinate systems" (*cf.* H. Brown, 2005, 75).

[197] A. Einstein, 1918; quoted by H. Brown, 2005, 179.

[198] *Cf.* E. Cassirer, [1936] 1956, Engl. Trans, 131.

designate and express the metrical properties of the four-dimensional space as well as the physical properties of the field of gravitation.[199]

Thus, the spatio-temporal variability of those magnitudes $g_{\mu\nu}$ and the occurrence of such *field* are equivalent assumptions which differ only in their expression. Hence, the new physical view no longer takes as an assumption that space-time and physical events are separate. There is only the unity of *certain relations* differently designated according to the reference system in which these fundamental concepts are expressed. Cassirer cites Weyl who showed that "the 'metric field' provides a unitary and supreme concept which links together the special viewpoints of space, time, and matter in an entirely new way. The world is defined with systematic unity as a (3+1) dimensional metric manifold; all physical field phenomena are expressions of world metrics.[200]

When Cassirer claims that transcendental philosophy "no longer regards space and time as things, but as 'sources of knowledge,'"[201] it means, in my opinion, that this *transcendental philosophy* is no longer identical with Kantian transcendental idealism; since Cassirer takes proper account of Leibniz' notion of the objective ideality of space-time and of the group concept of Klein in order to define the nature of the space-time of physics. Cassirer had to clarify that he accepted the Kantian conception of *pure intuition,* but with more restrictions than previously, while in 1921 he declared that "the general theory of relativity must implicitly recognize the methodic presupposition, which Kant calls 'pure intuition'."[202]

It is true that Kant conceives of space only in its unity with time. And there is for him no dualism between space and matter. Indeed, Cassirer shows that Kant repeatedly refers to the indissoluble connection and the reciprocal correlation between spatio-temporal form and empirical content in the existence and structure of the world of experience: "Even space and time, however pure these concepts may be of all that is empirical, and however certain it is that they are represented in the mind entirely *a priori,* would lack nevertheless all objective validity, all sense and meaning, if we

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[199] *Cf.* E. Cassirer, [1921] 1953, Engl. Trans., 397–98. See also M. Schlick, [1917 first edition] 1979, 246, 247.

[200] H. Weyl, *Raum, Zeit, Materie,* secs. 12, 35; quoted by E. Cassirer, [1929] 1957, Engl. Trans., 472; and E. Cassirer, [1921] 1953, Engl. Trans., 398.

[201] E. Cassirer, [1921], 1953, Engl. Trans., 411.

[202] E. Cassirer, [1921], 1953, Engl. Trans., 417.

could not show the necessity of their use with reference to all objects of experience. Nay, their representation is a pure schema, always referring to that reproductive imagination, which calls up the objects of experience, without which objects would be meaningless."[203] Cassirer holds that Kant's union of space and time has been verified and proved by the general theory of relativity in a new way, since it recognizes more deeply than all preceding physical theories the dependency of all empirical measurement on determinations of concrete spatio-temporal relations.[204]

But it seems contradictory and problematic to see Cassirer claiming to show in 1921 the continuing relevance of Kant's transcendental idealism through the unification achieved by the general theory of relativity between space and time on the one hand, and between space-time and physical events on the other. The starting point of Cassirer's argument seems to be problematic. It is not pertinent, as Edgar Wind remarks, to turn the "attention exclusively to the question of how Einstein's unification of space and time, achieved through the measuring process, might be compatible with the understanding of space and time in 'transcendental aesthetics'."[205] Cassirer showed the limits of the Kantian conception of space and time as *a priori* forms of sensibility and that of experience as not exceeding the frame of perception and sensation. It means that even taking Newton's mechanics into consideration, Kant's conceptions of space and time must be corrected. This is why Cassirer refers to Leibniz and to Klein in order to denote the real scientific nature of space and time. It is true that he would want to save something which owing to Kant, namely the notion of *pure intuition* and the idea considering space and time as conditions of objectivity; but his approach takes, later on, a completely different direction which is no longer Kantian.

Since he had realized the significance of *implicit definition*[206] by revising Kant's *a priori forms* and by showing that the objects by means of which

[203] I. Kant, *Kritik der reinen Vernunft,* Ed. 2, 1787, 195; *cf.* Müller trans., 127 f; cited in E. Cassirer, [1921], 1953, Engl. Trans., 425–26.

[204] Cf. E. Cassirer, [1921], 1953, Engl. Trans., 426.

[205] E. Wind, [1934] 2001 Engl. Trans., 4.

[206] To define a "concept implicitly is to determine it by means of its relations to other concepts. But to apply such a concept to reality is to choose, out of the infinite wealth of relations in the world, a certain complex or grouping and to embrace this complex as a unit by designating it with a name"(M. Schlick, *General Theory of Knowledge,* 71; quoted by J. M. Krois, 1987, 117–18).

space and time acquire value no longer represent scientific objects as such, Cassirer could no longer pursue a Kantian approach. It would make more sense for him only to save, with an eye toward Leibniz's and Klein's contributions, some Kantian idea of space-time, as a *presupposition* of 'physical knowledge,' than to affirm that Einstein's General Relativity confirms the Kantian unification of space-time and matter, etc.[207] The structure of Newtonian space-time has an *a priori* component in the constitutive sense, relative to Newtonian mechanics; but, as Friedman maintains, "for Newton, in [his] opinion, space-time is not in intuitive level. It means that we must accept this Kant's analysis with more restrictions."[208]

Cassirer overcomes this paradoxical situation in his *Determinism and Indeterminism in Modern Physics* and in some of his last articles, where he sharply distances himself from Kant. He no longer repeats his previous assertions and clearly indicates that he is taking the opposite approach to Kant. This dynamism in Cassirer's position is, in my opinion, key to developing a proper understanding of his thought.

For him, the important thing is to maintain that physical events are characterized by their space-time coordinates (x_1, x_2, x_3, x_4; x'_1, x'_2, x'_3, x'_4). Thus, physical reality "consists merely in assertions concerning the coincidences or meetings of such points,"[209] to which the content and the form of all laws of nature are reduced. Accordingly, Schlick affirms that "the whole of physics may be regarded as a quintessence of laws, according to which the occurrence of these space-time-coincidences takes place."[210] And for Cassirer, "the whole of the space-time manifold is nothing else than the whole of such coordinations."[211] These coordinations[212] are understood

207 Here, it is difficult to understand Cassirer's argument which states, for instance, that "necessary and consistent as this conclusion appears in the framework of Kant's general formulation of the problem, we must go beyond it, once the formulation of the problem is broadened, once we attempt to state the transcendental question itself in a more comprehensive sense." (*cf.* E. Cassirer, [1929] 1957 Engl. Trans., 13.) Cassirer uses this expression '*to go beyond Kant'* (*Cf.* E. Cassirer, [1921] 1953, Engl. Trans., 355, 415, 439.) several times in his book on Einstein's Relativity.

208 M. Friedman, 1999, 61.

209 E. Cassirer, [1921], 1953, Engl. Trans., 417.

210 M. Schlick, [1917 first edition] 1979, 241.

211 A. Einstein, *Die Grundlagen der allgemeinen Relativitätstheorie,* Lpz, 1916, 13 and *Über die spezielle und die allgemeine Relativitätstheorie,* Braunschweig, 1917, 64; quoted in E. Cassirer, [1921], 1953, Engl. Trans., 417.

as *forms of intuition*, which constitute the *a priori* of space and time as the condition of every physical theory. These forms denote, according to Cassirer, the fundamental form of coexistence and succession and their reciprocal relation and union which are unmistakably contained in the expression of the general linear element [*cf.* Equation (2)]. He clarifies "that the theory, as has been occasionally objected, [does not] presuppose[e] space and time as something already given, for it must be declared free of this epistemological circle, but in the sense that it cannot lack the form and function of spatiality and temporality in general."[213]

This means that for Cassirer the constitutive sense of space-time is always associated with its regulative sense. From this point of view, *a priori* strictly concerns only the ultimate logical invariants, which lie in the basis of any determination of a connection according to natural law. In any sense *a priori* does not mean "*prior* to experience" but a "necessary premise in every valid judgment concerning facts."[214]

It is clear that for Cassirer, as Friedman also showed, Newtonian mechanics and Einstein's theories of special and general relativity are respectively associated with an invariance group of transformations. The Galilean group acts as a group of transformations in Newtonian mechanics; and in this context the underlying structure of Newtonian space-time is constitutively a priori. The Lorentz group is a group of transformations in special relativity, where the underlying structure of Minkowski space-time is constitutively a priori. And, in general relativity the relevant group includes all one-one bidifferentiable transformations (diffeomorphisms), where only the underlying topology (sufficient to admit a Riemannian structure) remains constitutively a priori.[215]

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[212] Ghins thinks that it is not correct to claim, as Cassirer does, that, in the general theory of relativity the concepts of space and time appear solely as functional forms of succession and coexistence. There is much more structure involved in a general relativistic metric than mere succession and coexistence, and this structure is of course allowed by the formulation of the principle of general covariance stipulating that the smallest invariance group of the fundamental laws is the group of diffeomorphisms. (Ghins, M., Rynasiewicz, R. and Bas van Fraassen, "*Review of Thomas Ryckman, The Reign of Relativity. Philosophy in Physics 1915–1925*." With replies by Thomas Ryckman. *Metascience* 16, 2007, 397–407).

[213] E. Cassirer, [1921], 1953, Engl. Trans., 418, 433.

[214] E. Cassirer, [1910], 1953, Engl. Trans., 269.

[215] For more details on this question, I refer to the works of Ghins (M. Ghins, 1990, 21, 22, 93 and 2007, 397–407), Friedman (*cf.* M. Friedman, 1999, 66).

These *a priori* space-time structures are connected to the formulation of the principles of reproducibility, namely the relativity principle for the special theory of relativity and the general covariance[216] for the general theory of relativity. Ryckman and Friedman show that these principles are for Cassirer and even for Reichenbach (who calls them axioms of coordination[217]) the *a priori* elements in physical theories, but also dynamical and relativized: "changing over time, with each such change representing a transformation of the concept of physical objectivity. In the broadest sense, these are 'meta-empirical' principles relative to a given physical theory, 'constitutive' of theory's objects in the sense of delimiting the space of 'possible objects', but nonetheless not immune from experience, changing with the progress of physical science."[218]

The logical empiricists imposed, however, an anti-aprioristic interpretation on Einstein's theory of General Relativity, by rejecting the idea of absolutely fixed and unrevisable *a priori* principles of knowledge. Schlick developed an extensive criticism of Cassirer's 1921 book in his "Critical or Empiricist Interpretation of Modern Physics". For him, General Relativity is not compatible with the synthetic *a priori*. But it is known today through to work of John Michael Krois, Michael Friedman[219] and Thomas Ryckman[220] that Moritz Schlick (who took over the mantle of authority on relativity theory within logical empiricism) and Einstein confused *a priori* with 'prior

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[216] In the general relativity, as Ghins clarifies, the principle of general covariance guarantees the reproducibility of measurements but this repeatability seems to be threatened, since space curvature may vary from point to point, and space-time resembles a changing landscape (*cf.* Ghins, M., Rynasiewicz, R. and Bas van Fraassen, "*Review of Thomas Ryckman, The Reign of Relativity. Philosophy in Physics 1915–1925*." With replies by Thomas Ryckman. *Metascience* 16, 2007, 397–407).

[217] See M. Friedman, 1999, 9, 61.

[218] T. Ryckman, 2005, 27, 15.

[219] M. Friedman, 2000, 115, 116: "what is happening here is that Schlick is attempting to hold Cassirer to Kant's original conception of the synthetic *a priori*, whereas Cassirer himself is articulating a quite different conception." (see M. Friedman, 2000, 116–17).

[220] T. Ryckman, 2005, 5, 6, "Schlick's argument bears not upon Cassirer's understanding of the 'synthetic *a priori*' as regulative principles or 'rules of the understanding' governing the development of concepts of physical objectivity, but upon a more traditional Kantian conception of apodictically certain and unrevisable principles." (see T. Ryckman, 2005, 50). "Schlick located 'the essence of the critical viewpoint' in the claim that the constitutive principles of physical knowledge "are to be *synthetic judgments a priori* in which to the concept of the *a priori* inseparably belongs the characteristic of *apodicticity* (universal, necessary and inevitable validity)" (Schlick, 1921, 98; Engl. Trans. 1979, 323).

to experience' and 'fixed'.[221] As I have shown, in agreement with Friedman, the sense of a priori as necessary and unrevisable must be separated from its second meaning as constitutive of the concept of the object of knowledge[222]. This criticism was based on a misunderstanding of Cassirer's sense of *a priori*. Cassirer conceives of the synthetic a priori in purely regulative terms; it represents for him not a fixed and unrevisable set of axioms but an ideal of scientific knowledge. That means that Schlick's criticism did not succeed in reaching its designated target.

Nevertheless, Schlick developed in 1917 a meta-empirical or an *a priori* conception of space-time very close to that of Cassirer[223]. It is true that Schlick gave absolutely no place or no role to the intuition in the constitution of physical knowledge. Physical space, according to Schlick, is only a product of our conceptions and has nothing to do with the space of intuition. This is the point of disagreement between him and Cassirer. However, I see no opposition between the two philosophers when Schlick declares that physical space does not depend on our sense impressions but is dependent on physical objects. It is only in conjunction with these objects that physical space can achieve reality: "Space and time are never objects of measurements in themselves; only conjointly do they constitute a four-dimensional scheme, into which we arrange physical objects and processes by the aid of our observations and measurements."[224] Moreover, he adds that the "picture of the world, as presented by physics, would then be a system of symbols

[221] See D. Howard, "Realism and Conventionalism in Einstein's Philosophy of Science: The Einstein-Schlick Correspondence," in *Philosophia Naturalis* 21, 1984, 626; quoted by J. M. Krois, 1987, 120–21.

[222] See M. Friedman, 1999, 9, 61; and M. Friedmann, "Kant, Kuhn, and the Rationality of science", in M. Heidelberger and F. Stadler (eds.), *History of Philosophy and Science,* 25–41. Kluwer Academic Publishers. Dordrecht/Boston/London.2002, 27.

[223] I refer to Friedman's book, namely *Reconsidering Logical Positivism* (1999), where he shows that the logical empiricists (Schlick, Reichenbach and Carnap) offered "a new conception of a priori knowledge and its role in empirical knowledge. The positivists, under the influence of late nineteenth- and early twentieth-century developments in the foundations of geometry, logic, and mathematical physics, effected a profound transformation of the Kantian conception of synthetic a priori principles. The result is a relativized conception of a priori principles, which evolve with the progress of empirical science itself, but continue nevertheless to serve as a background framework for empirical principles properly so-called" (*cf.* M. Friedman, 1999, xii, xv, 25).

[224] M. Schlick, "Space and Time in contemporary Physics. An Introduction to the Theory of Relativity and Gravitation." Vol. 1 [1909–1922] Engl. Trans. By Peter Heath, London (ed. H. Mulder and B. van de Velde-Schlick), [1917] 1920, 240.

arranged into a four-dimensional scheme, by means of which we get our knowledge of reality, that is, more than a mere auxiliary conception, allowing us to find our way through given intuitional elements."[225]

At this time and on this point, it is striking to see Schlick strongly criticizing Mach's empiricism. He is convinced that "the quantities which occur in physical laws do not all indicate elements in Mach's sense. The coincidences which are expressed by the differential equations of physics are not immediately accessible to experience. They do not directly signify a coincidence of sense-data; they denote non-sensory quantities, such as electric and magnetic field strengths and similar quantities."[226] Thus, he sees no grounds or arguments which could force us to claim that only the observable or intuitional elements, such as colors, tones, etc., exist in the world. For instance, electric forces, electron, etc. can just as well signify elements of reality. They are *measurable*: And this is all that is required, as Cassirer emphasized under Planck's influence, to fulfill the criterion of physical reality or objectivity.

4. Conclusion: Cassirer's conception of the space-time of physics is not at all Kantian

I hope that the foregoing considerations have convinced the reader that the historical dimension of physics is an essential aspect of Cassirer's thought. Indeed, the dynamical change of space-time structure illustrates this historical dimension. Considering the transition from Newtonian mechanics to the special theory of relativity and from this latter to the general theory of relativity, we have seen how space-time structure takes on a particular form. These physical theories are respectively associated with a definite group of transformations, where a particular space-time structure is constitutively *a priori* and invariant. Even in Newtonian physics, space and time as physical objects are not opposed to the ideas of relation, of order or continuum and of structure which define, according to Cassirer, the nature of space and time.

Thus, space and time are essentially dynamical categories, deprived of any relation to the inner or external senses. They intervene in the physical process of measurements and constitute a necessary premise in every valid

[225] M. Schlick, [1917] 1920, 265.
[226] M. Schlick, [1917] 1920, 265.

judgment concerning the facts. They are *a priori* concepts, true and ultimate invariants of physical experiment itself. In this sense, they condition the constitution of the physical concept of reality. And this constitutive sense of space-time is connected to a regulative sense, because Cassirer considers the form and function of spatiality and temporality in general which is present in every physical theory. Therefore, the space and time of physics are not *a priori* forms of sensibility and thus do not act as the mere conditions of how objects are sensed. Moreover, as pure intuitions they are formal and ideal. Given these premises, it can be safely asserted that Cassirer's conception of the space and time of physics is not at all Kantian.

Cassirer's Conception of *Scientific Experiment*

Keywords: measurement/methodic procedure/induction/deduction/ fertilization of intuition/implicit definitions/ideal case/intellectual objects/ *a priori*/invariance/transformation.

Abstract

Before his famous article on the *group-theory* published in 1944, it is important to point out that Cassirer already spoke of the significance of the group-concept and of the notion of *invariance* in his main publications of 1910 and 1929. It is still to be found in more detail in his fourth volume of *Erkenntnisproblem;* etc. The notion of *invariance* thus constitutes a core issue of Cassirer's conception of scientific objectivity. For him, physical theory and geometrical system (as a theory of invariance of a definite group) share the same structure of an invariant sort. It is the procedure of scientific experiment which establishes the physical structure of invariants. In 1921 and 1937, Cassirer ascribes to experiment a clearer and more central role than before. He adopts Planck's realism and distinctly claims that no physical objects can be grasped outside of the realm of measurement. But he never sustains the thesis of *experimentum crucis,* with which the empiricism of geometry is often associated. He questions the position adopted by Schlick, who inspired Einstein to defend in 1921 (even in 1923 and 1925) the thesis of practical geometry. Practical geometry had, according to Cassirer, already been developed by Newton.

I want to show here that experiment constitutes in Cassirer's thought a sphere of necessity and universality within which the reality concept of physics is to be established. He always sustains a dialectical relationship between theory and experiment, in which induction and deduction logically complement each other. Both theory and experiment cannot be appreciated separately. And experiment always begins with the *ideal case*, which treats simple scientific fact as theory. The concepts of number and magnitude, of space and time, of permanence and change, of causality and reciprocal action represent, according to Cassirer, the true and *ultimate invariants* of experiment itself. All these concepts constitute a frame outside of which no objectivity can be established. However he insists on the *a priori* and

conceptual or logical meaning of physical experiment, Cassirer's approach is no longer Kantian. Cassirer's concern is now the analysis of the actual procedure of physical investigation of facts and measurements.

1. Relationship between geometry, experience and physics

Under Schlick's influence, Einstein published "geometry and experience" in 1921, whose ostensible main point is, as Ryckman highlights, "the argument that the metric of the space-time continuum is empirically determinable (and non-Euclidean)."[227] Einstein's argument is the following: the very applicability of Riemann's geometry to the physical world has, as its presupposition, the existence of infinitesimal rigid rods and ideal clocks. Thus, the possibility of the empirical confirmation of Einstein's General Relativity is based upon the supposition that these idealized bodies provide physical meaning to the concepts *unit measuring rod* and *unit clock*.[228]

But Henri Poincaré pointed out that since it is impossible to meet truly rigid bodies in physical world, purely geometrical formulations have nothing to do with experience. They have to be combined with statements of physics, in order to affirm something related to the experience. Accordingly, Einstein thinks that this view is concisely represented in the following formulation, namely: 'Total theory= *G*+*P;*' that is, a geometry *G* can be chosen arbitrarily and also a part of the system of physical laws *P,* as long as the remainder of *P* enables the total theory to be brought into agreement with experience. Schlick adopted this sort of a holist and conventionalist conception of physical geometry.[229] Thus, this Einstein's article from 1921 becomes "a founding hymn of logical empiricism […] a paradigm-defining text."[230]

Ryckman is convinced that Einstein did not give up this combination of holism with conventionalism in his "Fundamental Ideas and Problems of the

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[227] T. Ryckman, 2005, 60.
[228] *Cf.* T. Ryckman, 2005, 62.
[229] *Cf.* T. Ryckman, 2005, 62.
[230] T. Ryckman, 2005, 52, 59. Ryckman remarks on the same page that "Schlick chose to ignore the *pro tem* character of Einstein's defense of rigid rods and ideal clocks as metrical indicators in the general theory of relativity, a hypothesis Einstein knew to be inconsistent with the spirit, if not the law, of his field equations of gravitation."[230]

Theory of Relativity" (1923) and "Non-Euclidean geometry and Physics" (1925), even if he brought up the deficiency of method in the stipulation that measurement bodies are rigid: "According to [the] more refined conception of the nature of the fixed body and of light, there are no natural objects which correspond *exactly* in their properties to the basic concepts of Euclidean geometry. The fixed body is not rigid [*starr*], and the light ray does not rigorously embody the straight line; of course in general, it is not a one-dimensional structure. According to modern science, geometry by itself […] anyway corresponds to no experiences, but rather only geometry together with mechanics, optics, and so on."[231] This combination of holism with conventionalism seems, according to him, to be problematic; because the dynamical character of the space-time metric of general relativity provides ample grounds for separating epistemological holism from conventionalism. For Poincaré did not think that geometry could be dynamical: he remarked that Riemann's geometries of variable curvature, which are incompatible with the motion of a rigid figure, could never therefore be other than purely formal.

For Friedman, both non-Euclidean geometries and Einstein's General Relativity teach us that the Kantian a priori must not be rejected completely, but rather that the constitutive aspect has to be separated from the apodictic aspect. In this sense, physical geometry is "non empirical and constitutive – it is not itself subject to straightforward observational confirmation and disconfirmation but rather first makes possible the confirmation and disconfirmation of properly empirical laws […] Nevertheless, physical geometry can still evolve and change in the transition from one theoretical framework to another: Euclidean geometry, for example, is *a priori* in this constitutive sense in the context of Newtonian physics, but only topology (sufficient to admit a Riemannian structure) is a priori in the context of general relativity."[232] In principle, Cassirer agrees generally with logical empiricists in this point of view. In his private notes, Cassirer declares: "I believe I stand closer to no other philosophical 'school' than to the thinkers of the Vienna Circle."[233]

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[231] A. Einstein, „Nichteuklidische Geometrie und Physik," *Die Neue Rundschau* 36, 1925, S. 17, 18–19 ; quoted in T. Ryckman, 2005, 66.

[232] M. Friedman, 1999, 9.

[233] Ernst Cassirer Papers, Beinecke Rare Book and Manuscript Library, Yale University; quoted in John Michael Krois, "Ernst Cassirer und der Weiner Kreis," in *Element moderner*

Thus, Friedman thinks that the logical empiricists embrace neither an empiricist conception of geometry nor that of space-time framework of physical theory as such: "the question whether space is Euclidean or non-Euclidean is nonetheless not a straightforwardly empirical question."[234] He deplores misleading ideas about the origins, motivations, and true philosophical aims of the positivist movement.[235] For him, we have to revise fundamentally our understanding of logical positivism and its intellectual significance. He notices that "the positivists' main philosophical concerns did not arise within the context of the empiricist philosophical tradition at all [the tradition of Locke, Berkeley, Hume, Mach, and Russell's external-world program]. Rather, the initial impetus for their philosophizing came from nineteenth-century work on the foundations of geometry by Riemann, Helmholtz, Lie, Klein, and Hilbert – work that, for the early positivists, achieved its culmination in Einstein's theory of relativity."[236] All the early positivists[237] maintained that there is no direct route from sense experience to physical geometry: essentially non-empirical factors, *coordinating definitions*, for instance, must necessarily intervene between sensible experience and geometrical theory.

Unfortunately, however, Wittgenstein agrees with the logical empiricists and radically denies the synthetic a priori truth in the Kantian sense. Although he bases his reflection not on the developments in modern physics but on the consideration of pure semantics, his influence (as that of "Geometry and Experience" of Einstein) stands out as decisive: the *Tractatus* drew logical empiricists closer to Mach, by reinforcing their attachment to Einstein's thesis of practical geometry and also distanced them from their early neo-Kantian origins.

In spite of the authority of Einstein and Schlick relative to this complete change, Cassirer always maintains his previous position; that is, he agrees with Poincaré that no experiment can teach us anything about the *ideal*

Wissenschaftstheorie: Zur Interaktion von Philosophie, Geschichte und Theorie der Wissenschaft, ed. Friedrich Stadler, Vienna: Springer, 2000, S. 105.

234 M. Friedman, 1999, 60.

235 *Cf.* M. Friedman, 1999, 2.

236 M. Friedman, 1999, 6.

237 See M. Schlick, "The Philosophical Significance of the Principle of Relativity", [1915] 1978–9; M. Schlick, *Space and Time in Contemporary Physics,* [1917] 1920, 1978–9; H. Reichenbach, *The Theory of Relativity and A Priori Knowledge* [1920] 1965, and R. Carnap, *Der Raum. Ein Beitrag zur Wissenschanftslehre*, 1922.

structures (straight lines, circle, etc.), as basic elements of geometry. Experiment always gives us only knowledge of the relations of material things and processes. The propositions of geometry are therefore neither to be confirmed nor refuted by experience[238]. The compatibility of geometry with experience cannot be conclusively demonstrated. Rather, geometry can acquire a positive usefulness and serve as the basis of experience. No one kind of geometry is truer than another; it can only show itself to be more suitable to the purposes of experiment; that is, to be an instrument that provides richer knowledge for a systematic description of the states of facts.[239] The language of non-Euclidean geometry, in which the relations of measurement concerning physically real objects find their simplest exact expression in Einstein's Theory of General Relativity, is and remains purely ideal and symbolic. The structures of geometry, whether Euclidean or non-Euclidean, possess no immediate correlate in the world of *existence:* their validity and truth consist in their ideal *meaning*.[240]

For Cassirer, what characterizes the thinking of modern geometry as well as modern physics is that in both fields the process of measurements is increasingly considered as a logical and epistemic problem. It is the question of accurately explaining the presuppositions that underlie the act of measurement.[241] Here, we begin with pure relations of order and relations of incidence, such as 'the place of a point on a right', or the 'passage by a point', etc.; and from there, we develop the fundamental principles. The introduction of a determination of measurement is only the second stage which appears in organic cohesion of the process. In geometry, it is above all the discovery of the non-Euclidian systems which required and opened the way to this explanation. The question of the meaning and the role of experiment appear only when it is a question of the specification of the general concept of space by the introduction of a determination of measure.

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[238] *Cf.* E. Cassirer, [1921] 1953, Engl. Trans., 430–31.

[239] *Cf.* E. Cassirer, [1950 english first edition] 1957, *Das Erkenntnisproblem ,* Vierter Band, S. 116: „Keine Geometrie ist ‚wahrer' als die andere; wohl aber kann sich die eine für die Zwecke der Erfahrung als ‚bequemer', d.h. als ein brauchbareres Erkenntnisinstrument für die systematische Beschreibung der in ihr gegebenen Tatbestände erweisen."

[240] *Cf.* E. Cassirer, [1921] 1953, Engl. Trans., 433.

[241] *Cf.* E. Cassirer, [1950 English first edition] 1957, *Erkenntnisproblem,* IV, S. 59: „sobald man sich die Voraussetzungen des Meßverfahrens in voller Strenge klar zu machen versucht."

Then, a new point of view derived from the consideration of motion can intervene.[242]

Nevertheless for Cassirer, physics always needs a "*fundamentum in re.*"[243] He clarifies that this "foundation cannot be disclosed in any particular thing, in an individual 'this' and 'that,' but follows only from a synthesis of experience as a whole."[244] Science not only needs a method, but also an ontology (not of individual things and substances but that of a form of experience). It necessarily requires a field of objective realities, and it does not only need a mere mathematical reality; that is, a field of connections without support. We must acknowledge a type of order and linking inherent in the world formed by physical facts (or things), so that it can be possible to connect it to a system of necessary concepts and laws. It does not mean that we must deal with naïve realism, because all subjectivist contributions of reason have been eliminated. The conditions of measurement provide the physical object with an objective validity.

Cassirer always keeps the link with perception as primary phenomena (*Urphänomene*)[245]. He claims that "when the transcendental critique seeks to disclose the structure of objective knowledge, it may not limit itself to the intellectual 'sublimation' of experience, to the superstructure of theoretical science, but must also learn to understand the substructure, the world of 'sensory' perceptions, as a specifically determined and specifically organized context, as a spiritual cosmos *sui generis.*"[246] Even here, he does not truly follow Kant's direction. Indeed, in the *Critique of Pure Reason*, as he remarks, Kant by no means closed his eyes to this requirement; but in this work he did not explore in all directions the complex of problems which he had so clearly designated on the basis of his own presuppositions. For the methodic task of the *Critique* pointed from the start in another direction.

[242] *Cf.* E. Cassirer, [1950 English first edition] 1957, *Erkenntnisproblem,* S. 59.

[243] *Cf.* E. Cassirer, [1929] 1957, 421; E. Cassirer, [1950 English first edition] 1957, *Erkenntnisproblem,* S. 82; E. Cassirer, [1910] 1953, Engl. Trans., 288; E. Cassirer, "Newton and Leibniz", [1943], 151; E. Cassirer, [1936] 1956, Engl. Trans., 120 ; etc.

[244] E. Cassirer, [1929] 1957, 421.

[245] See M. Friedman, 2000, 117.

[246] E. Cassirer, [1929] 1957 Engl. Trans., 10.

2. Cassirer's conception of experiment

2.1. Experiment as theory of invariants

Space and time belong, according to Cassirer, to the invariant structure of scientific experiment as such and no longer refer to the perceptual forms. Experience is a sphere of necessity and universality. Sensibility constitutes by no means a clause of the empirical characteristic of physics[247]. Kant did not go beyond this level of perceptions. Experience does not, according to Cassirer, deal only with mere relations. Cassirer also underscores here the limits of Kant's transcendental system[248], on which some philosophers of logical empiricism (Moritz Schlick, Philipp Frank, etc.) and Edgar Wind (Cassirer's student)[249] insisted.

[247] Hans Reichenbach, for instance, to whom Cassirer is very close, was surprised to see how little use Kant made of particular scientific results and material in the elaboration of his transcendental system. He claimed that Kant "must have seen the scientific conception of knowledge as a whole and created his system out of this experience, which produced, as the result of an analysis of pure reason, the very conception of knowledge of the mathematical physics of his time." (*Cf.* H. Reichenbach, [1928] 1957, 1958, xi–xii)

[248] Cf. E. Cassirer, [1921], 1953, Engl. Trans., 352–353 ; E. Cassirer, [1936], 1956, Engl. Trans., 58, 59, 74, 166 ; etc.

[249] In *Experiment and Metaphysics*, Wind is convinced that *in Kant's structuring of experience there is absolutely no logical place for the experiment* (see E. Wind, [1934] 2001 Engl. Trans., 4). At precisely the point at which the verification of an idea by experiment suggests itself to the inquirer, Wind says that Kant refers to the 'reality of sensation'. This latter can never test out the formation of categories, but only be subject to it. Drawing on ideas of embodiment, Wind argues that the process of physical measurement provides answers to the Kantian antinomies of reason. For instance, Einstein's theory of general relativity, which presupposes the notions of non-Euclidean space-time, allows for the testing by physical means of whether the universe is *spatially* finite or infinite. According to Wind therefore, nothing can be known in *a priori* manner (see E. Wind, [1934] 2001 Engl. Trans., 5–6). Cassirer and Wind analyzed the nature of physical experiment. Wind maintains that metaphysics is dismissed by Kant as an entirely speculative science. For Wind, the outcome of physical experiment has to be regarded as a *metaphysical manifestation*. Experiment allows us, according to Wind, to decide between different physical theories and geometrical systems. Cassirer thinks that Wind provides excellent presentations concerning the *Circle of physical investigation*. But Cassirer disagrees with Wind on the systematic conclusions Wind draws from this circle concerning the relationship between physics and metaphysics (see E. Cassirer, 1936, Engl. Trans. 1956, note n° 45, 137). Cassirer's philosophical approach of physical experiment shows the difficulty of sustaining what Wind calls *experimentum crucis* and renders problematic the relationship established by Wind between geometry and experiment. There is, according to Cassirer, an *a priori* signification of physical experiment.

Cassirer refers to physical experiment as such, within which measurements have to be made. For him, the formation of physical knowledge is characterized by an essential and dynamical organization between three levels of statements, namely: statements of facts, statements of laws and statements principles. These levels are always interconnected. In this organization "the statements of the results of measurements may indeed be designated as the *alpha* and *omega* of physics, its beginning and end. From them all its judgments take their departure and to them they must all lead back again."[250] Only through the mediation of the statements which result from *measurements* can the concepts and judgments of physics refer to an object and thus arrive at objective significance and validity[251]. Measurements are important; and the final decision about accepting, conserving or changing the conceptual means (theoretical concepts, principles, etc.) is decided only by experiment.

Cassirere accepts "Planck's neat formulation of the physical criterion of objectivity, that *everything that can be measured exits*"[252] For him, "reference to experience, regard for phenomena and their unified exposition, proves to be everywhere the fundamental feature."[253] He also speaks of the empirical foundation of physical theories; for instance, he agrees with physicists who claim that Michelson-Morley Experiment gave the impetus and starting point for the development of the theory of relativity.[254]

For Cassirer, experiment is to be understood within the frame which constructs the theoretical system of physical theory as such. This system is formed of empirical and ideal or formal components, which are in intimate symbiosis. Newton's principles, for instance, on which his system of mechanics rests, are not considered "as absolutely unchanging dogmas; they can rather be regarded as the temporarily simplest intellectual 'hypotheses,' by which we establish the unity of experience."[255] These principles are, for Cassirer, *a priori,* but also dynamical and relativized elements in physical theories. Indeed, it is the dynamism of experiment, which causes and

[250] E. Cassirer, [1936] 1956, Engl. Trans., 36.
[251] *Cf.* E. Cassirer, [1936] 1956, Engl. Trans., 36.
[252] E. Cassirer, [1921] 1953, Engl. Trans., 357.
[253] E. Cassirer, [1921] 1953, Engl. Trans., 375.
[254] *Cf.* E. Cassirer, [1921] 1953, Engl. Trans., 375.
[255] E. Cassirer, [1910], 1953, Engl. Trans., 268.

explains this change of principles and categories. Cassirer clarifies that "it is the 'functional form' itself, that changes into another."[256]

In the empirical structure of the special theory of relativity, Cassirer thinks that two presuppositions stand in inseparable connection. On the one hand it is a question of "the assertion of a general fact, a constant of nature, which results from the experimental findings of optics and electrodynamics. […] it is empirically established that there is a peculiar velocity with a definite finite value, which retains this value in any system independently of the state of motion of the latter."[257] But on the other hand, there is a requirement, which we make of the *form* of natural laws. This demand is the principle of relativity representing a general *maxim*, which is established for the investigation of nature and serving "as a 'heuristic aid in the *search* for general laws of nature.'"[258] Cassirer iterates that Einstein speaks of "the characteristic 'penetration' (*Spürkraft*) of the principle of relativity."[259] This principle of relativity is a non-empirical principle. It functions as a principle of reproducibility. As an invariance principle for fundamental equations in simple vector forms, Ghins clarifies that this principle ensures that space and time are homogeneous: a physical object cannot be constituted without the repetition of consistent measurements.[260]

In his analysis of Einstein's theories of Relativity, we can realize the importance for Cassirer of considering physical phenomena or facts with which a physical theory deals. In other words, it is very revealing to see how he clarifies the choice of the system of reference in which measurements take place. Considering, for instance, the Special Theory of Relativity, Cassirer states that it concerns all reference systems in rectilinear, uniform and non-rotary motion: any definite given Galilean reference body relatively to which a body *left to itself* persists in its state of rest or of uniform motion in a straight line.[261] Cassirer thinks that "the decisive step is

[256] E. Cassirer, [1910], 1953, Engl. Trans., 268.

[257] E. Cassirer, [1921] 1953, Engl. Trans., 377.

[258] E. Cassirer, [1921] 1953, Engl. Trans., 377.

[259] A. Einstein, *Über die spezielle und die allgemeine Relativitätstheorie* (*Sammlung Vieweg, Heft 38*) 2. Aufl., Braunschweig, 1917, pp. 28, 67; quoted in E. Cassirer, [1921] 1953, Engl. Trans., 377.

[260] Ghins, M., Rynasiewicz, R. and Bas van Fraassen, "*Review of Thomas Ryckman, The Reign of Relativity. Philosophy in Physics 1915–1925.*" With replies by Thomas Ryckman. *Metascience* 16, 2007, 397–407

[261] *Cf.* E. Cassirer, [1921] 1953, Engl. Trans., 370.

taken when it is seen that the measurements, to be gained within a system by definite physical methods of measurement, by the application of fixed measuring-rods and clocks, have no 'absolute' meaning fixed once [and] for all, but that they are dependent on the state of motion of the system and must necessarily result differently according to the latter."[262] It means that only experiment teaches us, for instance, through the method of measuring time and the fundamental role that the velocity of light plays in all our physical time measurements, the *relativity of simultaneity*.

Space-time measurements depend on different reference systems; that is, they are relative. However, physical knowledge can reach truth and universality, because all these measurements exist in mutual correspondence and are coordinated with each other according to definite and unvarying rules. The independence of the accidental standpoint of observer precisely explains the natural object and the laws of nature as determinate in themselves. Both of Einstein's theories of relativity teach, according to Cassirer, "first in the equations of the Lorentz-Transformation[s] and then in the more far-reaching substitution formulae of the general theory, how we may go from each of these particularities to a definite whole, to a totality of invariant determinations."[263] Thus, the "anthropomorphism of the natural sensuous picture of the world, the overcoming of which is the real task of physical knowledge is here again forced a step further back."[264]

For Cassirer, it is experience which had shown us the "difficulty into which philosophical thought had fallen in its attempt to find a particular privileged system of coordinates."[265] To describe physical processes of nature does not imply postulating a particular reference body which is to be privileged above any other; "since experience offers no certain criterion that we have before us such a privileged reference system, we can never reach a truly universal and determinate description of natural processes. This is only possible if some determinations can be pointed out, which are indifferent to every change in the system of reference taken as a basis."[266]

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[262] E. Cassirer, [1921] 1953, Engl. Trans., 371–72.

[263] E. Cassirer, [1921] 1953, Engl. Trans., 381.

[264] *cf.* M. Planck, *Die Einheit des physikalischen Weltbildes,* Leipzig, 1909, S. 6; and, *Die Stellung der neuen Physik zur mechanischen Weltanschauung,* Leipzig, 1911, S. 74; quoted in E. Cassirer, [1921] 1953, Engl. Trans., 381–82.

[265] E. Cassirer, [1921] 1953, Engl. Trans., 382–83.

[266] E. Cassirer, [1921] 1953, Engl. Trans., 383.

It is clear, here, to see how the dialectical connection between transformation and invariance is always affirmed. All invariants of a theory are found and grounded through the variation of the measurements of space and time as a necessary condition: "Such invariants are found in the equal magnitude of the velocity of light for all systems and further in a series of other magnitudes, such as the entropy of a body, its electrical charge or the mechanical equivalent of heat, which are unchanged by the Lorentz-transformation[s] and which thus possess the same value in all justified systems of reference."[267] Within the individual system, space-time magnitudes are taken as changeable, as transformable, and this fact means "to press though to the true invariance of the genuine universal constants of nature and [the] universal laws of nature."[268]

What Cassirer would like to note is that the fundamental logical relation which characterized every geometrical system is verified in the structure of a scientific theory resting on experiment. He compares the procedure of *transcendental philosophy* with that of geometry: "Just as the geometrician selects for investigation those relations of a definite figure, which remain unchanged by certain transformations, so here the attempt is made to discover those universal elements of form, that persist through all change in the particular material content of experience."[269] Thus, all experience aims at "gaining certain 'invariant relations,' and first in these reaches its real conclusion. The conception of the empirical natural object originates and is grounded in this procedure; for it belongs to the concept of this object, that it remains 'identical' with itself' in the flow of time."[270]

For Cassirer, experiment preserves a *general form*[271]. The history of physical theories manifests a sort of conservation of a fundamental form. The dynamism or change of physical categories and principles is not opposed to the idea of a fundamental and invariant form. It is possible to deduce "an ultimate constant standard of measurement of supreme principles of experience in general. (…) In this sense, the critical theory of experience would constitute the *universal invariant theory of experience,* and thus fulfill a requirement clearly urged by inductive procedure itself."[272]

[267] E. Cassirer, [1921] 1953, Engl. Trans., 374.
[268] E. Cassirer, [1921] 1953, Engl. Trans., 375.
[269] E. Cassirer, [1910], 1953, Engl. Trans., 268–269.
[270] E. Cassirer, [1910], 1953, Engl. Trans., 250.
[271] *Cf.* E. Cassirer, [1910], 1953, Engl. Trans., 268.
[272] E. Cassirer, [1910], 1953, Engl. Trans., 268.

Incidentally Maxwell adapts, according to Cassirer, the general causal law to express this requirement.

Thus, Cassirer re-examine the a priori concept and the invariants of experience. Indeed, the categories of space and time, of magnitude and the functional dependency of magnitudes, etc., are established as elements of form, which cannot be absent from any empirical judgment or system of judgments[273]. According to the critical theory of knowledge, space and not color is *a priori,* because only space forms an invariant in every physical construction[274]. From this point of view, *a priori* concerns only the ultimate logical invariants that lie at the basis of any determination of a connection or a form according to natural law. In any sense *a priori* does not mean "*prior* to experience" but a "necessary premise in every valid judgment concerning facts."[275] Cassirer emphasizes that this fundamental relation has never been seriously rejected by even the most radical form of empiricism.

The role of scientific experiment in Cassirer's thinking, his correspondences with the modern physicists and philosophers of logical empiricism demonstrate how he distances himself from the ideas of Kant's transcendental philosophy. Sometimes it is difficult to understand why he was always attached to some of Kant's concepts, such as the concepts of *a priori* and of *transcendental*; even if these concepts are used by him in a completely different way.

Owing to this difficulty, a strongly anti-aprioristic conception of scientific knowledge was adopted by some logical empiricists and physicists. Max Born, for instance, declares that *a priori* is fatal because it seems to be an insurmountable obstacle to the timid and conservatively minded.[276] Nevertheless, this criticism of Cassirer's conception of a priori was based on a misunderstanding of the sense he attributed to this concept. Later on, even Einstein changed his position[277] when he claimed that "unless wanting

[273] *Cf.* E. Cassirer, [1910], 1953, Engl. Trans., 269.

[274] *Cf.* E. Cassirer, [1910], 1953, Engl. Trans., 270.

[275] E. Cassirer, [1910], 1953, Engl. Trans., 269.

[276] *Cf.* Max Born's Letter to Ernst Cassirer, 19 March 1937 (S. 160–162), in Ernst Cassirer, 2009, Band 18, 161: „Mir ist das Wort „a priori" fatal, weil es für konservative und ängstliche Gemüter ein Felsblock zu sein scheint, auf dem sie das Alte und „Bewährte" vor dem Ansturm neuer Gedanken retten können."

[277] Accordingly, Ryckman shows that "Ironically, Einstein's own philosophical evolution after 1915 carried him further and further away from the empiricism Schlick viewed as

to claim that the theory of relativity is contradictory to reason, we cannot preserve the Kantian system of the concepts and the a priori rules or norms. At first, the theory of relativity does not exclude the consideration of a Kantian problem, as Cassirer for example treats it. I think that it is the point of view which no evolution of the science of nature can strictly refute."[278]

Einstein clarifies that what seems to him the most important thing in Kant's philosophy is that we speak of *a priori* concepts in order to build or to constitute science. He sees the rational element, which explains the comprehensibility of the world of phenomena and the data of experiment, as fundamental. And, Enriques believes that these considerations about the rational element to which Einstein grants a particular importance demonstrate the existence to him of a kind of *a priori* which does not have at all the same meaning as Kantian *a priori*. This conception of *a priori* relative to the mode of the constructive function of reason can be found in Cassirer's philosophy of physics.[279]

Cassirer asserted since 1907 that epistemology has to explain the conditions which constitute scientific objectivity.[280] Categories and principles are regarded as non empirical elements in physical theory and are models of the comprehension and of the constitution of physical objects. The physical objects acquire through these categories and principles some characteristics such as invariance[281], unity and determinateness[282], relativity, etc. The invariance of the object is relative to the groups of transformations.[283]

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present in general relativity and toward neo-Kantian conceptions and the mathematical speculative methodology for which he had once chastised Weyl." (see T. Ryckman, 2005, 9).

[278] A. Einstein, 1924, S. 1688.

[279] Cf. F. Enriques, 1941 ; quoted in M. PATY, 1993, p. 474.

[280] *Cf.* E. Cassirer, [1907 (1911)] 1991, *Das Erkenntnisproblem.* II, S. 738.

[281] *Cf.* E. Cassirer, [1921], 1953, Engl. Trans., 375.

[282] *Cf.* E. Cassirer, [1921], 1953, Engl. Trans., 385–86.

[283] *Cf.* E. Cassirer, [1921], 1953, Engl. Trans., 398, 381.

2.2. Michelson-Morley Experiment and Cassirer's conception of *a priori* or the logical meaning of scientific experiment

2.2.1 The logical meaning of physical experiment

Cassirer begins to point out that scientific experiment goes beyond the level of mere perceptions and sensations: "we never measure with mere sensations, but in general to gain any sort of relations of measurement we must transcend the 'given' of perception and replace it by a conceptual symbol, which possesses no copy in what is immediately sensed. […] It is verified again that every physical theory, to gain conceptual expression and understanding of the facts of experience, must free itself from the form in which at first these facts are immediately given to perception."[284] Considering the electro-magnetic theory of light, for instance, electricity and light are phenomena of the same sort. For Cassirer, this affirmation does not lie in "an agreement capable of being grasped by perception, but on the *form of the equations*."[285] These equations are set up as a quantitative expression of the phenomena as well as the relations between the numerical constants characteristic of the two fields. There is a true identity in the mathematical system of conditions between these two phenomena and this identity constitutes a logical invariant. Here, Cassirer thinks that both empiricism-positivism and critical idealism "grant to experience the decisive role, and both teach that every exact measurement presupposes universal empirical *laws*."[286]

Scientific experiment deals with facts and measurements but also with empirical laws and hypotheses. Cassirer thinks that the relation between fact and law is not an opposition of a metaphysical sort between the universal and the particular: "the law and the fact appear no longer as two eternally sundered poles of knowledge; but they stand in living, functional connection, related to each other as means and end. There is no empirical law, which is not concerned with the connection of the given and with inferring

[284] E. Cassirer, [1921], 1953, Engl. Trans., 427.

[285] E. Cassirer, [1910], 1953, Engl. Trans., 252.

[286] E. Cassirer, [1921], 1953, Engl. Trans., 426; see also E. Cassirer, *Substance and Function*, 191; and E. Sellien, *Die erkenntnistheoretische Bedeutung der Relativitätstheorie,* Berlin, 1919, S. 14.

not-given groups of facts; as, on the other hand, each 'fact' is established with reference to a hypothetical law, and receives its definite character through this reference."[287] Cassirer deplores in the philosophy of nature a metaphysics of the particular opposed with that of the universal. This latter affirms that concepts denoting the necessary connection of experiences (as in Kant's idealism) are postulated as independent realities, whereas for the former, the simple sensation is made in its individual character the bearer and content of true reality (according to the empiricism and the sensationalism of Mach, etc.).

The judgment of natural science realizes change transforming sense-data into a new form of being, by imprinting on them a new form of knowledge. For Cassirer, the element of knowledge is devoid of a metaphysical content or character as such. The judgment of knowledge is, first of all, endowed with a new sort of temporal validity, a kind of "existence and a permanence, which the fleeting sense-experience as such cannot establish."[288] For instance, the following propositions: "sulphur melts at a definite temperature, […] water freezes at a definite temperature,"[289] denote something that is to be restricted to no isolated temporal moment. These propositions affirm that, when conditions embraced by the subject concept are realized, then consequences expressed in the predicate concept will always necessarily follow, signifying the *logical function*, which ascribes to each experiment its particular importance as proof. Each scientific conclusion grounded on an experiment lies in the latent presupposition that, what is found to be valid here and now remains valid for all places and all times, in so far as the conditions of investigation are unchanged. This is the way through which the immediate and subjective facts of sense-perception are transformed into the objective facts of scientific judgment.

Thus for Cassirer, as Goethe claimed, "all that is factual is already theory."[290] The real purpose of induction is not to isolate absolutely the temporal fact as such, but to subordinate it to the whole process of nature. The real kernel function of inductive procedure is to trace an empirical content beyond its given temporal limits and retain it in its determinate

[287] E. Cassirer, [1910], 1953, Engl. Trans., 237.
[288] E. Cassirer, [1910] 1953 Engl. Trans., 243.
[289] E. Cassirer, [1910] 1953 Engl. Trans., 243.
[290] E. Cassirer, [1910] 1953 Engl. Trans., 243; E. Cassirer, [1929] 1957, Engl. Trans., 25; E. Cassirer, [1936] 1956 Engl. Trans., 136.

character for all points of the time series.[291] This is a *symbolic meaning* of every inductive inference. In this sense, the particular determination given by the sensuous impression becomes a norm. This latter is retained as a permanent feature in the intellectual structure of empirical reality: "Each particular experience, that has been established according to the objective methods and criteria of science, claims to be absolute; what methodically tested experiment has once shown, can never be entirely logically annulled."[292] In the changing process of inductive procedure, there are always certain permanent connections which can be grasped and retained.
Cassirer acknowledges that the logical moment given here cannot be rejected even in all forms of empiricism.[293]

Scientific experiment is characterized by what Cassirer calls an analytical process, without which "all our empirical evidence would remain sterile; it could not bear its fruit. In all the different fields of physical inquiry Newton always insisted upon this character of his 'analytical induction'."[294] For Cassirer, Newton and Galileo did not succeed in building their fundamental theories by simply collecting new facts. The most important and the most characteristic feature of Newton's work, for instance, was not so much the discovery of new facts as the new interpretation of data already available in the work of Galileo and Kepler, of Snellius and Fermat, of Christian Huyghens, and of Halley or Hooke.[295] That is why Cassirer acknowledges that the "new facts, which we discover, do not displace the earlier experiences in every sense, but only add to them a definite conceptual determination."[296] Thus, he asserts that no former scientist before Newton clearly conceived and understood what a theoretical physics is and means. In Newton's ideal of a scientific induction "the empirical and theoretical elements are welded into an indissoluble unity."[297]

Galileo declared that there is "no human or divine authority […] that may be placed above the authority of experiment and mathematical deduction."[298]Strictly speaking, experiment has never to do with the real case,

[291] *Cf.* E. Cassirer, [1910] 1953 Engl. Trans., 247.
[292] E. Cassirer, [1910] 1953 Engl. Trans., 247.
[293] *Cf.* E. Cassirer, [1910] 1953 Engl. Trans., 264.
[294] E. Cassirer, "Newton and Leibniz", [1943] 2007, 139.
[295] *Cf.* E. Cassirer, "Newton and Leibniz", [1943] 2007, 140.
[296] E. Cassirer, [1910] 1953 Engl. Trans., 244.
[297] E. Cassirer, "Newton and Leibniz", [1943] 2007, 143.
[298] E. Cassirer, "Galileo: a New Science and a New Spirit", [1942] 2007, 54.

lying before us here and now in all the wealth of its particular qualities and determinations, but it rather deals with an *ideal case*. The real beginnings of scientific induction never upheld an empiricist point of view: "Galileo did not discover the law of falling bodies by collecting arbitrary observations of sensuously real bodies, but by defining hypothetically the concept of uniform acceleration and taking it as a conceptual measure of the facts."[299] Galileo began with his statement of the law of inertia and he 'conceived in his mind' the conditions of a physical body being free from any influences of an external force. Such a body is neither a mere physical fact nor simply given in nature. In his letter to Carcaville, Galileo pointed out that "he had to begin in his theory of mechanics with certain assumptions and postulates that could not be directly verified. From these postulates he deduced certain inferences the truth of which could be proved by experiments."[300]

In this direction, according to Galileo, "'Archimedes' theorems about motions in a spiral were true and important, although there is no natural body that moves in spiral."[301] It is not possible to describe the logical structure of Galileo's natural philosophy by mere categories of empiricism or rationalism taken in their traditional sense; because there is, for him, no separation between reason and experience. Galileo rather sets up between them an entirely new relationship. So, a "law of nature must be based on facts; it must contain no element incapable of verification, of experimental proof. But the facts themselves are not derived from sensory experience alone. The brute facts, before they can become the basis for what we call a law of nature, must be analyzed and brought into a logical order."[302]

The same ideas are to be found in Newton's mechanics as well as in Leibniz's philosophy of nature. For Cassirer, both Newton and Leibniz "follow the maxim laid down by Galileo, they are convinced that without mathematics nature would remain a sealed book."[303] They rejected the thesis defended by English empiricism and sensationalism; since "space and time cannot be described and defined in terms of mere sense perception. With this negative statement Newton and Leibniz are in complete agreement."[304] For this reason, Newton cannot be regarded as a mere empiricist: "to speak

[299] E. Cassirer, [1910], 1953, Engl. Trans., 254.
[300] E. Cassirer, "Galileo's Platonism", [1944/1946] 2007, 347.
[301] E. Cassirer, "Galileo's Platonism", [1944/1946] 2007, 347.
[302] E. Cassirer, "Galileo: a New Science and a New Spirit", [1942] 2007, 54, 61.
[303] E. Cassirer, "Newton and Leibniz", [1943] 2007, 149.
[304] E. Cassirer, "Newton and Leibniz", [1943] 2007, 155.

of Newton as if he was a precursor of Comte and his positivistic philosophy is, indeed, impossible."[305]

According to Newton, of all the facts of nature, motion is the most general one and we can't exclude it from the realm of pure mathematics, as did Plato.[306] Motion, for him, as Cassirer shows, "could no longer be regarded as a mere physical fact; it became a basic concept, a category of mathematics. Such was the problem solved by Newton's theory of fluxions. A physical concept, the concept of velocity, was admitted to geometry and algebra."[307] The principal purpose of Newton's theory of fluxions was to legitimatize this concept of motion. For this goal, his system of mechanics is no longer subordinated to geometry but becomes the very basis of geometry. Newton claims that it is the glory of geometry that from a few principles, brought from without, it is possible to generate so many things. Thus, "geometry is founded in mechanical practice, and is nothing but that part of universal mechanics which accurately proposes and demonstrates the art of measuring."[308] In this sense, abstract quantities as generated by continuous motions express a real act; that is, such generations of quantities are neither figments of the human mind nor mere mathematical conventions; they "have a 'fundamentum in re' – a support and basis in the nature of things. We do not merely conceive or imagine, we see and experience, these generations."[309] Thus, Newton's idea of the relationship between geometry and mechanics, in my opinion, is very closer to Einstein's thesis of practical geometry. And even if he does not defend the empiricism of geometry, Cassirer's realism has also its roots in Newton's realistic view of mechanics.

It is true that Newton argues from a principle that at first sight seems, for Cassirer, to admit of no doubt: "If there is any truth, it must be found '*in rerum natura*'. All truth must be based on facts. Even mathematical truth – the so-called 'ideal truth' – forms no exception to this general rule. Newton had found a new type of mathematics – the mathematics of variable quantities."[310] Cassirer never accepted this definition of truth. For him

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[305] E. Cassirer, "Newton and Leibniz", [1943] 2007, 156, 157.

[306] *Cf.* E. Cassirer, "Newton and Leibniz", [1943] 2007, 149–150.

[307] E. Cassirer, "Newton and Leibniz", [1943] 2007, 150.

[308] *Cf.* I. Newton, *Mathematical Principles,* Preface to the First edition, p. XVII; quoted in E. Cassirer, "Newton and Leibniz", [1943] 2007, 151.

[309] E. Cassirer, "Newton and Leibniz", [1943] 2007, 151.

[310] E. Cassirer, "Newton and Leibniz", [1943] 2007, 153–154.

however, Newton was convinced that this new form of mathematics (the mathematics of variable quantities), the doctrine of *fluxions*, would not be possible without a substantial foundation, a substratum in reality. Newton's substantialism is justified relative to the logical coherence of his system of mechanics. For this reason, it is difficult to affirm that Newton's mechanics only defends a mere empiricist conception of physical investigation. Cassirer shows that the importance of Newton's mechanics is no longer compromised or undermined by its substantialist character, since Einstein recognized that "theoretical physics outgrew Newton's framework, which for nearly two centuries had provided fixity and intellectual guidance for science."[311]

2.2.2. Michelson-Morley Experiment

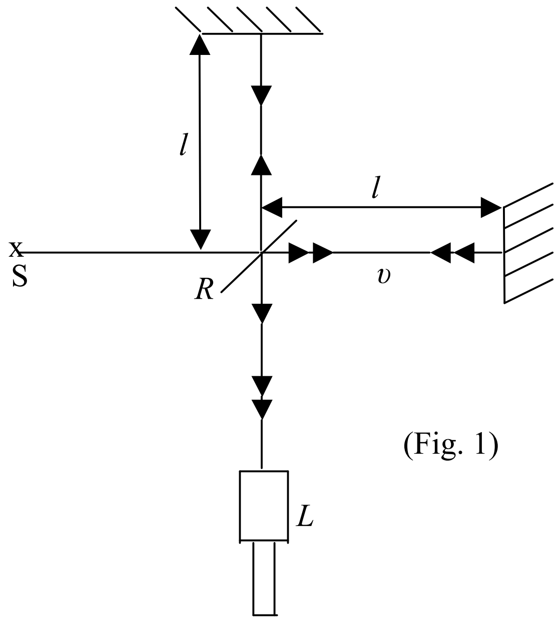
The efforts of physicists had always solely been aimed at postulating the *substratum* which occupied space-time. They taught us with growing precision the constitution of matter and the regularity of phenomena in *vacuum* or in *ether*. Space and time were considered in a sense as vessels containing this *substratum* and providing fixed systems of reference, with the help of which the mutual connections or relations of bodies and events must be determined. In brief, space and time played effectively the following role (attributed by Newton): "Absolute, true and mathematical time, of itself, and from its own nature, flows equably without relation to anything external ... Absolute space stays by virtue of nature, and without relation in a some outside object, always the same and the immovable."[312] Physics had no motive to modify these suppositions about space, time and ether.

That is why, for example, several physical experiments sought to demonstrate the influence of the motion of our instruments vis-à-vis the ether. Is it possible by empirical procedure to establish an absolute rectilinear and

[311] A. Einstein, "Isaac Newton. His Mechanics. Influence on Growth of Theoretical Physics, in: The Manchester Guardian, Marc 19, 1927, pp. 11f; quoted in E. Cassirer, E. Cassirer, "Newton and Leibniz", [1943] 2007, 159.

[312] Isaac Newton, *The Principia. Mathematical Principles of Natural Philosophy* (1687). University of California Press, Berkeley (1999) (translation of Newton *Philosophia Naturalis Principia Mathematica* by I. Bernard Cohen and Anne Whiteman), See Harvey Brown, 2005, 18. Hermann Weyl also shows how Newton bases the development of his mechanics upon the ideas of absolute time, absolute space and absolute motion (*cf.* H. Weyl, [1927] 1949, Engl. Trans., 99).

uniform motion in nature? The Michelson-Morley experiment[313] has often been referred to as the most famous negative experiment in the history of physics. This experiment aimed to test a supposed difference in the speed of the propagation of light. For this purpose, a device named interferometer was conceived, constituted of a source *S*, of a half-silvered mirror *R* and of two mirrors arranged perpendicular at an equal distance *l* from *R*. In all cases, mirror and light source are held rigidly at a fixed distance *l* from each other by the arm of apparatus.



(Fig. 1)

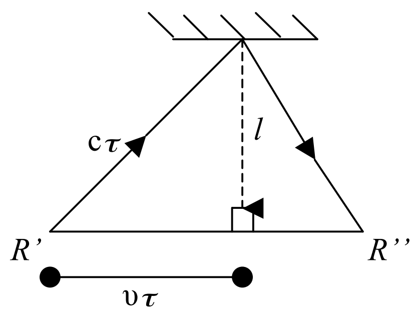
It is supposed that we can direct this device so that one of the arms is parallel to the speed of earth with regard to ether as a privileged reference system. The apparatus moves through ether with a speed *v*. And with respect to ether, the speed of light is the following: $c = 3.10^5 km/s$. This

[313] Albert Michelson (1852–1931) was the chief designer of this experiment, an American experimental physicist who devoted the major part of his professional life to making extremely accurate measurements of the speed of light. In 1907, these efforts brought him the Nobel Prize in physics, thus making him the first American scientist to be so honored. He carried out his first experiment to measure the speed of light in 1881 and the second together with Edward Morley (1838–1923) in 1887 (*cf.* J. T. Cushing, 1998, 199).

landmark experiment is predicated upon Newtonian concepts (in particular, the existence of a universal time for all observers). Results are obtained immediately by using the bases of classical mechanics (the classical law of the addition of velocities, by realizing that the speed of light relative to the apparatus arm is $(c-v)$ in the first case and $(c+v)$ in the second; and the hypothesis of Lorentz-Fresnel where the earth crosses freely through ether without affecting it in any way). The total time of flight down and back, parallel to *v*, is the following:

$$t_{//} = \frac{l}{c-v} + \frac{l}{c+v} = \frac{2l}{c}\frac{1}{1-\frac{v^2}{c^2}}\text{ ; (1)}$$

Considering the case in which the apparatus is aligned perpendicular to *v* (in a stationary ether), the $t_{\perp}$ along the perpendicular arm in the speed of earth is more easily calculated. On the figure below (Fig. 2), *R'* and *R''* describe the position of the half silvered mirror (reflector) *R* at the beginning and at the end of this journey, and τ half the time the light takes to travel.



(Fig. 2)

Reasoning from Pythagoras' Theorem we obtain:

$$(c\,\tau)^2 = (\upsilon\,\tau)^2 + l^2 \text{ . (2)}$$

Thus,

$$t_{\perp} = 2\ \tau = \frac{2l}{c}\frac{1}{\sqrt{1-\frac{v^2}{c^2}}}\text{.} \quad (3)$$

Since $t_{//}$ and $t_{\perp}$ are different, observation through the mirrors *L* (*cf.* Fig. 1) should indicate a displacement of interference fringes, when the roles of the parallel and perpendicular arms to *v* are inverted. But the experiment failed to uphold this proposition[314]. To justify this failure, noticed by Michelson and Morley, Lorentz independently hypothesized the contraction of the parallel arm of the interferometer according to the relation $\sqrt{1-v^2/c_2}$ (4); where this contraction restores the equality of $t_{//}$ and $t_{\perp}$.

Einstein recognized that there is in principle a much simpler way to explain this negative result of Michelson's experiment. There is no need for a particular physical hypothesis, it is sufficient to admit the principle of relativity, according to which a rectilinear and uniform absolute motion can never be noticed; the idea of motion has a physical sense only with regard to a material reference body. In other words, the hypothesis of the contraction of the lengths of a factor (*cf.* 4) introduced by Lorentz, which has no justification in electrodynamics, supports the law of motion which the experiment confirmed with great precision; and the Special Theory of Relativity for example leads to the same law of motion without needing any hypothesis about the structure and the behavior of the electron.

For Cassirer, the interpretation of this experiment by Einstein's Special Theory of Relativity provided the most satisfactory explanation: no privileged system of reference is required to introduce the idea of ether, neither, consequently, the wind of ether, nor experiments needed to prove or to verify it. The contraction of bodies in motion follows here, without the need for special hypotheses, from the unification of both fundamental principles on which the special theory of relativity rests, namely: the principle of invariance of the speed of light in vacuum and the principle of relativity. What counts in this contraction, it is not motion in itself to which we can attach no sense, but motion with regard to the reference body chosen

[314] The light questions the addition theorem of the speeds of classic mechanics: $W = v + w$. The speed of light is constant in vacuum; its propagation is rectilinear and uniform. This speed does join neither to that of its source nor to that of another body with regard to which it would propagate.

in every particular case. And so, the system of mirrors of Michelson and Morley is not shortened for a reference system in motion with earth, but for a reference system which is in rest relative to the sun.

Cassirer shows how Einstein arrived at explaining this difference between $t_{//}$ and $t_{\perp}$ only through a criticism of the concepts of space and time: "it now appears that in fact the incompatibility of the principle of relativity with the law of the propagation of light is not to be found; that rather there is only needed a transformation of these concepts in order to reach a logically unobjectionable theory."[315] The application of fixed measuring-rods and clocks have no absolute meaning fixed once for all, but that they are dependent on the state of motion of the system and must necessarily result differently according to the latter. The history of science consists in the change of the conditions of the measurements. If the former conditions of the measurements are used for the explanation of new phenomena, then science stumbles into an impasse (*aporie*). Thus, this result (that is, the unification in Special Theory of Relativity between classical mechanics and Electrodynamics) "was not reached entirely by heaping up experiments by newly instituted investigations, but it rests on a critical transformation of the system of fundamental physical concepts."[316] A dialectical relationship between experiment and theoretical concepts becomes evident, and Cassirer shows it clearly here: "this transformation too is not accidental but occurs under the pressure of experience. To this pressure, however, there corresponds a counter pressure from the side of theory; and action and reaction here also tend toward a state of equilibrium."[317]

With Einstein's Theory of Relativity there is no doubt that experiment acquires a fundamental significance, but at the same time Cassirer is convinced, in the words of Goethe, that "experience is always only half experience."[318] Indeed, Cassirer clarifies that the theory of relativity receives the basis of its real value and advantage over other types of explanation, not by a mere observational material as such, rather by virtue of the ideal form and the intellectual explanation that it provided. Lorentz explained the Michelson-Morley experiment in a manner which fulfilled all purely physical demands. And his hypothesis was sufficient to give a

[315] E. Cassirer, [1921], 1953, Engl. Trans., 371.
[316] E. Cassirer, [1921], 1953, Engl. Trans., 373.
[317] E. Cassirer, [1921], 1953, Engl. Trans., 75.
[318] E. Cassirer, [1921], 1953, Engl. Trans., 375.

complete explanation of all known observations. Cassirer thinks that an "experimental decision between Lorentz's and Einstein's theories was thus not possible; it was seen that between them there could fundamentally be no *experimentum crucis.*"[319]

Here, Cassirer confirms what he already affirmed in 1910. He had stated that physical concepts and physical facts no longer exist in pure separation. There are facts "only by virtue of the totality of concepts, just as, […] we conceive the concepts only with reference to the totality of possible experience. It is the fundamental error of Baconian empiricism that it does not grasp this correlation; that it conceives the 'facta' as isolated entities existing for themselves, which our thought has only to copy as faithfully as possible. […] Those thinkers, also, who urge strongly that *experience* in its totality forms the highest and ultimate authority for all physical theory, repudiate the naïve Baconian thought of the '*experimentum crucis.*'"[320] Cassirer is convinced that pure experience, in the sense of a mere inductive collection of isolated observations, can never provide the fundamental scaffolding of physics, because it is denied the power of giving mathematical form. The intellectual work of understanding, which connects the bare fact systematically with the totality of phenomena, only begins when the fact is represented and replaced by a mathematical symbol.

Schlick also analyzes, as Cassirer does, the Michelson-Morley experiment. Their philosophical position on this question seems to be generally the same. Schlick states that the "contraction which in Lorentz's theory was a real physical effect of absolute motion, is for Einstein merely an expression of the relativity of all measurements of length. […] According to the former, a real influence of absolute motion *does exist*, but besides that a series of other physical influences is hypothetically assumed in order to explain why this influence is not observed. According to Einstein, on the other hand, no influence of absolute motion exists, there being no such thing as absolute motion; and agreement with experience is not arrived at through sundry particular hypotheses invented *ad hoc,* but emerges quite self-evidently on the basis of a single bold epistemological idea."[321] For him, in both theories we found exactly the same mathematical form of the laws

[319] E. Cassirer, [1921], 1953, Engl. Trans., 375.
[320] E. Cassirer, [1910], 1953, Engl. Trans., 147.
[321] M. Schlick, "The Philosophical Significance of the Principle of Relativity" [1915] 1979, 161.

governing the course of natural processes; but they differ in its interpretation. The most significant thing on which Schlick insists is that "there is no experimental, or therefore experiential, means whereby […] it is possible to refute one of the two standpoints and so demonstrate the sole truth of the other. […] The question is thus undecideable on physical grounds."[322]

As I have shown with Friedman, Schlick (and the other logical empiricists) did not begin to develop a strictly empiricist conception of physical theories as such. Although he radically denied the role of intuition and perception in the objective structure of scientific knowledge, Schlick[323] is very much closer to Cassirer, when in 1915 and 1917[324] he rejected the positivism of Mach and the phenomenalism of Russell's external world program. For him, there are in physics real unobservable entities (called by himself 'transcendent' entities or 'things-in-themselves'), which cannot be understood as mere logical constructions from sense-data: "the quantities which occur in physical laws do not all indicate 'elements' in Mach's sense. The coincidences which are expressed by the differential equations of physics are not immediately accessible to experience. They do not directly signify a coincidence of sense-data; they denote non-sensory quantities, such as electric and magnetic field strengths and similar quantities. […] The conception of an electron or an atom would then not necessarily be a mere working hypothesis, a condensed fiction, but could equally well designate a real connection or complex of such objective elements."[325] We cannot experience these unobservable entities such as atoms, electrons, and the electromagnetic field. They are only to be caught in the net of our concepts.

Schlick acknowledges the existence in relativity theory of important elements of unobservable and theoretical structure. It is true that the theory of relativity possesses fewer unobservable elements than the ether-theory of Lorentz-Fitzgerald, but it does not overcome such elements completely. The Theory of Relativity especially eliminates absolute rest and velocity, but it

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322 M. Schlick, "The Philosophical Significance of the Principle of Relativity" [1915] 1979, 164.

323 These ideas are also developed by M. Friedman, 1999, 19, 20, 23, 24, 25.

324 *Cf.* M. Schlick, "The Philosophical Significance of the Principle of Relativity" [1915] 1979, in Moritz Schlick Philosophical Papers, vol.1 (1909–1922), Engl. Trans. by Peter Heath, London: D. Reidel Publishing Company; and M. Schlick, "Space and Time in contemporary Physics. An Introduction to the Theory of Relativity and Gravitation" [1917 first edition] 1979, in Moritz Schlick Philosophical Papers, vol.1 (1909–1922).

325 M. Schlick, [1917 first edition] 1979, 265.

does not eliminate *absolute acceleration and rotation*.[326] In this sense, the Theory of Relativity no longer realizes the type of limitlessness of the relativity of motion upheld by Mach on empiricist grounds.[327] Strictly speaking, all space-time coincidences are not literally observable. Real physical coincidences comprise such point-events, which are completely measurable but not strictly observable, as the collision of two elementary particles or the electromagnetic field strength taking on a particular value.[328] Schlick's post–1917 writings take on an increasingly verificationist tone; and Friedman is right to wonder why Schlick (and therefore logical positivism generally) moved away from his earlier neo-Kantian considerations.[329]

A similar conception of the existence of unobservable entities is defended by Cassirer. Physical reality is also, for him, not identifiable merely with what can be experienced. He proves this through reference to the principles of quantum mechanics: "in the stationary orbits the electron moves continuously, without radiating: as Sommerfeld phrases it, 'according to quantum theory, the electron is, as it were, immunized against radiation'. But how is this immunization compatible with the basic requirement of observability, since radiation is the only way we can obtain knowledge of the electron? […] In the stationary orbits of the electron something is posited to which nothing empirical corresponds."[330] Therefore, Cassirer mentions that there is only a method whereby the functional relations of mathematical structure, to which we have access, can be provided precisely and completely. Statements about the position of the electron, about its period of rotation or the shape of its orbit no longer appear accurately as only the radiation laws are completely established.

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[326] See also M. Ghins, 1990, 217, 215, 219.
[327] *Cf.* M. Schlick, [1915] 1979, 179–84; see also M. Friedman, 1999, 23.
[328] *Cf.* M. Schlick, [1915] 1979, 179–84; see also M. Friedman, 1999, 264–66.
[329] *Cf.* M. Friedman, 1999, 20.
[330] E. Cassirer, [1936] 1956, Engl. Trans, 134–35.

3. Conclusion

The foregoing reflections have taught us to distinguish between Cassirer's critical idealism or transcendental philosophy and Kant's transcendental idealism. It is true that both idealisms highlight the epistemological problematic of the constitution of physical knowledge. But the former defends a structural realism which grants a decisive and significant role to scientific experiment whereby physical objectivity has to be established and with regard to which theoretical elements (categories or concepts and principles) are thought and produced; whereas the latter ascribes to the pure laws of the understanding the power and the task of the constitution of experience and physical objects. Strictly speaking, Kant didn't base his system of scientific knowledge on scientific experiment as such, on the tools and materials of science.

Cassirer's structural realism finds its roots in the world of intuition and perception; since physics always needs a *fundamentum in re*. Physics also possesses ontology (not of individual things and substances but that of a form of experience). It necessarily requires a field of objective realities, and it does not only need a mere mathematical reality. There is a type of order and linking inherent in the world formed by physical facts (or things), so that it is possible to connect this world to a system of necessary concepts and laws. In the objective structure of physical knowledge there is also a place for perception and intuition.

But physics does not remain at this primitive level. The method of implicit definitions relative to the power of the mathematical formalism permits physics to fertilize and enrich this primitive world by transforming it into the domain of scientific objects as such. In opposition to naïve realism, Cassirer's realism rests upon the field of empirical facts and measurements and establishes the dynamical connection with the theoretical elements, such as categories and non empirical principles. It establishes a field of intellectual objects, where the thought-things are placed in relation to each other: current objects or their relations can indeed correspond to this field but there is never mere congruence between them. Therefore, the reality of physics no longer possesses a substantial or metaphysical character but encompasses an ensemble of invariants relations based on particular laws. Physical theories contain unobservable entities of a structural and mathematical variety.

Cassirer's interpretation of Causality and Objectivity

Keywords: causality/transcendental statement/the truth concept/objectivity/invariance/determinism of scientific laws/the uncertainty relations/relativity of knowledge.

Abstract

Newton did not believe that his mathematical laws could in themselves be enough to predict the long-term stability and the future evolution of universe. His law of gravitation determines what will occur under the presupposition of a certain distribution of masses in space; but, it does not provide any information concerning the state of this distribution. In the face of this relative uncertainty, Newton thinks that at this point another kind of explanation has to be introduced. Cassirer remarks that Newton takes refuge in teleological considerations. The marvelous arrangement of the solar system cannot have merely mechanical causes. Newton assumes that God is responsible for the orderly evolution of the physical universe. Why and how did physicists after Newton believe in the determinism of science?

Physicists were not satisfied with a merely instrumentalist view of the laws of science, in which these laws required only their own empirical adequacy and nothing more; and they regarded them realistically as literally true representations of the world.[331] Could all the phenomena be, in principle, explained by means of the determinist laws of the mechanics of points?

I aim, first of all, to show how Cassirer answers these questions. He rejects the metaphysical and unobservable character of the famous Laplacean Spirit. The ideal of scientific knowledge drawn by Laplace resolves itself into an idol: the infinite spirit obtains at once the complete knowledge of the initial conditions (positions and velocities) of all particles, which would require an intuitive and immediate understanding void of all calculation and mediations.[332] For Cassirer, there are no scientific and

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331 *Cf.* J.T. Cushing, 1998, 172–73.

332 *Cf.* E. Cassirer, [1936] 1956, Engl. Trans, 10, 9.

experimental grounds for Laplacean determinism. The real core of the problem underlying the Laplacean Formula lies in the world view of the system of classical rationalism. The Laplacean Formula constitutes a pregnant summary of this philosophical system. Thus, before Laplace this model of metaphysical determinism is to be found in Leibniz's system; whose conviction of the identity of mathematics and nature Cassirer by no means shares. Cassirer formulates the principle of causality differently and from a new perspective, in order to be "logically coherent and empirically useful, applicable to the procedure of 'actual' physics and to its formation of concepts."[333] This principle states nothing about the metaphysical essence of things or the internal essence of nature; "it presents solely the answer to the question of how, from that which occurs, one may arrive at a determinate experiential concept."[334]

Secondly, Cassirer clarifies that his investigation of the principle of causality does not deal with the causal problem as such but with the causal problem of physics, by considering its epistemological significance and by understanding it "as a question of the methodology of physics."[335] And the important thing is, for Cassirer, to claim that for "the purposes of this inquiry we do not need to go beyond that version of the causal principle which is presented in the critical studies of Hume and Kant."[336] It is true that Cassirer speaks of a transcendental meaning of the principle of causality, but this transcendental sense is no longer Kantian. Cassirer analyzes the actual procedure of physics and its historical dynamism; he interrogates the fact of physical science, in order to grasp the principle of causality. I think that this principle is to be grasped through the connection he establishes between it and his conception of objectivity as *invariance*.

1. The meaning of the concept of objectivity in relation to the truth concept

Cassirer upholds a symbolic conception of scientific objectivity, which always assumes mediations: "'objectivity' is nothing in 'itself'; we can establish the sense of this concept only by bringing in a condition of the

[333] E. Cassirer, [1936] 1956, Engl. Trans, 10.
[334] E. Cassirer, [1936] 1956, Engl. Trans, 29.
[335] E. Cassirer, [1936] 1956, Engl. Trans, 24.
[336] E. Cassirer, [1936] 1956, Engl. Trans, 24.

knowledge."[337] And for him, in truth, "the problem of reality has always been inseparably connected with the problem of space."[338] Here, I repeat that this conception considers *categories* and *principles* of thought as theoretical means of bringing about the constitution of physical objects. Newtonian mechanics, Einstein's theories of special and general relativity are respectively connected to an invariance group of transformations. The Galilean group acts as a group of transformations in Newtonian mechanics; and in this context the underlying structure of Newtonian space-time is constitutively a priori. The Lorentz group is a group of transformations in special relativity, where the underlying structure of Minkowski space-time is constitutively a priori. And, "in general relativity the relevant group includes all one-one bidifferentiable transformations (diffeomorphisms), where only the underlying topology (sufficient to admit a Riemannian structure) remains constitutively a priori."[339]

Cassirer asserts that the answer that an epistemology of science gives to the problem of causality never stands alone but always depends on a certain assumption as to the nature of the object in science[340]. The objectivity of physics does not lie in the world of the *given*. The constitution of the scientific object depends on conditions and mediations; and this object denotes an ensemble of invariants relations according to the laws. The relativity of knowledge always needs to be established, according to Cassirer, in order to free the scientific object from substantialism and naïve realism. This frame of scientific objectivity devoid of subjectivism and anthropomorphism is exactly what the principle of causality requires in its heuristic role. Objectivity is connected to the truth concept.

Here, Cassirer rejects two kinds of skepticism, namely ancient and modern skepticisms: while "the ancient skeptic could not reach the absolute substance because of the relativities in which the phenomenal world involved him, the modern skeptic fails to reach laws as universal relations because of the absolute particularities of sensation. While in the former it is

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[337] E. Cassirer, [1907 (1911)] *Das Erkenntnisproblem.* Zweiter Band : Darmstadt, Wissenschaftliche Buchgesellschaft : 1991, S. 738: „‚Gegenständlichkeit' ist nichts an sich selbst; sondern was mit diesem Begriff gemeint ist, kann immer erst durch die Hinzufügung einer bestimmten Erkenntnisbedingung festgestellt werden."

[338] E. Cassirer, [1910] 1953, Engl. Trans., 286.

[339] For more details in this question, I refer to the works of Ghins (M. Ghins, 1990, 21, 22, 93 and 2007, 397–407), of Friedman (*Cf.* M. Friedman, 1999, 66).

[340] *Cf.* E. Cassirer, [1936] 1956, Engl. Trans, 6.

the certainty of things that is questionable, in the latter it is the certainty of causal connections. […] what remains is only their particular atoms, the immediate data of sensation."[341] Cassirer renounces the absoluteness and the rigidity of things and that no longer "involves […] renunciation of the objectivity of knowledge. For the truly objective element in modern knowledge of nature is not so much things as laws."[342]

Laws are also expressions of functions and Cassirer's interest in the concept of function comes from his study of the work of Leibniz, Frege and Russell on modern logic. For him, ancient or classical logic is entirely grounded on the relation between subject and predicate, on the relation between the given concept and its given and final properties. The goal of this logic is "to grasp the absolute and essential properties of absolute self-existent substances."[343] But modern logic, in the course of its development, progressively gives up this classical ideal by adopting a doctrine of pure form and relation. Cassirer clarifies that the "possibility of all determinate character of the content of knowledge is grounded, for it [modern logic], in the laws of these forms, which are not reducible to mere relations of subsumption but include equally all the different possible types of relational construction and connection of elements of thought."[344]

Cassirer insists that the rigorous meaning of objectivity and reality of physics, which moves them away from all substantialism and naïve realism, is based upon the concept of truth. The idealistic concept of truth "does not measure the truth of fundamental cognitions by transcendent objects, but it grounds conversely the meaning of the concept of object on the meaning of the concept of truth. Only the idealistic concept of truth overcomes finally the conception which makes knowledge a copying, whether of absolute things or of immediately given 'impressions.' The truth of knowledge changes from a mere pictorial to a pure functional expression."[345] That also means, for Cassirer, in general, that the further we advance into the particular conditions of the problem of reality, the more clearly it unites with the problem of truth.[346] The meaning of the truth implies the joining of the formal with the empirical. For Cassirer, there is no possible separation

[341] E. Cassirer, [1921] 1953, Engl. Trans., 390.
[342] E. Cassirer, [1921] 1953, Engl. Trans., 388.
[343] E. Cassirer, [1921] 1953, Engl. Trans., 389.
[344] E. Cassirer, [1921] 1953, Engl. Trans., 389.
[345] E. Cassirer, [1921] 1953, Engl. Trans., 391.
[346] *Cf.* E. Cassirer, [1910] 1953, Engl. Trans., 286.

between the purely formal or mathematical and the purely empirical, but an intimate symbiosis between them. The truth has to deal with statements as principles or axioms of theory that express a legality unifying physically different systems. Thus, the truth of the object depends on the truth of these principles; and it possesses no other and no firmer basis.[347]

The way Cassirer approaches the problem of reality or the object of physics in connection with the notion of truth demonstrates that he is aware of the importance of language and logic in the epistemological problematic of the constitution of the scientific object. The concept of a scientific object, which is not an immediate object, is based on the concept of truth. It concerns the connection between formal system and experiment. Truth is to be expressed in a symbolic system; that is, a system formed of symbols obeying certain rules. It is, according to Cassirer, a functional expression. The truth of physics remains an ideal and is relevant to its universal statements (principles) which aim at the unity and unification of physics.

Therefore, since there are for Cassirer different levels in the language of physics (statements of the results of measurement, statements of laws, statements of principles); in my view, truth concerns for him the connection between language and meta-language. The statements of measurements to which laws are connected occupy a foundational level, whereas the statements of principles denote a sort of meta-language. And the truth of physics is, indeed, to be grasped in the interaction of these levels of statements or languages. Thus, we can understand Cassirer's position by following what Wittgenstein, Frege and Tarski studied. Wittgenstein, indeed, established the relationship between truth and sense (its conditions) in a theory of a rigid object. Frege studied the truth in the connection between sense and reference in a theory of a non rigid and plural flexible object. Tarski examined this by differentiating between language and meta-language, and for him there is plurality of levels of truth. In this line of thought, it is clear that Cassirer is closer to Frege and Tarski than to Wittgensein.

Cassirer corrects, with regard to the empirical character of physical knowledge as such, the Kantian thesis of the relativity of knowledge which sought to free the Leibnizian concept of truth from all the unproved metaphysical assumptions that were contained in it. For Cassirer, the theory of relativity puts the functional theory of knowledge ahead of the copy

[347] *Cf.* E. Cassirer, [1910] 1953, Engl. Trans., 297–98.

theory.[348] This theory does not refer any more to a privileged reference system for the description of the phenomena of nature: it "teaches not that what appears to each person is true to him, but, on the contrary, it warns against taking appearances, which hold only from a particular system, as the truth in the sense of science, *i.e.,* as an expression of an inclusive and final law of experience."[349] This is exactly what the realistic point of view of Planck's realism highlights: the removal of the anthropomorphism of the sense-data of sensation, by taking account of what unifies the reference systems and of what really constitutes the real meaning of the concept of the scientific object. Thus, Cassirer thinks that Planck's realism "is not the opposite but the correlate of a rightly understood logical idealism. For the independence of the physical object of all particularities of sensation shows clearly its connection with the universal logical principles; and it is only with reference to these principles of the unity and continuity of knowledge, that the content of the concept of the object is established."[350]

2. Cassirer's interpretation of the principle of the causality of physics

2.1. The principle of causality as a statement of a fourth level: a transcendental statement, a constitutive but also regulative principle

Cassirer begins to criticize the picture of the Laplacean Spirit presented in his *Théorie analytique des probabilités*, where he "envisages an all-embracing spirit possessing complete knowledge of the state of the universe at a given moment, for whom the whole universe in every detail of its existence and development would thus be completely determined. Such a spirit, knowing all forces operative in nature, and the exact positions of all the particles that make up the universe, would only have to subject these data to mathematical analysis in order to arrive at a cosmic formula that would incorporate the movements both of the largest bodies and of the lightest atoms. Nothing would be uncertain for it; future and past would lie

[348] *Cf.* E. Cassirer, [1921] 1953, Engl. Trans., 392.
[349] E. Cassirer, [1921] 1953, Engl. Trans., 393.
[350] E. Cassirer, [1910] 1953, Engl. Trans., 308.

before its gaze with the same clarity."[351] Cassirer mentions that this Laplacean formula only represented, for Laplace himself, an incidental, an ingenious *aperçu*, a thought-experiment which was audaciously sketched out and developed to its logical conclusions, but whose true grounds, unfortunately, remained in darkness.

Cassirer does not share the opinion according to which the defenders as well as the attackers of the causality principle of classical physics seem to state boldly that this Laplacean picture is to be used spontaneously in order to clarify the nature of a strictly deterministic view of the world.[352] He finds it almost incomprehensible that it has played so a significant or decisive role in the debate on the general problem of causality in the beginning of atomic physics. How should this Spirit have, asks Cassirer, acquired the complete knowledge of the initial conditions of all particles? Now, modern physics "has given up the presupposition on the basis of which the cognitive ideal of the Laplacean spirit was conceived. It denies the possibility of grasping all physical happening by reduction to the motions of simple mass points."[353]

Cassirer affirms that "long before Laplace, Leibniz had formulated very precisely the conception that was at the basis of his thought. In fact, he had even created the characteristic symbol that incorporated this conception. That everything is brought forth through an established destiny."[354] That means that Leibniz has already thought out the metaphysical character of the causal problem: "Substance is for Leibniz nothing else than this necessary law of self-unfolding, and the strict concept of causality must be restricted to this alone […] Causality only signifies a connection to be assumed in the simple substance itself between its original force and the products or effects produced by it."[355] Cassirer maintains that "Leibniz' determinism is metaphysical mathematicism."[356] Mathematics has access to physical nature, because nature is endowed with same infallibility possessed by the rules of mathematical thought and inference: the "causal demand of Kepler and Galileo, of Descartes and Leibniz expressed no more than the conviction of the identity of mathematics and nature."[357]

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[351] E. Cassirer, [1936] 1956, Engl. Trans, 3.
[352] *Cf.* E. Cassirer, [1936] 1956, Engl. Trans, 3.
[353] E. Cassirer, [1936] 1956, Engl. Trans, 8–9.
[354] E. Cassirer, [1936] 1956, Engl. Trans, 11.
[355] E. Cassirer, [1936] 1956, Engl. Trans, 14.
[356] E. Cassirer, [1936] 1956, Engl. Trans, 12.
[357] E. Cassirer, [1936] 1956, Engl. Trans, 12.

For Cassirer, the principle of causality belongs to the structure of scientific experiment within which the objects as such are to be constituted or have to be established. He is convinced of "the fact that epistemology in general has not yet distinguished sharply and clearly between the different types of physical statements."[358] Leaning on Russell's theory of the types, which managed to remove certain paradoxes and confusions of set theory, by stipulating that "it is not permissible to treat elements and classes as objects of like order, that they are heterogeneous with respect to each other and belong to different spheres (*sphärenfremd*),"[359] Cassirer points out that "physical statements confront us with a similar problem."[360] Strictly speaking, the world of physics has nothing to do with the world of the given. Statements of the results of measurements represent the first step in that decisive transition which leads from the world of the given to the world of scientific knowledge, from the world of sense to the world of physics.

As I have already stressed, it is important for Cassirer to insist that only through the mediation of the statements of the results of measurements "can the concepts and judgments of physics refer to an object and thus attain to objective significance and validity."[361] Here, it is only possible to define a physical entity and property by stating its characteristic numerical values. In determining, for instance, the pressure, volume, and temperature of a gas, the potential or kinetic energy of a system, the electric or magnetic field strength, we gain precisely in this way what physics grasps by its different objects. In other words, the determination of the constancy of a particular physical entity depends on the specific properties ascribed to it by the values of the determining system applied to it. Hence, there is no need to posit objects as sundered beings-in-themselves underlying these determinations.

The second level of physical statements is that of the statements of laws. As in Russell's theory of types, laws no longer denote the mere aggregate of physical facts and are in their nature completely different from the facts resulting from their measurement. For Cassirer, the mere 'Here-thus' which characterizes the particular statements of the results of measurement "undergoes a characteristic transformation in the statements of laws: it is

[358] E. Cassirer, [1936] 1956, Engl. Trans, 30.
[359] E. Cassirer, [1936] 1956, Engl. Trans, 31.
[360] E. Cassirer, [1936] 1956, Engl. Trans, 31
[361] E. Cassirer, [1936] 1956, Engl. Trans, 36.

converted into an 'If-then.' And this 'If-then,' this hypothetical judgment, *If x, then y,* does not merely combine particular quantities which we consider as belonging to and localized in definite points in space-time, but pertains rather to whole classes of magnitudes, classes which consist generally of infinitely many elements."[362] More precisely, it is impossible, according to Cassirer, to affirm, as does Mill, that a physical law is nothing more than an aggregate of particular truths, that a statement of law is nothing but a comprehensive expression, whereby an indefinite number of individual facts are asserted or denied at once; since "the question always remains open as to what right one has to say anything at all about 'an indefinite number of individual cases,' if each one has not been previously tested and examined."[363]

But, it is evident for Cassirer, that physical experiment offers a proper and solely legitimate foundation for all statements of law. On this ground, it no longer entails such a comprehensive examination but rather actually rejects it. Here, let me repeat that Cassirer always stresses the necessary and universal character of scientific experiment which ascribes to the individual fact of measurement a kind of factor of permanence; that is, experiment attaches to the established datum, which in and of itself refers and is limited to a specific here and now, an inference free of restriction and endowed with reproducibility. Nevertheless, this "represents not an extension within the space-time realm but in a certain sense an abrogation of the whole realm. Advance is made in a new dimension, and it is this change of dimension that distinguishes the statements of laws from the mere statements of the results of measurements."[364]

The statements of principles represent the third level of physical statements. Through a detailed study of the evolution of the principle of 'least action' under its various successive forms as developed by Fermat, Leibniz, Maupertuis, Euler, Lagrange, Gauss, Helmholtz, Hamilton, Einstein, Schrödinger etc., Cassirer identifies the essence and the function of physical principles.[365] These are rules permitting thought to connect various laws with each other. It is by means of such rules that Maxwell, for instance, was able to discover and to establish the identity of essence between light and

[362] E. Cassirer, [1936] 1956, Engl. Trans, 41.
[363] E. Cassirer, [1936] 1956, Engl. Trans, 40, 41.
[364] E. Cassirer, [1936] 1956, Engl. Trans, 41–42.
[365] *Cf.* E. Cassirer, [1936] 1956, Engl. Trans, 48–51.

electricity. Principles are also matrices from which it is possible to generate new laws. They possess a regulating character and are heuristic. They "do not stand on the same level as laws, for the latter are statements concerning specific concrete phenomena. Principles are not themselves laws, but rules for seeking and finding laws. This heuristic point of view applies to all principles. […] They refer not directly to phenomena but to the form of the laws according to which we order these phenomena."[366] For Cassirer, as I have already shown, the principles of physics only possess a hypothetical value: they are basically "means of orientation, means for surveying and gaining perspective."[367] Nevertheless, the difference between principle and law is not to be strictly established; for Cassirer asserts that the energy principle, for example, "which has so well justified itself in its universality, is and remains a particular law of nature."[368]

To characterize these three levels of physical statements purely formally and methodologically is, for Cassirer, to establish that the statements of the results of measurements are individual, statements of laws general, and statements of principles universal. However, the significant thing is that these three levels belong to a definite logical rhythm, which "expresses an organization within empirical knowledge, an organization which is an integral part of the concept of empirical knowledge and is indispensable for it."[369] Thus, it is evident that the entire system of physics no longer denotes "a mere aggregate or simple sum of these statements."[370] These latter "are determined through one another, they mutually condition and support one another, and their specific 'truth' is due precisely to this mutual interconnection. This reciprocal interweaving and bonding constitutes one of the basic features of the system of physics. […] There is only a functional coordination in which all the elements, all the determining factors of physical truth, uniformly participate."[371] In this organization the statements of the results of measurements are considered by Cassirer "as the alpha and omega of physics, its beginning and end. From them all its judgments take their departure and to them they must all lead back again."[372]

[366] E. Cassirer, [1936] 1956, Engl. Trans, 52.
[367] E. Cassirer, [1936] 1956, Engl. Trans, 53.
[368] E. Cassirer, [1936] 1956, Engl. Trans, 57.
[369] E. Cassirer, [1936] 1956, Engl. Trans, 54.
[370] E. Cassirer, [1936] 1956, Engl. Trans, 36.
[371] E. Cassirer, [1936] 1956, Engl. Trans, 35.
[372] E. Cassirer, [1936] 1956, Engl. Trans, 36.

The principle of causality constitutes for Cassirer a kind of fourth order in the types of physical statements. It adds nothing to the content of physical knowledge as such. It is neither a faith, nor an innate idea, nor an effect of our mental organization; because this principle has a transcendental function. This principle is not a natural law in the usual sense of the word. In this respect, Cassirer thinks that Mach is correct in affirming that "there is no cause and no effect in nature; for nature is present only once, and those same events to which we refer when we say that under the same circumstances the same consequences occur do not exist in nature but only in our schematic reproduction of it."[373] What does this transcendental function mean exactly? Does Cassirer simply adopt the Kantian meaning of this concept and does he merely opt for Kantian critical determinism?

Kantian critical determinism denied any principles lying in trust and faith; it cannot appeal to a mere compulsion of thought, to a necessity grounded in our mental organization. Kantian a priori does not deal with this kind of appeal. Kant rejects the subjective view: the concept does not rest on an arbitrary subjective necessity implanted in us.[374] Cassirer clarifies that the causal law must not to be looked upon as an *idea innata* in which we may trust simply on the basis of its evidence; instead, its validity to nature must be demonstrated for the things of experience, but at the same time restricted to nature. In the Kantian sense, this restriction does not imply that its significance is diminished, for we cannot carry the concept of objectivity beyond the realm of experience.[375] However, Cassirer criticizes Kant for not following to the end the road the arguments he used in developing his solution to "the Humean problem. In the deduction of the causal principle which he gave in the 'Analogies of Experience,' he directed the question once more to empirical things and phenomena, instead of directing them exclusively to empirical cognition, to the form of experience."[376]

[373] E. Mach, „Die Ökonomische Natur der physikalischen Forschung," *Populärwissenschaftliche Vorlesungen* (2d ed. 1892), p. 221; English trans., T. J. McCormack, *Popular Scientific Lectures,* Chicago, 1895; quoted by E. Cassirer, [1936] 1956, Engl. Trans, 58.

[374] *Cf.* I. Kant, *Kritik der reinen Vernunft* (2d ed.), S. 167; quoted in E. Cassirer, [1936] 1956, Engl. Trans, 59.

[375] *Cf.* I. Kant, *Kritik der reinen Vernunft* (2d ed.), S. 272; quoted in E. Cassirer, [1936] 1956, Engl. Trans, 59.

[376] E. Cassirer, [1936] 1956, Engl. Trans, 59–60.

For Cassirer, not only Laplacean or Leibnizean metaphysical determinism but also the Kantian conception of causal law, do not deal with the principle of the causality of physics as such. Their critical determinism only provides to him "a point of departure;"[377] but it no longer means that Cassirer opts for it. It is evident, for Cassirer, that Hume and Kant reached the decisive advance in the analysis of the causal problem; for they rendered obsolete a formulation according to which it is possible to consider the causal problem as a simple connection between things, or to prove or disprove it in this sense.[378] He is convinced, however, that Hume and Kant continue to talk the language of daily life, when "they discuss the causal connection in concrete examples."[379] In the context of his general methodological approach, Hume tries to hold as closely as possible to the sphere of the immediately familiar, of the given in sense perception. He establishes the thesis that between cause and effect there must be a direct relationship, as though it were visible and tangible, that they have to be connected through their direct contiguity in space and their immediate sequence in time. The process of association can gain validity only through such contiguity, whereupon the formation of the causal concept is grounded.[380]

Kant also "speaks not infrequently as though it were sufficient, in order to define a causal connection, to observe the different states of one and the same thing in their simple succession and as though from this observation we could ascertain immediately the earlier state as the cause of the latter."[381] For instance, whether we observe a ship being carried downstream, we cannot arbitrarily affect the order of our perceptions of this ship at various times. The perception of it downstream always follows the perception of it upstream, and this objective sequence, which differs from mere subjective apprehension, is determinable only if one state is regarded as cause and the other as effect. But, it appears, according to Cassirer, that "from the standpoint of a scientific clarification of causality this example is an inadmissible simplification. In order to connect the two positions upstream and downstream, it is not sufficient to note merely their temporal sequence. We must ask about the forces with which we are here dealing. If we dismiss from the

[377] E. Cassirer, [1936] 1956, Engl. Trans, 24.

[378] *Cf.* E. Cassirer, [1936] 1956, Engl. Trans, 20.

[379] E. Cassirer, [1936] 1956, Engl. Trans, 21.

[380] *Cf.* D. Hume, *A Treatise of Human Nature,* Bk. I., Pt. III, sec. 2 ; quoted in E. Cassirer, [1936] 1956, Engl. Trans, 21.

[381] E. Cassirer, [1936] 1956, Engl. Trans., 21.

notion of these forces all connotations of thing or substance, we will obtain ultimately certain universal laws – the law of gravity, the laws of hydrostatics and hydrodynamics, etc. – which we regard as determining the movements of the ship. These laws are the real components of the assumed causal connection, but in order to formulate them exactly physics has to employ its own symbolic language, which is far removed from the language of 'thing.'"[382]

Cassirer maintains that the causality principle is "a transcendental statement, referring, not to objects, but rather to our cognition of objects in general […] Instead of being a direct statement about things, it must be viewed as a statement about our empirical knowledge of things – that is, about experience"[383]. Here, it is important to point out that Cassirer's use of the transcendental concept is not at all Kantian, for it is essentially dealing with experience, whereas Kant highlights the transcendental concept as "the mode of our knowledge insofar as this mode of knowledge is to be possible *a priori*;"[384] that is, Kant sets up the primacy of this *a priori* mode of knowledge over the objects which are to be known. For Cassirer, it is not the pure rules or laws of the understanding but the experience itself which represents the main factor defining the causality principle connected to the objectivity concept. Hence, the conditions of objectivity prove to be *eo ipso* conditions of the possibility of objects of experience, they provide the conditions for the existence of these objects.

Cassirer explains that the causal principle does not denote a new insight which concerns content, but is one which only deals with method. It designates a postulate of empirical thought, which postulate specifies fundamentally nothing more than that a process without limitation is possible. This process is precisely a process of translating the data of observation into exact statements of the results of measurements, or a process of gathering together the results of measurements into functional equations by means of general principles. Thus, this process remains a task which is never complete. What the causal principle requires and axiomatically presupposes is: "that the completion can and must be sought, that the

[382] E. Cassirer, [1936] 1956, Engl. Trans., 22.
[383] E. Cassirer, [1936] 1956, Engl. Trans, 58.
[384] E. Kant, *Kritik der reinen Vernunft,* 2. Auf., S. 25: „Ich nenne alle Erkenntnis transzendental – ... – die sich nicht sowohl mit Gegenständen, sondern mit unserer Erkenntnisart von Gegenständen, sofern diese a priori möglich sein soll, überhaupt beschäftigt;" quoted in E. Cassirer, [1936] 1956, Engl. Trans, 17.

phenomena of nature are not such as to elude or to withstand in principle the possibility of being ordered by the process we have described."[385] The causal principle is to be understood in this sense: it "belongs to a new type of physical statement, insofar as it is a statement about measurements, laws, and principles. It says that all these can be so related and combined with one another that from this combination there results a system of physical knowledge and not a mere aggregate of isolated observations."[386] Therefore, it is clear that for Cassirer the causal principle is endowed with a constitutive but also regulative sense.

2.2. Causality as 'conformity to laws'

In his *Queries* to his *Optics*, Newton believed that the mechanical universe required the active intervention of God, not just to create and to order it, but also to maintain it. Newton postulated the existence of a God, who is responsible for the orderly evolution of the physical universe. But he did not believe that the mathematical laws as represented in his *Principia* were in themselves sufficient to explain or to predict the long-term stability and future evolution of the physical universe. Thus, for James Cushing, it "was only after Newton that the determinism and complete predictive accuracy of his laws of mechanics became accepted."[387] How did physicists and mathematicians arrive at the establishment of determinism?

A strong reason for believing in the determinism of science is grounded on the fact that the laws of mechanics and of gravity accounted for the locations of the planets and of comets over long periods of time; that is, physicists started with the observed phenomena of the world (astronomical data as embodied in Kepler's three empirical laws) and then built a theoretical framework, namely: Newton's laws of motion and of gravitation, to account for these phenomena and to make new quantitative predictions. It was in these Newtonian laws or equations, which represent our world, that they discovered and explored the property of determinism. They went beyond a mere instrumentalist view of the laws of science (in which they require only the empirical adequacy of our laws and nothing more) and

[385] E. Cassirer, [1936] 1956, Engl. Trans, 60.
[386] E. Cassirer, [1936] 1956, Engl. Trans, 60.
[387] J.T. Cushing, 1998, 170.

considered them realistically as literally true representations of the world.[388] Can determinism be both a property of the theories or equations of physics and a property of the actual world itself? Could all the phenomena be, in principle, explained by means of the determinist laws of the mechanics of points?

The deterministic view of mechanics can be understood if we consider an example of an isolated system consisting of two massive points in gravitational interaction obeying the laws of the classic mechanics of points. In this case, the exact and precise knowledge of what we call the initial state, the initial conditions (position and velocity) of material points and of force at a given time, would allow to determine, in a unambiguous way, the position and the velocity of the material points at any other time. Could all the natural phenomena or processes be reducible to motions of massive points, obeying the laws of Newton's mechanics of points? Could physics be reduced to mechanics?

Physics also deals with other physical phenomena, such as weather, for which it can obviously possess only short-term predictive power (two or three days at best), rather than the long-term predictive power it seems to have for the planets of the solar system. The previous conception of the determinism of science stipulated that systems consisting of only a few parts, for instance the planets moving about the sun, are amenable to the precise calculations necessary for meaningful prediction; whereas complex systems, such as a collection of gas molecules or the atmosphere are simply beyond our calculational abilities. The state of certain physical systems can be designed by magnitudes other than positions and velocities; and the evolution of these systems obeys, for instance, the laws of thermodynamics, of quantum mechanics. If nature is such as Laplace thinks it, we have to try hard to discover the determinist nature of causal laws. Does the failure of mechanism entail the denial of determinism as such? Does probabilism involve indeterminism? Are the laws which govern elementary processes, such as the motions of the molecules of a gas, determinist laws? Do the uncertainty relations mean an absence of determinism?

Quantum mechanics is probabilistic. For Werner Heisenberg, determinism would have been demolished by quantum mechanics. Concerning the uncertainty relations, Heisenberg asserts that "all statements in physics have a relative character in that they can express the state of the observed object

[388] *Cf.* J.T. Cushing, 1998, 172–73.

never 'in itself' but merely in relation to the means of observation used."[389] This dependence on the instruments of observation becomes decidedly significant within the realm of microphysics, which said dependence "prevents us in principle and once and for all from making statements which exceed a certain measure of precision."[390] For Cassirer, the most important and also epistemologically significant thing is that Heisenberg's uncertainty relations impose a limit which can no longer be ignored in microphysics. This limit concerns both the experimental techniques and the formulation of physical concepts.[391]

Whenever and wherever he formulates a physical concept, a physicist has to be aware of this limit in order to remove any ambiguity from it. For instance, when he speaks of the position of an electron, he has to "indicate definite experiments for determining this position. The electron could be illuminated and observed under a microscope. It then turns out that the shorter the wave length of the light used, the more precise will be the determination of position. But on the other hand, the shorter the wave length chosen, the more strongly the 'Compton effect' becomes noticeable: the light which hits the electron and is reflected or deflected by it changes the momentum of the electron. The electron receives a recoil which becomes greater the greater the frequency – that is, the smaller the wave length chosen."[392] In the light of this illustration, we understand the way it is basically not possible to measure simultaneously the position and the velocity of an electron with the desired accuracy: the more accurate the measurement of position, the more inaccurate will be that of velocity, and vice versa. Due to the 'Compton effect' the uncertainty relations are established. The product of the quantity Δx (measurement of position) and that of Δmv (measurement of momentum) can never be reduced below a certain value which is of the order of magnitude of the elementary quantum of action.

There is uncertainty, because the influence of the means of observation on the object to be observed has to be regarded as a not entirely controllable disturbance. It is exactly in such a way that the speed of an electron is altered by the Compton recoil through the simple fact of observation due to

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[389] E. Cassirer, [1936] 1956, Engl. Trans, 122.
[390] E. Cassirer, [1936] 1956, Engl. Trans, 122.
[391] *Cf.* E. Cassirer, [1936] 1956, Engl. Trans, 122.
[392] E. Cassirer, [1936] 1956, Engl. Trans, 122–23.

the light rays – required to carry out the observation. This means, according to Heisenberg, that we have to finally and forever to abandon the idea of objective occurrences in space-time which do not depend on all observation.[393]

Hence, Cassirer cites Heisenberg who asserts that in the precise formulation of the causal law: 'if we possess exact knowledge of the present, we can determine the future,' "not the consequence but the antecedent is wrong. As a matter of principle, we cannot come to know the present in all its determinative factors. […] Since all experiments are subject to the laws of quantum mechanics (and thus to the equation $\Delta x\ \Delta mv\ \geqq\ h$) the invalidity of the causal law is definitely established by quantum mechanics."[394] However, Cassirer objects to Heisenberg's interpretation which leads to his direct denial of the causal law. First of all, from the point of view of physics itself, Cassirer shows that we are dealing of course in Heisenberg's argument with a truly precise formulation of the causal law. What Heisenberg rejects is rather a certain form of the causal principle presented by the model of the Laplacean Formula which Cassirer finds to be subject to grave theoretical faults, even without considering the uncertainty relations. Whether to this inexact formulation we substitute Helmholtz's critically refined formulation of the causal principle expressing "the demand of causality merely by the general requirement of conformity to law, the Heisenberg uncertainty relations no longer constitute an exception."[395]

More precisely Cassirer clarifies that in classical physics, Helmholtz had already reflected upon this procedure of physics with the greatest clarity and precision. Helmholtz' formulations constitute the highest and most mature insights which classical physics had gained in its determination of the causal problem. But Cassirer remarks that it is "strange and striking that in modern discussions of the causal problem the name of Laplace is met with almost constantly, the name of du Bois-Reymond very often, but the name of Helmholtz seldom or never."[396] This strikes him as a palpable shortcoming; since in critical perspective and depth he feels that there is hardly another

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[393] *Cf.* E. Cassirer, [1936] 1956, Engl. Trans, 128–29.

[394] W. Heisenberg, "Über den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik", *Zeitschrift für Physik, 43* (1927), 197; quoted in E. Cassirer, [1936] 1956, Engl. Trans, 123.

[395] E. Cassirer, [1936] 1956, Engl. Trans, 123.

[396] E. Cassirer, [1936] 1956, Engl. Trans, 61.

scientist of the nineteenth century who compares with Helmholtz. Helmholtz is "the genuinely classical representative of modern empiricism. On the one hand he covered almost the whole range of the natural sciences – he was a physicist, electrochemist, physiologist, and psychologist; and on the other hand, he was concerned in all his specialized investigations with extending and making precise the evidences for empiricism."[397] Hence, Cassirer thinks that if we need a truly representative expression of what classical physics understood by the causal problem, it is to be found in the writings of Helmholtz: causality expresses "orderliness according to law (*das Gesetzliche*) in phenomena. What we call 'cause' can be understood and justified only in this sense, even though in the common use of language the word is employed in a very confused way for antecedent or condition."[398]

In fact, Cassirer acknowledges that the way Heisenberg proves and derives uncertainty relations does not evidently contradict causal thought and inference as such; because the theory of the Compton Effect, upon which this proof is grounded, uses precisely this type of thought. Obviously, the mechanism of interaction between electrons and photons, in the sense of introducing definite forces acting between particles of matter and light and describing the temporal process of the observed events in the usual manner of mechanical systems, does not apply. Moreover, the directions assumed by particle and photon after collision, cannot be determined accurately. But, Cassirer mentions that "the mechanical laws of particle collisions are applied to the collisions between light quanta and electrons in such a way that the final results are determined on the one hand by the principles of the conservation of energy and momentum, and on the other by Planck's relation between energy and frequency."[399] Thus, the basic postulate of quantum theory is linked in a definite and characteristic manner to the principles of conservation of energy and momentum, both of which have to be regarded as pure and typical causal principles. For this reason, the uncertainty relations have served to reinforce the bridge between quantum theory and classical physics; and the causal principle remains a true invariant.

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[397] E. Cassirer, [1936] 1956, Engl. Trans, 61.
[398] E. Cassirer, [1936] 1956, Engl. Trans, 62.
[399] E. Cassirer, [1936] 1956, Engl. Trans, 124.

Secondly from an epistemological and logical point of view, Cassirer proves that uncertainty relations no longer contradict the causal principle. He reminds us that the logical form of the causal law is a hypothetical statement of the type: *If x, then y* ($x \rightarrow y$). According to logic, this statement can also be true, even if x (antecedent) is false; that is, the fact that x is false does not imply that the hypothetical relation is invalid. The universal validity of this relation is not altered. Therefore, Cassirer stresses that when "the uncertainty relations show that certain causal judgments in physics contain a false premise, they still say nothing about the form of the hypothetical conclusion. […] the problem does not concern the causal relation as such, but only the places for the independent variables in this relation: the values for the variable x must be 'permissible' values, in order to give the causal relation a definite unambiguous meaning. From the point of view of physics, however, only those values are permissible that can be determined by a certain mode of measurement which must be accurately stipulated."[400] In physics, determinism is established even if the initial conditions are not completely known.

It is true that Planck asserted that an event is to be regarded as causally determined if it can be predicted with certainty. He added at once, however, that this simple definition was not adequate. For even in classical physics it is not possible in a single instance to really predict a physical event accurately[401]. To avoid this dilemma Cassirer thinks that the principle of causality should be formulated as "a proposition concerning cognitions, instead of trying to understand it as one concerning things and events. We must think of it as a guide-line which leads us from cognition to cognition and thus only indirectly from event to event, a proposition which allows us to reduce individual statements to general and universal ones and to represent the former by the latter. Understood in this sense, every genuine causal proposition, every natural law, contains not so much a prediction of future events as a promise of future cognitions"[402]. Cassirer defends the determinism of the equations of scientific laws. Later on, in his *The Concept of Causality in Physics*, Planck finally makes a similar point by asserting that "there remains causality, or mathematically deterministic evolution, for

[400] E. Cassirer, [1936] 1956, Engl. Trans, 124–25.

[401] *Cf.* M. Planck, "Die Kausalität in der Natur", *Wege zur Physikalischen Erkenntnis* (Leipzig, 1933), S. 236; E. Cassirer, [1936] 1956, Engl. Trans, 65.

[402] E. Cassirer, [1936] 1956, Engl. Trans, 65.

the wave function (ψ) itself in the sense that a knowledge of the present value for ψ uniquely determines, via the dynamics of the Schrödinger equation, the value of ψ at any future time."[403]

If causality is conformity to law in phenomena, it is necessary to recognize that the functional laws do not exhaust classical scientific rationality. In the nineteenth century probabilistic laws were interpreted in a such way as to conceive a different understanding of scientific rationality. For Cassirer, von Mises has offered the simplest and most consistent solution concerning the determinable characteristic of probability laws. Von Mises defines the concept of the collective by means of two postulates: the postulate of the existence of a 'limiting value of the relative frequency,' and the so-called postulate of 'randomness,' the principle of the impossibility of a gambling system. When he explains a collective as being a mass phenomenon, or a repetitive process, an extended sequence of individual observations appearing to justify the assumption that the relative frequency of the occurrence of each particular observed feature tends toward a definite limiting value, he is emphasizing that such a collective is not an empirical object but an idealized conception similar to that of the sphere in geometry or of the rigid body in mechanics[404].

Boltzmann succeeded in introducing a new kind of physical conformity to law and gave the second law of thermodynamics equal rank with 'dynamic' laws. He gave it "exact form in his law that entropy is proportional to the logarithm of the probability $S = k \log W$."[405] The statistical laws apply to the knowledge of the initial conditions of the phenomena, whereas the dynamic laws refer to the knowledge of the course of events. For Cassirer, the characteristic difference between causality and probability remains but they have to "exist side by side when we want to determine an event as completely as possible."[406] Both probability laws and dynamic laws interweave and only in this way the universal form of 'orderliness according to law' arises.

It is obvious, as Cassirer points out, that this epistemological justification of statistical statements does not materially escape the path already drawn by Galileo for the all the exact sciences. It must begin with the process that

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[403] J. T. Cushing, 1998, 298.
[404] *Cf.* E. Cassirer, [1936] 1956, Engl. Trans, 94.
[405] E. Cassirer, [1936] 1956, Engl. Trans, 77.
[406] E. Cassirer, [1936] 1956, Engl. Trans, 104.

Galileo called *mente concipio,* of which he makes great use, for example, in formulating his inertia law. It is just as impossible to encounter a collective as it is to find a body independent of external influences, but "there is a significance in the search for empirical facts that approximate the requirements contained in both concepts. These facts can then be subsumed under the ideal, hypothetically established concept – that is, they can be determined by means of the conditions deducible as consequences from it."[407]

Besides, for Cassirer, this methodological difference by no means concerns only statistical mechanics. He finds its exact analogy in Newton's mechanics, which has also to acknowledge a realm of contingency in addition to the realm of necessity; a distinction through which serious epistemological difficulties arise. Newton has fully understood that the mathematical formulations of the mechanical laws he established are by no means capable of answering "all the questions put to us by the structure of the universe. Newton's law of gravitation determines what will happen under the presupposition of a certain distribution of masses in space; however, it does not give any information concerning the state of this distribution. Newton concludes, in the face of this relative uncertainty, that we have to introduce at this point a different kind of ground; he takes refuge in teleological considerations."[408] Newton went on to emphasize the fact that the orbits of the different planets of the solar system "are nearly in the same plane and that their movements follow the same direction, and that the same is true of the satellites which accompany the individual planets: all this cannot have 'merely mechanical' causes. This marvelous arrangement of the solar system could only arise from the dominion of a wise and powerful being. Here we have to go back to an immediate divine decree: *Deus corpora singular ita locavit*."[409]

Modern positivism has not only set up the requirement of *savoir pour prévoir*, but has finally explained the *savoir* by the *prévoir*; that is, it has reduced the former to the latter. Helmholtz criticizes such a pragmatic limitation. He defends a purely theoretical ideal of physical truth which leads him to the analysis of the causal concept: "Any particular fact taken by itself", he once said, "may perchance arouse our curiosity or amazement,

[407] E. Cassirer, [1936] 1956, Engl. Trans, 95.

[408] E. Cassirer, [1936] 1956, Engl. Trans, 105.

[409] *Cf.* I. Newton, "Scholium Generale," *Principia,* ed. T. Le Seur and F. Jacquier, *3* (Geneva, 1742), 672f ; quoted in E. Cassirer, [1936] 1956, Engl. Trans, 105.

or it may be useful to us for practical application. Only the coherence of the whole, however, and precisely because of its conformity to law, yields intellectual satisfaction."[410] The concept of complete prediction of the future from the past is no longer a sufficient indicator or the sole determining factor in the formulation of the causal law: "The knowledge of this conformity proves and justifies itself by predicting the future; but this prediction together with the technical mastery of nature founded upon it is not the sole and essential significance of this knowledge."[411] In fact, the strict prediction always needs not only the knowledge of general laws, but also the exact knowledge of initial conditions, which knowledge is attainable only within definite limits. Helmholtz does not reject the character of the prediction of the laws of nature as such, but if it is true that the conformity to law is verified by the prediction, it is not merely to be reduced to it. Cassirer reinforces this point of view by noticing that "the strict Laplacean ideal enjoyed validity only in certain particular domains, such as astronomy, whereas it lost this validity in fields like hydrodynamics or elasticity theory."[412]

Indeterminism signifies by no means that, because of the use of the probability in the quantum statements, these statements lose their rigor. There is in quantum mechanics a total certainty at the level of the fundamental constants which are absolutely invariant and defined: the essential precision and constancy is gained by affirming the invariability in all theoretical descriptions of natural events. A definite system of universal constants of nature is established; namely: the speed of light, the charge or mass of an electron, the mass of a proton, etc. which are regarded as absolutely definite quantities that always have the same value.[413] Thus, nothing is indefinite. Heisenberg assures us that "the general procedure of quantum mechanics consists of ascribing to every quantity in classical mechanics, such as the momentum or energy of the electrons, a corresponding matrix. Then, in order to go beyond a mere presentation of the empirical situation, these matrices must be combined according to laws, in the same

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[410] Helmholtz, "Über die Erhaltung der Kraft" (Vorttragszyklus 1862), *Vorträge und Reden*, 1, 191; quoted in E. Cassirer, [1936] 1956, Engl. Trans, 64.

[411] E. Cassirer, [1936] 1956, Engl. Trans, 64.

[412] E. Cassirer, [1936] 1956, Engl. Trans, 65 ; in this connection Cassirer refers to P. Frank, *Das Kausalgesetz und seine Grenzen* (Vienna, 1932), pp. 41 ff.

[413] *Cf.* E. Cassirer, [1936] 1956, Engl. Trans, 121.

way the corresponding quantities in classical mechanics are combined by the equations of motion."[414]

There are particular certainties, for example, in Planck's law of radiation, in the Balmer series of the hydrogen spectrum, in the formula for atomic heat, etc. which always lead back to the general certainty. Furthermore, the elementary quantum of action represents "the fixed frame, into which all statements of quantum theory are fitted; and the security and firmness of this frame alone ought to be sufficient to protect the indeterminism of the theory against those speculative interpretations to which it was exposed in the transition from physics to general conclusions concerning man's *Weltanschauung*."[415] And Cassirer is convinced that the uncertainty relations do not deviate from this frame of quantum theoretical determinism. Whenever a physicist formulates scientific laws, he has to take account of the uncertainty relations in order to make them conform to the conditions of our empirical knowledge. To face a new problem requires for physics a fresh determination and interpretation of the old concepts in order to be applicable without ambiguity.

The uncertainty relations make possible the creation or the outcome of a definite empirical concept of what occurs. Cassirer emphasizes that the purpose of this outcome has to be led by experience itself when it comes to the establishment of empirical concepts. Experience teaches us that there are definite, precisely definable limits in our empirical formulation of concepts. Thus, the form of our causal judgments has to remain compatible with them, in conformity with the new conditions which are now indicated for the application of causal thinking. For Cassirer, quantum mechanics has by no means renounced the requirement of determination; but it had to arrive at new conceptual means in order to do justice to it and, by means of it, to penetrate successfully into the factual realm newly discovered by the quantum physicists. Thus, Schrödinger's wave equation, Heisenberg's square array, Born and Jordan's matrix mechanics, Dirac's "*q*-numbers", constitute conceptual means by which a strict coordination of observable quantities is made possible. Hence, Cassirer agrees with Heisenberg that "a causal law of quantum mechanics which states that if at any one time certain physical quantities are measured as accurately as in principle possible, there exist quantities at any other time whose value can be precisely calculated, or

414 E. Cassirer, [1936] 1956, Engl. Trans, 121.
415 E. Cassirer, [1936] 1956, Engl. Trans, 122.

in other words for which the results of measurement can be precisely predicted."[416]

This statement expresses the conformity to law, which is, according to Cassirer, prior to objectivity and determines what exactly objective reality denotes. Objectivity or objective reality is "attained only because and insofar as there is conformity to law – not vice versa"[417]. The principle of causality concerns the demand for order according to law, the demand for functional determination, which is not affected in quantum mechanics but rather proves still to be the *true invariant*.[418] The concrete form of natural knowledge is completely determined by this invariant.

3. Conclusion

To summarize the foregoing developments, two subsequent facts stand out. On the one hand, Cassirer's conviction is that the determinism of nature defended by Laplace is no longer a scientific but a metaphysical thesis. In agreement with Mach and Helmholtz, Cassirer upholds the determinism of laws and not that of the physical events themselves as such. But these laws are to be grasped in their connection with measurements and principles; that is, scientific determinism deals with the statements in which measurements, laws and principles interweave. The principle of causality concerns the demand for order according to law. It is endowed with a constitutive but also a regulative sense. Hence, objectivity is to be defined and grasped within this frame of the conformity to law. It is important, as Kant emphasized, that the general concept of causality has to be specified in a definite sense, in order to be usable and applicable empirically. However, Cassirer no longer seeks this specification in the same way that Kant did; for Kant still continued to talk the language of daily life and was satisfied by merely referring the concept of causality to the purely sensuous schemata, to the perceptual forms of space and time.

On the other hand, since the failure of mechanicism by no means entails the denial of determinism as such, Cassirer supports the claim that uncertainty relations do not threaten the determinism of physics. They only

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[416] W. Heisenberg, *Die physikalischen Prinzipien der Quantentheorie*, p. 45; E. CASSIRER, 1956, Engl. Trans, p. 127–128.

[417] E. Cassirer, [1936] 1956, Engl. Trans, 132.

[418] *Cf.* E. Cassirer, [1936] 1956, Engl. Trans, 166.

impose significant limitations upon the scope and extent of determinism. In both classical and modern physics only a relative knowledge can be attained and secured. The precision of measurements can never be increased beyond a certain limit; the results of measurements depend on the nature of the employed physical apparatus and are determinable not absolutely but only in relation to it. This condition could only be avoided if physicists were able to know immediately or intuitively the initial conditions of physical events.

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Georges Ibongu shows that Cassirer adopts a sort of structural realism in his writings on physics. Cassirer does not deny the existence of physical entities. For him, however, a physical entity loses its absolute fixity and is involved in the process of physical knowledge. The electron is a definite object but cannot, as an individual, be designated by being here and now. The individuality of simple particles means, for Cassirer, that they are only describable as *points of intersection* of definite relations or structures.

With a doctoral scholarship and a scientific supervision of the "Université catholique de Louvain-La-Neuve" Georges Ibongu had defended the entitled thesis: ≪Fonctionnalité et symbolicité en physique. Eléments dépistémologie cassirérienne≫ at the "Facultés catholiques de Kinshasa" in 2007. In acknowledgment of his scientific achievements, Dr. Georges Ibongu has been granted an Alexander von Humboldt Fellowship to carry out his postdoctoral research at Humboldt University of Berlin.

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