HISTORY AND FOUNDATIONS OF PHYSICAL THEORIES.

THE PHYSICISTS’ MISSED PATH FOR DISCOVERING THE FOUNDATIONS OF SCIENCE

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**Abstract:** I will use the wording "Foundations of Physics" rather than “Philosophy of science” because I will argue that in the past four centuries philosophy was unable to understand modern science. The main responsible for this failure was mathematics, which included a metaphysical core that for a long time proved inaccessible to scientists' research and remained unknown to philosophers. Thus, this metaphysics and the more general metaphysics of Newtonian paradigm were rejected by almost only those few physicists who were looking for alternative theories. For the first time some alternative physicists were successful around the time of French revolution. Yet, next Restoration hid or marginalized their new theories whose bases were incompatible with Newtonian metaphysics. However, in the second half of 19th century within theoretical physics new theories born, which were conflicting in technical and philosophical terms with Newtonian paradigm; a period of a left unspecified co-existence of Newtonian theories and new theories started. In the early 1900s, further new theories disproved even the basic notions of Newtonian paradigm (e.g. space, time, continuum), which therefore was dethronized. Afterwards, albeit lacking of any philosophers' help, an unprecedented, collective intellectual effort of physicists' community was capable of constructing a new, formidable theory, quantum mechanics. Although having radically changed basic concepts and techniques, however physicists did not discover the foundations of Physics, which in the same times have been missed out by also the group of neo-positivist philosophers and then by the new historiographers Koyré and Kuhn. Physicists were caught off guard by some fundamental discoveries: a new kind of mathematical Logic (the intuitionist one) and a new kind of Mathematics (the constructive one); hence new formal foundations of theoretical physics were possible. Yet, quantum mechanics had already been established and it had introduced physicists into a great field of new fascinating research; therefore, physicists preserved their traditional kinds of mathematics and logic, although the same of the old Newtonian paradigm; the paid cost was to miss out their past leading role in the research for discovering the foundations of the entire science. They persisted in a monistic view of their discipline, i.e. ignored that the two dichotomies in respectively mathematics and Logic gave birth to the pluralism in science; which however entered into theoretical physics as the birth of the pluralism of the mathematical technique, owing to the great relevance acquired since the ‘60s by the symmetry technique, whose present role is at all comparable with that of the ancient technique of differential equations.

**Keywords:** Theoretical and philosophical domination of Newtonianism, Alternative theories, Scientific restoration, Co-existence and conflict, Crisis of the early 1900s, Theoretical physics of the early 1900s, Neo-positivism and its failure, New historiography of science and its blind alley, Discovery of two dichotomies in the foundations of science. Withdrawal of physicists into the old paradigm, although more abstract. Pluralism.

**1. Premise**

In the following I will deal in a few pages with four centuries of history of both science and the philosophy of knowledge. I will be able to do this task only by seeing the subject in a quick bird's eye view. For this reason I will not indicate the corresponding huge bibliography (apart some exceptions). I also warn that I will illustrate a personal point of view which has no analogues in the literature on the subject, but which in its support has sixty years of research. Moreover, here I will be concerned with the historical evolution of exclusively physical theories. Finally, I will not deal with the externalist approach to history of physics because it presents even more difficulties than the internalist one and gives little help to our investigation.

Last, but not least, the explanation why my use of the term "Foundations of Physics" and not "Philosophy of knowledge". Unfortunately, modern philosophers, proud to be the heirs of the great philosophies of Plato and Aristotle, have believed themselves to be the leaders of the entire intellectual world. However, among them a divergence has arisen between the empiricist attitude and the rationalist attitude; this divergence echoed in philosophical terms the two polarities of the internal dialectic of the scientific process. The philosophers contrasted these polarities so much to elevate them to an all-encompassing and all-pervading divergence. When a philosopher, Immanuel Kant, claimed to have conciliated them, his solution was hailed as the liberation from a centuries-old problem. But soon after Georg W.F. Hegel overturned a fundamental assumption of it: it is not true that there is only classical logic, as Kant believed. This new philosophy re-opened the problem of the foundations of knowledge. But, in turn, Hegel was unable to indicate the new logic which after a century arose in a completely independent way of his philosophy (the intuitionist logic). The subsequent decline of Western philosophy as a whole followed. This fact manifests that philosophers were unable to solve the main philosophical problem of modern times, i.e. the problem of science; in a retrospective view we easily recognize that as a fact science grew independently of the philosophies of the philosophers.

Along these centuries the scientists waiting philosophers’ suggestion of an adequate account of science, didn't even realize that the topic investigated by philosophers had remained very limited: there was no debate about why modern science was born, why in the West, why at that time, why in male-dominated societies, why in the same time of the birth of capitalism, why it remained separate from, beyond religion, also philosophy.

I will therefore base my analysis on the following proposition: today it is necessary to acknowledge that along four centuries there has been no philosophy of knowledge that could provide an adequate understanding of science and that the philosophies of the past all have proved inappropriate to the novelty of the birth of it.

So, it is better to indicate past investigations on the subject as a mere attempt to build a new philosophy of science, hence to modestly speak of a search (about "foundations of science"), not a completed system achieved in the past times; this my diction does not claim to have already found them; rather it indicates a program of research which hopefully may approach them.

**2. Orphans of philosophy**

Here and in the following section I offer more justifications for my appraisal of incapacity of past philosophies to understand modern science. First, I point out that theoretical physics suggests questions that are elementary, but which at present have no answers (which would be clearly of a philosophical nature). These questions indicate some of the main topics of present research on the foundations of science.

Albert Einstein said that “The most incomprehensible thing is that nature is comprehensible.” In other words: why the experimental data alone cannot assure a scientist that his understanding of reality is valid?

By making recourse to theology André Weil expressed the profound disappointment of the experience of 20th century mathematicians in their search for the foundations of mathematics: "We know that God exists because mathematics is consistent. We know the Devil exists because we can't prove it."

In 1970 Eugene Wigner posed a question, which then spread among mathematicians and physicists; but it did not receive a clear answer: "Why the unreasonable effectiveness of mathematics in the natural sciences?"

Imre Lakatos has paraphrased a Kant’s motto to characterize the curious relationship that has been established between two types of study on the subject of science, the philosophy of science and the historiography of science: “The history of science without philosophy of science is blind. The philosophy of science without the history of science is empty." Unfortunately, most philosophers did not support their studies with specific analyses of historical case-studies; while only in the last times historians appealed to philosophical hypotheses.

**3. Principles of Physics**

I provide a further justification for my negative appraisal by adding some unresolved problems concerning topics that are constitutive of physical theories: their principles.

The first problem is why physical theories have principles that are separate from other propositions. Euclid already posed abstract principles to then deduce operational geometric propositions; the same occurs within many other scientific theories. But why must science is built at two levels? Why aren't the propositions expressing principles entirely experimental?

Moving beyond this problem, let us ask what principles stand for, or what they mean. Exploring the literature on the subject we get radically different answers. Principles are usually written to be "safe" statements, so much so as to warrant any inference that follows from them. But, examining in depth a principle of a physical theory, it is often not clear how much its experimental part is and how much that of an idealized reality (which can also be metaphysical). For Henri Poincaré, principles are conventions (at least in the case of geometry); therefore they can be changed radically, without affecting the scientific nature of the theory. For Gerald Holton's textbook, the principles of Isaac Newton's mechanics (in particular, the inertia law), if exhaustively examined, turn out to include tautologies! But it may be objected to him that in logic to be a tautology means that it has no content; then, how is it possible that a theory locates at its very beginning statements empty of content?

Another aspect of this lack of in-depth knowledge of the principles is that the first principle of modern science that of inertia actually has four different versions: L. Carnot, Cavalieri-Torricelli, Descartes-Newton, Enriques (Vella 2004). Why four and why usual textbooks remember only one version of the possible four?

Furthermore, there is no shared definition of a “scientific theory” (Stanford 2017). Finally, remember that Paul Feyerabend confessed that he "amused himself" to disprove any claimed demonstration that there is a unique scientific method. After the heated debates he caused, it is now recognized that this crucial concept has in fact proliferated into many different concepts (Hepburn, Andersen 2021).

All the above indicates that science navigates in the midst of many philosophical problems, which are due to the lack of a minimal philosophy of science able to anticipate, support, direct it and to evaluate its results in general terms.

**4. Detachment of philosophy from science owing to the mathematics of the latter one**

One wonders: why, despite having behind them more than two millennia of philosophy of knowledge and despite having the support of the great Western philosophers, have scientists become orphans of an appropriate philosophy of science? To answer, we must begin by resolving the central question: What is the essential novelty of modern science with respect to the ancient science knowledge? Notice that the answer exists and is clear: modern science was born from the conjunction of experiments about reality and ideas-hypotheses translated into accurate mathematical formulas. The ancient philosophers did not anticipate this conjunction at all; not Plato, who idealized mathematics and separated it from reality ("God geometrizes", while men would only see the "shadows" of true reality); nor Aristotle, who did not conceive of a mathematics that is independent of reality. The former was too idealistic and the latter too realistic[[1]](#footnote-1).

In modern times was apparent that this connection was certainly not of a causal or mechanical nature. However, philosophers have not been able to find an answer to the problem of the role of mathematics in modern science; Francis Bacon did not keep it in mind, while vice versa the mathematician René Descartes did not have a clear understanding of the experimental method. Later, Kant thought he could solve the problem of what a physical law is with one of his combinations of analytic/synthetic and a priori/a posteriori. At present, very few scientists recall Kant’s suggestions. Ultimately this intellectual knot has escaped the usual capacities of philosophers.

The major reason for this lack of philosophical analyses is what Edwin A. Burtt icastically expressed a century ago:

Scientists, as far as they could, have purged science of all metaphysics; but for what little metaphysics we have left, they have used it as the keystone for interpreting the universe (Burtt 1924, p. 303)

The residual metaphysics indicated by Burtt is clear when we attribute it to the mathematics of that time: in fact at the beginning of modern science the irrationals numbers (note the name) and the infinitesimals were not born from reality, but from abstract, even metaphysical elaborations. Along a century in this transfigured mathematics it was disputed whether an infinitesimal was a "zero" and what kind of zero it could be, as well as whether the presence of infinitesimals makes invalid the equality of a mathematical formula. Jean D'Alembert's response to a doubter about the foundations of this type of mathematics is famous: "Calculate, calculate, faith [in it] will come to you". Afterwards, the metaphysics of advanced mathematics, being covered by abstract formal calculations, acted as an insuperable barrier to philosophers’ critical analyses.

Newton is responsible for metaphysics within theoretical physics for his use of infinitesimal calculus in the very foundation of theoretical physics (it does not matter if this calculus was its "geometric" version of Cavalieri and Torricelli, or the version leading to compose differential equations, which have become currents fifty years later, thanks to Euler). Here there is the unexplained passage from the partially empirical formula *F* = *ma* to an abstract differential equation *F(x, v, t) = m d2x/dt2*ruling all mechanical phenomena; i.e. the passage from a semi-experimental notion of force to a force-cause managing all mechanical phenomena. Later, the great efficiency of this kind of calculation which completely mathematized the physical theory attracted so much physicists’ attention that they disregarded a search for investigating on both its philosophical meaning and the foundations of the resulting theory. The subsequent intellectual triumphs of Newton's theory exalted the new science in its entirety. It is therefore not surprising that later scientists accepted almost blindfolded the metaphysics of that calculation and its basic ideas.

Moreover, the metaphysical ideas that had remained within that mathematics (the infinitesimals) addressed the building of the same theoretical structure of modern physics. Newton had no qualms in basing upon metaphysics his ideas of: space and time (he declared them absolute), force (he considered it as a metaphysical cause), because he felt justified not only by a philosophical metaphysics which at that time was shared by many, but also by the intrinsic metaphysics of his new mathematics; as a consequence, absoluteness was a common feature of basic mathematical notions and the basic physical notions.

His introduction of metaphysics indirectly supported by the great results he obtained by means of the new mathematics; not only he was able to predicted the grandiose motions of the heavenly bodies, but also he reduced optics to the equations of his mechanical theory (by interpreting light rays as trajectories of massive, very little corpuscles). In the subsequent times his mechanics, which was founded on its metaphysical notions and made use of an astonishing mathematics of infinitesimals, resulted to be so highly impressive that it monopolized the entire theoretical physics.

In the history of physics the main results of this kind of Newton's theory were three: 1) to base physics on a mathematics containing a specific metaphysics, plus a declared metaphysics of the basic notions of physics; 2) to monopolize the entire theoretical physics; 3) to obtain so clamorous achievements to establishing a paradigm that in subsequent science persisted for a long time (by the word "paradigm" I mean a complex of choices, including philosophical ones, preconstitutive of physical reality; in particular, the apparently inevitable metaphysics of infinitesimals). In such a way the specific metaphysics of Newton’s mechanics substantially determined the course of Western thinking. Newton was “the Aristotle of the modern times”.

This Newtonian metaphysics was completely unexpected by those philosophers (the empiricists) who saw in science a novelty of a merely operative nature, determined by no more than facts; or by whom (the rationalists) who saw in it an application of a metaphysics that was only partially supported by physical experimentation; or by those who saw in it an instrument of democracy put in the hands of all men. All they remained extraneous from the progress of new scientific attitude. We conclude that Burtt was right in recognizing in (Newtonian) metaphysics the main difficulty on which the philosophers got stuck.

**5. The "spontaneous metaphysics" of first scientists**

Rather, philosophers paid attention to the encroachments that various scientists made in proposing new metaphysical ideas. The strong conjunction of René Descartes' physics with his metaphysics is well-known (it was characterized by the division between *res extensa* and *res cogitans*, in parallel with the division in physics between experiment and mathematics). He suggested the mechanistic philosophy which then dominated along centuries.

While putting a barrier to any philosophical objection with his celebrated motto “Hypotheses non fingo”, Newton actually introduced an unexplained gravitational force (intended by him as God's intervention within the world); furthermore he referred to space and time declared absolute and therefore distinguished by him from the "vulgar, measurable" ones. In addition, he based mechanics on the metaphysical concept of cause, represented by the physical concept of force, translatable into a mathematical function. Finally he became even more involved in metaphysics when at the end of his last work on physics (Newton 1704) he left as his scientific testament the research program on a series of problems (31 “Queries”); this program expressed his dream of omniscience (which was already indicated by the initial word of its principle of inertia: “Every body…”, i.e. even those bodies that we will discover in the more distant future). He begins the Queries with the problems left open by his mechanical theory; then moves on to those of chemistry and those of biology; he ends with the problem of what are the appropriate foundations of ethics: since through the new theory of mechanics man had discovered the true laws given by God to the whole universe, then it was necessary to go beyond the traditional seven virtues, by re-founding ethics on these new mechanics’ laws.

It should be noted that even the phenomenon of the collision of bodies was based on a metaphysical abstraction: a perfectly hard body (as opposed to a totally plastic one); it is so much hard that it does not rebound and, if it meets an equal one centrally, it remains stationary together with the other. It is clear that this idea is incompatible with the conservation of energy; which therefore for a century and a half was treated as an occasional rule.

The metaphysical tension originated by Newton’s mechanics had its peak with Euler: who proposed to replace all the old metaphysics, hitherto elaborated in an intuitive way, with the new metaphysics that rigorously arose from mechanics, since this theory had shown itself capable of interpreting the entire reality.

Finally in 1799 Laplace expressed in *Le sistème du monde* a metaphysical dream of a mechanical omniscience; it is based on the capability of the Newtonian differential equation to describe the entire evolution of both the universe and the smallest particle, just after knowing the forces and the initial conditions of the case under consideration. This was a metaphysical vision supported by a formidable mathematical algorithm and claiming to describe in detail the totality of physical reality.

Among philosophers only George Berkeley and Thomas Hobbes had (in addition to the intellectual courage) the knowledge necessary to counter some incursions of scientists into metaphysics. In particular, they argued that science had right to use neither infinitesimals’ actual infinity, nor a priori concepts or principles, even if supported by a very important metaphysics. But their criticisms remained marginalized even in England, where Newton's metaphysics (and even his awkward notation for calculus) stood as indubitable until the early 1900s.

**6. The time of the French revolution: the new physical theories exiting out the metaphysics and the Newtonian paradigm**

Some other physicists have built valid alternative approaches to the problem of the foundations of science.

The French Revolution was prepared by the *Encyclopédie Française* of Denis Diderot and Jean Le Ronde D'Alembert. It radically questioned Newtonian science: e.g. in the entry "Elémens" D'Alembert addressed a precise criticism to the axiomatic organization of a theory: "it builds a net of deductions, which however always leaves holes" (D'Alembert 1754; this is an intuitive anticipation of Kurt Goedel’s theorem of 1930); in addition, he suggested an alternative theoretical organization; whose, however, he only indicated a philosophical feature, the "empirical" nature.

As a fact, the Newtonian paradigm did not receive easy extensions to all physical phenomena. The study of Chemistry was refrained by Newton’s suggestion of gravitational force as universal in nature and hence also constituting the intermolecular force, the chemical bond. Owing to this Newton’s wrong idea the revolutionary birth of Chemistry was “postponed” a century after. In theoretical physics the nature of heat represented a major problem: a motion of particles, or a material or even immaterial fluid? Also its production of work was a difficult problem. Furthermore, the physicists who studied electric and magnetic phenomena were immersed within completely new problems, first of all because most of those phenomena did not produce bodily sensations; for the first time physicists had to invent a lot of experimental devices for acquiring knowledge of the effects of this unknown world of phenomena. In addition, a great part of these phenomena escaped the usual Newtonian theoretical notions. In order to find out a theory, various new kinds of mechanical fluids have been invented, but with only partial successes.

During the French Revolution the triumphal march of Newtonian physics received even a strong popular opposition, based on the slogans: instead of celestial science, terrestrial science; instead of abstract science, science for us (Gillispie 1959a and the more extensive, but less characterizing Gillispie 1959b). In this time theories arose that were alternatives to the Newtonian paradigm, also because they were anti-metaphysical.

In mathematics the metaphysics changed or disappeared. Giuseppe-Luigi Lagrange became famous for having eliminated all metaphysics from calculus because he reduced it to essentially the calculus of the Taylor series of a function. In the same year, 1797, Lazare Carnot published a famous book on the subject; it reduced all the basic notions of that mathematics, as first the notion of limit, to only operative ones.

In the same year of the political revolution (1789) Antoine-Laurent Lavoisier published his main book, in whose preface he wrote that he declared to start "a scientific revolution". After a century of unsuccessful research on the gravitational force as causing the chemical bond, Lavoisier abandoned Newton’s idea and only focused the attention on experimental facts: chemical reactions of analysis and synthesis, both evaluated on the basis of a single law of an experimental nature (the conservation of mass). Furthermore, his theory, far from being deductive, was based on the problem of discovering the elementary components of matter, lacked of geometry and used the mathematics of rational numbers only.

In Physics, Lazare Carnot also published a new formulation of mechanics in 1783. He did it without relying on the notions of absolute space and time (therefore the theory was explicitly based on the relativity of the motions) and of the force-cause (which he declared a "metaphysical and obscure concept"); he did not use infinitesimal calculus (except in applications), but, the algebraic-trigonometric one; he declared that his mathematics derived from experience. He based his theory on the operative principle of virtual works. He gave to his theory a theoretical organization which called, like D’Alembert, "empirical", and moreover sketchily illustrated this ideal model in opposition to the model of the axiomatic organization (L. Carnot 1783, pp. 101-103). His theory correctly resolved the problem of the collision of bodies by mathematically deriving for the first time the motion invariants. Some years later, in 1788 Lagrange founded (although using here the dominant mathematics, that of infinitesimals) a further formulation of mechanics. He explicitly based it not on the Newtonian equation *F = ma*, but he also on the principle of virtual works, which he declared the true basic principle of the theory of a mechanical system which is subject to constraints and hence a theory having to solve the problem of how take into account the unknown constraints reactions.

The new physical theories, based on ideas very different from those of Newtonian mechanics and having a different theoretical organization and a different relationship with mathematics, have broken the theoretical monopoly of Newtonian mechanics on science. Moreover, together with the new interpretations of mathematical analysis, they in fact, denied Newtonian metaphysics (at the same time of the fall of the aristocracy’s absolute power in France). However the scientific mainstream maintained the old metaphysics because it appeared indispensable to ensure the still dominant theories of the Newtonian paradigm. So in this period there was a real scientific and philosophical revolution, which however did not destroyed (by denying) past theories; both Lazare Carnot and Lagrange coexisted in the same town and in the same *Ecole Normale Supérieure* with the scientific leader of his time, the Newtonian Laplace without polemics (apart the exclusion of L. Carnot from the teaching charges in the *Ecoles Supérieures*, founded by him).

**7. The parallel scientific restoration to the political Restoration**

Since 1815 the political Restoration followed. It also led to an authoritarian social organization of science. In the next decades Societies of scientists of various scientific disciplines were founded; they structured scientists’ activities within precise professional roles. No longer had a scientist his political independence (Ben David 1975).

Only Lavoisier's chemistry, though much thwarted, resisted; in fact, it had on its side an important traditional profession, that of pharmacists, who maintained an independent judgment from academy’s one. The other newborn alternative theories to the Newtonian paradigm have been marginalized (for example, L. Carnot’s mechanics was almost forgotten; while the mechanics of Lagrange and then that of Hamilton were considered as technical innovations for making easier the applications of Newtonian theory).

During the Restoration, further alternative theories to the Newtonian paradigm arose. But their lives were so difficult that they risked not surviving. The mathematical works of Nicolai I. Lobacevsky (on the first non-Euclidean geometry and on the re-founding infinitesimal analysis through operative notions) were subject (as were the books for primary schools) to the censorship of Sergei Magnitsky (later called to Moscow as restorer for all of Russia). His first publication on the new geometry (deliberately lacking of Euclidean metaphysics) occurred in a local newspaper of his far eastern town, Kazan; the second was a Western review (1935), but without reactions by mathematicians; then he published a booklet in Berlin (1840), but it was noticed by only Karl Friedrich Gauss; who appointed him academician of Gottingen; but again without consequences. (Years later Gauss almost obliged the student Bernhard Riemann to choose a thesis on the subject of the non-Euclidean geometries; when the latter defended his thesis in 1854, Gauss left the thesis room rubbing his hands; on the subject he, the *princes mathematic rum*, has published nothing, because, as he wrote to a friend, he feared "the screeching of the Beotians [="stupid, vulgar people]”.

In 1824 Sadi Carnot founded the theory of thermodynamics without any metaphysics, any advanced mathematics and even any hypothesis on the nature of heat. His booklet was reviewed by the Academy of Sciences, but then was almost ignored for 25 years. On electric and magnetic phenomena Michael Faraday, who did not want advanced mathematics in physics, proposed very innovative ideas with respect to the Newtonian paradigm (e.g. he promoted the unification of electricity and magnetism); but the contemporary scientists distrusted so much his novelties that he suffered a serious nervous breakdown.

In conclusion, the mainstream re-proposed the theoretical monopoly of Newtonianism even in the face of the new physical theories, which were then canceled or assimilated to it. Newton’s metaphysics was also maintained, but reduced to the indispensable fundamental concepts of mechanics (absolute space and time; while a new theory, Rational Mechanics, tried to replace the basic notions as much as possible with those of infinitesimal analysis, with its metaphysics).

Before and during the Restoration, the philosophy of positivism born, also as in reaction to the renewal of a metaphysical attitude; many scientists circumscribed science to a clearly controllable truths, however elementary they were. In order to drastically deny all metaphysics it did not accept anything above the positive data. In particular, also following the example of Chemical theory which had drastically reduced mathematics to elementary mathematics, many scientists considered the advanced mathematics as the bearer of a philosophy which was inappropriate for a scientific theory; and therefore they reduced mathematics to the most simple as possible instrument. They, even without the help of valid philosophers’ accounts on science, in fact perceived the ultimate source of the difficulties: the advanced mathematics included ideas that cannot be scientifically tested.

**8. Light and shadows in the second half of the 19th century**

In this new period (socially characterized by the rise of the bourgeoisie to state power) the anti-Newtonian scientific theories of the past have been admitted and new ones of the same nature have emerged.

In Mathematics, the already born (some decades beforehand) non-Euclidean geometries have been recognized; hence the old Euclidean geometry lost its role as the foundational mathematical theory of the entire science. Moreover, the infinitesimal analysis depreciated its old metaphysics of the infinitesimals. Cauchy, and then Dedekind and Weierstrass tried to replace this calculus to an operative technique (however, they preserved a metaphysical content at a deeper level[[2]](#footnote-2)).

In physics, in 1811 the phenomenon of polarization was discovered, which disavowed Newton's corpuscular hypothesis on the nature of light; the scientific strength of this new experimental datum forced physicists to consider optics as an independent theory; this innovation definitively broke the monopoly of Newtonian mechanics on theoretical physics.

Some more physical theories that did not conform to Newtonian paradigm have been slowly recognized. In 1850 the birth of thermodynamics introduced, as inevitable, the conservation of energy (based on Gottfried W. Leibniz' ideas of the unity of all "forces"), and therefore recovered the Leibnizian model of the elastic body for the impact of bodies and at last gave rise to the kinetic theory of gases (it had been anticipated by the Leibnizian Daniel Bernoulli a century earlier)[[3]](#footnote-3). Thermodynamics no longer dealt with the force-cause (there force is only a component of the notion of pressure); rather, it introduced as basic an alternative physical concept, i.e. the transformation between states; moreover, in opposition to the mechanistic philosophy it introduced the limitation of the impossibility of a perpetual motion.

Furthermore, in 1858, by incorporating all of Faraday's previous depreciated work, James C. Maxwell formulated a theory which was fully responsive to the phenomena[[4]](#footnote-4). After some improvements this theory seemed to repeat some fundamental features of Newtonianism, especially the advanced mathematics; but it had other very different concepts and laws from Newtonian ones; e.g., the conjunction between electricity and magnetism, the basic laws were four and all on the same par; force had lost its nature of a metaphysical concept: its notion was mixed with geometry into the basic concept of force-field; plus there were dipoles, induction, etc..

At last, Chemistry has achieved the status of a self-sufficient theory through its classification of all elements of matter, i.e. the table of Mendeleev (1869). Through it he accurately predicted four new elements of matter (while, on the basis of the Newtonian metaphysics of space and time, physicists stubbornly supported the existence of a substance, the ether, which must have absurd physical properties). But even these extraordinary results did not give this theory, so different from the Newtonian paradigm, the right to be considered a full physical theory: it was placed merely side by side with physical theories.

Finally, thermodynamic theory revealed its entire anti-Newtonian attitude when in 1897 Max Planck freed the notion of entropy from representing a simple variant of the notion of energy and stressed that instead it is the crucial concept of the theory, together with the notion of irreversibility; in such a way thermodynamics appeared in a metaphysical opposition to the reversibility of Newtonian mechanics.

Due to the emergence of the above new theories, after the year 1850 the conflict with Newtonian paradigm came again to be manifest. A group of thermodynamicists, strengthening by the new, truly universal law of conservation of energy (suggested by Leibniz), launched the program to re-found on it the entire theoretical physics, first of all the theory of mechanics. A strong controversy has arisen, even with nationalistic alignments. The German chemist Ostwald (empowered by his first science-industry-society relationship) led the revolt of the Energetists against the Newtonian Mechanists, to the point of wanting to impose (at the Luebeck conference in 1895) on all scientists the choice in favor of the new conception of theoretical physics; his request split the entire community of scientists of the time between those in favor and against. In the opposite direction, Boltzmann doggedly pursued the program of reducing thermodynamics to Newtonian mechanics, considered as the universal theory.

The Energetists have been accused of being naïve because, being accostumated to the simple mathematics of thermodynamics, disregarded the advanced mathematics; as a fact, they failed to dethrone the Newtonian theoretical scheme also because the general framework of theoretical physics was at that time supported by the powerful infinitesimal analysis; which supported the birth of physics-mathematics, which promised to foresee new fields of physics and new physical laws by intensively studying all the possible differential equations and their solutions.

This battle opposed different metaphysics defining the foundations of theoretical physics by means of a single law (e.g. conservation of energy) or a single theory (either Newtonian mechanics or thermodynamics). This battle was definitively abandoned when the new theories of the early 1900 born. In particular, the Mechanists were overwhelmed by the birth of special relativity; and Physics-Mathematics was contradicted by the discovery of the quanta, whose discreteness was extraneous to its formalism.

**9. The philosophy of science around the beginning of the 20th century**

Having discovered the lack of valid philosophies of science, some scientists improved their theoretical efforts till up to produce "spontaneous philosophies" (but not English scientists that remained doggedly Newtonian). It is an exceptional fact that from an anti-metaphysical philosophical context, usually radical and even iconoclastic, a balanced scientist-epistemologist arose, Ernst Mach. Knowing how to handle mathematics (at least at the first levels of infinitesimal calculus), he went to the bottom of many problems; so much to provide a comprehensive interpretation of theoretical physics. To him we owe profound philosophical analyses of mechanics and thermodynamics, which remained unparalleled for almost a century (Mach 1883; Mach 1896). Further on, the mathematician Federigo Enriques constructed (despite the derision of the idealist philosopher Benedetto Croce) an epistemological conception of science which has a remarkable level of depth. Another important conception was offered by the mathematician and physicist Poincaré; he illustrated his reflections in popular conferences, and then collected in splendid books.

All this effort in reflecting on science have illuminated the concepts, techniques and theories of science to the point of making some scientists believe that they have also identified its foundations. Mach chose "the economy of the mind" at the basis of theoretical physics; this idea generalizes to the work of the human mind the physical principle of minimum action in theoretical mechanics; but the principle is of only a philosophical nature, without empirical support. Henri Poincaré listed the “essential principles” of theoretical physics (Poincaré 1904); which, however, were revolutionized exactly the next year by Einstein’s three papers.

In the early 1900s, the revolution of the two new physical theories (special relativity, quantum theory) was so profound that all past metaphysics has been removed from theoretical physics. Also the dominant positivist philosophy was surpassed; in fact the new physical ideas (space-time, the invisible division of light into quanta, etc.) far outstripped the empirical data. It was then evident that classical positivism had to accept that science includes beyond positive data at least some abstract ideas. The logical neo-positivists of the Vienna Circle believed to have found out the necessary advancement by introducing logic (of course the classical one), which in the meantime had become mathematical logic and therefore showed a certainty which was on a par with experimental data. But their novelty failed to express even the mathematical formulas that are basic to theoretical physics (e.g. the concept of pressure, as the ratio of force on surface area). After about a decade, they (in particular, the leader Rudolf Carnap) openly declared that they were unsuccessful neither they reformulated the initial project. Rather, another their idea obtained importance. They held that any proposition is scientific when it is strictly verified by experimental facts (plus logic); Karl Popper reversed the thesis: he argued that a proposition is scientific when it is fallible due to (obviously: negative) experimental results, while a proposition is metaphysical when it does not have the possibility of being disproved by experiments. Although disputable, this suggestion gave enlightenments on the philosophy and history of science.

Ultimately, the (collective!) neo-positivists attempt to approach science from a philosophical point of view had succeeded in (indirectly) suggesting at most a mere criterion of scientificity, but not the foundations of science.

**10. The “New Historiography”**

Rather, some historians of science of that time made a breakthrough that was astonishing in the depth of their advancements. It is sufficient to consider the two more important exponents.

"The new historiography" was born in the 1930s. Alexander Koyré characterized his historical analysis with two philosophical phrases wanting to synthetically grasp that "revolution in the conception of Being itself", represented by the birth of modern science. In almost every one of his writings he repeats (in a similar form) the two following propositions: "Dissolution of the finite cosmos and geometrization of space"; where the proposition "geometrization of space" indicates that essential conjunction between mathematics and reality which constitutes the core of modern science; and alludes to the intensive use of that infinitesimal analysis which made use for formalizing the laws of the entire universe. Hence the scientific revolution was not only to join mathematics and experimental data, but also to use the mathematics of infinity (viz. infinitesimals).

This crucial role played by the notion of infinity is confirmed by the same title of his most famous book, clearly stating this notion: *From the Closed Cosmos to the Infinite Universe* (Koyré 1957).

Koyré was even more profound, as he distinguished between the two kinds of infinity. In fact, the sentence best summarizing his thoughts on the birth of modern science is the following one: "Galilei explains reality with the ideal... Descartes and Newton with the impossible... Galilei does not do it" (Koyré 1966, p. 276). Here Koyré admirably illustrates the difference between the application of only potential infinity, as Galilei did, and to also make use of, as the other two scientists did, actual infinity (which is not a limit of reality, but transcends it as a separate concept from it).

In total, Koyré investigated history of physics by starting from some philosophical hypotheses; through them he was successful in giving detailed and suggestive historical accounts. Hence his the investigative hypotheses implicitly alluding to the foundations of physics, appeared to have approached the foundations of physics more than others.

Thomas S. Kuhn launched himself into a much more ambitious goal than Koyré’s: to offer a first interpretative overview of the history of all physical theories (at least the classical ones). Kuhn’s first book (1969) also belongs to the "new historiography" because he assumed philosophical preconceptions; which, however, are completely different from that of Koyré: his categories ignore the physico-mathematical relationship, while instead openly declare a philosophical relationship between natural science and social science; hence, the list of his categories includes not only scientific concepts (normal science, anomaly, incommensurability), but also some scientific notions having also social meanings (paradigm, Gestalt, revolution) and finally a crucial sociological notion (community of scientists). His book fulfills the title’s promise (announcing the structural treatment of "scientific revolutions") by analyzing what is known as the "chemical revolution"; which however we know to have had no effect on theoretical physics (as also results from his story). The most important revolution in the history of physics, the revolution of quanta, has remained outside his narrative. A crucial question remained open: did his notion of “revolution” introduce to a deeper view of the relationships among the physical theories?

The positive and almost glorious progression that Koyré and Kuhn seemed to have started in deepening the level of comprehension of the historical phenomena concerning science, had a setback in 1978, when the latter one published a book on the case study for which his previous book seemed to have prepared and which in theoretical physics represents the scientific revolution *par excellence*, the quantum revolution (Kuhn 1978). However, he couldn't explain it. Furthermore, Kuhn's basic concepts (in particular, the notion of two incommensurable theories which seemed to suggest an incommunicability phenomenon between scientists’ communities) have been radically criticized. The basic indictment against this historiography of scientific revolutions was: “Irrationalism”.

One could have gone back to Koyré's historiography. But this too had undergone criticism, albeit less destructive: Koyré is a Platonic idealist, because he sees in mathematics an idealization that transcends reality, so much as to distort even Galileo's experimentalism. The verdict was that while philosophers might like this kind of historiography scientists must reject it.

So that, after Kuhn's defeat on quanta, the whole evolution of the "new historiography" seemed to have entered a blind alley. It is not a chance that since the 1980s (starting from the book by Helge Kragh, 1989) the professionalism of the historian of science was strongly emphasized. It is clear that the criteria informing this suggested professionalization were those of traditional humanistic historiography, applied (to the extent that a humanist can manage the subject science that largely escapes his competences) to the history of science. Afterwards, history of science lost the autonomy that it had acquired through the great syntheses of Koyré and Kuhn; it received a subordinate role in the traditional academic hierarchy of history in general: at present is merely "one of many specialist histories". This result is unsatisfactory not only due to the consequent abandonment of the novelties suggested by Koyré and Kuhn, but also because humanistic historians do not offer an assured interpretative framework: after more than two centuries of studies on the French Revolution they have not still reached a common interpretation of this subject and therefore of the entire subsequent history.

**11. The lost chance of modern physicists to explain the foundations of Physics**

Having been abandoned by the traditional philosophy of knowledge and having they abandoned the Newtonian metaphysics, in the 1900s the scientists searching for the foundations of science had to hope to gain new foundational achievements exclusively through their scientific work. Let’s look at the work they have done in this regard[[5]](#footnote-5).

Since special relativity was born in 1905, most attention has been focused on its basic concepts that have dethronized those of the Newtonian paradigm. So the problem of finding the foundations of physics has changed in the following one: what is the foundational scope of the new concepts (space-time, reference frames, invariants, etc.)? This great attention to the basic notions increased after the birth of quantum mechanics which proposed astounding concepts. Among all these concepts what are those playing the foundative role of the entire theoretical physics?

The birth of relativity was a stroke of genius by both Einstein and Poincaré[[6]](#footnote-6), two of the greatest scientists of all time. On the other hand, the birth of quantum mechanics was the result of an extraordinary intellectual work in the history of humanity; it was the fruit of an unprecedented collective work, according to an astonishing progression, which, starting in 1900 from scratch (the physicists lacked both an appropriate mathematics and suitable notions for the quanta), built in just 25 years, from six fundamental discoveries (each about every five years), an entire physical theory and its appropriate mathematics (Drago 2002a, table III, p. 155). Ever more surprisingly, this theory turned out to be so technically accurate that even today it does not present any divergence between predictions and experimental data.

Yet, it is almost unbelievable that quantum theory was formulated with a heavy reliance on the continuum, although 1) the theory was caused by the discovery that all reality is discrete and 2) already Einstein's 1905 paper had emphasized a "dichotomy" between two distinct kinds of mathematics in theoretical physics: discrete and continuous (or, better, potential infinity and actual infinity)[[7]](#footnote-7). It is clear that this dichotomy is also foundational and therefore the whole theory should be reformulated with a new mathematics, that of the discrete or at most the potential infinity (also because this kind of reformulation would make the theory more adequate to experimental reality).

But the physicists attempting this re-foundation of mathematics (Henri Poincaré, Pierre Duhem, Werner Heisenberg, Paul Bridgman, etc.) ignored previous Brouwer’s attempt. The best attempt was by the physicst-mathematician Hermann Weyl, who however appealed to a naive notion of limit that just after von Neumann proved to be insufficient (Drago 2002b). Moreover the great advancement obtained by the mathematization of quantum mechanics (the omnicomnprehensive Hilbert space on which von Neumann founded the new theory) appeared as a new step ahead of the historical progress of theoretical physics. Hence, physicists conceived as unattainable the very advanced mathematics assumed by quantum mechanics

Unfortunately, not before 35 years after the birth of quantum mechanics, accurate formalizations of this new mathematics have born, thanks to not physicists, but the mathematicians Andrej A. Markov (1962) and Errett Bishop (1967). However, the dominant group of mathematicians has left unresolved this divergence between the two kinds of mathematics; they rather "loosened" Hilbert's program by accepting the two different mathematics as only formal variants.

Moreover, in the 1900s also in logic a divergence between the classical one (born in 1848) and the many non-classical logics born (they are all weaker, but are closer to real situations). As in the foundations of Mathematics, an analogous unresolved coexistence of different foundations occurred in mathematical logic.

Surprisingly, after ten years the birth of quantum theory it was discovered that quantum logic is different from the classical one. It is clear that this novelty, being of a foundational import as one more dichotomy, would have required the reformulation of the entire theory[[8]](#footnote-8). Several decades of research on this field resulted unsuccessful (a “labyrinth”, was called by van Fraassen 1974).

It is clear that a non-classical logic cannot be associated with a deductive theoretical organization, whose exact derivations can only be handled by the classical one; therefore this new logic introduces a new theoretical organization. Actually, today's cutting-edge research in theoretical physics has no longer obtained a deductive theory characterized by some axioms; at present in the advanced theoretical physics only there exist big problems, for the solutions of which it is necessary to find new theoretical methods through a great inductive work, i.e. the typical work of a non-classical logic and of a non-deductive theoretical organization. However, insofar no research was conducted by physicists for discovering a new kind of theoretical organization,

In the period 1900-1932 physicists carried out an intellectual work never seen before and also have extended themselves to deal with (new and astonishing) concepts (relativity, space-time, quanta, probability amplitude, wave-particle, indeterminacy, etc.). Yet, they did not accept to work at an deeper level of theoretical knowledge, that of choosing the type of Logic and the type of Mathematics. By 1932 the two main theories (special relativity and quantum mechanics) had been terminated: too many were the technical results achieved and too many those still foreseeable, to again turn the attention to search new formulations of the achieved new theories and at last solve the problem of what are the foundations of theoretical physics. The surprising and magnificent results of the acquired theories did not lead to clarify the problem of the foundations, a problem that in the end physicists considered of philosophical nature[[9]](#footnote-9).

In retrospect we see that according the two above dichotomies quantum mechanics was formulated according to the two typical choices of the old Newtonian paradigm: Classical mathematics (of infinitesimal analysis), and classical logic, i.e. the logic managing a deductive theoretical organization. Ultimately, one has to conclude that notwithstanding their formidable effort, the physicists had discovered a new, wonderful theory, but falling back into the basic choices of the previous paradigm, the Newtonian one, which they had contested in many its aspects. In order to complete the departure from that Newtonian paradigm, theoretical physicists, after the foundational innovations, should have founded the new theoretical physics on the alternative choices to the Newtonian ones. But many factors have discouraged good-willing physicists to acquire an in-depth and broad knowledge of such "hard" disciplines: 1) their exaggerated attention to the new notions of modern physics plus the unbounded imaginery they elicited; 2) the professional separations between the various scientific disciplines (Physics, Mathematics and Logic) arisen in early 1900; 3) the time lags of the discoveries with respect the birth of quantum mechanics; 4) the unattractive innovations of these discoveries (because they introduced limitations); 5) the ambiguous current evaluations on them; 6) last but not least, the turning back of Einstein, whose 1905 paper truly revolutioned theoretical physics, but thereafter *i*) forgot the groups of transformations for applying again the differential equations (although through the first application of tensorial calculus) and *ii*) opposed quantum mechanics without qualifying this opposition in a foundational way.

Then, a peaceful reconstruction of the history of physics has become mainstream. It justifies the innovations of the new theorization of the 1900s by contrasting the single crisis of physics of the early years of 1900s with the old mechanicism of the 18th century. This reconstruction leaves in obscurity (just as Kuhn's story did) the many alternative theories born before in 19 century (mainly thermodynamics, which had suggested a completely new theoretical framework; not by chance that mainstream assumes that this theory has been successfully interpreted by Boltzmann's statistical mechanics, although a deep analysis of its foundations result to be uncertain and insufficient (Uffink 2004, section 1.3)). This reconstruction suggests (as Kelvin thought it) that the mechanist attitude dominated also the entire 19th century; therefore it ignores the birth of alternative theories during the French revolution, the subsequent scientific restoration and the theoretical conflicts of the second half of the 19th century). Although the new physics has rejected or modified (by generalizing) Newtonian concepts this interpretation did not dismiss the fundamental choices of Newtonian paradigm. In such a way the history of the overcoming the crisis of the early 1900 may be presented as a widening the original circle of physical knowledge and even thorough the reductions of the two new theories by means of the two limit processes, respectively *c* *→ꝏ* and *h* *→* 0; they are presented as the seal of the truth; whereas instead it is well-known that unavoidably they are of a only partial nature.

That this kind of narrative is insufficient is demonstrated by the fact that, around the year 1960, the usual mathematical tool of theoretical physicists suddenly and drastically changed: from differential equations to symmetries; why this is happen? A commonly accepted interpretation is still missing; which instead would be simple, just by taking into account the alternative theories: the first theory introducing symmetries and invariants was L. Carnot’s one (Drago 1989), i.e. a theory based on the alternative choices to the Newtonian paradigm, making use of the differential equations.

**12. Conclusion**

Having discovered the two foundational dichotomies today we have to define science in a new way: science is the conjunction not only of experimental data with mathematical hypotheses (making use of either potential infinity or actual infinity), but also it the taking two choices on the aforementioned two formal dichotomies of Mathematics and Logic.

This new definition, taking in account also the two dichotomies, explains why before the 1960s it was impossible for philosophers or scientists to grasp the nature of the foundations of science: they lacked of formal definitions of the two dichotomies.

But it should be noted that in retrospect on the basis of intuitively defined dichotomies some scientists have succeeded. First of all, Galileo; who dedicated an entire Day of his *Dialogues* to the problem of what kind of infinity to use in Physics; and that in his last two books clearly distinguished the part of the deductive organization of his theory from the inductive one: he used Latin for the former one and the vernacular for the latter one. Furthermore, in the above we have seen that D'Alembert shortly illustrated the latter dichotomy and later Lazare Carnot both dichotomies. Finally, Einstein organized his two 1905 papers on special relativity and quanta according to the new theoretical organization, in which he made use of non-classical logic; in addition this second paper stated in intuitive terms the dichotomy on Mathematics (Drago 2010, Drago 2013); for these implicit definitions, his two exceptionally important writings acquire an even greater relevance.

Koyré's historiography has also managed to intuitively define the dichotomies. He based his historical analysis of the birth of modern science on the two concepts of infinity. His analysis was of intuitive nature, yet it was accurate because in the historical period at issue there was no need to refer to the two mathematical formalizations of the notion of infinity, it was enough to consider them intuitively; and Koyré did it very well, as it is showed by his previous sentence in sect. 10.

Finally, Leibniz substantially perceived by intuition the two dichotomies; he discovered that the activity of our mind encounters two labyrinths: that of infinity (potential and actual; and therefore today: constructive or classical mathematics) and the labyrinth " law or freedom" (which alludes to the subjective experience of elaborating a theory according to either stringent deductions or a free search of a new method for solving a given problem; therefore today: classical logic or non-classical inductive logic). Since these labyrinths have remained unsolved by human reason along three centuries of reflections on them, the time is come to rather consider them as two dichotomies of our reason.

Ironically, the physicists, who arrived in the 20th century full of glorious theories of reality, but orphans of philosophy, were "deceit" by history. Having achieved relativity theory and Hilbert space of quantum mechanics they believed themselves to be at the pinnacle of both the general scientific progress and also (owing to mainly their new notions of space-time, quanta, etc,) the philosophical progress.

Instead the alternative minorities among the logicians and the mathematicians have surpassed them in achieving the decisive steps for recognizing the foundations of science. Physicists have not noticed it because the explosive progress of physics took place before the decisive progress of the two disciplines determining the foundations of physics.

Although warned that there were alternatives in the basis of their new theories, physicists have not reformulated them on the alternative choices; they were satisfied with what they had already acquired technically, at the cost of losing the leading role they had played along three centuries, i.e. to be the first ones to discover the progress that could lead to the foundations of all science. Afterwards, from the viewpoint of the two dichotomies, the new marvelous theories of physicists turned out to be of relevance only for Physics, not for science in general; even the specific "philosophy" of quantum mechanics (the "spirit of Copenhagen") resulted to be of only local and therefore of lateral importance for the foundations of all science[[10]](#footnote-10).

All this shows how difficult it has been in the history of human intellectuality to get to investigate on the decisive aspects of the birth and then the historical development of modern science; it was not just a question of accumulating new experimental data, nor even of expanding concepts and theories; the main question was to abandon the metaphysical preconceptions of the Newtonian paradigm included the metaphysics of the exclusivism of the Newtonian choices on the two dichotomies; and finally to recognize the limits of human reason which, at the maximum effort of previous philosophers, has been suggested by Leibniz) as two labyrinths, without knowing how to deal with them.

Surely, science and in particular theoretical physics represent a gigantic theorization built by Western civilization. But at the same time the interpretation of this science along five centuries represented the greatest challenge to human thinking, in particular the philosophy of knowledge; which today has to build itself on a completely new basis with respect to two and half millennial tradition of Western civilization.

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1. One may think Archimedes (about 287 BC - Syracuse, 212 BC). Certainly he was very important for the later birth of modern science, but in the Hellenic scientific culture of his time he was isolated. [↑](#footnote-ref-1)
2. It is called "rigorous" because in the end (1870) it eliminated the unpresentable infinitesimals. But it did not eliminate metaphysics. According to it a unique limit value is obtained from a series of smaller and smaller approximation intervals, like the optical illusion of two tracks that at infinity seem to meet through the convergence of the two points of each their interval. This result is impossible in mathematics short of an idealistic leap from an interval (delimited by two extreme points) to a single point; in other words, only an idealistic, mental act allows to choose a single point inside the infinite points composing an interval, however little it is. So, even after this reform the metaphysics of infinitesimal calculus persisted in a more hidden form; and still persists in university teaching. [↑](#footnote-ref-2)
3. The usual appraisal on Leibniz’ thinking is that of an essentially metaphysical philosopher. For reasons of space, I cannot give a full rebuttal of this improper evaluation. I can only mention the clarity with which Leibniz 1) distinguishes the two levels of an analysis, the metaphysical one and the physical one, where "the facts must be explained with facts" and moreover 2) declares that idealistic mathematical ideas, such as the infinitesimals, must not be introduced into the foundations of a physical theory. Unfortunately, Kant's inappropriate criticisms (and Voltaire's ridiculing him) have marginalized him from the historical course of the philosophy of knowledge. [↑](#footnote-ref-3)
4. But according to a new metaphysical conception: space as filled by vortices. It was abandoned some years later. [↑](#footnote-ref-4)
5. There is no space to remember the existential crisis (called "of the antinomies") that took place in Mathematics in the early 1900s; this crisis was due to the custom of making use of the concept of actual infinity (e.g. infinitesimals, infinite set, Zermelo’s axiom, etc.). Most mathematicians believed that the solution to this crisis was David Hilbert's program: to give a sure foundation to all scientific theories by axiomatizing them. But in 1930 Goedel proved that this program is impossible even in elementary arithmetic. In the meantime Brouwer had launched the program of founding a mathematics only based on constructed mathematical entities, i.e. on the use of only potential infinity. [↑](#footnote-ref-5)
6. Einstein's special relativity was based on Leibniz's ideas of relativity of motion and invariants. Its birth has re-evaluated old Leibniz’ program for an alternative theory to Newtonian mechanics (Drago 2004). I recently discovered that a century after him Lazare Carnot carried out his program (Drago: “Preface” in L. Carnot 1873). [↑](#footnote-ref-6)
7. The dichotomy can also be seen in terms of the two different mathematical approaches to quantum mechanics (and in general to theoretical physics): algebraic and analytic; (making use of Hilbert space in the birth of the quantum theory); they correspond to the approach of (Hermann Weyl and of) Paul A. Dirac and the approach of von Neumann The latter approach is still dominant, although the same von Neumann already in 1935 "confessed" that he no longer believed that the Hilbert space is adequate for the foundations of quantum mechanics and thereafter intensely (but unsuccessfully) searched for new " specific algebras" for establishing a new algebraic foundation. So according to the two major theorists of quantum mechanics (von Neumann and Dirac) , the most valid approach to the new theory, is the algebraic one (today represented by Dirac’s book, unfortunately considered by the mainstream as a merely "didactic" introduction!). A rigorously algebraic foundation of quantum mechanics has recently been suggested by (Morchio and Strocchi 2009). [↑](#footnote-ref-7)
8. However, the authors of the discovery (Birkhoff, von Neumann 1936, sect. 17) used a method which a priori excludes intuitionist logic; which instead is exactly the one logic which is appropriate to a non-deductive theoretical organization. The following scholars actively searched the exact kind of quantum logic, but unsuccessfully. Therefore their discovery seems a partial one. [↑](#footnote-ref-8)
9. Many courageous people have tried to overcome this inertia relying on partial ideas on the foundations: 1) the hypothesis of hidden variables for a return to Newtonian mechanism; 2) the axiomatization of theories through set theory, at the cost of creating theoretical artifices ("Structuralism"); 3) catastrophe theory, chaos theory and complexity theory, which question the traditional mathematical tool (the analytical one), but without seeing an alternative either in the algebra nor in the mathematics of potential infinite alone. It is not surprising that all these attempts, being partial, have not had the general result hoped for. [↑](#footnote-ref-9)
10. Only Paul Bridgman took the change of special relativity as a general new foundation of physics; he wanted to ban all non-operative notion from theoretical physics. But he stopped when the needs of ideas, i.e. notions not directly linked to experimental data (e.g., entropy), occur. However, he elicited a general reform for a more operative view of the entire science. [↑](#footnote-ref-10)