Paolo Pecere

The Book of Nature and the Books of Men

Idea and History of the Book in Modern and Contemporary Philosophy and Science of Nature

> «Human thought, flying on the trapezes of the star-filled universe, with mathematics stretched beneath, was like an acrobat working with a net but suddenly noticing that in reality there is no net.»
>
> Vladimir Nabokov, *Glory* (1933)

After the publication of Newton's *Philosophiae naturalis principia mathematica* (1687) the gap between the ideal of scientific completeness and the actual content of the books of natural philosophy became a common topic of discussion among both scientists and philosophers. With his single book, indeed, Newton created a new standard of philosophical investigation, while at the same time declaring that he had not covered a major issue of natural philosophy, namely the investigation of natural causes. This feature of Newton's philosophy depended on his attempt to provide a solid methodological foundation of physics, grounded on the application of mathematics to phenomena, and thereby cope with the historical contingency of metaphysical hypotheses and systems. After Newton, as XVII^th^ century «natural philosophy» underwent new methodological and institutional subdivisions into different disciplinary domains, the ideal of a unitary exposition of natural science became more and more problematic. The reflection on the unity and structure of scientific knowledge, in turn, had a significant influence on the structure and organization of books such as treatises, encyclopaedic projects and histories of scientific systems. I will examine hereafter some key points of this relatively unexplored side of modern scientific literature, focusing on how the problematic tension between the unity of the book and the historical development of science connects early modern to contemporary reflections.

One overarching issue is the role of the historical and critical study of the tradition of books on natural philosophy as a fundamental element of scientific investigation: whereas this role of historical knowledge is widely acknowledged by contemporary philosophers of science, it is neglected by contemporary scientists and is greatly understated in scientific textbooks. Indeed – as I am going to show in the first paragraph – long before the establishment of the current disciplinary separation between philosophy and physics, the idea that scientific books of the past contain a collection of prejudices and mistakes and that, therefore, scientific inquiry requires a *fresh start* with respect to the tradition has been crucial

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for the very rise of modern science in XVII[th] century. Nonetheless, as I will also try to argue, the confrontation with past theories has been more and more reconsidered in the tradition of philosophy and science of nature. This reappraisal has led to the abandonment of the *ideal* of a ultimate book containing the foundations of physics and to a parallel, growing reconsideration of the role of *historical and critical analysis* of exemplary books of the past in theoretical scientific research.

> «How could the 'great book of Nature' be investigated, one is tempted to ask, without exchanging information by means of the 'little books of men'?»
>
> E. Eisenstein

I. The reflection on the role of the book in scientific practice and theory offers a vantage point to look at the inner tension between radical innovation and dependence on the past, which characterized the rise of modern physics. The printed book – as it has been shown by several recent studies – has been momentous for the development of new scientific ideas, helping in both the transmission of data and the diffusion of new theories, especially in the fields of astronomy and medicine[1]. There was even a self-awareness of the pivotal role played by the huge quantity of printed books for the establishment of new sciences, as it is shown for example by Kepler in reference to Paracelsian medicine and Copernican astronomy[2]. Some philosophers and scientists, as a consequence, took up the role of editors and publishers of their own works[3].

[1] The latter point was stressed by S. DRAKE, *Early Science and the Printed Book: The Spread of Science Beyond the University*, «Renaissance and Reformation» 6 (1970), pp. 38-52. The crucial role of printing for the development of modern science has been underscored in the groundbreaking study of E. EISENSTEIN, *The Printing Press as an Agent of Change: Communications and Cultural Transformations in Early Modern Europe*, Cambridge University Press, Cambridge 1979 (see in particular pp. 453-708). More recently see: A. JOHNS, *The Nature of the Book. Print and Knowledge in the Making*, University of Chicago Press, Chicago 1998 and M. FRASCA-SPADA / N. JARDINE (eds.), *Books and the Sciences in History*, Cambridge University Press, Cambridge 2000. The role of the book as a scientific instrument and the relevance of communication for the development of natural sciences are underscored in the synthetic account of M. BERETTA, *Storia materiale della scienza. Dal libro ai laboratori*, Bruno Mondadori, Milano 2002, pp. 26-27, 48-58.

[2] J. KEPLER, *De stella nova in pede Serpentarii*, Pragae 1606, p. 188: «Scriptorum vero in omnibus facultatibus, maxime post annum 1563. major quotannis excuditur numerus, quam mille ante actis fuerat universorum. Per hos nova hodie facta est Theologia, nova Iurisprudentia, novarunt et Paracelsistae Medicinam, et Copernicani Astronomiam». Kepler is here discussing the possible astrological influence on human history of a planetary conjunction occurred in 1563.

[3] On the activity of XVII[th] century philosophers in the process of publication see R. TUCK, *The Institutional Setting*, in D. GARBER / M. AYERS (eds.), *The Cambridge History of Seventeenth-Century Philosophy*, Cambridge University Press, Cambridge 1998, pp. 26-31. A detailed account of the case of astronomy (covering in particular the activity of Galilei and Tycho) is given in JOHNS, *The Nature of the Book* cit., pp. 6-28.

The publication of modern works, of course, ran parallel to the printing of scientific books of the Antiquity. Some previously unavailable texts, such as the poem of Lucretius (first printing in 1478) and the works of Archimedes and Pappus translated by Commandino (1558 and 1588 respectively), provided crucial insights for the development of the new mechanical and mathematical approaches in natural philosophy. New commentaries on already available Aristotelian or Neoplatonic texts, at the same time, could provide the occasion to find modern theories foreshadowed in a long forgotten tradition: Kepler highlighted heliocentrism in Aristoteles' *De coelo*[4], and Newton even wanted to find hints of an archaic knowledge about action at a distance in the writings of the presocratic philosophers[5]. On the whole a huge network of printed books provided a crucial instrument for the making of modern science.

In spite of this evidence, the break with the dominant Aristotelian-scholastic tradition has been connected by distinguished modern philosophers to a devaluation of the book itself as an indirect source of knowledge, compared to the direct investigation of nature by means of experience and reasoning. This view has left a persistent mark in the historical representation of scientific inquiry, and today it is still uncommon to include the book – together with the telescope and the microscope – among the essential *instruments* of modern science.

One early example is Paracelsus, who insists repeatedly on the contrast between nature as a «book» that must be the source of medical learning and the «paper books» («papirische bücher»), that cannot really teach the beginning of medical knowledge, since they cannot grasp nature itself[6]. Paracelsus even boasted, answering a charge of plagiarism, of not having read any book for 10 years[7].

[4] See N. Jardine, *The Birth of History and Philosophy of Science. Kepler's A Defence of Tycho against Ursus with Essays on its Provenance and Significance*, Cambridge University Press, Cambridge 1984.

[5] Notably in the posthumously published *De mundi systemate* (a non-technical draft of what was later to become Book III of the *Principia mathematica*) and in several other manuscripts, such as the so-called "classical *Scholia*" (Royal Society of London, Gregory Mss. 247, ff. 6-14), which where first published by Paolo Casini in 1981. P. Casini, *Newton: gli scolii classici. Presentazione, testo inedito e note*, «Giornale critico della filosofia italiana», LX, 1 (1981), pp. 7-53. Cf. «History of Science», 22 (1984), pp. 1-58 (English translation of this paper, by A.R. Hall). One more example is the unpublished Preface to the second edition of the *Principia*, UCL MS Add. 3968, fol. 109, transcribed in Newton, *Mathematical Papers*, ed. D.T. Whiteside, 8, Cambridge University Press, Cambridge 1981, pp. 442-459.

[6] See e.g. Paracelsus (T. von Hohenheim), *Labyrinthus medicorum errantium* (1553), in Id., *Sämtliche Werke*, I.11, Georg Olms, Hildeseim-Zürich-New York 1996, pp. 169, 175-176: «Ein baum der da stehet, der gibt on das alphabet den namen baum und darf keins alphabets zu seiner noturft, und er selbst zeigt an durch sein erzeigen, was er ist, was er gibt, was in inne ist, warzu er ist, und das on papir, dinten und federn. Also wie nun der baum sich selbst describirt und uns selbst leret, wie er ist, was da ist, also ist das buch des firmaments auch, von dem kompt der ursprung in das alphabet [...] der dis buch nicht erfert, der mag kein arzt sein noch geheissen werden. Dan der arzt wird gezwungen, wie einer ein buch auf dem papir list, also die sternen des firmaments zusamen buchstaben und den sentenz nachfolgend darasu nemen» (175).

[7] Id., *Buch Paragranum* (1530), in Id., *Sämtliche Werke* cit., I, 8, p. 33. See M.L. Bianchi, *Natura e*

Similar ideas can be found in later seminal works of XVIIth century philosophy of nature. Bacon's *Instauratio magna*, for example, is conceived as an «entirely different» beginning of natural science, which requires a dismissal of the whole tradition of scientific books started in Greek Antiquity. Bacon laments that the «variety of books on which the arts and sciences pride themselves» actually contains «endless repetitions of the same thing» and nothing new concerning «invention»[8]. Moreover these books provide a source of false prejudices (*idola theatri*), since they are «plainly impressed [*indita*] and received into the mind from the fables of the theories [*ex fabulis theoriarum*] and the perverted rules of demonstrations»[9]. The key to the innovation of philosophy is the adoption of a brand new method, characterized by the collection of observations and by inductive reasoning.

To be sure, Bacon considers writing to be a fundamental feature of scientific investigation. He argues that simple sensory observation is in itself illusory and has to be interpreted by means of the «literate experience [*experientia literata*]», which proceeds «according to a fixed law»; the making of this experience, in turn, necessarily needs the support of «writing»[10]. Yet only generations of men will be able to lead this new science to perfection; therefore Bacon, introducing the *Novum organum*, gives up for the time present the composition of a «perfect treatise» and organizes the matter «in aphorisms»[11].

A similar break with the book tradition, more specifically directed to the scholastic tradition, can be found in Galilei. In the *Dialogo sopra i massimi sistemi* the Aristotelian scholar Simplicio makes the boastful statement that «everything» is demonstrated in the books of Aristotle, if only one is able to read them skilfully:

> «bisogna [...] saper combinare questo passo con quello, accozzar questo testo con un altro remotissimo; ch'è non è dubbio che chi ci averà questa pratica, saprà cavar da' suoi libri le dimostrazioni di ogni scibile, perché in essi è ogni cosa»[12].

sovranatura nella filosofia tedesca della prima età moderna. Paracelsus – Weigel – Böhme, Olschki, Firenze 2011, pp. 7-9, 137-139.

8 F. Bacon, *Instauratio magna*, *Praefatio*, in Id., *The Works*, ed. J. Spedding / R.L. Ellis / D.D. Heath, Longman & co, London 1857, I, p. 125: «Nam si quis in omnem illam librorum varietatem qua artes et scientiae exultant introspiciat, ubique inveniet ejusdem rei repetitiones infinitas, tractandi modis diversas, inventione praeoccupatas».

9 Bacon, *Novum organum*, aphorism LXI, in Id., *The Works* cit., I, p. 294. In aphorisms LVII-LVIII Bacon refers to the books of Greek Antiquity and in particular to Aristotle.

10 Bacon, *Novum organum* cit., p. 310 (aph. C-CI).

11 Bacon, *Instauratio magna* cit., p. 229.

12 G. Galilei, *Dialogo sopra i massimi sistemi*, in *Le opere di Galileo Galilei*, Barbèra, Firenze 1968, VII, p. 134.

Sagredo ironically criticizes this view, stressing once again the problem of invention:

> «Questo è un modo di contener tutti gli scibili assai simile a quello col quale un marmo contiene in sé una bellissima, anzi mille bellissime statue; ma il punto sta a saperle *scoprire*»[13].

Aristotle himself – argues Salviati – would have corrected his books, if only he had *seen* the «novelties discovered in the sky»; his modern followers, by denying the need and relevance of new observations, do not deserve the title of «philosophers», but are rather to be named «doctors of memory» or «historians»[14]. Criticism of the tradition and ideal of a new science reach their climax in a famous page of Galilei's dialogue *Il Saggiatore* (1623), where the resort to authority in astronomy is severely criticized and philosophy written in books is contrasted with philosophy written in nature itself:

> «Parmi scorgere nel Sarsi ferma credenza, che nel filosofare sia necessario appoggiarsi all'opinioni di qualche celebre autore, sì che la mente nostra, quando non si maritasse col discorso d'un altro, ne dovesse in tutto rimanere sterile e infeconda; e forse stima che la filosofia sia un libro e una fantasia d'un uomo, come l'*Iliade* e l'*Orlando furioso* [...] La filosofia è scritta in questo grandissimo libro che continuamente ci sta aperto innanzi agli occhi (io dico l'universo), ma non si può intendere se prima non s'impara a intender la lingua, e conoscer i caratteri, ne' quali è scritto. Egli è scritto in lingua matematica, e i caratteri son triangoli, cerchi, ed altre figure geometriche, senza i quali mezzi è impossibile a intenderne umanamente parola: senza questi è un aggirarsi vanamente per un oscuro laberinto»[15].

The platonic view of a mathematical structure of nature, that finds expression in this metaphor and is defended in several places of Galilei's writings, establishes the possibility of a new demonstrative science in natural philosophy[16]. Galilei is stating thereby the possibility to decipher nature's own language and, consequently, to understand physical truth as well as God himself does (though

[13] Galilei, *Dialogo* cit., p. 135 (my italics).

[14] Galilei, *Dialogo* cit., pp. 136, 139.

[15] Galilei, *Il saggiatore*, in *Le opere* cit., VI, p. 232.

[16] See for example Galilei, *Dialogo* cit., pp. 229-234. To be sure, the possibility of a mathematical science of nature was put in doubt in Plato's dialogues. According to Plato, the world of becoming lacks the perfection of mathematical forms (see *Rep.* 529d sqq.; *Phil.* 59 a-b; *Tim.* 28a, 29c). Therefore Cassirer rightly argued that Galilei's «physical Platonism was a thing unheard of» and that «never before had such a Platonism been maintained in the history of philosophy and science». E. Cassirer, *Galileo's Platonism*, in F.A. Montagu (ed.), *Studies and Essays of Science and Learning. Offered in Homage to George Sarton*, Schuman, New York 1947; quoted from Id., *Gesammelte Werke* (= ECW), hrsg. B. Recki, Meiner, Hamburg 1998-2009, 24, p. 337.

God knows by intuition and not by reasoning[17]). Trusting these metaphysical hypotheses Galilei does not put emphasis on the *medium* of the new philosophy and, as regards the internal structure of his works, he merely adopts the humanistic dialogue as a rhetorical framework for the new mathematical science.

Indeed the metaphor of the book of nature, from Campanella to Galilei, from Bacon to Thomas Browne, supported in the XVII[th] century the idea that philosophy could – or even had to – *by-pass* the books of men in order to gain direct access to the works of God. Yet this ancient metaphor could not in itself express the original challenge, and problems, of modern mathematical science of nature[18]. Campanella, for example, used the same metaphor as he scorned the study of «dead books» written by men and invoked a return «to the original». But the signs of the *invisibilia Dei*, according to Campanella, are «the heavens and the stars themselves», rather than the abstract mathematical forms: the «book of nature» expresses the mysteries of astrology rather than the demonstrative truths of mechanics[19].

As we have seen, recent scholarship has argued against the myth of the immediateness of early modern science by underscoring the instrumental, communicative role of the books for the shaping of modern science[20]. Yet the transition from the gathering of information to the conception and exposition of a new physics presented a different kind of problem, whose solution involved the invention of new models of philosophical book.

II. The urgent need to express the idea of a new natural philosophy in the structure of a single book was a central issue for Descartes, who faced a hard chal-

[17] GALILEI, *Dialogo* cit., p. 129.

[18] A criticism of the cliché that «the Renaissance shook off the dust of yellowed parchments and began instead to read in the book of nature or the world» was advanced by Ernst Robert Curtius, who traced back the origins of the metaphor of the book of nature in the Late Antiquity. See E.R. CURTIUS, *Europäisches Literatur und lateinisches Mittelalter*, Francke, Bern 1948, English translation by W.R. Trask, Princeton University Press, Princeton New Jersey 1983, p. 319. The metaphor itself expressed quite different meanings in the course of its long history. Different aspects of its modern posterity are explored in H. BLUMENBERG, *Die Lesbarkeit der Welt*, Suhrkamp, Frankfurt a.M. 1979.

[19] T. CAMPANELLA, *Modo di filosofare*, in ID., *Poesie*, a cura di G. Gentile, Sansoni, Firenze 1939, pp. 30-31. The classical Galileian *locus* on the opposition between the «work» of God (the world) and the «words» of God (the Holy Writings) is the letter to Elia Diodati of 15 January 1633, in ID., *Le opere* cit., XV, p. 24. For a stimulating study on the metaphor of the book of nature in XVII[th] century, with particolar emphasis on Campanella and Galilei, see E. GARIN, *La nuova scienza e il simbolo del "libro"*, in ID., *La cultura filosofica del Rinascimento italiano*, Sansoni, Firenze 1961, pp. 451-465. Garin advances an intriguing suggestion (p. 457): «forse di proposito Galileo si servì dei termini tecnici magico-astrologici ['caratteri', 'figure', 'triangoli'] per trasferirli su un altro piano, svuotandoli di ogni carica misteriosa».

[20] As Eisenstein puts it: «how could the 'great book of Nature' be investigated, one is tempted to ask, without exchanging information by means of the 'little books of men'?» (EISENSTEIN, *The Printing Press* cit., p. 455).

lenge in trying to outline a new science of nature by innovating the model of academic schoolbooks. First of all, Descartes shared with Bacon and Galilei a pungent mistrust of the old books of natural philosophy. Though recognizing that «the books of the ancients have to be read», since they present the efforts of past men, expose their findings and suggest what has still to be found in all disciplines, Descartes considers the reading of these books as «nonetheless dangerous», since it can involuntarily lead to «contract» their errors: «Sed interim valde periculosum est, ne quae forsitan errorum maculae, ex illorum nimis attenta lectione contractae, quantumlibet invitis & caventibus nobis adhaereant»[21]. The ideal of an autonomous reconstruction of knowledge, typical of Descartes' new method, finds expression in his paradoxical exercise of solving philosophical problems without the guide of books and finding any truth promised in their titles by means of «some innate insight».

> «Quoties novum inventum aliquis liber pollicebatur in titulo, antequam ulterius legerem, experiebar utrum forte aliquid simile per ingenitam quamdam sagacitatem assequerer, caveabamque exacte ne mihi hanc oblectationem innocuam festina lectio praeriperet»[22].

The composition of the *Essais* was the groundbreaking result of this youth proposal, providing samples of a new understanding of nature in fields as different as astronomy and physiology. But in order to remove the faults of past natural philosophy from the academic teaching Descartes, later on in his intellectual career, decided to compose a new compendium of the whole philosophy, eventually titled *Principia philosophiae*. Descartes initially considered the possibility to have it printed together with an abridgement of the scholastic compendium of Eustache de Saint Paul, in order to show the superiority of the new philosophy on the former. This single book, so claimed Descartes, would be able to teach to «despise» the philosophy of the Schools and at the same time to teach the whole of his new philosophy[23]. Eventually he gave up this original project, but the exposition of the *Principia* is still organized in short articles. Thereby Descartes adopts a demonstrative «order and style» that is typical of the scholastic expositions:

[21] R. Descartes, *Regulae ad directionem ingenii*, in *Œuvres*, éds. C. Adam / P. Tannery (= AT), X, p. 366. The emotional and intellectual side effects of reading were widely debated in XVII[th] century: see Johns, *The Nature of the Book* cit., pp. 380-443.

[22] Descartes, *Regulae* cit., p. 403.

[23] Descartes, Letter to Mersenne, December 1640, in AT III, p. 260: «ceux qui n'ont point encore appris la Philosophie de l'Ecole, l'apprenderont beaucoup plus aisement de ce livre que de leurs maistres, à cause qu'ils apprendront par mesme moyen à la mépriser».

> «[...] sed alio ad scholarum usum magis accomodato, brevibus scilicet articulis singulas quaestiones includendo, talique ordine ipsas exequendo, ut sequentium probatione ex solis praecedentibus dependeat, omnesque in unum corpus redigantur»[24].

The result is as a truly demonstrative book, which reflects in its structure the rational order of nature itself. In the opening letter of the French edition of the *Principia* (1647) Descartes insists that his book satisfies the two necessary and sufficient conditions that are required for a perfect philosophy, that is clarity of the principles and possibility to deduce from them all the other truths:

> «J'aurois voulu mettre ici les raisons qui servent à prouver que les vrays Principes par lesquels on peut parvenir à ce plus haut degré de Sagesse, auquel consiste le solverai bien de la vie humaine, sont ceux que j'ay mis en ce Livre: & deux seules son suffisantes à cela, dont la premiere est qu'ils sont tres-clairs, & la seconde, qu'on en peut deduire toutes les autres choses: car il n'y a que ces deux conditions qui soient requises en eux»[25].

In spite of the exemplar role played by Descartes' book for the successive development of modern physics, it is important not to overplay the originality of this style of exposition, as it is suggested by the quoted lines of the letter to Dinet. Axiomatic foundation and deductive connection of scientific propositions were mainstream features of the very Aristotelian tradition that Descartes intended to supersede and it can indeed be argued that the diffusion of the *more geometrico* style of demonstrative reasoning in contemporary scholastic philosophy occasionally influenced Descartes' expositive style in a somewhat misleading way[26]. For example, it is significant that Descartes, in his replies to the objections raised by "theologians and philosophers" to his *Meditationes de prima philosophia*, was actually pushed by Mersenne to put his arguments about God and the soul in a geometrical form, precisely in order to satisfy the style of the scholastic exposition; he wrote in this occasion that the «rationes» were now

[24] Descartes, *Epistola ad P. Dinet*, AT VII, p. 577.

[25] Descartes, *Lettre de l'autheur*, AT IX-2, p. 9.

[26] See H.J. De Vleeschauwer, *More seu ordine geometrico demonstratum*, Universiteit van Suid-Afrika, Pretoria 1961. This work is still useful for an overview of the scholastic background and of Descartes' own critical view of geometrical method. More recently, Descartes' misleading adoption of the demonstrative style of exposition has been the object of several illuminating studies. See D. Garber / L. Cohen, *A Point of Order: Analysis, Synthesis, and Descartes'* Principles (1982) and Garber, *J.-B. Morin and the second* Objections (1995), now in Id., *Descartes Embodied. Reading Cartesian Philosophy through Cartesian Science*, Cambridge University Press, Cambridge 2001, pp. 52-63 and 64-84; S. Gaukroger, *The Sources of Descartes' Procedure of Deductive Demonstration in Metaphysics and Natural Philosophy*, in J. Cottingham (ed.), *Reason, Will and Sensation. Studies in Descartes' Metaphysics*, Clarendon Press, Oxford 1994, pp. 47-60.

«more geometrico dispositae», rather than *demonstratae*[27]. On the contrary, Descartes rejected the syllogistic form of reasoning and insisted in the *Discours de la méthode* on the heuristic function of the analysis of ideas as a fundamental feature of his philosophy. According to his own account, the ancient «analytical» method of solving geometrical problems (which Descartes rediscovered through the translation of Pappus' *Collectiones*) inspired his elaboration of a new philosophical method of problem solving by means of a resolution of complex to simple problems, designed eventually to lead to self-evident principles[28].

The relevance of this methodical innovation was eventually reflected in the *joint* publication of a Latin translation of the *Discours*, the *Essais* and the *Principia philosophiae* in 1644. This single *volumen* would therefore sketch the whole course of human knowledge, starting from methodical preparation and following a synthetical path that goes from the first principles of human knowledge down to the explanation of particular phenomena of nature and culminates in the science of man and its conduct.

> «Puis, lors qu'il [the reader] s'est acquis quelque habitude à trouver la verité en ces questions, il doit commencer tout de bon à s'appliquer à la vraye Philosophie, dont la premiere partie [Book I of the *Principia*] est la Metaphysique, qui contient le principes de la connoissance, entre lesquels est l'explication des principaux attributes de Dieu, de l'immaterialité de nos ames, & de toutes les notions cairese & simples qui sont en nous. La seconde est la Physique, en laquelle, apres avoir trouvé les vrays Principes des choses materielles [Book II], on examine en general comment tout l'univers est composé [Book III], puis en particulier quelle est la nature de cette Terre & de tous les corps qui se trouvent le plus communement autour d'elle, comme de l'air, de l'eau, du feu, de l'aymant & des autres mineraux [Book IV]. En suitte de quoy il est besoin aussi d'examiner en particulier la nature des plantes, celle des animaux, & sur tout celle de l'homme, afin qu'on soit capable par apres de trouver les autres sciences qui luy sont utiles [Books V-VI, unwritten]. Ainsi toute la Philosophie est comme un arbre, dont les racines sont la Metaphysique, le tronc est la Physique, & le branches qui sortent de ce tronc sont toutes les autres sciences, qui se reduisent à trois principales, à sçavoir la Medecine, la Mechanique & la Morale»[29].

In this famous page Descartes outlines the task of grounding a mechanistic physics on metaphysical roots, leaving to experimental inquiry the task of com-

[27] Descartes, *Secundae responsiones*, AT VII, p. 160: «Rationes dei existentiam & animae a corpore distinctionem probantes more geometrico dispositae».

[28] Descartes, *Discours de la méthode*, AT VI, pp. 19-20; Id., *Secundae responsiones* cit., p. 156. In the latter place, after discussing the method of analysis and synthesis in geometry, Descartes openly rejects the application of synthesis in metaphysics, since the most controversial point of metaphysical issues precisely lies in the clear and distinct perception of first notions.

[29] Descartes, *Lettre de l'autheur* cit., p. 14.

pleting the particular deductions of phenomena[30]. The actual realization of this program was contested by followers as well as opponents, on the side of both metaphysics (think of mind-body interaction and the idea of matter) and mechanics (think of the laws of motion and the rules of impact); yet the program itself, with its metaphysical and geometrical inspiration, influenced whole generations of philosophers and physicists, long beyond the decline of Cartesian philosophy and the rise of Newtonianism. In spite of Descartes' warnings and caution about the ancient demonstrative method, his research program in physics was mainly understood as an aprioristic enterprise, crowned by the exposition of the Laws of motion. From the point of view of his reception Descartes can even be considered – as it has been suggested by Helmut Pulte – as the starter of a tradition of «mechanical Euclidism» which played a major role in the structuring of rational mechanics until the middle of XIX^th^ century and whose main tenets are: *a*) to ground physics on concepts and principles that express the essential order of nature; *b*) to adopt in the structure of the exposition the axiomatic and demonstrative method of Euclid's geometry[31].

In the perspective of the metaphysical foundation of mechanics, natural philosophers of the second half of XVII^th^ century taking up or confronting this "Cartesian" program had to face a preliminary dilemma: either to fully accept the challenge and attempt the realization of a rational, demonstrative system of nature as a whole, or to give up the metaphysical explanation and – adopting a more Galileian view – concentrate on the demonstrative, mathematical science of motion, considering it as an autonomous field of knowledge characterized by gradual progresses and open problems. This alternative eventually gave rise to a division between books of metaphysics and books of mathematical physics, producing a gap inside the modern tradition of natural philosophy.

According to the first option, chosen by thinkers such as Malebranche, Spinoza and Leibniz, physics and metaphysics merged together in a single system, spanning from the basic ideas of metaphysics to the explanation of human sense perception and thought. The realization of such an ambitious rational architecture tended to highlight the formulation and defence of general principles, reducing physics to a sketchy and unaccomplished extension of metaphysics. This is particularly evident in Spinoza's works, which include the exposition of a mechanistic natural philosophy in very short outline and for the sake of metaphysical

[30] Descartes made clear that general principles could lead to *different* particular explanations, therefore arguing that experimental inquiry should necessarily support the development of physical explanations and leaving this open problem to future researchers (*Discours de la méthode* cit., pp. 64-65).

[31] H. PULTE, *Axiomatik und Empirie. Eine wissenschaftstheoriegeschichtliche Untersuchung zur Mathematischen Naturphilosophie von Newton bis Neumann*, Wissenschaftliche Buchgesellschaft, Darmstadt 2005.

issues[32]. The main point of this mechanistic physics is to confirm the parallelism between ideas and affections of the bodies, while the mathematical details of mechanics stay out of focus. The full completion of a *more geometrico* demonstrative philosophy, on the model of Euclid's *Elements*, reduces natural philosophy to a marginal discipline, without addressing its main issues in a detailed way.

Leibniz presents a more interesting case, since he devotes hundreds of pages to rational mechanics and the foundation of the science of motion on the metaphysics of substances. In the early dialogue *Pacidius Philaleti* (1676) Leibniz advances the idea of a «logica physica», which will treat substance and moving force and thereby complement Galilei's geometry, considered as a «logica mathematica». The realization of this idea is presented, through the words of Filaletes, not as an «opus absolutum», but rather as a collection of loose leaves: «schedas sparsas, et subitanearum meditationium vestigia male expressa, et memoriae tantum causa nonnumquam servata»[33]. This fragmentary state of physics will not change substantially after the dynamical turn in Leibniz's «new system» and the publication of the *Specimen dynamicum* (1689). Leibniz writes several different, partial expositions of his new science, the most articulate being the unpublished *Dynamica de potentia* of 1690. Nonetheless his dynamics never gets to the point of fitting its wider metaphysical framework and remains a work in progress. The unaccomplished state of this project does not depend much on the rejection of Newton's mathematical theory of gravity, but rather on the failure to connect in a fully successful way the basic mechanical concepts, such as space and matter, to the metaphysical domain of substance[34].

Leibniz inserted his dynamical research in a wider philosophical framework, insisting that physics as the knowledge of natural beings could not be separated from an encyclopaedic body of knowledge, encompassing both logic and ethics. The encyclopaedic exposition could be realized in a synthetic order and only had to include cross references in order to avoid repetitions[35]. The whole of science,

[32] See for example B. Spinoza, *Ethica*, II, *prop*. 13, *scholium*, in Id., *Opera*, hrsg. C. Gebhardt, Winters, Heidelberg 1925, II, pp. 96-103. Spinoza admits that he cannot explain here the nature of bodies and claims that he does not need this full explanation in order to demonstrate what he wants: he expounds therefore «pauca de natura corporum» in order to clarify the unity of mind and body.

[33] G.W. Leibniz, *Pacidius Philaleti* (1676), in Id., *Sämtliche Schriften und Briefe* (Akademie-Ausgabe), Reihe VI, Hrsg. Leibniz-Forschungsstelle Münster, 3, p. 533.

[34] In the late *Entretien de Philalete et Ariste* (1713) Leibniz touches on both points and advocates the possibility to explain extension of space and exension of bodies by means of the concept of «diffusion» of properties of true subjects, respectively «situation or locality» and «antitypy or materiality» (Leibniz, *Die philosophischen Schriften* [= GP], hrsg. C.J. Gerhardt, VI, pp. 584-585). But Leibniz fails, here and elsewhere, to give a full account of how this diffusion descends from the properties of substance. For a fascinating account of this problem in Leibniz's metaphysical and geometrical writings (both published and unpublished) see V. De Risi, *Geometry and Monadology. Leibniz's* Analysis Situs *and Philosophy of Space*, Birkhäuser, Basel-Boston-Berlin 2007.

[35] See e.g. Leibniz, *Nouveaux essais sur l'entendement humain*, IV, 21, in GP V, p. 504.

in turn, was but a way of expressing an infinite «ocean» of knowledge by means of the human finite intellect: «Le corps entier des sciences peut estre consideré comme l'ocean, qui est continue partout, et sans interruption ou partage, bien que les homes y conçoivent des parties, et leur donnent des noms selon leur commodité». Perfect knowledge transcends therefore any specific form of symbolic expression[36]. In order to express this gap between the ideal and the real domain of human knowledge Leibniz, himself a librarian and erudite besides a philosophical genius, revived the metaphor of the book. At the end of the *Essais de theodicée* (1710), in a conclusive attempt to clarify his theory of predestination, Leibniz elaborates on Lorenzo Valla's dialogue *De libero arbitrio* and adds a different ending to the story. Theodore falls asleep in the temple of Athena and dreams of being led by the goddess to the «palace of destinies». According to Athena's explanations, each of the different infinite apartments of the palace is here the «representation» of one of the possible worlds considered by Jupiter before the creation, which includes the life of Sextus (another character of the dialogue) as he existed in this particular world. Inside each apartment there is a large quantity of volumes, which compose «the book of destinies» of each world. On the forehead of Sextus there is a number, which corresponds to a place (*endroit*) in the book, where the life of Sextus is told in all details. The paradoxical nature of this infinite book is expressed by a significant observation: by putting a finger on a particular line of this written story, Theodore will see «representé effectivement dans tout son detail ce que la ligne marquée en gros»[37]. The ideal of the book of nature actually corresponds to a perfect duplication of the world itself, which cannot be realized by any symbolic representation, and implies the transcendence of the written page by means of an intuitive act. The metaphorical representation of the infinite «book of destinies» therefore reflects the intrinsic *impossibility to complete* natural philosophy as the demonstrative knowledge of any physical event, insofar as this science actually corresponds to an abstract, symbolic knowledge, which is a feature of the human finite intellect[38].

[36] The quotation reproduces the first lines of a manuscript which is conserved at the Landesbibliothek in Hannover (LH IV, 8, 25, f. 94). The text was originally published by Couturat in his *Opuscules et fragments inédits*, and has been critically edited, together with thematically connected manuscripts, in LEIBNIZ, *De l'horizont de la doctrine humaine. La restitution universelle*, éd. M. Fichant, Vrin, Paris 1991, p. 35. Cf. *Meditationes de cognitione, veritate et ideis*, in GP IV, p. 422, where Leibniz introduces the subdivision of adequate knowledge in symbolic and intuitive knowledge and thereafter comments: «si [cognitio] simul adaequata et intuitiva sit, perfectissima est».

[37] LEIBNIZ, *Essais de théodicée*, in GP VI, p. 363.

[38] A similar point about the paradoxical nature of perfect demonstrative knowledge in natural philosophy was made by Cassirer in his discussion of another classical myth of modern determinism, Laplace's omniscient «spirit». See CASSIRER, *Determinismus und Indeterminismus in der modernen Physik*, «Göteborgs högskolas årsskrift», 42/3 (1936), Stockholm 1937; in ECW 19, pp. 17-18; cf. pp. 19 and sqq.

III. Turning back to the dilemma of Descartes' heritage, we find in Newton's *Philosophiae naturalis principia mathematica* (1687) an alternative and more successful solution of the problems faced by the systematic ideal of Cartesian natural philosophy. Newton himself considered the book as his own «*Principia philosophiae*»[39]. Indeed the structure of the book grossly reminds the Cartesian outline: first come the definitions of the fundamental concepts (space, time and the different kinds of moving force) and the exposition of the *leges motus*, which Newton and the Newtonians, adopting Descartes' wording, usually called *leges naturae*; there follow three books of mathematical propositions, that culminate in the deduction of particular phenomena in Book III, «*De mundi systemate*». But this similarity is accidental: Newton's book is actually about rational mechanics, and it aims at superseding the Cartesian metaphysical and mechanical model by means of a mathematical approach. Definitions and axioms strictly regard the quantities that are involved in the measurement of movement. Books I and II contain purely mathematical propositions about possible movements of bodies and the measure of the corresponding moving forces. Book III, by help of astronomical and terrestrial observations, finally determines the actual universal law of the motion of bodies, which is connected to the concept of gravity, without solving the issues of the nature of gravity and of the causal explanation of phenomena. The first lines of this book contain an important programmatic statement about the structure of the whole *Principia*:

> «In libris praecedentibus principia philosophiae tradidi, non tamen philosophica sed matematica tantum, ex quibus videlicet in rebus philosophicis disputari posit. Haec sunt motuum & virium leges & conditiones, quae ad philosophiam maxime spectant. Eadem tamen, ne sterilia videantur, illustravi scholiis quibusdam philosophicis, ea tractans quae generalia sunt, & in quibus philosophia maxime fundari videtur, uti corporum densitatem & resistentiam, spatia corporibus vacua, motumque lucis & sonorum. Superest ut ex iisdem principiis doceamus constitutionem systematis mundani. De hoc argumento composueram librum tertium methodo populari, ut a pluriuso legeretur. Sed quibus principia posita satis intellecta non fuerint, ii vim consequentiarum minime percipient, neque praejudicia deponent, quibus a multis retro annis insueverunt: & propterea ne res in disputationes trahatur, summam libri illius

[39] The words 'principia' and 'philosophiae' are printed in larger letters in the title page of the first two editions of the work, and even printed in red ink in the third edition. A direct reference of Newton to the work as his «*Principia philosophiae*» is made in his anonymous *Account* of the *Commercium epistolicum*, the report of the Royal Society on the controversy about the priority of the invention of the calculus («Philosophical Transactions», 29/342 (1714-1715), p. 206; facsimile reprint in A.R. HALL, *Philosophers at War: The Quarrel between Newton and Leibniz*, Cambridge University Press, Cambridge-London-New York 1980). For a discussion of the title of the *Principia* and Newton's critical reference to Descartes see I.B. COHEN, *A Guide to Newton's* Principia, in I. NEWTON, *The Principia*, University of California Press, Berkeley-Los Angeles-London 1999, pp. 43-48.

transtuli in propositiones, more matematico, ut ab iis solis legantur qui principia evolverint»[40].

The unpublished manuscript of the original *De mundi systemate*, where we can see the result of this «popular method» of exposition, contains a qualitative description of the Solar system which presents a parallel and alternative account to Descartes' *Le monde* by eliminating mechanical vortexes and introducing the concept of universal gravitation. In the unpublished manuscript *De gravitatione* (whose dating is still controversial) we can see how Newton was very deeply involved in the study and criticism of Descartes' *Principia* before (and possibily on the very eve of) writing his own book[41]. The main reason why Newton dropped the idea of the «popular» exposition was to avoid the controversy with the mechanistic philosophers, which could be (and actually were) disappointed with Newton's introduction of gravity. Action at a distance was simply unconceivable in the framework of Cartesian mechanism, and was notably considered by Huygens and Leibniz as a return back to the «qualitates occultae» of the scholastic philosophers. These were most probably the «prejudices» that the mathematically trained reader of Newton's *Principia* would be forced to abandon. The whole architecture of the *Principia* was carefully designed to prevent such controversies, without insisting on the opposition to mechanical explanations in Cartesian style[42].

This crucial point inspired much of Newton's work on the different editions of the book published during his lifetime (1687, 1713, 1726), whose tormented story has been studied by the help of the several unpublished manuscripts and alternative drafts[43]. Before publishing the first edition, Newton even considered

[40] I. NEWTON, *Philosophiae naturalis principia mathematica*, the third edition (1726) with variant readings, ed. A. Koyré / I.B. Cohen, Cambridge University Press, Cambridge 1972, p. 549.

[41] The text was first published in *Unpublished Scientific Writings of Isaac Newton*, ed. A.R. Hall / M. Boas Hall, Cambridge University Press, Cambridge 1962. The editors considered it to be a juvenile work. On the contrary, Betty Dobbs contended that it is a mature work, written between 1684 and 1685 (B.J. DOBBS, *The Janus Faces of Genius: The Role of Alchemy in Newton's Work*, Cambridge University Press, Cambridge 1991, pp. 141-146). Cf. H. STEIN, *Newton's Metaphysics*, in I.B. COHEN / G. SMITH (eds.), *The Cambridge Companion to Newton*, Cambridge University Press, Cambridge 2002, p. 302 n. 39. On the influence of Descartes' *Principia* see I.B. COHEN, *Newton and Descartes*, in G. BELGIOIOSO ET AL. (a cura di), *Descartes: il metodo e i saggi*, Istituto della Enciclopedia Italiana, Roma 1990, pp. 607-634.

[42] Descartes is named only four times in the *Principia*, and none of these references regards the main issue of the vortex hypothesis. Newton writes indeed, in the second edition of the work, that «the vortex hypothesis is beset with many difficulties», but he does not explicitly name the Cartesians (NEWTON, *Principia mathematica* cit., p. 759, *Scholium generale*: «Hypothesis vorticum multis premitur difficultatibus»). In the *Account* of the *Commercium epistolicum* cit., pp. 222-224, Newton himself summarizes the methodological strategy adopted in the *Principia* and the *Opticks,* and thereby rejects the charge advanced by continental philosophers about his alleged use of hypotheses in the theory of gravity.

[43] For a short summary of this story see COHEN, *A Guide to Newton's* Principia cit., pp. 11-25.

not to include Book III at all. He eventually adopted his mathematical style, renounced to publish a planned conclusion with a treatment of microscopic forces and took pains in several places of the book to clarify that by his mathematical argument he did not address the issue of the nature of gravity, leaving it to «natural philosophy». In several places Newton suggested the possibility that the mathematical concept of gravity could be physically interpreted in a mechanical fashion, denying any inference from his use of the word 'attraction'[44]. This was not enough to avoid the charge of adopting the very speculative and irrational hypothesis of gravity, and therefore, in the second edition, Newton heavily modified the non-mathematical sections of the text: he eliminated the «*Hypotheses*» section, dividing its short propositions in the new sections *Regulae philosophandi* and *Phenomena*, and inserted the new *Scholium generale*, which includes the characterization of the new «experimental philosophy» as both *intrinsically incomplete* and *sufficient*. This text includes some hints of Newton's own metaphysical ideas on God and the world and underscores once more that the mathematical and experimental foundation of gravity lacks a full account of the *causes* of phenomena; but Newton insists on the principle of avoiding hypotheses – whether «metaphysical or mechanical» – in philosophy and concluded that the new approach is sufficient in itself to satisfy the explanatory demands of natural philosophy:

> «Rationem vero harum gravitatis proprietarum ex phaenomenis nondum potui deducere, & hypotheses non fingo. Quicquid enim ex phaenomenis non deducitur, *hypothesis* vocanda est; & hypotheses seu mechanicae, seu physicae, seu qualitatum occultarum, seu mechanicae, in *philosophia experimentali* locum non habent. In hac philosophia propositiones deducuntur ex phaenomenis, & redduntur generales per inductionem. Sic impenetrabilitas, mobilitas, & impetus corporum & leges motuum & gravitates innotuerunt. Et satis est quod gravitas revera existat, & agat secundum leges a nobis expositas, & ad corporum celestium & maris nostri motus omnes sufficiat»[45].

With these famous words the unknowability of causes, which was already a

[44] NEWTON, *Principia mathematica* cit., p. 44-46 (*Def.* VIII, *Scholium*): «Voces autem attractionis, impulsus, vel propensionis cuiuscunque in centrum, indifferenter & pro se mutuo promiscue usurpo; has vires non physice sed mathematice tantum considerando. Unde caveat lector, ne per hujusmodi voces cogitet me speciem vel modum actioni causamque aut rationem physicam alicubi definire, vel centris (quae sunt puncta matematica) vires vere & physice tribuere». Cf. p. 298 (I, *Sec.* XI, *Scholium*).

[45] NEWTON, *Principia mathematica* cit., p. 764 (*Scholium generale*). Again, Newton decided *not* to include in the second edition a conclusion that, drawing on experiments conducted by Francis Hauksbee, supposed the cause of gravity to lie in an «electric spirit». See the unpublished draft UCL MS Add. 3965, fols. 351-352; MS 3970, fols. 602-604, now presented and translated in COHEN, *A Guide to Newton's* Principia cit., pp. 283-292.

diffused issue of philosophy in the late XVII^th^ century[46], received an official sanction in Newton's magisterial treatise. Could this sufficiency be just a *temporary* feature of natural philosophy? Newton considered the theoretical possibility of a future synthetic, "top-down" exposition of philosophy from the causes to the effects, and after the second edition of the *Principia* he still considered to mention this future accomplishment in a new *Preface*: «finally it will be possible to come down from the causes of the causes (established by phenomena) to their effects, by arguing a priori»[47]. Eventually, though, he declared the *pro tempore* status of truth to be an essential feature of natural philosophy[48]. This excluded – contrary to Descartes – the very possibility of a conclusion of the analytical investigation of problems by help of intellectual insight. Thereby the *Principia* introduced a new, self-sufficient model of natural philosophy, grounded on the bracketing of metaphysical questions and the demonstrative power of mathematics, that would influence all mechanics and would determine a scission in the old natural philosophy.

But, as it is well known, this is not the whole story behind Newton's book. In spite of the attempt to divide the demonstrative part of science, which regards *effects* and the laws that best describe them, from the hypotheses about their unknown *causes*, Newton's «experimental philosophy» still depended on several metaphysical presuppositions and conjectures. They find expression not only in the huge mass of unpublished dynamical, alchemical and theological Newtonian manuscripts, but also in the marginal, non-demonstrative sections of the *Principia* and the *Opticks* and in some letters to distinguished scholars of the time (including those of Samuel Clarke to Leibniz, in the famous correspondence, since Newton took part to the formulation of Clarke's arguments from the background): think of the concept of absolute space as God's «sensorium» and the effect of his omnipresence, to the «creation» of «absolutely hard» atoms, to God's «design» of

[46] For a wide overview of texts on this topic in Cartesian, Lockean and Newtonian traditions see G. Tonelli, *Die Anfänge von Kants Kritik der Kausalbeziehungen und ihre Voraussetzungen im 18. Jahrhundert*, «Kant-Studien», 57 (1966), pp. 417-456.

[47] Newton, UCL Ms Add 3968 fol. 109, quoted from the English translation in Cohen, *A Guide to Newtons'* Principia cit., p. 53. Newton made explicit reference to the analysis and synthesis of the ancient geometers as a model for his method in natural philosophy (see e.g. Newton, *Opticks*, Dover, New York 1952, based on the fourth edition – William Innys, London 1730 –, *Query* 31, p. 404); yet he actually superposed in a rather confusing way this geometrical model with the method of resolution of the late Scholastic: the former leads from the unknown to the known, whereas the latter leads from the known (effects) to the unknown (causes). See N. Guicciardini, *Isaac Newton on Mathematical Certainty and Method*, The MIT Press, Cambridge Mass.-London 2009, p. 323. On the scholastic background of Newton's views see S. Ducheyne, *Newton's Training in the Aristotelian Textbook Tradition: from Effects to Causes and Back*, «History of Science», 43 (2005), pp. 217-237.

[48] See for example Newton, *Opticks* cit., p. 404. Cf. Id., *Principia mathematica* cit., p. 555 (*Regula* IV).

the Solar system and his action in the conservation of cosmic movements. The very homogeneity of geometry and nature, that grounds the possibility of a demonstrative rational mechanics, was a "Platonic" (or "Galileian") metaphysical tenet, as rightly argued by historians such as Koyré, and a main point of disagreement of Newton with Descartes' presentation of physics as a «fable»[49]. The real presence of geometrical forms in physical space, for example, is clearly argued in the unpublished essay *De gravitatione*[50]. The problematic status of this metaphysical postulate encouraged again – as in Galilei – the use of metaphorical expression: Newton often refers in his writings to the «geometer God» and this idea is depicted in an engraving included in a collection of Newtonian mathematical texts, where the *putti* draw ellipses that retrace the archetypes held in hand by the goddess[51]. The metaphysical conjectures did not regard only the most general and basic concepts of philosophy, but overlapped with a vast number of experimental open issues, as Newton could not resist recognizing in the final lines of the *Scholium generale*, introducing the hypothesis of a *spiritus subtilissimus*, whose action would produce phenomena as different as cohesion and electrical attraction, light emission and sensation, and even voluntary movement[52].

The Newtonian attempt to reconcile experimental philosophy with essentialist and demonstrative features of natural philosophy (laws of nature; axiomatic-deductive method), though enormously influent, resulted in a fragile compromise. First of all, the certainty of Newton's three famous *leges motus* was not absolute, even though they were in agreement with any known experience and, as we have seen, were guaranteed against hypothetical criticism in the fourth rule of philosophy. According to Newton's own account of experimental method, indeed, any law could not be considered as definitively true, since it could always

[49] The revival of this demonstrative ideal was a feature of Newton's philosophy since the early writings and was meant to contrast, together with Descartes' alleged probabilism, the dominant experimental trend of the Royal Society. For a detailed account see GUICCIARDINI, *Newton on Mathematical Certainty and Method* cit.

[50] NEWTON, *De gravitatione* cit., English translation in ID., *Philosophical Writings*, ed. A. Janiak, Cambridge University Press, Cambridge 2004, p. 22. Space itself is considered here as an «emanative effect» of God (p. 26).

[51] See e.g. NEWTON, *Mathematical Papers* cit., VII, p. 286; II, p. 243. The engraving is in ID., *Analysin per Quantitatum*, ed. W. Jones, ex officina Pearsoniana, Londini 1711, p. 69.

[52] NEWTON, *Principia mathematica* cit., pp. 764-765: «Adjicere jam liceret nonnulla de spiritu quodam subtilissimo corpora crassa pervadente, & in iisdem latente; cujus vi & actionibus particulae corporum ad minimas distantias se mutuo attrahunt, & contiguae factae cohaerent; & corpora electrica agunt ad distantias majores, tam repellendo quam attraendo corpuscula vicina; & lux emittitur, reflectitur refringitur, inflectitur, & corpora calefacit; & sensatio omnis excitatur, & membra animalium ad voluntatem moventur, vibrationibus scilicet hujus spiritus per solida nervorum capillamenta ad externis sensuum organis ad cerebrum & a cerebro in musculos propagatis. Sed haec paucis exponi non possunt; neque adest sufficiens copia experimentorum, quibus leges actionum hujus spiritus accurate determinari & monstrari debent».

be superseded in the light of new experiments[53]. In turn, the provisional nature of these «axioms» rendered superfluous the deduction of propositions according to the archaic geometric style, that moreover did not match Newton's own analytical methods and presented problems even to the mathematically learned readers[54]. Finally, the huge number of phenomena which were not included in the demonstrative account strongly limited any hope of ever completing Newtonian philosophy: Newton's attitude against «complete systems», indeed, was praised by his followers as a sign of his philosophical greatness, while the ideal of future completion of Newtonian philosophy was projected into a remote future as a task possibly realized by generations of scientists[55].

IV. The "experimental" side of Newtonianism would eventually lead to a completely new ideal of knowledge, which takes into account the historical contingency of philosophy and the book. The French *Encyclopédie* satisfies the need for the collection and organization of past and present knowledge, typical of modern encyclopaedism, but it is expected to retain its own validity only for a limited time. Diderot shows how this awareness was present in the planning and the swift execution of the work:

> «Une *Encyclopédie*, ainsi qu'un vocabulaire, doit être commencée, continuée, & finie dans un certain intervalle de tems, & qu'un intérêt sordide s'occupe toûjours à prolonger les ouvrages ordonnés par les rois. Si l'on employoit à un dictionnaire universel & raisonné les longues années que l'étendue de son objet semble exiger, il arriveroit par les révolutions, qui ne sont guere moins rapides dans les Sciences, & sur-tout dans les Arts, que dans la langue, que ce dictionnaire seroit celui d'un siecle passé, de même qu'un vocabulaire qui s'exécuteroit lentement, ne pourroit être que celui d'un regne qui ne seroit plus»[56].

[53] Newton himself declared his belief in the certainty of the laws of motion in a letter to Roger Cotes (NEWTON, *Correspondence*, Cambridge University Press, V, Cambridge 1975, pp. 391 sqq.). On the other hand, as we have seen, he conceded that demonstrative certainty was in principle excluded by his own analytical method. Newton considers this opinion, in contrast to the Cartesian view, in Ms. 3970 f. 479, quoted and commented in G.A.J. ROGERS, *Locke's* Essay *and Newton's* Principia, «Journal of the History of Ideas», 39 (1978), p. 231-232. According to William Emerson this method, by admitting only experimentally grounded propositions, was sufficient to establish the ultimate validity of Newton's philosophy and defend it against its critics: «the *Newtonian* philosophy, being thus built upon this solid foundation, must stand firm and unshaken; and being once proved to be true, it must eternally remain true, until the utter subversion of all the laws of nature [...] it may indeed be improved and further advanced; but it can never be overthrown» (W. EMERSON, *The Principles of Mechanics*, Richardson, London 1754, p. V).

[54] On this aspect of Newton's method see N. GUICCIARDINI, *Reading the* Principia*: The Debate on Newton's Mathematical Methods for Natural Philosophy from 1687 to 1736*, Cambridge University Press, Cambridge 1999; ID., *Isaac Newton on Mathematical Certainty* cit., pp. 293-305.

[55] See for example C. MACLAURIN, *An Account of Sir Isaac Newton's Philosophical Discoveries*, Nourse, London 1775[3] (1748[1]), pp. 12-13, 100-101.

[56] D. DIDEROT, "Encyclopédie", in D. DIDEROT / J.B. D'ALEMBERT (éds.), *Encyclopédie, ou dictionnaire raisonné des sciences, des arts et des métiers, etc.*, Briasson / David *et al*., Paris 1751-1777, V, p. 636.

The «revolutions in the sciences» depend on both new experiments and new rational reflections and they result in the inevitable aging of any conceptual dictionary.

> «La révolution peut être moins forte & moins sensible dans les Sciences & dans les Arts libéraux, que dans les arts méchaniques; mais il s'y en fait une. Qu'on ouvre les dictionnaires du siecle passé, on n'y trouvera à *aberration*, rien de ce que nos Astronomes entendent par ce terme; à peine y aura-t-il sur l'*électricité*, ce phénomene si fécond, quelques lignes qui ne seront encore que des notions fausses & de vieux préjugés. Combien de termes de *Minéralogie* & d'*Histoire naturelle*, dont on en peut dire autant? [...]
> Quand on traite des êtres de la nature, que peut-on faire de plus, que de rassembler avec scrupule toutes leurs propriétés connues dans le moment où l'on écrit? Mais l'observation & la physique expérimentale multipliant sans cesse les phénomenes & les faits, & la philosophie rationelle les comparant entr'eux & les combinant, étendent ou resserrent sans cesse les limites de nos connoissances, font en conséquence varier les acceptions des mots institués; rendent les définitions qu'on en a données inexactes, fausses, incompletes, & déterminent même à en instituer de nouveaux»[57].

The rigorous restriction underscored by Diderot can be appreciated on the background of Chamber's *Cyclopaedia*, the model of the French *Encyclopédie*. Chamber's book was intended not only to answer the practical need of concentrating a full library in single book, but also to organize knowledge in a rational «system»[58]. In the epistemological framework of the *Encyclopédie*, a 'system' is strictly speaking a kind of metaphysical undertaking, such as Descartes', and as such it is no longer able to match the ideal of a perfect knowledge; on the contrary, *systems* are included in the encyclopaedia as episodes in the history of knowledge, whose validity strictly depends on the conformity to experimental facts[59]. Thereby a new problem is presented for the post-Newtonian investiga-

[57] DIDEROT, "Encyclopédie" cit.,V, p. 636 A.

[58] The *Cyclopedia* would «answer all the Purposes of a Library, except Parade and Incumbrance; and contribute more to the propagating of useful Knowledge thro' the Body of a People, than any, I almost said all, the Books extant» (E. CHAMBERS, *Cyclopedia; or, an Universal Dictionary of Arts and Sciences*, James and John Kapton (*et alia*), London 1728, 1738[2], *Preface*, p. II). Therefore, though organized in alphabetical order, the book would include a «system», whose unity would be clarified by means of a «chain of references» (CHAMBERS, *Cyclopedia* cit., p. I; ID., *Proposals for Printing by Subscription, "Cyclopaedia"*, London 1726, s.p.). Cf. R. YEO, *Encyclopaedic Knowledge*, in FRASCA-SPADA / JARDINE (eds.), *Books and the Sciences* cit., pp. 207-215.

[59] Cf. the account (largely derived from Condillac's ideas) in the article "Systeme (mètaphysique)", in DIDEROT / D'ALEMBERT (éds.), *Encyclopédie* cit., XV, pp. 777-778. This attitude of French Encyclopaedism will be revived in the 1930s by Otto Neurath in his programmatic writings about the International Encyclopaedia of Unified Science: «the system is the "big scientific lie"»; «*the* system is opposed to *an* encyclopaedia» (O. NEURATH, *Einheit der Wissenschaft als Aufgabe* [1935] and *Einheitswissenschaft als enzyklopädische Integration* [1938], in ID., *Gesammelte philosophische und methodologische Schriften*, Hölder-Pichler-Tempsky, Wien 1981, II, pp. 626, 889 respectively).

tion of nature, as the very unity of natural philosophy has to be justified in the light of the historical change of scientific concepts and laws.

This post-Newtonian conceptual dynamics encouraged a subdivision of the problems of natural philosophy into different disciplinary domains. This subdivision involved first of all the separation of the investigation of the causes from the investigation of the effects. According to John Harris' *Lexicon technicum*, natural philosophy, or Physics, is that «Science which contemplates the powers of Nature, the Properties of Natural Bodies, and their mutual Action one upon another», while rational mechanics is the «Mathematical Science which shews the Effects of *Powers*, or moving Forces so far as they are applied to Engines»[60]. On the whole, the domain of philosophy was subdivided into (at least) three different disciplinary groups: *applied mathematics*, which included rational mechanics, *non-mathematical physics*, which included empirical inquiries about chemical, biological and psychological phenomena, and a «*general physics*» or «*metaphysics of bodies*», which regards the universal properties of matter without any reference to their particular experimental and mathematical investigation. The coexistence of these disciplines under the general title of a «science of nature», represented in the table of the *Encyclopédie*, conceals a theoretical problem that finds different solutions in the textual organization of XVIIIth century books[61].

Rational mechanics textbooks present an almost purely mathematical discipline, whose dependence on empirical observations and metaphysical conjectures is carefully removed from sight. This non-mathematical residuum is considered as a field of uncertainty, which does not offer the possibility of fruitful investigations and is often explored in very short memoirs, elementary handbooks or popular writings, whose authors are often distinguished scientists themselves[62]. A good example are the works of Euler. His Latin mechanical treatises (*Mechanica sive motus scientia*, 1736, and *Theoria motus corporum solidorum seu rigidorum*, 1765) dedicate a minimal space to definitions and the laws of motion; the philosophical inquiry into the concepts of space, time and force is conducted in short essays such as the *Réflections sur l'espace et le tems* (1750) and the *Recherches sur l'origine des forces* (1752), or the unpublished *Anleitung zur Naturlehre*; the larger horizon of human knowledge, including an account of unexplained phenomena and a discussion of controversial metaphysical issues, is

[60] J. HARRIS, *Lexicon Technicum: Or, An Universal English Dictionary of Arts and Sciences: Explaining not only the Terms of Art, but the Arts Themselves*, Brown *et al.*, vol. I, London 1704 (repr. Johnson Reprint Corporation, New York-London 1966): "Mechanicks"; "Natural Philosophy"; s.p.

[61] DIDEROT / D'ALEMBERT (éds.), *Encyclopédie* cit., I, *Systéme figurè des connoissances humaines. Entendement*.

[62] On the popular literature of Newtonianism see M. TERRALL, *Natural Philosophy for Fashionable Readers*, in JARDINE / FRASCA-SPADA (eds.), *Books and the Sciences* cit., pp. 239-254.

represented in the *Léttres a une princesse d'Alemagne sur divers sujet de physique & de philosophie* (1768, 1772).

A more dismissive attitude towards metaphysics is typical of D'Alembert and Lagrange. In their correspondence, they mock the German Academy of Sciences for having proposed a question on the «fundamentum virium», since the latter question lacks both intelligibility and universality in the context of the scientific community[63]. In Lagrange's *Méchanique analytique* (1788), indeed, the definitions of space, time, matter and force are not spelled out; the three Newtonian laws of motion are replaced by a single axiom, the principle of virtual velocities, which allows the deduction of all mechanical relations but does not correspond to any essential property of bodies. Moreover, the conservation of energy excludes the need for a divine intervention in the mechanical history of the world. Lagrange praises his own work because it is purely mathematical. Contrary to Euler, he does not even bother to write about metaphysical issues of natural science. Metaphysics of force, for example, is not anymore recognized as a piece of scientific inquiry, and is rather considered as a local, German problem:

> «Cette science [metaphysics], si c'en est une, n'est nullement de mon gibier. Il me semble que chaque pays a Presque sa Métaphysique particulière comme sa langue, et la question proposée [on the nature of force] est de Métaphysique allemande et leibnitienne»[64].

V. The delimitation and subdivision of natural philosophy, typical of Newtonianism, received a wide opposition in German academic institutions, where *Schulmetaphysik* and the Leibnizian heritage favoured renewed attempts at a metaphysical foundation of physics in a single systematic architecture. According to Wolff, Newtonian physics has indeed an undeniable value in its mathematical part, but it lacks a metaphysical foundation of the basic concepts and laws of physics[65]. Wolff tried to correct this flaw in his influent system of philosophy, by adopting again a metaphysical framework and a *more geometrico* demonstrative form of exposition. The three main pillars of his rationalistic system are presented in his books *Philosophia prima sive Ontologia* (1730), *Cosmologia generalis* (1731) and *Psychologia rationalis* (1734)[66]. The exposition of

[63] D'Alembert to Lagrange (22 September 1777) and Lagrange to D'Alembert (27 January 1778), in J.L. Lagrange, *Oeuvres complètes*, éds. J.-A. Serret / G. Darboux, Gauthiers-Villars, Paris 1867-1892, XIII, pp. 332, 336.

[64] Lagrange, Letter to D'Alembert cit., p. 336.

[65] See Ch. Wolff, *Elogium Godofredi Guilielmi Leibnittii*, «Acta eruditorum» (July 1717), repr. in Id., *Meletemata mathematico-philosophica*, Renger, Halae Magdeburgicae 1755, p. 446 (repr. Olms, Hildesheim 1974, p. 975). On the diffusion of Newtonianism in XVIIIth century German philosophy and physics see P. Casini, *Newton in Prussia*, «Rivista di filosofia» 91/2 (2000), pp. 251-282.

[66] On the systematical framework of Wolff's philosophy and its origins in the late Scholastics see M.

the metaphysical elements of rational physics in the *Cosmologia* revives the Cartesian ideal of connecting a purely rational metaphysics with empirical physics, and updates its physical content, by including tentative demonstrations of the Newtonian laws of inertia and action and reaction[67]. Wolff's systematic organization, though it did not provide any genuine theoretical advance in natural philosophy, sketches the program for a new synthesis of empiricist – and Newtonian – with rationalist – and Leibnizian – elements which will largely influence German scientific textbooks[68] as well as the research on natural philosophy of later thinkers such as Formey, Gottsched, Knutzen, Lambert and Kant.

Kant praises Wolff's «rigorous method» in the *Kritik der reinen Vernunft*, where he presents the plan for a full reorganization of a system of metaphysics, which will include a foundation of natural philosophy[69]. Wolff, to be sure, failed to present metaphysics as a science because he (as much as all the philosophers of the past) did not firstly prepare the ground with a critique of the organ of philosophy, namely reason itself. Yet reason itself, according to Kant, is systematic and therefore science has to be presented in the form of a system. Indeed, the systematic character of reason offers the possibility to «unify all systems as members of a whole», in a «system of human knowledge», and the times are ripe for collecting past materials and realize this system[70]. In order to establish the resulting «system of metaphysics», including the «metaphysics of nature» which Kant presents as the ultimate systematic accomplishment of his critique of theoretical reason[71], the different (pure and empirical) sources of knowledge have

LAMANNA / C. ESPOSITO, *Dalla metafisica all'ontologia: storia di una trasformazione editoriale (secoli XVI-XVII)*, in this volume, pp. 255 sqq.

[67] WOLFF, *Cosmologia generalis*, Officina libraria rengeriana, Frankfurt-Leipzig 1737² (1731¹), *De legibus motus*, pp. 228-392 (repr. Olms, Hildesheim 1964).

[68] For an overview of German textbooks of natural science and applied mathematics see G. LIND, *Physik im Lehrbuch 1700 - 1850: Zur Geschichte der Physik und ihrer Didaktik in Deutschland*, Springer, Berlin 1992.

[69] I. KANT, *Kritik der reinen Vernunft*, Hartknoch, Riga 1781(= A), 1787² (= B), B XXXVI-XXXVII; *Kants gesammelte Schriften* (= KgS), hrsg. Königlich Preußlichen Akademie der Wissenschaften (und Nachfolgern), Berlin 1900sqq., III, pp. 21-22.

[70] KANT, *Kritik der reinen Vernunft* cit., A 835/B 863, KgS III, p. 540: «nicht allein ein jedes [System ist] für sich nach einer Idee gegliedert, sondern noch dazu alle unter einander in einem System menschlicher Erkenntnis wiederum als Glieder eines Ganzen zweckmäßig vereinigt sind und eine Architektonik alles menschlichen Wissens erlauben, die jetziger Zeit, das schon so viel Stoff gesammelt ist, oder aus Ruinen eingefallener alter Gebäude genommen werden kann, nicht allein möglich, sonder nicht einmal so gar schwer sein würde». I will use here the English translation by P. Guyer and A.W. Wood, Cambridge University Press, Cambridge UK 1998. In this paragraph and in paragraph VII I consider some aspects of Kant's reflection on the book, focusing on the textual organization of natural philosophy; for an exhaustive and penetrating account of Kant's views on the philosophical book see M. CAPOZZI, *Philosophy and Writing: the Philosophical Book according to Kant*, in this volume.

[71] KANT, *Kritik der reinen Vernunft* cit., A XXI, KgS IV, pp. 13-14; B XXXVI-XXXVII, KgS III, pp. 21-22.

to be investigated and separated; this will be of the foremost utility in order to distinguish the domain of objectively valid knowledge from the ever unfruitful field of speculative metaphysical questions about the «unconditioned».

Kant never realized his projected «metaphysics of nature» in a single book, deciding to concentrate on the fundamental philosophical problems that underlie his plan; the metaphysical foundation of natural science, in particular, turned out to be of the outmost importance for the establishment of the system. In order to understand this crucial point it is necessary to consider the systematic project outlined by Kant in the first *Critique*. In this systematic plan[72], the «metaphysics of nature» is subdivided into transcendental philosophy, which does not refer to any object in particular (it is the critical version of ontology, which investigates the possibility of knowledge in general), and «physiology of pure reason», which regards different kinds of objects; the latter, in turn, is subdivided into «immanent» and «transcendent physiology», the latter including (in correspondence with Wolff's system) «rational cosmology» and «rational theology», which – as it is shown in the *Transcendental Dialectic* – cannot ever attain the status of sciences. Immanent physiology, finally, is subdivided in «rational physics» and «rational psychology», as the *a priori* sciences which presuppose the empirical intuition of external objects (bodies) and inner objects (soul; the pure rational theory of the soul, corresponding to Wolff's «rational psychology», is also denied any scientific status in the *Transcendental Dialectic*). Trying to expound this metaphysics of nature in a new work, in 1785, Kant will find that rational psychology, in his sense, contains a very poor set of principles about inner experience, which, moreover, cannot provide examples *in concreto* of crucial metaphysical categories, such as substance: therefore he will not include the latter's exposition in the definitive version of the *Metaphysische Anfangsgründe der Naturwissenschaft* (1786)[73]. In the end, bodily nature remains the *only field* of knowledge where the traditional concepts of metaphysics can get a full objective application by receiving a «meaning *in concreto*».

There is indeed an interdependence between Kant's new metaphysics and physics: metaphysics requires the intuition of physical objects in order to provide any meaning to its pure concepts, and therefore successfully determine the domain of objective truth, while physics requires the «pure part», corresponding to the principles of metaphysics, in order to provide universal validity to its laws. This «pure physics» will provide the ultimate, "top-down" foundation that

[72] See KANT, *Kritik der reinen Vernunft* cit., A 845-849/B 873-877, KgS III, pp. 546-548.

[73] KANT, *Metaphysische Anfangsgründe der Naturwissenschaft*, Hartknoch, Riga 1786; KgS IV, p. 471. Cf. Kant's letter to Christian Schütz of 13 September 1785, where he explains his intention to reduce the rational theory of the soul to an Appendix (KgS X, p. 46).

was lacking in Newtonian philosophy, since it is drawn from purely intellectual sources and as such it can attain «absolute completeness»[74]. This interdependence between metaphysics and physics is examined in the *Metaphysische Anfangsgründe*, where Kant provides philosophical proofs of some fundamental tenets of Newtonian physics, while challenging previous natural philosophy for having denied the necessity of metaphysical principles[75]. In a footnote to the *Kritik der reinen Vernunft*, elaborating on the idea of «rational physics», Kant also claims that «mathematicians», by lacking a scientific treatment of metaphysics, have made an implicit and uncontrolled use of hypotheses[76].

According to Kant, which clearly refers to Newton's merely inductive foundation of philosophy, Newton was right in defending natural philosophy from metaphysics, insofar as the latter makes no reference to experience; nonetheless, empirical physics requires the joint use of mathematical *and* metaphysical principles (e.g. principle of conservation of substance, principle of causality) in order to introduce fundamental concepts «such as movement, impenetrability, inertia etc.». In a later manuscript, Kant will turn back to this claim by writing that the title of Newton's book contains a «contradiction with itself», since philosophy and mathematics depend on different sources of *a priori* knowledge and therefore go «side by side» (*neben einander*) in the foundation of empirical science of nature: the correct title would have been «*Scientiae naturalis principia mathematica*»[77]. It is evident, then, that Kant had ambitiously conceived his *Metaphysische Anfangsgründe der Naturwissenschaft* as a philosophical *pendant* to Newton's *Principia mathematica*.

In order to highlight this idea of a complementarity between philosophy and mathematics, Kant wrote his *Metaphysische Anfangsgründe* according to the

74 Kant, *Metaphysische Anfangsgründe* cit., KgS IV, p. 473.

75 Kant, *Metaphysische Anfangsgründe* cit., KgS IV, p. 472: «Alle Naturphilosophen, welche in ihrem Geschäfte mathematisch verfahren wollten, haben sich daher jederzeit (obschon sich selbst unbewußt) metaphysischer Principien bedient und bedienen müssen, wenn sie sich sonst wider allen Anspruch der Metaphysik auf ihre Wissenschaft feierlich verwahrten».

76 Kant, *Kritik der reinen Vernunft* cit., A 847/B 875, KgS III, p. 547: «[...] selbst Mathematiker, indem Sie gewissen gemeinen, in der Tat doch metaphysischen Begriffen anhängen, die Naturlehre unvermerkt mit Hypothesen belästigt haben, welche bei einer Kritik dieser Prinzipien verschwinden, ohne dadurch doch dem Gebrauche der Mathematik in diesem Felde (der ganz unentbehrlich ist) im mindesten Abbruch zu tun».

77 Kant, *Opus postumum*, KgS XXII, p. 512 (ca. 1799): «In einem besondern Werke betitelt: metaphysische Anf. Gr. Der NW. wurden philosophische Prinzipien derselben aufgestellt [...] nun zeigt sich aber hier ein Nebenbuhler nämlich kein gringerer Mann als Newton selbst in seinem unsterblichen Werke: *Philosophiae* naturalis principia *mathematica*./Da ist aber schon in der Betitelung dieses seines Buchs ein Wiederspruch mit sich selbst: den so wenig es *philosophische Principien der Mathematik* geben kann eben so wenig kann es *mathematische Principien der Philosophie* geben (dergleichen doch die Physik enthalten soll). Es hätte lauten müssen Scientiae naturalis principia mathematica; diese Principien aber können nicht *unter* sonder müssen *neben* einander geordnet werden».

mathematical (synthetical) method of exposition adopted by Newton in the *Principia*. The choice of this form of exposition depends on Kant's hope that a «more adept hand» may realize the systematic unification of natural philosophy into a single book following his «sketch»:

> «Ich habe in dieser Abhandlung die mathematische Methode, wenn gleich nicht mit aller Strenge befolgt (wozu mehr Zeit erforderlich gewesen wäre, als ich darauf zu verwenden hätte), dennoch nachgeahmt, nicht um ihr dadurch ein Gepränge von Gründlichkeit besseren Eingang zu verschaffen, sonder weil ich glaube, daß ein solches System deren wohl fähig sei und diese Vollkommenheit auch mit der Zeit von geschickterer Hand wohl erlangen könne, wenn, durch diesen Entwurf veranlaßt, mathematische Naturforscher es nicht unwichtig finden sollten, den metaphysischen Theil, dessen sie ohnedem nicht entübrigt sein können, in ihren allgemeinen Physik als einen besonderen Grundtheil zu behandeln und mit der mathematischen Bewegungslehre in Vereinigung zu bringen»[78].

This statement must not be taken as a revival of a *more geometrico* philosophy in the Wolffian sense: according to Kant's doctrine of method, philosophy cannot properly speaking include axioms, definitions and demonstrations in the mathematical fashion, since it cannot construct its objects in the pure intuition of space and time; therefore, Kant explicitly writes that philosophy «cannot provide, nor imitate» these mathematical propositions, «in the sense in which the mathematician takes them»[79]. Nevertheless, Kant believes that «pure physics» can be exposed in a mathematical style, insofar as it realizes a connection of purely rational philosophy with mathematics in order to provide «principles of the *construction* of concepts that belong to the possibility of matter»[80]. This intimate connection of pure physics to mathematical physics encourages Kant to suggest the former's inclusion in physical treatises, as a separate and yet indispensable part.

Kant's project to restore the unity of natural philosophy in a single treatise would not be satisfied, even though his legacy would play a major role in the later philosophy and science of nature (see below §§ VII-VIII). The *Metaphysische Anfangsgründe* were actually unable to attract the interest of physicists, not only because of the technical difficulty of the exposition, but probably also because they only regard the very general features of matter as the object of mechanics (impenetrable extension), and do not address the problem of those vast domains of natural science that since Newton's time awaited to be connected to general

[78] KANT, *Metaphysische Anfangsgründe* cit., *Vorrede*, KgS IV, p. 478.

[79] See KANT, *Kritik der reinen Vernunft* cit., A 726/B 754, KgS III, p. 477, and sqq.

[80] KANT, *Metaphysische Anfangsgründe* cit., *Vorrede*, KgS IV, p. 472.

physics and mechanics, such as chemistry, theory of heat, electricity, magnetism, physiology. According to Kant's systematic foundations of physics, indeed, most of the phenomena of nature had to remain outside the domain of science «proper» with its *a priori* foundation, and therefore be subject to the very empirical methods which Kant considered inadequate to provide a solid foundation to physics. The risk that Kant's theory of *a priori* knowledge could leave the way open to scepticism was detected by some of the most original followers of Kant's philosophy (such as Maimon and Schelling), but Kant himself was aware of it. He devoted his last years (1796-1803) to the composition of a new book that had to include a complete «elementary system» of moving forces and thereby provide a «transition [*Übergang*] from the metaphysical principles of natural science to physics»[81]. The manuscripts of this unaccomplished work – known as Kant's *Opus postumum* – include diverse attempts at sketching a systematic organization of the concepts of natural science of late XVIII[th] century, notably ether, caloric, light-matter and different kinds of attractive and repulsive central forces. Kant took pains to conceive and justify a connection between the pure concepts and principles of philosophy of nature laid down in the *Kritik der reinen Vernunft* and the *Metaphysische Anfangsgründe* and this system of concepts of empirical physics. He considered the concepts of empirical physics as both «a priori thought» and necessary for the construction of the physical object by the synthesis of perceptual data[82]. This is probably the reason why he dedicated exceptional efforts to this project, considering it as a fundamental missing piece of his system of philosophy[83].

In spite of Kant's very ingenious insights about the conceptual elements of physics, his late reflections in the *Opus postumum* (which were partially published only in 1883) would turn out to be insufficient to cover the full theoretical challenges of XIX[th] century physics, such as the philosophical interpretation of the 'field' concept. But the fragmentary form of Kant's «system» is significant

[81] A critical edition of these manuscripts was first published in 1938 as KANT, *Opus postumum*, hrsg. G. Lehmann, KgS XXI-XXII. The title adopted by Kant himself, *Übergang von den Metaphysische Anfangsgründe der Naturwissenschaft zur Physik*, shows that this work was conceived as a prosecution of the *Metaphysische Anfangsgründe* of 1786, even though some manuscripts eventually came back from physics to issues of transcendental philosophy itself. For recent accounts of these manuscripts and their place in Kant's critical philosophy see M. FRIEDMAN, *Kant and the Exact Sciences*, Harvard University Press, Cambridge Mass. 1992, pp. 212-431; E. FÖRSTER, *Kant's Final Synthesis. An Essay on the 'Opus postumum'*, Cambridge University Press, Cambridge Mass.-London 2000; P. PECERE, *La filosofia della natura in Kant*, Edizioni di Pagina, Bari 2009, pp. 665-794.

[82] See KANT, *Opus postumum* cit., 'c', KgS XXI, pp. 289-290.

[83] Kant declared that the new work had to fill a «gap» (*Lücke*) in his system. See the letter to Christian Garve, 21 September 1798, KgS XII, p. 257 and the letter to Johann Kiesewetter, 19 October 1798, Kgs XII, p. 26.

in itself, since it exemplifies – as it were – the fate of later attempts to capture in a fixed framework of concepts the uninterrupted conceptual development of physics. The completion of similar attempts, in the early XIX^th^ century *Naturphilosophie*, presents different tentative solutions to the problem of organizing the multifarious content of *Naturlehre* by distinguishing different conceptual spheres of nature itself, in order to give an interpretive account of new discoveries and logical connections in chemistry and the study of electricity. Schelling's *Ideen zu einer Philosophie der Natur* of 1797 and Hegel's *Philosophie der Natur* in the *Enzyklopädie* of 1827 are among the monumental accomplishments of this idealistic *Naturphilosophie*. But the completion of these daring books will not avoid the growing scepticism among physicists about "philosophy of nature", and in the second half of XIX^th^ century, as chemistry and electromagnetic theory were attaining a successful mathematical formulation, Kantian criticism will be preferred to speculative idealism by many distinguished German scientists, such as Helmholtz[84]. By this time, the idea of a philosophical book about the totality of nature will be definitely removed from "official" science.

VI. The abandonment of the essentialist and demonstrative ideals of mechanics took place in the second half of XIX^th^ and resulted in the ultimate disappearance of Newton's model of a single book as the systematic exposition of the principles of natural philosophy. In winter 1847-8 Carl Gustav Jacobi declared in his *Vorlesungen über analytische Mechanik* that the laws of mechanics are «conventions» and as such they are merely «probable» and never ultimately true[85]. The identification of mechanical principles with axioms, as well as their connection with essential properties of matter, tended to disappear in successive mechanics (think of the law of inertia in Neumann and Mach). Since Lagrange, the very distinction between principles and theorems had been shown to be relative to theoretical arrangements. Hertz's *Prinzipien der Mechanik* (1894) contain an exemplar statement of this relativity of any mechanical principle to a the-

[84] According to Helmholtz, the divide between *Naturwissenschaften* and *Geisteswissenschaften* had been developed, or at least highlighted, under the influence of Schelling's and Hegel's philosophies. This divide, on the contrary, was absent in Kant's philosophy: «Denn am Ende des vorigen Jahrhunderts unter dem Einflusse der Kant'schen Lehre war eine solche Trennung noch nicht ausgesprochen; diese Philosophie stand vielmehr mit den Naturwissenschaften auf genau gleichem Boden». H. HELMHOLTZ, *Über das Verhältnis der Naturwissenschaften zur Gesamtheit der Wissenschaften* in *Heidelberger Universitätsprogramm 1862*, repr. in ID., *Vorträge und Reden*, Vieweg, Braunschweig 1884, I, p. 122 and sqq.

[85] C.G.J. JACOBI, *Vorlesungen über Analytische Mechanik. Berlin 1847/48*, hrsg. H. Pulte, Vieweg/Teubner, Braunschweig 1996, p. 6 (cf. pp. 32 sqq., 59). See H. PULTE, *C.G.J. Jacobis Vermächtnis einer 'konventionalen' analytischen Mechanik. Vorgeschichte, Nachschriften und Inhalt seiner letzten Mechanik-Vorlesung*, «Annals of Science», 51/5 (1994), pp. 487-517.

oretical choice (*Auswahl*) and the consequent impossibility to identify any «concrete» exposition with the abstract scientific truth:

> «Der Begriff des mechanischen Prinzips ist demnach kein scharf festgehaltener. Wir wollen deshalb zwar jenen Sätzen in Einzelaussagen ihre herkömmliche Benennung belassen; wenn wir aber schlechthin und allgemein von den Prinzipien der Mechanik reden, so wollen wir darunter nicht jene einzelnen konkreten Sätze verstanden wissen, sondern jede übrigens beliebige Auswahl unter ihnen und unter ähnlichen Sätzen, welche der Bedingung genügt, dass sich aus ihr ohne weitere Berufung auf die Erfahrung die gesamte Mechanik rein deduktiv entwickeln lässt»[86].

The deductive process of mechanics does not have to be understood in the sense of the old identity between mathematical forms and nature; it is sufficient that the chosen symbols of mechanics allow the deduction of propositions, which in turn correctly describe the evolution of phenomena. Drawing on this theory of signs (largely indebted to Helmholtz's), Hertz presents and discusses *different* sets of fundamental mechanical concepts. The only way of selecting among them is the empirical success, and we cannot tell «whether our representation correspond with things in some other respect»[87]. Hertz's book, therefore, is just *one* among many possible and empirically successful systems of mechanics. As Hertz himself puts it:

> «Verschieden Bilder derselben Gegenstände sind möglich und diese Bilder können sich nach verschiedenen Richtungen unterscheiden [...] Nicht das einzig mögliche Bild der mechanischen Vorgänge, noch auch das beste Bild, sondern überhaupt nur ein begreifbares Bild wollte ich suchen und an einem Beispiel zeigen, dass ein solches möglich sei und wie es etwa aussehen müsse»[88].

Hertz's awareness of the compatibility of different mechanical systems, though grounded on mere epistemological concerns (which were shared and

[86] H. HERTZ, *Die Prinzipien der Mechanik in neuem Zusammenhange* dargestellt (= *Werke* III), Barth, Leipzig 1894, p. 4.

[87] HERTZ, *Die Prinzipien der Mechanik* cit., p. 1: «Das Verfahren aber, dessen wir uns zur Ableitung des Zukünftigen aus dem Vergangenen und damit zur Erlangung des erstrebten Voraussicht stets bedienen, ist dieses: Wir machen uns innere Scheinbilder oder Symbole der äusseren Gegenstände, und zwar machen wir sie von solcher Art, dass die denknotwendigen Folgen der Bilder stets wieder die Bilder seien von den naturnotwendigen Folgen der abgebildeten Gegenstände [...] Die Bilder, von welcher wir reden, sind unsere Vorstellungen von den Dingen; sie haben mit den Dingen die eine wesentliche Übereinstimmung, welche in der Erfüllung der genannten Forderung liegt, aber es ist für ihren Zweck nicht nötig, dass sie irgend eine weitere Übereinstimmung mit den Dingen haben. In der That wissen wir auch nicht, und haben auch kein Mittel zu erfahren, ob unsere Vorstellungen von den Dingen mit jenen in irgend etwas anderem übereinstimmen».

[88] HERTZ, *Die Prinzipien der Mechanik* cit., pp. 2, 39-40.

much appreciated by many philosophers and scientists after the publication of the *Prinzipien*), also reflects substantial changes in the contemporary culture of the book. The diffusion of the mechanical printing press, in the early XIXth century, resulted in an immense multiplication of publications; at the same time, the original scientific contributions appeared more often in specialized periodicals than in books (Darwin's *Origin of the Species*, published in 1859, is among the last examples of revolutionary scientific books)[89].

The problem of mastering this proliferation of texts, joint with the awareness of the historical changes in scientific concepts and systems, promoted the adoption of a historical method of understanding physical theory. Ernst Mach, in his seminal book *Die Mechanik historisch-kritisch dargestellt* (1882), derives the theoretical exposition of mechanics from its history. In the *Preface* Mach notably declares that his book is not a textbook of mechanics, and contains few mathematics, since «a full understanding of the general results of mechanics» can be best derived from the «historical analysis of knowledge»[90]. In Mach's view, historical study is the only way to critically examine the scientific propositions that are «proposed as self-evident» in the elementary and superior studies, thereby avoiding to misunderstand their concepts as «metaphysical». Historical studies, in this sense, provide «the only way to Enlightenment» («hier gibt es nur einen Weg zur Aufklärung: Historische Studien!»)[91]. In this perspective, the ideal of a ultimately valid exposition, let alone a completion of physics, completely disappears, as science appears similar to Herakleitus' river: «Die Versuche den schönen Augenblick durch Lehrbücher festzuhalten, sind stets vergeblich gewesen [...] Die Geschichte hat alles getan, die Geschichte kann alles ändern»[92]. The most prominent physicists and epistemologists of the end of XIXth century, such as Hertz, Duhem, Poincaré, share this attitude of being at the same time «philosophers» and «historians» of their discipline (to quote Galilei's opposition): they handle books of the past, more than telescopes and balances.

To sum up, the basic ideas about the book that we have highlighted discussing Bacon, Galilei and Descartes (immediacy of experience, break with the tradition, ideal of a perfect book) appear to be reversed in the development of XIXth century philosophy and science of nature: the modern systematic *ideal* of the book of modern natural philosophy disappears from scientific thought and practice with

[89] See J. Secord, *Progress in Print* and T. Broman, *Periodical Literature*, both in Jardine / Frasca-Spada (eds.), *Books and the Sciences* cit., pp. 369-392 and pp. 225-238 respectively.

[90] E. Mach, *Die Mechanik historisch-kritisch dargestellt*, F.A. Brockhaus, Leipzig 1933^{9} (repr. Wissenschaftliche Buchgesellschaft, Darmstadt 1963),*Vorwort zur ersten Auflage* (1883), p. v.

[91] Mach, *Die Geschichte und die Wurzel des Satzes von der Erhaltung der Arbeit*, J.G. Calve, Prag 1872, pp. 1-2.

[92] Mach, *Die Geschiche* cit., p. 3.

the technical reproducibility, the parcelling out and the historicisation of science; at the same time, there is a growing recognition of the value of the *books*, as indispensable instruments for the interpretation and modification of the world, insofar as they are vehicles of a modern tradition in the sciences of nature which no individual can master, let alone reconstruct by himself[93]. Finally, as the extraordinary development of sciences such as astronomy and geology gains new insights into the most remote distances in space and time, the *mutual dependence* of books and the scientific image of nature becomes a widely recognized fact.

This latter point is nicely illustrated by an engraving contained in a popular work of Victorian England, the *Gallery of Nature* by Thomas Milner: it depicts nebulae sustained by books, which reveal their existence[94]. This does not only mean that the common man can learn about the objects of astronomy by reading a popular exposition of modern discoveries; scientific knowledge itself depends on the printed calculations and reasonings about beings, such as nebulae, which can hardly (if ever) be directly observed in the sky (think, by contrast, to Galilei's revolutionary pictures of his observations of the Moon in the *Sidereus Nuncius*). This theoretical dependence of physical experience from the scientific tradition finds a pregnant expression in the words of Hermann Cohen, one of the main Neokantian philosophers of XIX^th^ century Germany, as he writes (1883):

> «Nicht am Himmel sind Sterne *gegeben*, sondern in der Wissenschaft der *Astronomie*. Bezeichnen wir diejenigen Gegenstände als gegebene, welche wir von [...] Erzeugungen und Bearbeitungen des *Denkens* als in der Sinnlichkeit gegründet unterscheiden. Nicht im Auge liegt die Sinnlichkeit, sondern in den raisons de l'astronomie»[95].

VII. Cohen's work is exemplar of the different kinds of Neokantian *Erkenntniskritik* or *Erkenntnistheorie*, flourished in the second half of the XIX[th] century as an alternative to speculative idealism and positivism, which will largely influence the views about scientific knowledge of both later philosophers and scientists[96]. In par-

[93] For a recognition of the importance of libraries and especially bibliographical instruments in order to find orientation in the «labyrinth of scholarship [Labyrinth der Gelehrsamkeit]» see H. HELMHOLTZ, *Über das Verhältnis der Naturwissenschaften zur Gesamtheit der Wissenschaften* cit., p. 128.

[94] T. MILNER, *The Gallery of Nature: A Pictorial and Descriptive Tour through Creation, Illustrative of the Wonders of Astronomy, Physical Geography, and Geology*, W.S. Orr & co., London 1846, p. 192, quoted and reproduced in SECORD, *Progress in Print* cit., p. 382.

[95] H. COHEN, *Das Prinzip der Infinitesimal-Methode and seine Geschichte: Ein Kapitel zur Grundlegung der Erkenntniskritik*, Dümmler, Berlin 1883 (repr. in ID., *Werke*, hrsg. H. Holzey, V.1), § 88, p. 127. The latter words are a reference to DESCARTES, *Meditationes de prima philosophia*, AT VII, p. 39. Here Descartes draws a distinction between the idea of the Sun derived from the senses and the idea of the Sun derived from astronomical calculations («ex rationibus Astronomiae»).

[96] See K.C. KÖHNKE, *Entstehung und Aufstieg des Neukantianismus: die deutsche Universitätsphilosophie zwischen Idealismus und Positivismus*, Suhrkamp, Frankfurt 1986.

ticular, it provides an original interpretation of Kant's basic views about scientific objectivity in the light of the new culture of the book.

In Kant's thought, since the intellect is given a constitutive power in the representation of physical objectivity, and takes up the role of legislator of nature, the ancient idea of the book as the transcription of a transcendent model (imagined as the book of nature) had been discarded. Kant himself had interpreted the whole tradition of modern natural science – from Bacon to Galilei and Newton – as the original, progressive realization of a «revolution in its way of thinking [*Revolution ihrer Denkart*]», according to which «what reason would not be able to know of itself and has to learn from nature, it has to seek in the latter (though not merely abscribe to it) in accordance with what reason itself puts into nature»[97]. According to Kant's philosophical extension of this fruitful idea to metaphysics, the categories that enable men «as it were to spell out [*buchstabieren*] appearances, so that they can be read as experience» are functions of the intellect itself, and do not have any meaning if referred to things themselves, independently from the synthetic act of knowledge[98]; the very physical thing, in turn, is represented by «the system» of concepts itself, which transforms perceptions into a net of logical and mathematical relations[99]. From this point of view, the old problem of the multiplicity of systems in natural philosophy, solved by the encyclopaedists by recognizing the historical contingency of the book, can no longer be considered as an accidental feature of human efforts to catch the essential features of the world in itself – since the latter can *only* be defined in the framework of a given natural philosophy – and it presents therefore a challenge for the very possibility of scientific knowledge. Now, as we have seen (§ V), Kant's solution to this problem involves a new idea of systematic metaphysics, grounded on an *a priori* set of concepts derived from the intellect itself, whose application to phenomena results in the formulation of objectively valid principles of natural science. However, as we have also seen, Kant's attempt to list the

[97] KANT, *Kritik der reinen Vernunft* cit., B XIII-XIV, KgS III, p. 10.

[98] KANT, *Prolegomena zu einer jeden künftigen Metaphysik, die als Wissenschaft wird auftreten können*, Riga 1783, KgS IV, p. 312 (Engl. transl. by G. Hatfield in KANT, *Theoretical Philosophy After 1781*, ed. by H. Allison / P. Heath, Cambridge University Press, Cambridge 2002, pp. 105-106): «Daher haben auch die reine Verstandesbegriffe ganz und gar keine Bedeutung, wenn sie von Gegenständen der Erfahrung abgehen und auf Dinge an sich selbst (*noumena*) bezogen werden wollen. Sie dienen gleichsam nur, Erscheinungen zu buchstabieren, um sie als Erfahrung lesen zu können».

[99] The identification of the object of knowledge with a net of «relations» is a result of the *Critique*: see e.g. KgS B 66-67, KgS III, p. 69. In a number of places of the *Opus postumum* manuscripts Kant clarifies that the object of knowledge is not the immediately given phenomenon, but is rather the result of a «composition» of dynamical concepts that logically precedes experience. «Das System ist die Sache selbst» is written, with reference to the physical object, on the margin of sheet 'G' (KANT, *Opus postumum* cit., KgS XXII, p. 343).

fundamental concepts of physics by following the guiding thread of the table of categories failed to escape the bounds of historical contingency.

In his *Logik der reinen Erkenntnis* (1902) Cohen takes an inverse way, and extracts the logical content of categories from the history of philosophical and scientific systems. This historical turn in epistemology, according to Cohen, is already implicit in Kant's critical philosophy, in spite of his occasional statements about the impossibility to learn philosophy from books. Kant wrote that his *Kritik der reinen Vernunft* was not «a critique of books and systems of pure reason, but rather that of the pure faculty of reason itself», which is occupied «not so much with objects, but rather with our mode of cognition of objects insofar as this is to be possible *a priori*»[100]. In Cohen's reading, this methodological exclusion of the philosophical tradition is not only unacceptable in the light of the new *Erkenntniskritik*, but it does not correctly describe Kant's own elaboration of criticism either, as the latter depended from a deep meditation of the modern classics of natural philosophy. Kant's transcendental method, therefore, regards in Cohen's reading no fixed set of «elements» of human knowledge, but rather «the supreme principles of an experience that has obtained objective reality *in printed books* [*in gedrückten Bücher wirklich gewordene Erfahrung*]»[101].

These intriguing words reveal the influence on Cohen's philosophical programs of the coincidence between truth and history maintained by Hegel at the start of the century. In particular, Cohen was certainly aware of the soberer methodological development of Hegel's «objective spirit» in contemporary *Geisteswissenschaften*. He published his first essays in the «Zeitschrift für Völkerpsychologie und Sprachwissenschaft» directed by Hermann Steinthal and Moritz Lazarus. In the latter's methodological writings, the book is considered as one of the vehicles of the «embodiment [*Verkörperung*] of thinking». In this sense, «books and writings» are among the «supports» (*Träger*)» for the «enduring expression» of the «objective spirit» that, in turn, serves as a collective «*content*, *norm* and *instrument* [*Organ*] for men's subjective activities», such as science[102].

100 KANT, *Kritik der reinen Vernunft*, B 27, KgS III, p. 44 (first sentence); B 25, KgS III, p. 43 (second sentence).

101 COHEN, *Kants Begründung der Ethik*, Dümmlers, Berlin 1877, p. 27 (repr. in ID., *Werke* cit., II). Italics are mine.

102 See M. LAZARUS, *Einige synthetische Gedanken zur Völkerpsychologie*, «Zeitschrift für Völkerpsychologie und Sprachwissenschaft», 3 (1865), pp. 44-45 (cf. p. 54): «Zum Theil nämlich existirt der geistige Inhalt nur als Gedanke oder sonstiges geistiges Element (Gefühl, Wille usw.) in den lebenden Trägern des Volksgeistes [...] zum anderen Theil aber erscheint er gestaltet und befestigt durch Hineinbildung in irgend einen materiellen Träger des Gedankens [...] In Büchern und Schriften aller Art [...] kurz in der Herstellung von allen körperlichen Dingen zum realen oder symbolischen Gebrauch findet der objective Geist eines Volkes seinen bleibenden Ausdruck». For this notion of 'objective spirit' cf. p. 41: «Wo

Cohen's systematic survey of scientific knowledge, by applying these methodological guidelines to natural science, shared the diffused practice of forcing historical data within a narrative of progress, and presented the path of scientific research as leading «safely and uninterruptedly to idealism»[103]. Cohen's perspective was taken up with more philological caution in Cassirer's monumental work *Das Erkenntnisproblem in der Philosophie und Wissenschaft der neuren Zeit* (1906) and in his more systematically oriented *Substanzbegriff und Funktionbegriff* (1910). In the *Preface* to the *Erkenntnisproblem* Cassirer declared that the «concept of history of science itself» presupposes a certain «continuity of thinking», which finds expression in the «conservation of a universal logical structure» in the succession of systems of knowledge[104]. The «critique of knowledge» indeed cannot postulate the logical structure which best supports the knowledge of nature, and is forced to search for «invariants of experience» in the historical development of modern natural philosophy and the particular sciences of nature[105].

As it is suggested by these mathematical analogies – 'continuity', 'invariants' – Cassirer aims at the rigorous formulation of an idea of scientific progress in physics that was already diffused among contemporary scientists, such as Poincaré and Einstein. According to this view, in the historical series of theories in exact sciences determinate «images» and hypotheses tend to be abandoned with the superseding of the theories themselves, while some mathematical «relations» remain valid inside new theories, independently of the images originally attached to them. For example, according to Poincaré, electromagnetism preserves the validity of certain relations of previous electrical theory, while discarding the image of moving molecules[106]. According to Einstein, special rela-

immer mehrere Menschen zusammenleben, ist dies das notwendige Ergebniß ihres Zusammenlebens, daß aus der subjective geistigen Thäthigkeit Derselben sich ein objective, geistiger Gehalt entwickelt, welcher dann zum *Inhalt*, zur *Norm* und zum *Organ* ihrer ferneren subjective Thätigkeiten wird». As Lazarus points out in a footnote, his concept of 'objective spirit' is different from Hegel's, since it includes «theoretischen und künstlerischen Gebiete» besides «den praktischen Geist» (for a recent edition of this text see: Id., *Grundzüge der Völkerpsychologie und Kulturwissenschaft*, hrsg. K.C. Köhnke, Meiner, Hamburg 2003, pp. 176; 179-180, cf. p. 190).

[103] Cohen, *Einleitung mit kritischem Nachtrag zu F.A. Lange, "Geschichte des Materialismus"*, Baedeker, Iserlohn und Leipzig 1914[3] (1896[1], 1902[2]), repr. with critical apparatus, in Id., *Werke* cit., V, p. 92. This work contains a detailed account, updated in every new edition, of Cohen's views on the history of modern and contemporary physics. On the *Fatalisierung* of natural sciences in the post-Romantic period see D. von Engelhardt, *Historisches Bewusstsein in der Naturwissenschaft von der Aufklärung bis zum Positivismus*, Karl Alber, Freiburg-München 1979, in part. p. 166.

[104] Cassirer, *Das Erkenntnisproblem in der Philosophie und Wissenschaft der neueren Zeit*, Bd. I, Bruno Cassirer, Berlin 1906, in ECW II, p. 13.

[105] Cassirer, *Substanzbegriff und Funktionbegriff. Untersuchungen über die Grundfragen der Erkenntnisskritik*, Bruno Cassirer, Berlin 1910, in ECW VI, p. 289.

[106] H. Poincaré, *La science et l'hypothèse*, Flammarion, Paris 1914[2] (1902[1]), pp. 256-257 sqq. Cf. Cassirer, *Substanzbegriff* cit., pp. 176-177.

tivity preserves most of the statements of classical electrodynamics and optics by inserting them in a theoretically simpler framework and reducing the number of independent hypotheses that ground the deduction of the respective laws, such as the existence of ether[107]. Elaborating on this widely recognized transition from images to mathematical invariants, Cassirer argued that the philosophical understanding of nature has to give up the idea of a preliminary determination of the language of nature, and rather derive the elementary functions of knowledge by means of the history of scientific languages and systems, in analogy to how general linguistic tries to master the diversity of historic languages. And it is precisely for this reason that Cassirer's own philosophy of science is not presented in a single systematic treatise, but in books – such as the *Erkenntnisproblem* and *Substanzbegriff und Funktionbegriff* – in which historical analyses and theoretical arguments are deeply intertwined.

Nevertheless Cassirer recovers the idea of a systematic framework for natural science in his ambitious *Philosophie der symbolischen Formen*. The third volume, the *Phänomenologie der Erkenntnis*, contains Cassirer's most general survey of the philosophy of natural science: here basic concepts of physics such as space and time are no longer considered in the perspective of scientific knowledge alone and appear in the framework of a vast discussion of the different «symbolic forms» – such as myth, religion, art and scientific knowledge itself – that organize human experience in its historical development. Scientific knowledge, from this point of view, is not the objective and only true description of the world in itself, it is rather the most universal form of symbolic organization of experience. Cassirer's «critique of knowledge», therefore, culminates in an «encyclopaedic» project, openly reminiscent of Hegelian philosophy, which is rooted, rather than in a metaphysics or first philosophy, in the tradition of the historical humanities of the time. It is very significant, indeed, that Cassirer found a correspondence between his own systematic project and the disciplinary organization of the Warburg library[108]. The ideal of encyclopaedic knowledge was no longer illustrated by the image of a transcendent, infinite book or library (as in Leibniz), but by the structure of a real, exemplar collection of interdisciplinary erudition, whose aim was to show the survival of the Antiquity in modern culture.

[107] A. Einstein, *Über die spezielle und die allgemeine Relativitätstheorie (Gemeinverständlich)*, Vieweg, Braunschweig 1917, § 15, now in *The Collected Papers of Albert Einstein*, Vol. 6: *The Berlin Years: Writings, 1914-1917*, ed. by A.J. Kox / M.J. Klein, R. Schulmann, Princeton Univ. Press, Princeton (N.J.) 1996, pp. 453-457.

[108] Cassirer, *Der Begriff der symbolischen Form im Aufbau der Geisteswissenschaften*, in F. Saxl (Hrsg.), *Vorträge der Bibliothek Warburg*, I, Teubner, Leipzig-Berlin 1923, pp. 11-12 (ECW 16, pp. 75-76).

VIII. With the crisis of mechanical philosophy at the end of XIXth century and the rise of revolutionary physical theories, such as relativity theory and quantum mechanics, the possibility of objective knowledge in the science of nature became a debated issue among both philosophers and scientists. The Neokantian program of researching a kind of structural continuity among successive scientific systems represented a possible way to reconcile objectivity with the intrinsic incompleteness of physics, that depended not only on the incessant collection of new data but also on conceptual change. This view influenced the reflections on scientific change of the leaders of the new «scientific philosophy», such as Reichenbach and Carnap, as well as of prominent physicists such as Einstein and Heisenberg[109]. A common subject of these reflections was the systematic form of classic scientific books.

Both Einstein and Heisenberg discussed the problem of scientific change confronting the model of Newton's *Principia*. According to Einstein, Newton's systematic account of the primary concepts of physics in the *Principia* appeared indeed defective and oversimplified from the point of view of the theory of relativity, yet this oversimplification had provided a «fortunate» circumstance, since it had allowed physicists to develop the foundations of classical mechanics without bothering about temporarily unsolvable conceptual issues. Deep conceptual changes had been needed in order to produce a simpler and empirically more effective account of perceptual data, notably in the special and general theories of relativity: but this, again, was not the end of the story. Einstein argued that relativity theory itself was a partial accomplishment and moreover he firmly denied the objective truth of quantum mechanics in its «orthodox» form, considering it as an «incomplete» theory. The quest for a «complete theory» was still ongoing: an analogous of Newton's *Principia* was still not available[110].

According to Heisenberg, in a similar perspective, Newton's *Principia* represent the most relevant example of a «closed theory», i.e. a rigid set of concepts and axioms, which has been a useful form of exposition in the development of physics.

> «The concepts of natural science can sometimes be sharply defined with regard to their connections. This possibility was realized for the first time in Newton's *Principia* and it is just for that reason that Newton's work has exerted its enormous influence on the

[109] An overview of the Kantian elements in XXth century physics, with particular reference to Einstein and Heisenberg, can be found in my *Fisica quantistica e realtà*, in N. ARGENTIERI / A. BASSI / P. PECERE, *Meccanica quantistica rappresentazione realtà*, Bibliopolis, Napoli 2012, in part. pp. 135-159 («Kantismo e fisica quantistica»).

[110] EINSTEIN, *Physik und Realität*, «Journal of the Franklin Institute», CCXXI/3 (1936), pp. 313-347, Engl. transl. in ID., *Out of My Later Years*, Philosophical Library, New York 1959, pp. 69-70, 82-84, 88.

> whole development of natural science in the following centuries. Newton begins his *Principia* with a group of definitions and axioms which are interconnected in such a way that they form what one may call a 'closed system'»[111].

In the light of successive theories of electromagnetic phenomena by Maxwell Lorentz and Einstein, this closed system has been shown to be valid only within a restricted domain of experiences. More generally, according to Heisenberg, it has been shown that physics can never be ultimately axiomatized. Physics' lasting results must be investigated by comparing different theories:

> «The hopes that had accompanied the work of the scientists since Newton had to be changed. Apparently progress in science could not always be achieved by using the known laws of nature or explaining new phenomena. In some cases new phenomena that had been observed could only be understood by new concepts which were adapted to the new phenomena in the same way as Newton's concepts were to mechanical events. These new concepts again could be connected in a closed system and represented by mathematical symbols, But if physics or, more generally, natural science proceeded in this way, the question arose: What is the relation between the different sets of concepts? If, for instance, the same concepts or words occurs in two different sets of concepts and are defined differently with regard to their connection and mathematical representation, in what sense do the concepts represent reality?»[112].

A particular example of this problem was the very debated connection between Einstein's theory of relativity and quantum mechanics. Heisenberg's treatment of this issue in *Physics and Philosophy* – as he was working to a «unified theory of field», in order precisely to solve this problem – is exemplar of a shift from the systematic ideal of modern physics to the historical-critical epistemological perspective, which was shared in these years by many physicists, as well as by philosophers and historians.

From the side of philosophy, for example, Carnap recognized that scientific change had shown how «misleading» (*irreführend*) was Galilei's image of the book of nature, since mathematical language is always interpreted by means of changing sets of concepts[113]. This problem had led Carnap, since the 1930s, to his seminal syntactic and semantic analyses of different scientific languages and

[111] W. HEISENBERG, *Physics and Philosophy. The Revolution in Modern Science*, Allen & Unwin, London 1958, p. 85.

[112] HEISENBERG, *Physics and Philosophy* cit., pp. 88-89.

[113] R. CARNAP, *Beobachtungssprache und theoretische Sprache*, «Dialectica» XII (1958), pp. 236-248: 240. Cf. R. CARNAP, *Philosophical Foundations of Physics: an Introduction to the Philosophy of Science*, Basic Books, New York 1966, p. 236, where Carnap claims that the interpretation of mathematical theories is «always incomplete», since theoretical terms do not have an ultimately fixed meaning and are always open to modifications.

to the claim that scientific change actually depends on a pragmatic choice among coexistent and linguistically different theories. A historiographical development of Carnap's issues was notably proposed by Kuhn in *The Structure of Scientific Revolutions* (1964)[114]. Kuhn abandoned Carnap's logical approach to scientific theories, considered as abstract formal systems. He claimed that only some fortunate *books* happen to be vehicles of scientific «paradigms» in determinate times and communities and that they can play this role since they are not mere instruments of transmission of knowledge (such as academic textbooks), but they share both the novelty of results and the opening of new problems:

> «Aristotle's *Physica*, Ptolemy's *Almagest*, Newton's *Principia* and *Opticks*, Franklin's *Electricity*, Lavoisier's *Chemistry*, and Lyell's *Geology* – these and many other works served for a time implicitly to define and legitimate problems and methods of a research field for succeeding generations of practitioners. They were able to do so because they shared two essential characteristics. Their achievements was sufficiently unprecedented to attract an enduring group of adherents away from competing modes of scientific activity. Simultaneously, it was sufficiently open-ended to leave all sorts of problems for the redefined group of practitioners to resolve»[115].

Kuhn's theses about the role of the scientific book – as a model for both normal scientific practice and revolutionary scientific change – are still useful for an analysis of contemporary scientific research. Direct reference to classic textbooks, though growingly absent in the formation of physicists, is still relevant in the case of open criticism to leading theories.

Take for example John Bell's influent writings about quantum mechanics, which are considered as a groundbreaking reference for all the physicists working on alternative theories (such as Bohmian mechanics and Collapse models). Bell has argued that textbooks of quantum mechanics, starting with Dirac's "paradigmatic" *Principles of Quantum Mechanics*, include in their postulates inconsistent claims about the measurement process, and that therefore these handbooks have misled decades of scientists in their theoretical research. The provisional and potentially misleading reference to textbooks is analyzed as follows by Bell in the course of his analysis of the measurement problem:

> «WHY NOT LOOK IT UP A GOOD BOOK?
> But *which* good book? In fact it is seldom that a 'no problem' person is, on reflection,

[114] For the connection between Carnap's «logical syntax» and Kuhn «theory of paradigms» see M. FRIEDMAN, *Kuhn and Logical Empirism*, in T. NICKLES (ed.), *Thomas Kuhn*, Cambridge University Press, Cambridge UK 2003, pp. 19-44.

[115] T.S. KUHN, *The Structure of Scientific Revolutions*, University of Chicago Press, Chicago 1962, p. 10.

willing to endorse a treatment already in the literature. Usually the good unproblematic formulation is still in the head of the person in question, who has been too busy with practical things to put it on paper. I think that this reserve, as regards the formulations already in good books, is well founded. For the good books known to me are not much concerned with physical precision»[116].

As the example of Bell's writings makes clear, the critical reference to the past is not only a source of stability (and potential sterility) in scientific practice, but it also includes the possibility of invention. This latter point is being widely recognized in contemporary history and philosophy of physics. According to Nicholas Jardine, the «calibration against precedents and standards» conducted by means of historical knowledge has been, «at least in certain traditions and disciplines in the sciences», a crucial strategy not only in order to legitimate theories, but also to provoke methodological and conceptual change[117]. The critical confrontation with books of the past, in the perspective of the present, is therefore not only a tool for the historian and philosopher, who both aim at grounding a theory of objective truth and face the challenge of relativism (as advanced most recently by the sociology of science); professional scientists themselves should «break with science», considered as a methodologically self-enclosed inquiry, they should recover their «lost literary and scientific consciousness» and «re-engage in historical reflection»: the reflection on books of the past would then result in a «proliferation and enrichment of the sciences», as it happened in modern times[118].

This method of «calibration against precedents», as a way to establish objective truth, reminds of Neokantian ideas[119] and these ideas actually have received a renewed attention in the last two decades. Kuhn himself, trying to develop a new framework for his controversial concept of «paradigm», declared in 1990 that this concept was deeply indebted to the Neokantian theory of a «relativized a priori», since both admit of historically changing sets of principles and theories which are «constitutive of the possible experience of the world»[120]. Fol-

[116] J. Bell, *Against 'Measurement'*, in «Physics World», August 1990, pp. 33-40 (now in Id., *Speakable and Unspeakable in Quantum Mechanics*, Cambridge University Press, Cambridge 2004^2, pp. 213-231): pp. 33-34.

[117] N. Jardine, *The Scenes of Inquiry. On the Reality of Questions in the Sciences*, Clarendon Press, Oxford 1991, pp. 229-230.

[118] Jardine, *The Scenes of Inquiry* cit., pp. 238-239. Jardine elaborates on the connection between the understanding past theories and the explanation of scientific innovation in *Original Meanings and Historical Interpretation* and *Original Significances and Historical Explanation*, both appended to the second edition of *The Scenes of Inquiry* (2000). Cf. Id., *Books, Texts, and the Making of Knowledge*, in Jardine / Frasca Spada, *Books and the Sciences* cit., p. 396.

[119] Jardine himself makes reference to Kant's theory of «objective validity» as a «precedent» for his account of reality in *The Scenes of Inquiry* cit., pp. 66-67.

[120] T. Kuhn, *Afterwords*, in P. Horwich (ed.), *World Changes: Thomas Kuhn and the Nature of Science*,

lowing this suggestion, Michael Friedman has devoted several writings to show how philosophical or philosophically oriented books play a fundamental role in «directing and mediating» scientific change. The criticism of past theories and the introduction of new ideas, indeed, always take place by means of a historical analysis of tradition[121].

Nowadays there is a growing recognition of the need to restore these views among professional scientists, since contemporary sciences of nature are widely unaware of the historical (and contingent) roots of their theories. On the contrary, such an awareness was typical of the revolutionary age of physics at the beginning of XX^th^ century. Einstein, on the one hand, was aware that the old ideal of Newton's time was typical of the «happy childhood of science», when nature was to the scientist like an «open book, whose letters he could read without effort»[122]. On the other hand, his confrontation with the living tradition of scientific and philosophical books (from Newton to Kant, from Mach to Weyl) was a fundamental element of his practice of what was once known, simply, as 'philosophy', and Einstein actually considered his own physical research as a philosophical enterprise. In 1944, answering to the letter of the young philosopher of science Robert Thornton, who asked for Einstein's opinion about his intention to put «as much of the philosophy of science as possible» into his modern physics course, Einstein wrote:

> I fully agree with you about the significance and educational value of methodology as well as history and philosophy of science. So many people today – and even professional scientists – seem to me like somebody who has seen thousands of trees but has never seen a forest. A knowledge of the historic and philosophical background gives that kind of independence from prejudices of his generation from which most scientists are suffering. This independence created by philosophical insight is – in my opinion – the mark of distinction between a mere artisan or specialist and a real seeker after truth[123].

MIT Press, Cambridge Mass. 1993, p. 331. Khun's was making to the seminal reappraisal of kantian *a priori* knowledge elaborated (and later rejected) by Hans Reichenbach in his *Relativität und Erkenntnis a priori* (Springer, Berlin 1920).

[121] This view is first presented in M. FRIEDMAN, *Dynamics of Reason*, 2001. The most recent assessment is in FRIEDMAN, *Synthetic History Reconsidered*, in M. DOMSKI / M. DICKSON (eds.), *Discourse on a New Method. Reinvigorating the Marriage between History and Philosophy of Science*, Open Court, Chicago-La Salle, Illinois 2010, pp. 571-813.

[122] EINSTEIN, *Foreword* to NEWTON, *Opticks* cit., p. LIX.

[123] Einstein to Thornton, 7 December 1944, Einstein Archive (EA) 61-574. For Thornton's letter to Einstein of 28 November 1944 see EA 61–573. Both letters are quoted in D. HOWARD, *Einstein's Philosophy of Science*, Stanford Encyclopedia of Philosophy (http://plato.stanford.edu/entries/einstein-philscience/notes.html#1).

On the whole, modern science involved since its first development a critical confrontation with a long tradition of books, and I take every step of the itinerary that I have sketched as involving a growing recognition of this intrinsic historicity of science of nature. Moreover, as a result of the historiography of philosophy and science of the last two centuries, I take this historicity to involve a critical examination not merely of abstract systems, but rather – as Kuhn has rightly stressed – of clusters of theories that gained paradigmatic status by the help of single fortunate books. The latter confrontation, in turn – as we have seen discussing a few remarkable case studies –, always involves logical and metaphysical reflections, which play a crucial role for the formation and the overthrowing of scientific ideas.

Abstract: The rise of XVIIth century natural philosophy determines a significant break with the tradition and enthe idea of a new beginning of scientific investigation grounded on mathematics and experiment; at the same time, the diffusion of printed books represents an essential factor for the dissemination of the new philosophy. The *ideal* of the book, as an expression for this new philosophy, results from the speculation about the correspondence between the language and structure of the philosophical book and the "book of nature" written by God. At the same time, the pursuit of this ideal requires the critical knowledge of the book tradition and the awareness of the imperfection that characterizes any given accomplishment of the ideal. This inner tension finds an exemplary solution in Newton's *Principia mathematica*, where the *incompleteness* of the book of natural philosophy is recognized as an intrinsic feature, which directs Newton's own selection and ordering of the material in the process of editing his work. After Newton, several attempts have been made to recover the systematic unity of natural philosophy in a single book, in a system of books or in encyclopaedies. In late XIXth century, as the specialization and multiplication of scientific disciplines establishes the impossibility to master natural philosophy as a whole, the intrinsic *historicity* of natural philosophy is recognized as a crucial factor of scientific thought itself. This significant change of perspective, compared to early modern philosophy, produces the need for different ways of understanding the unity of science and the role of books in scientific practice. Nowadays several distinguished scholars in the history and philosophy of science underscore the need to restore the historical awareness of late XIXth-early XXth century science among scientists, in order to promote the development of new scientific ideas.

Key words: Natural Philosophy; History; Incompleteness; System; Encyclopaedia.

Mailing address:
Università degli Studi di Cassino e del Lazio meridionale
Dipartimento di Scienze umane, sociali e della salute
via Mazzaroppi, 6
I - 03043 Cassino (Fr)
paolopatch@yahoo.it