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THE PROBLEM OF CONTINUITY AND DISCONTINUITY IN THE DEVELOPMENT OF SCIENCE FROM ANCIENT TIMES TO THE PRESENT: A REAPPRAISAL

Part I The proclaimed views

1. Methodological introduction

In order to explore the problem I adopt two complementary approaches, the historical and supra-historical ones. The former is applied to examine the practise and theory of science in historical contexts in detail, and the latter to find the supra-historical contexts of the practise and theory of science, that is all such elements that are constant, independent of particular historical contexts.

The historical approach is applied to examine the practise and theory of science in historical contexts in detail: the scientific terminology, the methodological principles, the problem situation, the measurement instruments, empirical data, and also the socio-political, that is, religious, institutional and intellectual, conditions in which science is developed. We have two variants of this approach: the progressive analysis (starting from a chosen moment in the past) and the retrograde one (starting from the current time)¹.

The supra-historical approach is applied to find the supra-historical contexts of the practise and theory of science, that is all such elements that are, *in principle*, constant, independent of particular historical contexts. In this manner we can try to find *the stable core of science or the stable minimal set of views on science*, meant here as methods of enquiring of knowledge and of social organisation².

2. Scope of interest

I aim to discuss the problem of continuity and discontinuity in the development of science throughout history, the focal points of my interests are:

¹ It should be noted that – if we are aware what we are doing as interpreters of history of science – it is entirely justifiable to apply the retrograde analysis in our research also. In other words, I think that the clear statement that the historian of science writes, then a Whig or Whiggish history of science (that is *distorted by present-focused views*) is at least a great simplification.

² It should be noted that this approach is not un-historical! It is similar to the strategy assumed in the history of ideas, when we look for the history of an idea.

- the commonly accepted view of the 18th–20th century that only modern science was a mature science: Copernicus or rather F. Bacon, Galileo, Kepler and Newton are considered the founding fathers of this science,
- the debate on the continuity and discontinuity of ancient, medieval and modern science (P. Duhem, A. Mayer, H. Butterfield, A. C. Crombie, A. Koyré, R. Hooykaas, E. Moody, M. Clagett, J. A. Weisheipl, W. A. Wallace, E. Grant),
- the debate on Ancient Chinese, Indian, Babylonian, Egyptian and Greek science (J. Needham, O. Neugebauer, J. de Solla Price, T. Huff),
- the debate on medieval Arabic science (E. Kennedy, G. Saliba, R. Morelon, R. Rashed, M. Kokowski, M. Heydari-Malayeri),
- the debate on the Scientific Revolution and scientific revolutions (K. Popper, A. Koyré, T. S. Kuhn, P. Feyerabend, I. Lakatos, H. F. Cohen, I. B. Cohen, S. Shapin, M. Kokowski),
- the debate on the Copernican revolution (T. S. Kuhn, N. R. Hanson, A. Kestler, O. Neugebauer, N. M. Swerdlow, I. B. Cohen, R. Ariew, P. Barker, M. Kokowski, A. Bala),
- the debate about individual scholars such as Nicholas Copernicus (T. S. Kuhn, N. R. Hanson, A. Kestler, O. Neugebauer, N. M. Swerdlow, M. Kokowski), Francis Bacon, Galileo Galilei (A. Koyré, A. Kestler, Finocchiaro, W. A. Wallace, W. R. Shea), and Isaac Newton (A. Koyré, ...),
- the debate on the method of ancient, medieval, modern and contemporary science (K. Popper, T. S. Kuhn, P. Feyerabend, I. Lakatos, W. Krajewski, W. A. Wallace, M. Kokowski).

The main results of the issues mentioned will be analysed in the light of the supra-historical and historical approaches.

3. The Spectrum of Views in Debates on the Continuity and Discontinuity of the Development of Science

3A. The debate on the continuity of ancient and modern science: When did modern science begin? And where did it come from? Let us recall the main theses on the subjects mentioned.

According to 18th-, 19th- and 20th-century scholars, e.g. D'Alembert, E. Cassirer, E. Mach, and the majority of representatives of the exact sciences, modern science stems either from Nicholas Copernicus or rather from Francis Bacon, Kepler, Galileo Galilei, René Descartes and Isaac Newton. In this spirit of thought, all the previous stages of science are sometimes pejoratively called only *the prehistory of science*. However, this view, still offered in many faculties of the exact sciences in every part of the world, is simply naïve, which is shown in 20th century research regarding the history of science and the history of philosophy of science.

The debate started with Pierre Duhem. He stated that modern science was born in 1277¹, when the bishop of Paris Etienne Tempier, standing on the grounds of Christian faith and, especially, the doctrine of theological volunt-

¹ See P. Duhem, *Le système du monde*, vol. 6, p. 66.

arism according to which human reason has no right to determine any limits to God's power, condemned a great many Averroist theses that introduced Greek necessitarianism into the philosophy of nature and theology among others putting the Necessity of Nature above the sovereign will of God. Hence, bishop Tempier was an advocate of the metaphysical standpoint of the contingency of the world,

that is the not rationally deducible, not necessary character, the just-given-ness of the world, which has been made by God's incomprehensible will. On this view, only a posterior can we put together a science of nature, as rational as possible in our own eyes; and such a system will be at best highly probable though not absolutely necessary, since God could have willed a different world with different rules¹.

Let us note that the basis of Duhem's thesis was an assumption that the essence of modern science is its metaphysics with the standpoint of the contingency of the world and the probable status of all systems of physics.

However, Duhem's thesis has a weak point, noticed by Duhem himself² and then by Hooykaas³, Lindberg, Pedersen⁴. Namely, Tempier's condemnation influenced science only in the 14th century when Parisian nominalists criticizing Aristotelian philosophy of nature formulated *via moderna*, and especially when Jean Buridan framed the theory of *impetus* treated as the beginning of modern mechanics (Galileo's mechanics) and when he and his followers such as Nicole Oresme considered the possibility of motions of the Earth treated as precursory to Copernicus's views. According to Duhem, these achievements constitute the sharp line that separates ancient science from modern science. This is the reason to re-date the beginnings of modern science. Thus, modern science was born in the 14th century by Parisian nominalists and especially by Jean Buridan's works on *impetus* theory⁵.

The thesis was not left unchallenged. Duhem's thesis that Parisian scholars were at the start of modern science and that medieval nominalism is the fundamental basis of seventeenth-century physics was criticized and clarified in the works of A. Maier⁶, K. Michalski⁷, E. A. Moody, M. Clagett⁸,

¹ R. Hooykaas, *The Rise of Modern Science: When and Why?*, p. 24.

² See P. Duhem, *ΣΩΖΕΙΝ ΤΑ ΦΑΙΝΟΜΕΝΑ*.

³ See R. Hooykaas, *Religion and the Rise of Modern Science*.

⁴ See D. C. Lindberg, *The Beginnings of Western Science* and O. Pedersen, *The book of nature*.

⁵ See P. Duhem, *Etudes sur Léonard de Vinci*, vol. 2, p. 411, vol. 3, p. XI.

⁶ See A. Maier, *Die Vorfürer Galileis*, A. Maier, *Zwei Grundprobleme der Scholastischen Naturphilosophie* ..., A. Maier, *An der Grenze von Scholastik ...*.

⁷ See K. Michalski, *Tomizm w Polsce na przełomie XV i XVI w.*, K. Michalski, *Jan Buridanus i jego wpływ na filozofię scholastyczną w Polsce*, K. Michalski, *Na zakończenie dwu jubileuszów (św. Tomasza i Kanta)*, K. Michalski, *La physique nouvelle et les différents courants philosophiques au XIV^e siècle*, K. Michalski, *Zachodnie prądy filozoficzne w XIV wieku i stopniowy ich wpływ w Środkowej i Wschodniej Europie*.

⁸ See E. A. Moody & M. Clagett (eds), *The Medieval Science of Weights (Scientia De Ponderibus)*

M. Clagett¹, A. Koyré², P. King³, and many others. For example, before Parisian scholars, Oxford scholars, of the so-called Merton school, made important contributions to mechanics (Crombie), Ockham didn't frame the modern concept of inertia (A. Maier), the theory of impetus is not a beginning of modern mechanics (A. Maier), Galileo's dynamics had roots not only in the Latin Middle Ages but in an earlier Greco–Arabic tradition (E. A. Moody), medieval scholastics did not perform any measurement (P. King).

Taking into account the first correction mentioned above, A. C. Crombie formulated a more general view than Duhem's. Crombie emphasized the role of medieval scholastics in the genesis of modern science:

The experimental science that was to reach maturity only in the early 17th century developed in a tradition that was different either the Greek or the Arabic. It owes its origins to the marriage of the manual habits of technics with the rational habits of logic and mathematics that took place in 13th–century Christendom. It was nursed in 13th– and 14th–century Oxford, Paris, and Germany; it grew up in 15th– and 16th–century Italy; it burst from the constraining hands of its late scholastic guardians in the 17th century and conquered all Europe.⁴

Furthermore, Crombie singled out Grosseteste commentary to Aristotle's *Posterior Analytics* as a representative of a new concept of scientific methodology⁵.

Crombie's thesis was discussed critically. One the one hand, scholars such as A. Koyré⁶, N. W. Gilbert⁷, E. McMullin⁸, N. Jardine⁹, J. Murdoch¹⁰, P. King¹¹, E. Grant¹², and E. Jung¹³ negated Crombie's thesis on the continuity of medieval and modern science. A. Koyré started this critique emphasizing two points. Firstly, Aristotelian science did not apply experimental methods such

¹ See M. Clagett, *The science of Mechanics in the Middle ages*, M. Clagett, *Archimedes in the Middle Ages*.

² See A. Koyré, *Etudes galinéennes*, A. Koyré, *The Origins of Modern Science. A New Interpretation*, A. Koyré, *From the Closed World to the Infinite Universe*, A. Koyré, *The astronomical revolution: Copernicus – Kepler – Borelli*.

³ See P. King, *Mediaeval Thought-Experiments: The Metamethodology of Mediaeval Science*.

⁴ A. C. Crombie, *Augustine to Galileo*, p. 218.

⁵ See A. C. Crombie, *Robert Grosseteste and the Origins of Experimental Science 1100–1700*.

⁶ See A. Koyré, *The Origins of Modern Science. A New Interpretation*.

⁷ See N. W. Gilbert, *Galileo and the School of Padua*.

⁸ See E. McMullin, *Medieval and Modern Science: Continuity or Discontinuity*.

⁹ See N. Jardine, *Galileo's road to truth and the demonstrative regress*.

¹⁰ See J. Murdoch, *The Analytic Character of Late Medieval Learning. Natural Philosophy without Nature*.

¹¹ See P. King, *Mediaeval Thought-Experiments: The Metamethodology of Mediaeval Science*.

¹² See E. Grant, *The Foundations of Modern Science in the Middle Ages ...*.

¹³ See E. Jung, *Miedzy filozofią przyrody a nowożytnym przyrodoznawstwem*.

as the ones practiced in the 17th century. Secondly, scientific investigations and methodological considerations belong to two different streams of intellectual reflection and, in principle, the former is rather a summary of the latter. N. W. Gilbert questioned Randall's interpretation of Galilean texts and their dependence on the Padua school. These texts stem rather from the application of the method of analysis and synthesis used by Archimedes and Pappus. N. Jardine showed that Galileo was very critical of the method of *regressus*. J. Murdoch, P. King, E. Grant and E. Jung noted that the application of mathematics in the philosophy of nature in Late Medieval Ages is not the beginning of modern mathematical physics, since this philosophy of nature had, in principle, the character of hypothetical speculations not connected with empirical research. It was *philosophy of Nature without Nature* (see Murdoch) which metamethodology were thought experiments (see King).

On the other hand, however, scholars such as J. H. Randall Jr.¹, A. Carugo and A. C. Crombie², and W. A. Wallace³ developed Crombie's initial views. For example, J. H. Randall Jr.⁴ argues that Galileo's conception of science was ultimately dependent on Zabarella's notion of *regressus*, which in turn is based on medical commentaries on Galen's writings such as of Pietro Abano, and stated that *the whole of great literature on this method that fills the scientific writings of the seventeenth century is at the bottom a series of footnotes to the Organon of Aristotle*. W. A. Wallace, A. Carugo and A. C. Crombie showed the dependence of Galileo's early works on the traditional commentaries on Aristotelian natural philosophy and logic elaborated in the Jesuit Collegio Romano.

Taking into account A. Koyré's critique, A. C. Crombie modified in the second edition of *Augustine to Galileo*⁵ his thesis on continuity of medieval and modern science:

It must not be supposed that this philosophical conception of experimental science, developed largely in commentaries on Aristotle's Posterior Analytics and the problems found in it, was accompanied by single-minded reliance on the experimental method such as is found in the 17th century. Medieval science remained in the general within the framework of Aristotle's theory of nature, and deductions from the theory were by no means always rejected even when contradicted by the results of the new mathematical, logical, and experimental procedures. Even in the midst of otherwise excellent work, medieval scientists

¹ See J. H. Randall, Jr, *The development of scientific method in the school of Padua*, J. H. Randall, Jr, *The School of Padua and the Emergence of Modern Science*.

² See A. Carugo & A. C. Crombie, *The Jesuits and Galileo's Ideas of Science and Nature*.

³ See W. Wallace, *Galileo and His Sources: The Heritage of the Collegio Romano in Galileo's Science*.

⁴ See J. H. Randall, Jr, *The School of Padua and the Emergence of Modern Science*.

⁵ See A. C. Crombie, *Augustine to Galileo*.

sometimes showed a strange indifference to precise measurements, and could be guilty of misstatements of fact, often based on purely imaginary experiments copied from early writers, which the simplest observations would have corrected. Nor must it be supposed that when the new experimental and mathematical methods applied to scientific problems, this was always the result of the theoretical discussions of method. [...] in the Middle Ages, as in other periods, discussions of the method and actual scientific investigations belonged to two separate streams, even though their waters were so often and so profoundly mingled, as certainly they were.¹

There is an opinion that modern science started with the Italian Renaissance² which was the re-birth of sciences³.

However, more wide spread is the idea that the modern science emerged either during the Copernican revolution, from Copernicus's times to Newton's times, or during the Scientific Revolution in the 17th century, from Francis Bacon, Galileo, Kepler, Descartes to Newton⁴.

In turn, the ideas of the Copernican revolution and of the Scientific Revolution were criticized severely by two groups of scholars. Firstly, the historians of Arabic science, such as E. S. Kennedy and V. Roberts⁵, O. Neugebauer⁶, and G. Saliba⁷, discovered that Copernicus applied certain Arabic data in his astronomical theory and certain solutions of several crucial theoretical problems. Thus, among others O. Neugebauer⁸, N. M. Swerdlow and O. Neugebauer⁹, and I. B. Cohen¹⁰ stated that [t]here was not a Copernican revolution in science. I. B. Cohen¹¹ added that this myth was already

¹ A. C. Crombie, *Augustine to Galileo*, vol. 2, pp. 10–11.

² See Age-of-the-sage.org, Jakob Burckhardt: *Renaissance – Cultural history: The term Renaissance suggesting a re-birth of individualistic accomplishment after a long intermission since the Classical Age. The term itself had been coined in this regard by the French historian Jules Michelet circa 1855–1858.*

³ See J. Burckhardt, *Die Cultur der Renaissance in Italien*, E. Cassirer, *Individuum und Kosmos in der Philosophie der Renaissance*, W. K. Ferguson, *The Renaissance in Historical Thought*, G. Santiliana, *The Role of Art in the Scientific Renaissance*, E. Panofsky, *Artist, Scientist, Genius: Notes the Renaissance–Dämmerung*, M. Boas, *The Scientific Renaissance, 1450–1650*, J. Gadol, *Humanism, Natural Sciences, and Art*.

⁴ See H. Butterfield, *The Origins of Modern Science, 1300–1800*, A. Koyré, *Etudes galinéennes*, A. Koyré, *The Origins of Modern Science. A New Interpretation*, A. Koyré, *From the Closed World to the Infinite Universe*, A. Koyré, *The astronomical revolution: Copernicus – Kepler – Borelli*, A. Koyré, *Metaphysics and Measurement: Essays in Scientific Revolution*, A. Koyré, *Modern Science and Its Medieval Antecedents*, A. R. Hall, *The Scientific Revolution 1500–1800* . . . , T. S. Kuhn, *The Copernican Revolution*.

⁵ See E. S. Kennedy & V. Roberts, *The Planetary Theory of Ibn al-Shatir*.

⁶ See O. Neugebauer, *On the Planetary Theories of Copernicus*.

⁷ See G. Saliba, *The Rôle of Marāgha in the Development of Islamic Astronomy*

⁸ See O. Neugebauer, *On the Planetary Theories of Copernicus*.

⁹ See N. M. Swerdlow & O. Neugebauer, *Mathematical Astronomy in Copernicus's De revolutionibus*.

¹⁰ See I. B. Cohen, *Revolution in Science*, p. 106, p. 118, p. 119, p. 125.

¹¹ See I. B. Cohen, *Revolution in Science*, p. 106, pp. 498–500.

created by J. S. Baily and J. E. Montucla in the 18th century. Furthermore, the idea of revolution in science, that is of rapid changes in it, is only a metaphor that creates false connotations on the process of development of science. For example L. K. Nash¹, R. Hooykaas², R. Porter³, R. S. Westman and D. C. Lindberg⁴, P. Barker and R. Ariew⁵, S. Shapin⁶, and M. J. Osler⁷ maintained this opinion. Furthermore, G. Saliba⁸ noted that there was the Marāgha revolution in astronomy, and M. Kokowski⁹ justified this thesis on methodologico-astronomico-mathematical grounds. Finally, it is worth noticing that nearly all scholars debating the problem of the continuity and discontinuity of modern and medieval science – the exclusion, though for different reasons, is made for P. Feyerabend¹⁰, T. S. Kuhn¹¹ and M. Kokowski¹² – assumed as an axiomatic view that only modern science, that is science made in modern times, is a synonym of a mature science, that it is an empirically and methodologically well justified science.

3B. The debate on the continuity of ancient and modern science

• Let us recall the main theses on the subjects mentioned. Science began with the Greeks: A. C. Crombie¹³, A. Koyré¹⁴, K. R. Popper¹⁵. As it was expressed by Crombie:

I do not think that the opinion that science is organized common sense or generalized craftsmanship and technology survives comparison with the actual scientific tradition, a tradition which seems to

¹ L. K. Nash, *The Nature of the Natural Science*.

² See R. Hooykaas, *The Rise of Modern Science: When and Why?*

³ See R. Porter, *The Scientific Revolution: a Spoke in the Wheel*.

⁴ See R. S. Westman & D. C. Lindberg, *Introduction*.

⁵ P. Barker & R. Ariew (eds), *Revolution and Continuity. Essays in the History and Philosophy of Early Modern Science*.

⁶ See S. Shapin, *The Scientific Revolution*.

⁷ See M. J. Osler (ed.), *Rethinking the Scientific Revolution*.

⁸ See G. Saliba, *The Rôle of Marāgha in the Development of Islamic Astronomy ...*.

⁹ See M. Kokowski, *Copernicus's Originality ...*.

¹⁰ See P. K. Feyerabend, *Against Method*, P. K. Feyerabend, *How to Be a Good Empiricist*.

¹¹ See T. S. Kuhn, *Mathematical versus Experimental Traditions in the Development of Physical Science*.

¹² See M. Kokowski, *Copernicus and the hypothetico-deductive method of correspondence thinking ...*, M. Kokowski, *Copernicus's Originality ...*.

¹³ See A. C. Crombie, *Augustine to Galileo*, vol. 1–2, A. C. Crombie, *Robert Grosseteste and the Origins of Experimental Science 1100–1700*, A. C. Crombie, *The Significance of Medieval Scientific Method for the Scientific Revolution*, A. C. Crombie, *Medieval and Early Modern Science*, A. C. Crombie, *Sources of Galileo's Early Natural Philosophy*, A. C. Crombie, *Experimental science and the rational artist in early modern Europe*, A. C. Crombie, *The Styles of Scientific Thinking in the European Tradition*.

¹⁴ See A. Koyré, *Etudes galinéennes*, A. Koyré, *The Origins of Modern Science. A New Interpretation*, A. Koyré, *From the Closed World to the Infinite Universe*, A. Koyré, *The astronomical revolution: Copernicus – Kepler – Borelli*, A. Koyré, *Metaphysics and Measurement: Essays in Scientific Revolution*.

¹⁵ See K. R. Popper, *Conjectures and refutations: The Growth of Scientific Knowledge*.

*me be essentially Western and to begin with the Greeks. Impressive as the technological achievements of ancient Babylonian, Assyria, and Egypt, and ancient China and India, as scholars have presented them to us they lack the essential elements of science, the generalized conceptions of scientific explanation and of mathematical proof.*¹

- There exists an essential discontinuity of Western scientific tradition from Greek times up until the 17th century (A. C. Crombie²) and, hence, modern times (A. Koyré³, H. Butterfield⁴, A. R. Hall⁵, T. S. Kuhn⁶).

- There exists an essential continuity of Western scientific tradition from Greek times up until the 17th century. A. C. Crombie writes: *Especially I have tried to bring out, what I believe to be the most striking result of recent scholarship, the essential continuity of Western scientific tradition from Greek times to the 17th century, and therefore, to our own times*⁷.

He describes the genesis of modern science as a three-stage process. Firstly, *the Greeks invented nature as a permanent, uniform, abstract order from which the changing order of observations could be deduced*. Then, at the end of the ancient world Greek rationalism was combined with the Christian and Augustian idea of *nature as sacramental, symbolic of spiritual truths*. Finally, in the 13th century there emerged a synthesis of Aristotelian philosophy, Greek mathematical reason, and medieval technics and empiricism, which produced a new conscious empirical science seeking to discover the rational structure of nature⁸.

We may then see the origins of modern Western science in the recovery, exegesis and elaboration of the Greek conceptions of rational decision and proof and of rational system by medieval and early modern Europe. The recovery was made in a series of responses to ancient thought by a new society with some different mental and moral commitments and expectations, with a different view of nature and of man and his place in nature and his destiny, a

¹ A. C. Crombie, *The Significance of Medieval Scientific Method for the Scientific Revolution*, p. 81.

² See the works by A. C. Crombie from *Augustine to Galileo* to *The Styles of Scientific Thinking in the European Tradition*.

³ See A. Koyré, *Etudes galinéennes*, A. Koyré, *The Origins of Modern Science. A New Interpretation*, A. Koyré, *From the Closed World to the Infinite Universe*, A. Koyré, *La révolution astronomique, Copernic – Kepler – Borelli*, A. Koyré, *Metaphysics and Measurement: Essays in Scientific Revolution*.

⁴ See H. Butterfield, *The Origins of Modern Science, 1300–1800*.

⁵ See A. R. Hall, *The Scientific Revolution 1500–1800*

⁶ See T. S. Kuhn, *The Copernican Revolution*, T. S. Kuhn, *The Structure of Scientific Revolution*.

⁷ A. C. Crombie, *Augustine to Galileo*, Preface to the 2nd ed., p. xii.

⁸ A. C. Crombie, *Augustine to Galileo*, p. xiv, B. S. Eastwood, *On the Continuity of Western Science from the Middle Ages* ... , p. 88.

different theology, a different economy and a different view of technology, but also with a vision of continuity. It was sometimes mediated through the languages of other cultures, especially Arabic¹.

- The essential continuity in the development of Western thought from Greek times to the 17th century which does not obviate the novelty of the scientific activity of the 17th century:

It is generally agreed that the learning of antiquity was digested in the Middle Ages and Renaissance to form the chief nourishment for growth of early modern thought. Thus early modern science grew out of Greek science and philosophy as modified by the natural philosophers of Islam and the Latin West. The acceptance of this essential continuity in the development of Western thought does not obviate the novelty of the scientific activity of the 17th century, the century of Galileo, Boyle, Hooke, Leibniz, and Newton. It serves rather to clarify that novelty, to show how it arose in great part from the interplay, modification, and rearrangement of older stock ideas as they were fashioned into an essentially new system.²

- There are obvious similarities between Ancient Greek science and modern science. However, there are also great dissimilarities between them. Namely, the primary aim of the Ancient Greek and Hellenic was to arrive at a better contemplative understanding of the nature of things and that pursuit was strictly connected with moral and religious matters. Excluding such persons as Archimedes, they had a limited notion of using their speculations as a means of gaining control of nature or of altering the natural conditions of life³. There was great opposition between the contemplative approach to study of Nature in Greek and medieval times and the practical approach during modern times.

The opposition stemmed from the Greek ancient model of education based on the idea of *Paideia*, that is the radical distinction between θεωρία and πράξις, the *vita contemplativa* and the *vita activa et operativa*, the theoretical knowledge and the productive knowledge. The former included the liberal arts, as they were appropriate to be studied by noble/free men. The latter included illiberal arts, which were appropriate to be studied only by craftsmen whose social rank was similar to the rank of slaves in Ancient Greece. This distinction was abandoned in Italian Renaissance with the aid of the ideas of *virtù* (force or ability) and *virtuoso* (rational artist)⁴. Seeing such

¹ A. C. Crombie, *The Styles of Scientific Thinking in the European Tradition*, vol. 1, p. 23.

² M. Clagett, *Greek science in antiquity*, p. 3.

³ See A. Whitehead, *Science and the Modern World*, P. Rossi, *I filosofi e le machine (1400–1700)*, I. Johnston, *Ancient and Modern Science: Some Observations*.

⁴ L. Olschki, *Geschichte der neusprachlichen wissenschaftlichen Literatur*, vol. 1, E. Panofsky, *Artist, Scientist, Genius: Notes on the Renaissance–Dämmerung*, A. C. Crombie, *Experimental Science and the Rational Artist in Early Modern Europe*, O. Willmann, *The Seven Liberal Arts*.

differences between Ancient Greek science and modern science, I. Johnson states:

[M]any of the most important concepts which underpin the modern activity we call science originated in the work of the Classical Greek philosophers, so that we can talk usefully about Classical Greek science and establish links between what went on twenty-five hundred years ago and the modern research laboratory. But we need to be careful about over-emphasizing these similarities, for in many ways the science practiced by the Classical Greeks and by the Medieval Christians had a purpose fundamentally different from what we might call modern science, a comparatively recent form of understanding the world.¹

After displaying different stances assumed by previous scholars, we are ready to comment these views.

Part II A Commentary

0. Introduction: Four fundamental groups of issues

All discussions on the problem of continuity and discontinuity in the development of science throughout history are based on four fundamental groups of issues:

- Familiarity with the contemporary science and the history of science.
- The understanding of science.

We must be able to give clear answers to the questions such as *What is science?*, *What is its essence?*, *Of what parts is science composed?* or *What is its structure?*, *What are its relationships with the other parts of culture?*, *What social, economic, and political conditions were necessary for it to develop?*, *When and where did it start?*, *What was the dynamic of the processes of transmission of scientific knowledge from scientific centres to scientific peripheries?*, *What is a mature science?*, *What are paradigmatic examples of mature sciences?*

- Choice of indicators of important changes in science.
- Description of mechanisms of change in science.

1. Familiarity with the history of science

The crux in all discussions on the problem of the continuity and discontinuity in the development of science is hinged on our acquaintance with the history of science. But what history of science do we mean in this context? I think that, though it is really a very broad and difficult field of interests, it must be the comparative analysis of many aspects of science, such as terminological, empirical, theoretical, methodological, epistemological,

¹ I. Johnston, *Ancient and Modern Science: Some Observations*.

disciplinary–demarcational, worldview–cosmological and socio–political ones, throughout the history of science. Otherwise our dispute regarding the problem will be one–sided and fragmentary.

2. The understanding of science and of empirical sciences

There are three general views on the nature of science, which can serve as useful motifs in analyzing the history of science as a whole.

- True science is a sacerdotal knowledge, a body of secret and hidden knowledge on the natural and supernatural aspects of reality: alchemy, astrology and magic are the paradigmatic examples of that science.
- Science is the unselfish contemplation of truth. We can cultivate it with the help of our senses and natural reasoning only when all our trivial, practical needs and interests are realised. Based on this view, science is a body of theoretical knowledge, and such knowledge is something fundamentally different than and distinct from practical knowledge such as craft and technology.
- Science is organized common sense and generalized craftsmanship and technology: *On this view [...] prehistoric people are regarded as having contributed to the growth of science when, for example, they learned how to work metals ...*¹.

Then, scrutinising the current dictionary definitions of the term *science*, we can notice that this term has two fundamental meanings: the modern one, which originated as late as in the 18th and 19th centuries, and the classic one. The former means: *the branch of knowledge involving systematized observation and/or experiment*². The latter means the Greek *episteme* or the Latin *scientia*, that is *systematic and formulated knowledge* or *organized body of knowledge on a subject*.

Furthermore, studying science in its narrow sense during the course of history, that is examining the mathematical and empirical sciences such as the quadrivium, physics/natural philosophy, the *scientiae mediae*, the mixed sciences, the mathematico–physical sciences, the inductive sciences, the exact sciences and the applied sciences, we can find two poles in the practise and theory of it. Namely, it occurs in a creative dialog and tension between *episteme* (certitude) and *doxa* (belief, conjecture). The former is linked with applying in science the language of logic and mathematics, the latter with building hypothetical models, mechanisms of explanation of phenomena.

In the light of the historical approach, we can also see that in every historical epoch science in its narrow sense is always more or less linked with science in its broad sense, that is, with a more or less coherent system of all knowledge. Especially, the latter gives the former its epistemological, methodological and/or theological basis.

¹ D. C. Lindberg's formulation. See his *The Beginnings of Western Science*, p. 1.

² It is worth noticing that the term *science* is relatively young, because not until 1833, did William Whewell coin the derivative term *scientist* for scholars teaching and studying natural phenomena/inductive sciences in European universities then, which gained wide acceptance only at the turn of the 19th century.

3. The problem of mature empirical sciences

This was an axiomatic view of 18th–, 19th– and 20th–century scholars, that modern science was a synonym of a mature science, meaning empirically and methodologically well-justified science. However, in my opinion the very concept of modern science as a mature science appears to be dubious. Namely, in the perspective of methodological standards of modern science, Ptolemy's astronomy, Archimedes's statics and hydrostatics, and Copernicus's astronomy are mature sciences. Furthermore, Ptolemy, Archimedes, and Copernicus applied the same Platonic methodology, that is, mathematico-physical hypotheticism, and Copernicus and Ptolemy also used the methodological concept of the correspondence principle greatly appreciated in the 20th century. In other words, Ptolemy and Copernicus were as modern as Planck, Bohr, Einstein, Heisenberg and Schrödinger¹!

Analysing the basis of the view that modern science is a mature science, we can conclude that this idea stems from the modern philosophical idea of progress of knowledge – described, for example, by Burry² – and not from comparative studies of the history of science as it should have been.

4. What is the essence of empirical sciences?

As the essence of science itself, meaning its most important and characteristic part, one assumes a spectrum of views, such as:

- *positive knowledge* – L. Olschki, G. Sarton, L. Thorndike, P. Duhem, M. Claget, D. C. Lindberg,
- *metaphysics* – E. A. Burtt, A. Kozyré,
- *methodology (scientific method)* – E. Cassirer, K. R. Popper, Randall, A. C. Crombie, W. A. Wallace, E. A. Moody, N. W. Gilbert, E. McMullin, W. R. Shea, N. Jardine,
- *fundamental ideas, worldviews and cosmology* – A. O. Lovejoy,
- *socio-political conditions* – B. Hessen, J. D. Bernal, E. Zissel, R. Hooykaas, T. S. Kuhn, P. Feyerabend, S. Shapin; especially according to T. S. Kuhn *there is no solid scientific method*³, and according to P. Feyerabend *there is no scientific method and science is a form of ideology*⁴,
- *methodology and socio-political conditions* – R. Hooykaas, E. Grant.

In consequence, there is a variety of answers to the following questions:

5. When did science begin? And where did it come from?

The answers depend on our understanding of the essence of science and

¹ See M. Kokowski, *Copernicus and the hypothetico-deductive method of correspondence thinking ...*, M. Kokowski, *Copernicus's Originality ...*. In this context it is worth differentiating, with T. S. Kuhn, *Mathematical versus Experimental Traditions in the Development of Physical Science*, between the classical sciences (astronomy, optics, statics) and the Baconian sciences (studies of magnetism, electricity, heat, ...). The former were mature sciences in ancient times, while the latter, only in 18–19th centuries when they were mathematized in accordance with the methodological standards of the classical sciences.

² See J. B. Burry, *The Idea of Progress: An Inquiry into its Growth and Origins*.

³ See T. S. Kuhn, *The Structure of Scientific Revolutions*.

⁴ See P. Feyerabend, *Against Method*.

our better or worse knowledge of the history of science. For example,

- if, with L. Olschki, G. Sarton, L. Thorndike, P. Duhem, P. P. Wiener, and A. Noland we accept that the essence of science is positive knowledge, then should conclude that science has no absolute beginning in history, and all ancient cultures made contributions to its rise. Let us quote P. Duhem here:

*In the genesis of a scientific doctrine there is no absolute beginning; no matter how far back we trace the line of thought that prepared, suggested or asserted the doctrine, we still come across opinions which in their turn have been prepared, suggested or asserted; and the only reason we stop pursuing this linked procession of ideas is not that we ever grasp the first link, but because the chain disappears buried in the depths of a bottomless past. All of astronomy in the Middle Ages contributed to the development of the system of Copernicus; through the intermediary of Islamic science, medieval astronomy is linked to Hellenic doctrines; the most perfect Hellenic doctrines known to us derive from the teachings of ancient schools about which we know very little; these schools in their turn had inherited astronomical theories from the Egyptians, Assyrians, Chaldeans, Hindus, and we know almost nothing about their theories; the night of past centuries is quite impenetrable, and we feel even farther removed from the first men who observed the curse of the heavenly bodies, noticed their regularity, and tried to formulate the laws it obeys.*¹

- Accepting that the essence of science is its methodology and especially a combination of the generalized conceptions of scientific explanation and mathematical proof, we could state with A. C. Crombie that science arose only in Ancient Greece:

The [scientific] European style established by the ancient Greeks is unique in that no other has been based on those of central principles of causality and proof which would make any of them scientific in the Western traditions. No other civilisation or society seems to have committed itself to this logic of systematic science except by cultural diffusion from ultimately Greek sources. All other cultures have acquired science in that sense from the West. The numerical skills of the ancient Babylonians and Indians seem to have involved no central conception of mathematical proof, and either their cosmological

¹ P. Duhem, *Le système du monde*, vol. 1, p. 1 quoted in: P. P. Wiener & A. Noland (eds), *Roots of Scientific Thought: A Cultural Perspective*, p. 17.

*speculation nor those of the ancient Egyptians or Chinese or Maya seem to have been controlled by any general theory of natural causation embodying a logic of exclusion. It was not in their style to apply the critical criteria used in the practise of their mathematical investigations, and of their technology and medicine, either to the supernatural powers to which the control of events was attributed, or to the diverse and even contradictory images found in their myths of the state of things and how it came about. They developed no conception of nature. They could organize knowledge often with consummate technical skill, but evidently they had no natural philosophy in the Greek sense.*¹

I think that it is not a good idea to limit science only to Greek standards. Even if we accept Crombie's view, this thesis is definitively wrong for historical reasons. In my opinion, the real breakthrough was made by the Ancient Chinese, the authors of a system of medicine based on the concepts of flows of energy Qi and its forms yang and yin, and five elements of forces (tree, fire, earth, metal, water). The roots of this system of thought can be traced back to 5000 BC. For example, the terms Zhen (puncturation) and Tsju (cauterization) originated around 3000 BC when Yellow Emperor, Huang Ti ordered the surrender of the methods of pharmacological treatment and decreed the use of acupuncture as vital to the art of medicine. Furthermore, the system of ancient Chinese medicine was and still is very empirical².

- If we assume that the essence of science is either a combination of empirical research and a creation of true worldviews – meaning true cosmological views on the structure of the universe – or metaphysics, we might conclude that science begun only in modern times in Europe, during the Copernican Revolution with Copernicus, Galileo, Kepler and Newton or in the Scientific Revolution of the 17th century with Bacon, Galileo, Kepler and Newton.

However, the hidden basis of this view was the modern idea of progress with the programme of Europocentrism and scepticism towards Ancient and Medieval Ages, both caused by a lack of historical knowledge. For example, Copernicus's astronomical theory improved Ptolemy's by the so-called rejection of Ptolemy's equant, the restoration of Plato's axiom of astronomy and the introduction of cosmology of mobile Earth. The two former were already made by Arabic astronomers from the Maragha School in 13th and 14th centuries. Nevertheless, they did not reject geocentric cosmology. This was the true beginning of modern science: physics and astronomy of Galileo, Kepler and Newton, which unified terrestrial and heaven physics. On the other

¹ A. C. Crombie, *The Styles of Scientific Thinking in the European Tradition*, vol. 1, p. 22.

² See manuals on Chinese medicine. I used only manuals written in Polish, such as J. Pincel, *Prawo pięciu elementów w medycynie naturalnej*, T. Kasperekzyk & S. Smak, *Masaż punktowy i inne metody reflektoterapii*.

hand, the first idea of this unification stemmed from medieval impetus physics.

Furthermore, the origin of Copernicus's theory demonstrates the problem of the multicultural scientific heritage and of the transfer of knowledge from Ancient times to Renaissance.

• If we assumed that the essence of science is Baconian empiricism, we would agree with Francis Bacon that true science began only in 17th century Europe with the *recent* invention of printing, gunpowder, and the magnet:

Again, it is well to observe the force and virtue and consequences of discoveries, and these are to be seen nowhere more conspicuously than in those three which were unknown to the ancients, and of which the origin, though recent, is obscure and inglorious; namely, printing, gunpowder, and the magnet. For these three have changed the whole face and state of things throughout the world; the first in literature, the second in warfare, the third in navigation; whence have followed innumerable changes, insomuch that no empire, no sect, no star seems to have exerted greater power and influence in human affairs than these mechanical discoveries.¹

However, it is very well known that Bacon's thesis is evidently wrong for historical reasons. The three inventions mentioned by him were in fact invented in China: printing in the 1040's, gunpowder in the 9th century AD or a little earlier, the navigational compass (a pivoted lodestone spoon) was used in the first century AD and well before 1100, the true, fully developed compass was being used in navigation².

Hence we see that there is no single answer to the questions: *when did science begin?*, and: *where did it come from?*. All that is caused by two facts. Namely, interpreters of history of science, first, accept different assumptions on the essence of science and, secondly, appeal to different histories of science.

6. A neglected point: The structure of mathematico-empirical sciences

In order to consciously analyse the problem of continuity and discontinuity in development of science we need, first, to state something explicitly about the different strata of the structure of empirical sciences. Though this point is crucial in the discussion of the problem, it is, in principle, neglected by scholars.

Structure of mathematico-empirical sciences

Internal strata

Terminological stratum

- Terminology (signs + meanings)

¹ F. Bacon, *The New Organon and Related Writings*, p. 118.

² See J. Needham, *The Grand Titration: Science and Society in East and West*, pp. 62–76, N. Sivin, *Science and Medicine in Chinese History*.

Empirico-theoretical stratum

- Empirical data: phenomena, observations, detections, measurements by measurement instruments, predictions, experimentation
- Mechanics of explanations: mathematical language assumed, theoretical entities postulated.
- Rules of correspondence of theoretical notions and empirical data (theoretical–empirical)

Methodologico-epistemological stratum

- Methodological principles of gathering empirical data and making evidence and persuasions
- Epistemological principles – ontological status of mechanics of explanations (certitude or probable character)

Boundary strata

Disciplinary-demarcational stratum

- Disciplinary relationships with the other branches of knowledge such as mathematics, metaphysics, theology, ethics, technology, craft
- Criteria of demarcations of science and non- or pseudo-science

Worldview-cosmological stratum

- Science along with philosophy and theology create together worldviews/cosmologies of the epochs – the material–immaterial frameworks which play the role of *imaginative scene* for human life. This is reflected in all the domains of culture of any epoch, especially in the fine arts, such as literature, poetry and painting.

Socio-political stratum

- Forms of socio-political organisation of natural sciences

7. Traditions and paradigms of science, and problem situations in science

It is worth noticing that different combinations of views on the above issues bear different *traditions of cultivating science* throughout the course of history. In turn, the traditions bear different *paradigms of science*. Within the context of these paradigms, different *problem situations* in science arise. Then, the concepts of the scientific traditions and paradigms together can be helpful in the introduction of a *periodization of science* and of a *teritorialization of science*¹.

In all such cases, we, as interpreters of the history of science, should introduce a certain terminology, that is a set of terms understood as signs with certain meanings. Though such choices are ultimately always a matter of convention, they must be reasonable. Principally, we should try to justify our

¹ By the later term we mean the subject-matter of scientific centres, and scientific periphery, and the transfer of knowledge.

semantic choices: give a reference list of historical sources and show the usefulness of such terminology in research.

Then, if we want to discuss rationally the problem of continuity or discontinuity of the development of science, we should be able to show different traditions in science. We do so on the grounds of a certain understanding of science assumed by us and expressed explicitly in the point above on the one hand, and historical sources, on the other.

Throughout the course of history, I distinguish eight main traditions in philosophy having greater or lesser relationships with science:

- Hermetical (or sacerdotal)
- Chaldeo–Egyptian (or empiric with mathematics but without *physiologia*, the investigation of causes)¹
- Leucippo–Democritean Tradition
- Platonic Tradition
 - Plato's mathematical abstractionism (assumed in the *Republic*),
 - Plato's mathematico–physical hypotheticism (assumed in the *Laws*, and *Timaues*),
 - Euclid (optics), Ptolemy (optics, astronomy), Archimedes (statics, hydrostatics), Alhazen (optics), Copernicus (astronomy),
 - hypothetico–deductive method,
 - hypothetico–deductive method of correspondence–oriented thinking²
- Aristotelian Tradition
 - Aristotle's
 - Averoist
 - Albertian, Thomistic
 - School of Padua
- Stoic Tradition
- Plato–Aristotelian Tradition
 - Oxford Platonism (excluding mathematical considerations, argumentation in physics is only probable!)
 - Nominalism, Buridanism
 - Galileo's (= Archimedean–Aristotelo–Thomistic approach)³

¹ See A. C. Crombie, *The Styles of Scientific Thinking in the European Tradition*, vol. 1, p. 94: Peripatetic philosopher Adrasitus (2nd century A.D.) pointed to a fundamental innovation of Greeks when he declared the methods of the ancient Chaldean and Egyptian astronomers to have been imperfect because they had lacked *physiologia*, the investigation of causes.

² In my opinion, this method is the method of the mature exact sciences – see M. Kokowski, *Copernicus and the hypothetico–deductive method of correspondence thinking* ... , M. Kokowski, *Copernicus's Originality*

³ It reflects studies of, among others, A. Koyré, *Etudes galinéennes*, A. Koyré, *The Origins of Modern Science. A New Interpretation*, A. Koyré, *From the Closed World to the Infinite Universe*, A. Koyré, *The astronomical revolution: Copernicus – Kepler – Borelli*, A. Koyré, *Metaphysics and Measurement: Essays in Scientific Revolution*, A. Koyré, *Modern Science and Its Medieval Antecedents*, N. W. Gilbert, *Galileo and the School of Padua*, W. R. Shea, *Galileo's Intellectual Revolution*, W. Wallace, *Galileo's Early Notebooks: The Physical Questions*, W. Wallace, *Galileo and His Sources* ... , W. Wallace, *Galileo, the Jesuits, and the medieval Aristotle*, W. Wallace, *Galileo's Logic of Discovery and Proof* ... , A. Carugo & A. C. Crombie, *The Jesuits and Galileo's Ideas of Science and Nature*, O. Pedersen, *The book of nature*, and A. C. Crombie, *The Styles of Scientific Thinking in the European Tradition*.

- Baconian Tradition (inductivism)

– Darwin (theory of evolution) but only nominally Newton (optics, mechanics, astronomy), Robert Boyle (pneumatics, chemistry)

Furthermore, it is worth noticing that from the methodological point of view, the traditions mentioned above may be considered *ideal types in Weberian sense*. In other words, this means that, throughout the course of history, scholars used to mix, in more or less coherent ways, various different traditions in the research of nature. This simple conclusion explains many problems in the debate on the continuity of ancient, medieval and modern science such as the key cases of Copernicus, Galileo and Newton.

In this context, let us point out a fundamental error of many scholars, including T. S. Kuhn¹ or E. Grant². According to them, all medieval philosophers who knew and commented the works of Aristotle, especially his *Posterior Analytics*, are called Aristotelians, irrespective of whether they rejected his views and yet did accept radically different views of Plato! The crucial issue in a comparison of these scientific traditions is an analysis of the relationships between physics, mathematics and metaphysics, and of the ontological status of these disciplines³. In this context, if we assume that mathematics gives us a certain knowledge and physics and metaphysics only probable knowledge, this is definitively Plato's view stemming from his work *Timaeus*. Just this stance was accepted and advocated, for example, by Ptolemy⁴, by Oxford Platonists, for example, Robert Grosseteste⁵ and Roger Bacon, and Copernicus⁶.

8. Indicators of important changes in natural science

Discontinuous or continuous development of natural sciences can occur in all strata of empirical science: terminological, empirical, theoretical or explanatory, theoretico-empirical, methodological, epistemological, disciplinary-demarcational, worldview-cosmological and socio-political. Hence, it is justifiable to speak of the whole spectrum of discontinuity and the whole spectrum of continuity or the *multi-discontinuity* and *multi-continuity* of the development of science.

I think that medieval fourteenth-century physics and modern physics is a very good example of such discontinuity-continuity. Let us quote here the paper *Mediaeval Thought-Experiments: The Metamethodology of Mediæval Science* by King:

¹ See T. S. Kuhn, *The Copernican Revolution*, T. S. Kuhn, *The Structure of Scientific Revolution*.

² See E. Grant, *The Foundations of Modern Science in the Middle Ages*

³ A fact very well known by J. A. Weisheipl, *Classification of the Sciences in Medieval Thought*, p. 81.

⁴ See M. Kokowski, *Copernicus's Originality*

⁵ It is a great paradox that though E. Grant, *The Foundations of Modern Science in the Middle Ages* ... , p. 189 knew that according to Grosseteste argumentation in physics is only probable and in mathematics certain – he thought that Grosseteste was Aristotelian!

⁶ See M. Kokowski, *Copernicus's Originality*

The Duhemian tradition claims that the components of modern science are found or prefigured in earlier mediæval scientific writings: a claim which, at the very least, grossly distorts the facts. There are features of this claim I would not dispute; there is a genuine similarity between mediæval and modern authors in the vocabulary used and concepts at issue; if problems can survive radical changes in scientific paradigm, I am willing to concede that there is a continuity of problems as well—free fall, the nature of motion and speed, the analysis of force and resistance. But these similarities should not conceal the deep divergence between mediæval scientia and modern scientific method.¹

Namely, King showed five these divergences:

- (i) *the achievements of mediæval science, even the three achievements traditionally singled out as anticipating modern science (this is Heytesbury's Mean-Speed Theorem, Bradwardine's Function, and Buridan's theory of impetus), were part of a completely different scientific paradigm;*
- (ii) *this paradigm took as the measure of success of its theories and hypotheses not experimental confirmation, empirical justification, or saving the appearances, but rather the ability to deal with examples and purported counterexamples;*
- (iii) *the method of mediæval science was thought-experiment rather than actual experiment or testing;*
- (iv) *there was a developed body of reflection on the method of thought-experiment, found in treatises on obligations, which constituted the meta-methodology or philosophy of scientific method in support of mediæval scientific practice;*
- (v) *this method has its own virtues and vices quite distinct from those of modern scientific method.²*

In this context there are also three points worth noticing. Firstly, the intensity of scientific changes grows in the order listed above. Secondly, the most popular indicators of the scientific changes are the empirico-theoretical matters and methodologico-epistemological ones. Thirdly, the generalised correspondence principle of theories is a very important indicator of scientific changes in mature sciences. It defines very important type of scientific revolutions, such as the Einsteinian relativistic revolution, the quantum revolution.

¹ P. King, *Mediaeval Thought-Experiments: The Metamethodology of Mediæval Science*, p. 24.

² P. King, *Mediaeval Thought-Experiments: The Metamethodology of Mediæval Science*, pp. 1–2.

9. Mechanisms of change in science

In our analyses of mechanisms of change in science, we can apply three fundamental strategies. Namely, we can assume that this mechanism can be either an evolutionary model or a revolutionary model or a mixed evolutionary–revolutionary one. Thus, we also accept the general concepts of evolution or/and revolution in science. A further choice is to assume a particular model of changes in science, proposed for example by K. R. Popper¹, T. S. Kuhn², L. K. Nash³, I. Lakatos⁴, I. B. Cohen⁵, R. Porter⁶, S. Shapin⁷ or M. Kokowski⁸.

10. Scientific revolutions

It is worth noting that many considerations regarding radical scientific changes are modelled on the idea of socio-political revolutions. I mean, on the one hand, the descriptive idea of scientific revolution assumed e.g., by A. Koyné, H. Butterfield and A. R. Hall, and, especially, on the other hand, the models developed by T. S. Kuhn and P. Feyerabend. We know that these views were very often criticized, among others, by R. S. Westman and D. C. Lindberg⁹, S. Shapin¹⁰ and M. J. Osler¹¹ as the great narrative metaphor of *longe durée*, which unfortunately inadequately matched up against detailed historical facts.

In regard to this point, I agree that the criticism was justified with respect to the idea of identifying all the processes required for the development of science, with *scientific revolutions* understood as a synonym of the great and rapid changes in all aspects of science – this view copied from sociopolitical revolutions meant a total overthrow of the old social and political orders.

While I agree that it is the truth as concerns cosmology of theories, that is quasi-being of theories, and problem-situations, it need not be so regarding terminology, methodological and epistemological principles, and empirical predictions, etc. In consequence, scientific revolutions have little in common with political revolutions¹². These remarks hold especially for the Copernican

¹ See K. R. Popper, *Logik der Forschung: Zur Erkenntnistheorie der modernen Naturwissenschaft*, K. R. Popper, *Conjectures and refutations: The Growth of Scientific Knowledge*, K. R. Popper, *Objective Knowledge. An Evolutionary Approach*.

² See T. S. Kuhn, *The Structure of Scientific Revolution*.

³ See L. K. Nash, *The Nature of the Natural Science*.

⁴ See I. Lakatos, *Falsification and the Methodology of Scientific Research Programmes*.

⁵ See I. B. Cohen, *Revolution in Science*.

⁶ See R. Porter, *The Scientific Revolution: a Spoke in the Wheel*.

⁷ See S. Shapin, *The Scientific Revolution*.

⁸ See M. Kokowski, *Copernicus and the hypothetico-deductive method of correspondence thinking ...*, M. Kokowski, *Copernicus's Originality ...*.

⁹ See R. S. Westman & D. C. Lindberg, *Introduction*.

¹⁰ See S. Shapin, *The Scientific Revolution*.

¹¹ See M. J. Osler (ed.), *Rethinking the Scientific Revolution*.

¹² See M. Kokowski, *Copernicus and the hypothetico-deductive method of correspondence thinking ...*,

revolution. It was a real scientific revolution, since Copernicus's theory is linked with Ptolemy's by several generalized correspondence principles. Furthermore, in his research Copernicus applied the idea of a correspondence postulate of theories and other methodological means of hypothetico-deductive method of correspondence-oriented thinking¹.

I think that the idea of scientific revolution is still valid in interpretations of any fundamental scientific change. We may apply it in four general meanings. Firstly, like A. Whitehead² and A. Koyré³, in logical comparisons of notions, ideas, cosmological, methodological, epistemological and metaphysical in their nature principles and empirical results. The views are compared in a rather timeless perspective. Secondly, like A. Koyré⁴ and W. R. Shea⁵, in descriptions/explanations of rapid and fundamental changes of views of individual scholars – the so-called intellectual revolution – the views are compared in a temporal perspective. Thirdly, like A. Koyré⁶, H. Butterfield⁷ and A. R. Hall⁸, in descriptions of the development of science over the course of a long historical perspective – I mean *histoire longue durée* and *conceptual revolutions* – these views are compared in the temporal perspective. Fourthly, in the detailed research of exact sciences in short or long-temporal perspectives, when we analyse the problem of scientific discovery, especially relationships between theories linked by generalized correspondence principles⁹.

There are different kinds of scientific revolutions. They may regard different strata of scientific activities, corresponding to different strata of theories, such as worldview-cosmological matters, empirico-theoretical matters, methodologico-epistemological matters, disciplinary-demarcational matters, or the socio-political organisation of science.

Examples of different classes of scientific revolutions

- When any new type of measurement instrument is applied which makes it

M. Kokowski, *Copernicus's Originality*

¹ See M. Kokowski, *Copernicus and the hypothetico-deductive method of correspondence thinking* M. Kokowski, *Copernicus's Originality*

² See A. Whitehead, *Science and the Modern World*.

³ See A. Koyré, *The Origins of Modern Science. A New Interpretation*.

⁴ See A. Koyré, *La révolution astronomique, Copernic – Kepler – Borelli*.

⁵ See W. R. Shea, *Galileo's Intellectual Revolution*.

⁶ See A. Koyré, *Etudes galinéennes*, A. Koyré, *La révolution astronomique, Copernic – Kepler – Borelli*.

⁷ See H. Butterfield, *The Origins of Modern Science, 1300–1800*.

⁸ See A. R. Hall, *The Scientific Revolution 1500–1800*

⁹ It is worth noticing the difference between the three former meanings and the latter one. The former ones are metaphorical and the latter – mathematical. Namely, when in the three former cases we refer to *fundamental changes* (when we consider the order of ideas in the non-temporal sense) or *rapid fundamental changes* (when we consider the temporal order), we should also know what *a unit of speed of changes* is, what *a low or high speed of changes* is, and what *an acceleration of changes* is. All of these expressions are metaphors which stem from the 2nd law of Newtonian dynamics. In turn, the fourth meaning is based on the physico-mathematical idea of the correspondence of theories.

possible to observe a new region of the Universe, such as Galileo's telescope and his observations of Medicean stars (the satellites of Jupiter).

- When a first theory which mathematicizes a new class of phenomena is constructed.
- When a new theory is constructed which is linked with an older theory by generalized correspondence principles.

In other words, in the light of historical and supra-historical approaches it is clear that the idea of the scientific revolution, negated so radically by current historians of science, is still very useful in interpretations of the history of science. However, we must use it with methodological refinement. I explain the problem below.

11. The dual continuous-discontinuous nature of mathematico-empirical sciences, the idea of scientific (r-)evolutions and the stable core of science

It is an undisputable fact revealed by historians of science that there are both evolutionary and revolutionary aspects in development of science. For example, we can see this in the problem of generalized correspondence principles that link the pairs of theories. Taking into account this dual continuous-discontinuous nature of the exact sciences, we may mention the whole spectrum of scientific changes from evolutionary changes to revolutionary ones, on evolutionary-revolutionary changes in science and scientific (r-)evolutions. Thanks to this we can find the supra-historical contexts of the practise and theory of science in a long span of time, that is, any elements that are, *in principle*, constant, independent of particular historical contexts. In this manner we can find *the stable core of science or the stable minimal set of views on science* – understood here both as methods of enquiring knowledge and of social organisation – independent of particular historical contexts.

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