UNIVERSITAT DE LES ILLES BALEARS

Department of Philosophy

Concepts of the ´Scientific Revolution´: An analysis of the historiographical appraisal of the traditional claims of science

Doctoral thesis presented by:

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Doctoral thesis

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The ´Scientific Revolution´ is probably the single most important unifying concept in the history of science (Osler, 2000, 3)

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INTRODUCTION AND THESIS SUMMARY:

1.1 PRELIMINARY DISCUSSION

Scientific Revolution refers to the period, from the late sixteenth to the early eighteenth century in Europe, when new ideas in physics, astronomy, biology, human anatomy, chemistry, and other sciences led to the rejection of doctrines that had prevailed from ancient Greece through the middle Ages. It has been described as the movement which was forged by Johannes Kepler (1571- 1630) and Galileo Galilei (1564- 1642), developed by René Descartes (1596- 1650) and Gottfried Wilhelm Leibniz (1646- 1716), and completed by Isaac Newton (1642- 1727).[1] The unprecedented advancements in science during the early modern period yielded to enormous transformation of man´s thought and way of looking at the world, and laid the foundation of modern science.

The success of the early modern science was orchestrated by historical rise of mechanism and materialism, the mathematization of natural philosophy and the emergence of profound experimentalism. According to Richard Westfall, its victory, over the prevailing Aristotelian doctrine at the time, started with the acceptance of Copernican astronomy, the rise of the mechanical philosophy, the decline of astrology and transmutational alchemy, and the acceptance of Newtonian physics.[2] The synthesis of ´mechanic-corpuscularism´ (see section 2.11.7) with mathematics culminated the scientific revolution. This materialistic perception of reality precipitated the scientific experimentation and observation of the 17th century science, which have been defined as the *processes* that guaranteed the rise of modern science. The scientific processes allowed the scientists to conduct objective investigation and reach conclusions based on the results. Most importantly, the synthesis of the ´mechanic-corpuscularism´ with mathematics proved quite fertile that the human mind exploited various cognitive

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[1] Peter Hanns Reill, ¨The legacy of the ´Scientific Revolution´ : Science and the Enlightenment,¨ in *The Cambridge History of Science: Eighteenth-century Science,* ed. Roy Porter (Cambridge: Cambridge University Press, 2003) vol. 4, p. 23

[2] Richard S. Westfall, *The Construction of Modern Science: Mechanisms and Mechanics* (New York: John Wiley pub., 1971) pp. 30-31

frontiers never known before. These exploits aroused the euphoria of progress and imbued the modern man with strong optimism.

Modern science became the major force behind the development of the idea of progress. Interestingly, the progress or growth of scientific knowledge has been one of the central issues in the epistemology of science. It is an issue that has engaged not only philosophers; even ¨scientists and laymen similarly agree that one of the striking features of the diachronic development of science is the *progress* that it exhibits.¨[3] From the origins of modern science in the work of Copernicus, Galileo, and Newton in the sixteenth and seventeenth centuries, until the logical empiricists of the twentieth century, scientific progress has been viewed as an evolutionary process of uncovering truth in the physical world.

Traditionally, scientific progress was viewed as a cumulative process moving steadily toward the truth. But though the combination of mathematical science and corpuscularian conception of nature proved quite fertile, ´neither the mathematical exactitude of Kepler´ s laws of planetary motion nor the quantitative rigor of Galileo´s laws of falling bodies proved derivable by means of the explanatory tools accepted in the corpuscularian world-view.[4] This suggests that the scientific knowledge which ensued from the activities of these scientists did not strictly flow from those processes and norms which have been acclaimed as the principal factors that distinguished the science of the early modern period from its predecessors. Hence, the controversy has been on whether or not there was a ´Scientific Revolution´?

Various historiographies of the scientific revolution have sought to find answer to the questions of its periodization, personalities, content and context, motive, relevance and epistemological implications. These historiographies are represented in the positivist, antipositivist and sociologists views which tend to identify the structure, scope and constituents of the scientific revolution. But while some of them view Scientific Revolution as a concept that is ´philosophically general´, others see it as ´historically unique´. The former defines the changes in science as a continual process while the

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[3] Larry Laudan, *Science and Relativism* (Chicago: University of Chicago Press, 1990) p. 2

[4] H. Floris Cohen, *The Scientific Revolution: A Historiographical Inquiry* (Chicago: University of Chicago Press, 1994) p. 512

latter designate them, particularly, as the ´upheaval´ which took place during the early modern period.

Until the historiographical revolution of the early 1960´s the scientific processes or method of the 16th and 17th centuries were seen as functional parameter for the justification of the objectivity, truth, realism and rationality of the scientific knowledge. Before this time, positivism had reigned supreme for a century, from Auguste Comte to Rudolf Carnap. With respect to scientific authority, this philosophical account typically vindicated the acceptance of scientific claims or research programs as rationally warranted or reliable. For the logical empiricists and logical positivists the feature of science that make it scientific are formal relations between theories and data, whether through the rational construction of theoretical structures on top of empirical data or the rational dismissal of theories on the basis of empirical data. This feature of science illustrates the validity of its claims. It shows that if science demonstrates the formal relations between theories and data it is certain that its claims will be rational, true, real and objective. The progressiveness of science was viewed as the mechanism that certifies such feature. Consequently, we see in these philosophical accounts the conscious intertwinement of the progress of science with its realism, rationality, truth and objectivity.

Nevertheless, the early 1960´s witnessed unreserved criticisms and reactions to this unique feature of science that has been painted by the logical positivists and logical empiricists. The reactions consisted in demonstrating the stimulus given to (and the limitation placed upon) discovery and invention, in the early modern period, by industry, hermeticism, religion, capitalism and social structures, and conversely the ways in which science has altered economic, social, and political beliefs and practices. The concern was for a shift from the traditional ways of relying solely on the content of scientific beliefs and methods for the justification of scientific claims, to the veritable consideration of the context of their development. This move reiterated the need to reevaluate the scientific claims by discussing the scientific procedures of the early modern period within the context of their development. It was shown that the actual method used by scientists differed dramatically from the then-espoused method. The observations of science practice are described as essentially sociological and do not speak to how science is or can be practiced in other times and other cultures.

1.2 STATEMENT OF THE PROBLEM

The overthrow of the Aristotelian natural science by mechanic-corpuscular philosophy and mathematical physics inaugurated tremendous changes in the history of science and philosophy. The modern science that ensued afterwards was conceptualised primarily as a coherent body of knowledge unified by a common methodology developing teleologically toward universal truth.[5] It signifies that scientific progress is logically intertwined with its truth and objectivity. Such positivist view implies that science progresses when poor theories are replaced by good ones which are by all indications the more rational, true and objective. Genuinely progressive theories are those which have the capacity to explain and predict a larger range of facts than their rivals. According to this logical empiricist view,

> *... Newton´s theory of gravity is better than Descartes´s because Descartes´s theory was refuted by the fact that planets move in near-elliptical paths, and because Newton´s theory explained everything that Descartes´s theory had explained, and also explained the refuting facts... Newton´s theory was, in turn, refuted by the anomalous perihelion of Mercury, while Einstein´s explained that too.*[6]

More still, the Popperian Falsificationism (see section 3.2.1.2) insists that the prospective explanatory and predictive range of a theory determines its progressiveness. Carl Hempel went further to demonstrate that science evolved in a continuous manner. New theory did not contradict past theory: "theory does not simply refute the earlier empirical generalizations in its field; rather, it shows that within a certain limited range

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[5] See the discussion on falsificationism in Imre Lakatos, ¨Criticism and the Methodology of Scientific Research Programmes,¨ *Proceedings of the Aristotelian Society* (London: Blackwell Publishing, 1968), 69: 149-186

[6] Ibid., p.152

defined by qualifying conditions, the generalizations hold true in fairly close approximation."[7] New theory is more comprehensive; ¨the old theory can be derived from the newer one and is one special manifestation¨[8] of the more comprehensive new theory. The logical empiricists would agree, for instance, that Newtonian physics is a special case of, and can be derived from, Einsteinian physics.

Their conception of scientific progress was thus a continuous one; more comprehensive theory replaced compatible, older theory. Each successive theory's explanation was closer to the truth than the theory before. It was the truth, and the prediction and control that came with it that was the goal of logical-empirical science. Such perspective maintains that one theory´s known successes does not have anything to do with certain accidents of history than with the theory itself. However, as J. G Crowther has shown, science is ¨the system of behavior by which man acquires mastery of his environment.¨[9] Floris Cohen developed this concept further to argue that modern science is not just a thought-construction among others—it entails both an intellectual and an operative mastery of nature.[10] The operative mastery of nature implies that science should also be considered as a social phenomenon, though it is at the same time much more than that. This perspective drives from the fact that modern science has been one, or even, the principal motor of social transformation over the past two centuries, and also during the 16th and 17th centuries.

Consequently, some historicists would argue that the new ideas in science, during the early modern period were all situated in a wide cultural context. They were closely related to religious, political and socio-economic changes.[11] The historicist historiography demonstrates that the pursuit of purely ´objective´ scientific knowledge

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[7] Carl G. Hempel, *Philosophy of Natural Science*, eds. Elizabeth and Monroe Beardsley (Englewood Cliffs: Prentice hall, 1966), p. 76

[8] Ibid.

[9] J. G Crowther, *The Social Relations of Science,* revised ed. (London: The Cresset Press, 1967). p. 1

[10] H. Floris Cohen, *The Scientific Revolution: A Historiographical Inquiry.* p. 4

[11] Shapin examines four themes in the history of modern science: mechanism (the idea of nature as a machine); objectivism; methodology and impartiality; and altruism (the idea that science can better the lot of mankind). He does so in three deft, incisive sections: "What Was Known?"; "How Was It Known?"; and "What Was the Knowledge For?". The third section "What Was The Knowledge For?" explores the interactions of the new science with the political, religious and cultural dimensions of the European society in which it was embedded. It shows that Scientific Revolution cannot be framed in terms of autonomous ideas or disembodied mentalities.(p.4). See Steven Shapin, *The Scientific Revolution* (Chicago: University of Chicago Press, 1996), pp. 119 - 165

by disinterested individual is merely an aberration. However, it does not mean that knowledge is ´whatever people take to be knowledge.¨[12] Therefore, the following questions will be adequately treated:

1. If scientific practice is truly influenced by certain social factors how and to what extent does science generate true and justifiable knowledge?
2. If certain social factors have been really decisive in the progress and advancement of the scientific knowledge, what is the nature of the objectivity that could be identified in the scientific advancement?
3. If there are no non-contextual or ahistorical scientific processes and norms how do we explain the universality of modern science?

1.3 THEORETICAL FRAMEWORK AND HYPOTHESIS

Outside the implications of the sociology of science and social-constructivism that emanated from the historicist narrative of the scientific revolution, one fundamental argument that unites the different approaches involved is that scientific processes and norms are historically determined. It implies that scientific knowledge cannot be universally rational and objective since its processes and norms are historically determined. This crucial issue defines the basis of this research´s concentration on the historicist model of the scientific revolution.

This research will demonstrate that more than any other model of the scientific revolution narrative, the historicist model represents an assemblage in which the dual sense of the term ´Scientific Revolution´ is streamlined. This is certified by the fact that it is within this model that the concept of the scientific revolution was created and used as an analytical tool to give a close unity to the range of phenomena which together constitute the rise of early modern science. Precisely, this model argues that the new ideas in science, during the early modern period were all situated in a wide historical or cultural context. Its two principal tenets are identified:

1. Extra-scientific/social factors are decisive in the progress of science, and in most cases, become constituent of the scientific knowledge.

[12] David Bloor, *Knowledge and Social Imagery,* 2nd ed. (Chicago: University of Chicago Press, 1991) p.5

2. Scientific claims are so historically determined, just like the processes and norms from which they are developed.

Among the principal theses of the historicist model include: The Kuhnian thesis by Thomas S. Kuhn, Shapin thesis—Steven Shapin, Alfred Rupert Hall—Hall thesis, Boris Hessen—Hessen thesis, Robert K. Merton—Merton thesis, Alexandre Koyré—Koyré thesis, Pierre Duhem—Duhem thesis, Herbert J. Butterfield—Butterfield thesis, Joseph Needham—Needham thesis, Frances Yates—Yates thesis.[13] Most of these theses are also categorised under the following historiographies: Marxist historiography, ´territorist´ historiography, ´sociologist´ and the mystical-hermeticist historiographies.

This research examines their response to the question of the existence of the scientific revolution to show how in trying to affirm or deny its success they were more or less subsumed in the intricate reactions to the traditional claims of science, which include rationality, truth, objectivity and realism. It illustrates how the historicists´ critique of the notion of the progress of science is not typically about the success of early modern science, but the justification of the traditional claims of science on the basis of the scientific processes and norms of the 16th and 17th centuries.

One of the predominant issues the historicists theses press forth is the incorrectness of subsuming the success of the scientific revolution as a logical justification for the validity of the scientific claims, as has been manifested in the traditional authority of the modern science. In fact, the success of the scientific revolution lies in the fulfilment of the socials functions that have characterized early modern science ever since Francis Bacon proclaimed the idea of the dominion over nature by man through the application of science.

This research argues that their identification of the contextual and historical nature of scientific norms and processes leads us to the reconsideration of our notion of the universality of modern science. It illustrates that the notion of the universality of modern science has been the vantage point which makes the validity of those traditional

[13] This research bases its discussion of the respective theses of the Scientific Revolution on the works of authors written specifically on the subject. (See Shapin, 1996, Koyré, 1957; 1965; 1968; 1978, Kuhn, 2000;1996, Duhem, 1991; 1955; 1913-1959, 1996, Butterfield, 1997; 1959, Hall, 1966; 1981; 1983, Needham, 1969; 1954; 1981, Merton, 2001, Hessen, 1971, and Yates, 1964, 2010).

scientific claims seem plausible. But if there is no non-contextual or ahistorical scientific processes and norms it means we likely have to talk about the ´globality´ of the modern science and not its universality. Finally, it demonstrates that universality of modern science resides in the replication of equipment (*for experiment)*, the training of observes (*scientists)*, the circulation of routine practices and the standardization of methods and measures. When equipment, instruments, theories, statements, expressions of scientific laws and training are standardized, the same kinds of practices or units will become accepted as default options in multiple localities.

1.4 OBJECTIVES

The general objective of this thesis is to realise a comprehensive analysis of the concept of scientific revolution within the historicist context and its treatment of the cognitive and socio-cultural elements in science. Invariably, it demonstrates the implications for future studies on the progress of science and the authority of scientific knowledge. It illustrates that the lessons from the historicist historiography of the scientific revolution demands adequate reconsideration of the notion of the universality of modern science. How is it possible to reconcile the intuition that scientific knowledge can transcend the conditions of its production with the acknowledgment of the contingent and contextual nature of scientific work?

Since every shift in the notion of science has elicited a shift in the epistemological status of the scientific knowledge, it suggests that an interactionist epistemology will better demonstrate the variety of factors involved in scientific progress unlike the dichotomy and exclusion constituted in the objectivist and subjectivist epistemologies.

Interestingly, the popularity of the Kuhnian thesis, in the past half century, has overshadowed the vital contributions of other historicists' historiographies of the Scientific Revolution to the development of the history and philosophy of science. This research brings into focus their enormous contributions to the understanding of science and the development of philosophy of science. It is important to note here that all the theses of the scientific revolution discussed in this work are to be drawn from the aforementioned authors' different works written specifically on the Scientific

Revolution. It is the historical character of their works that made them to be grouped under the historicist model of the scientific revolution irrespective of the school of thought they belong. This forms the basis on which they are called *theses* of the Scientific Revolution unlike the positivist model that dwelled just on the analysis of the scientific advancement in general. In fact, there was little mention of scientific revolution as a philosophical topic in the works of logical empiricists and logical positivist.

1.5 METHODOLOGY

The procedure of investigation used in this thesis is mainly the bibliographical revision of the works of major authors who have written specifically on the Scientific Revolution from a historical perspective. Consequently, the terms; historicists, historicist historiography, historicist model and historicist narrative will be used interchangeably to refer to the authors´ analysis of the Scientific Revolution. It is from their works that a comprehensive selection of relevant text was made for the development of this theme, the approach and objectives of the thesis. The secondary data are mainly drawn from relevant sources, from journals, books and articles. The reason for incorporating both primary and secondary data is to provide adequate elaboration, on the theme, for readers, so as to facilitate proper understanding of the topic and the different variable that are involved in it.

This work is divided into three sections. The first section which treats on the historiography of the scientific revolution comprises the first two chapters. Chapters one describes the origin and history of the term ´Scientific Revolution´, while chapter two discusses the ten principal historicist historiographies of the Scientific Revolution. The second sections which consists of chapter three and four, illustrates the historicists reactions to the traditional claims of science and the theoretical mechanisms they employed to demonstrate that the justification of the traditional claims of science cannot be, plausibly, based upon the scientific processes and norms of the 16^{th} and 17^{th} centuries. The initial approval of those processes and norms as guarantors of the validity of scientific claims drives from the belief that the entities and processes of theory exist in nature, and science has the duty to discover them. However, certain developments in

the nineteenth-and twentieth-century science had shown such scientific realism to be wrong. A good example was the atomic physics of Werner Heisenberg. According to Cecil Schneer, Heisenberg´s indeterminacy led to the conclusion that ¨the world of nature is indeterminate. The behavior of the particle is uncertain and therefore the behavior of the atom is an uncertainty.¨[14] Thus at the atomic level, ¨even the fundamental principle of causality fail[ed].¨[15] Heisenberg wrote thus,

> *At the instant when the position is determined—therefore, at the moment when the photon is scattered by the electron—the electron undergoes a discontinuous change in momentum. This change is the greater the smaller the wavelength of the light employed—that is, the more exact the determination of the position. At the instant at which the position of the electron is known, its momentum therefore can be known only up to magnitudes which correspond to that discontinuous change. Thus, the more precisely the position is determined, the less precisely the momentum is known, and conversely.*[16]

Heisenberg used his thought experiment in measuring the position of an electron to show that there are limits to what we can know about the electron. Precisely, this indeterminacy principle is a variety of mathematical inequalities asserting a fundamental limit to the precision with which certain pairs of physical properties of a particle, such as position X and momentum P , can be known simultaneously. It implies that ´mathematical realism´[17] cannot wholly provide true and objective scientific knowledge as the works of Galileo, Kepler and Newton were shown to have done. Invariably, the chapters three and four argue that the scientific processes of the early modern period, alone cannot justify the validity of the traditional claims of science. These scientific processes are situated in history and are quite contextual. To understand

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[14] Cecil J. Schneer, *The Evolution of Physical Science* (New York: Grove, 1960), p. 364

[15] Ibid., pp. 358-9

[16] Werner Heisenberg, ¨The physical content of quantum kinematics and mechanics¨, in *Quantum Theory and Measurement*, eds. Wheeler, J. A and Zurek, W. H (Princeton NJ: Princeton University Press, 1983), p.64. See also pp.174-5 in W. Heisenberg, ´Üeber den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik´, *Zeitschrift für Physik* **43**, 1927, 172–198.

[17] See section 3.1 for the detailed discussion on the term

them and the way they relate to the scientific claims properly, we need to study them within the historical and socio-cultural context in which they are developed.

The last section which consists of chapter five, therefore, illustrate that if the scientific processes are historically conditioned there is need to re-examine the notion of the universality of modern science since such notion drives from the belief that the entities and processes of theory exist in nature and science is used in all places to discover them. It makes an elaborate illustration of the philosophical, epistemological, social and historical aspects of the universality of modern science to argue for the need of further research on the reconstruction of our notions of the scientific claims and progress at a higher level of integration.

1.6 EVALUATION AND CONCLUSION

The ´Scientific Revolution´ is primarily a historian´s conceptual category. It is for this reason that this research is being based on the historicist historiography of the scientific revolution, and not on any particular author. As we would see in Koyré formation of the term, it was developed mainly as an analytical tool for the study of an epoch in the history of science. However, its designation as an analytical tool did not define the method and scope of its application. There was neither any specific subject matter it was channeled to address. Hence, we will be coming across topics ranging from the demise of the Aristotelian natural philosophy to mechanism, experimentalism, hermeticism, corpuscularism and mathematical natural philosophy. These range of issues demonstrate the wanton search for the precise nature of the ´Scientific Revolution´, its origins, causes and results. Perhaps, the lack of a definite pattern for this search serve to demonstrate, as John Henry illustrated, that ¨there was nothing like our notion of science until it began to be forged in the scientific revolution out of previously distinct elements¨.[18] Therefore, the purpose of looking at the historical development of what we think of as science, should be to understand how the very concept ´science´ arose.[19]

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[18] John Henry, *The Scientific Revolution and the Origins of Modern Science.* 2nd ed. (New York: Palgrave, 2002) p. 6

[19] Ibid., p. 5

Finally, the historicist model of the scientific revolution not only shows us the real process of the fundamental changes in modern science, it also defines what should be the real nature of science claims.

SECTION I

HISTORIOGRAPHY OF THE SCIENTIFIC REVOLUTION:

CHAPTER ONE

1.1 HISTORY OF THE CONCEPT OF SCIENTIFIC REVOLUTION

The term ¨Scientific Revolution¨ was first given wide significance through Herbert Butterfield´s series of lectures on *The Origins of Modern Science*[20] delivered for the History of Science Committee in Cambridge in 1948. These lectures later came out in book form in 1949. However, it was the French historian and philosopher of Russian origin, Alexandre Koyré, who in the 1939 created it as a conceptual tool for understanding the birth of early modern science through the publication of his three essays collected together under the title *Études Galiléennes*[21].

The history of the concept of scientific revolution has common historical characteristics with the history of the concept of ´revolution´ itself. When one asks; what history lies behind the terms ´revolution´ and ´scientific revolution´? The answer that ensues would be an intriguing mix of accounts of physical phenomena, political fortunes, and conceptions of chance, fate, and history. Such answer indicates why it is necessary to have thorough study of the history of the concept of revolution in order to get a defined view of the concept of the scientific revolution since ¨such history has a number of closely related themes that are relevant to the subject of revolution in science.¨[22]

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1.1.1 THE MEANING OF REVOLUTION IN ANCIENT GREEK

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[20] Herbert Butterfield, *The Origins of Modern Science 1300-1800,* revised ed. (New York: Free Press, 1997) First published in 1949

[21] See Alexandre Koyré, *Études Galiléennes,* 2nd ed. (Paris: Hermann, 1966 [1939-1940]); Alexandre Koyré, *Galileo Studies*, trans. John Mepham (Hassocks: The Harvest Press, 1978)

[22] I. Bernard Cohen, *Revolution in Science* (Cambridge: Havard University Press, 2001[1985]), p. 52

The pre-historic and ancient Greek periods did not have any particular word with which the term¨ revolution¨ was designated. In the works of historians like Herodotus and Thucydides and philosophers such as Plato and Aristotle, various synonyms were used which demonstrated ´their fill of revolution´, though they had no single word for it.[23] Herodotus and Thucydides had both used the term ἐπανάστασις ´uprising´.[24] Thucydides further speaks of μεταβολή *πολιτείας* ´change of constitution´[25] or *νεωτερίζειν την πολιτείαν*[26] ´to revolutionize the state´. In Plato´s *Republic* and Aristotle´s *Politics* *νεωτερίζειν*[27], *νεωτερισμός*[28] (revolution) and μεταβολή και *στάσις*[29] (Change with uprising) were used respectively.

Generally, these Greek words were used to demonstrate changes in the political system or societal transformation, and were intermittently employed to illustrate both cyclical phenomena and radical change. The cyclic theory of revolution could be seen in Plato´s formation of the process of the ideal state in which timocracy deteriorates into Oligarchy and through democracy into tyranny. However, the cycle was perfectly completed later by Polybius who started by making kingship to pass to tyranny, through aristocracy and oligarchy to democracy and mob-rule which in turn produces the kingship again. But then, Aristotle was apt to reject this cyclical connotation and readily uses μεταβολή to reflect new change and ´μεταβολή και *στάσις*´ when it is accompanied by violence.

These illustrations of the Greek etymology of the term show that ´revolution´ is not just a modern concept. The Greeks knew about it and even express it in words. The only difference between the modern expression of the concept and the Greek is that the Greeks did not always choose the same word to express it, and sometimes two or more

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[23] Arthur Hatto, ¨ ´Revolution´: An Enquiry Into the Usefulness of an Historical Term¨, in *Mind* (Oxford: Oxford University Press, 1949) p.498

[24] Ibid. (See also Herodotus, *The Histories,* trans. Aubrey de DeSélincourt. (London: Penguin, 2003); E.S. Shuckburgh, *Herodotus* Book VI (New York: Cambridge University Press, 1976) pp.30-50. First published 1889

[25] Ibid.

[26] Ibid.

[27] Plato. *Republic*, Book IV, 424b, 565b (Cf. Plato. *Platonis Opera*, ed. John Burnet. Oxford: Oxford University Press. Vol. III, 1903)

[28] Ibid.

[29] Cf. Aristotle. *Aristotle´s Politica*. Book 1, 1252a ed. W. D. Ross (Oxford: Clarendon Press, 1957)

words were used. It could be asked why didn´t they have a particular word for such familiar concept they knew about and lived in their daily encounters? Arthur Hatto offers a very clear and historic answer. He wrote thus,

> *The reason for this must be sought in the fact that their civilisation had experienced no classic revolution as did ours in the Revolution of 1789.*[30]

What he seeks to emphasise is that though the Greeks experienced many revolutions and near-revolutions or proto-revolutions as well, they were not witness to a classic revolution in the sense that Europe did in the French revolution of 1789. It was from this period that the concept of revolution gained the status of total change and radical overturn and became frequently identified with similar events.

The Greek sources serve to demonstrate the origin of the cyclical notion of revolution and the traditional sense in which it was used during the ancient period. Nevertheless, such notion did not stop with the ancient. It prevailed the medieval and renaissance sense of the word and has continued to be concurrently functional with the modern ´radical change´ connotation that was initially introduced during the enlightenment period.

1.1.2 NOTIONS OF REVOLUTION IN THE MEDIEVAL AND RENAISSANCE CONTEXT

In general etymological sense, ´revolution´ is derived from the mediaeval Latin *´revolutio´* which means a rolling back or a return, usually with an implied sense of revolving in time.[31] Its Latin root verb is ´re-volere´ which means ´to roll back´.

In later Latin, the noun ´revolutio´ had the sense of ´conversio´ of classical Latin, of which its root verb ´convertere´ has the sense of turning on an axis or of rotating, and so is akin to revolving. The latin word that is very similar to the modern notion of revolution is ´mutatio rerum´ as could be found in Machiavelli's *The Prince* Ch. 26,

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[30] Arthur Hatto, *´Revolution´ : An Enquiry Into the Usefulness of an Historical Term*, p. 500

[31] See Felix Gilbert, ¨Revolution,¨ in *Dictionary of the History of Ideas*, ed. Philip P. Wiener. 5 vols (New York, 1973), IV, 152-67

though he employed it in an Italian form ´mutazione di stato´[32]. In this chapter, the phrase that occurs is *´tante revoluzioni d´Italia´* (meaning, many revolutions in Italy), although it was used in the general sense of *mutazioni* (mutations), rather than in the special sense of ´revolution´.[33]

However, the medieval Italian word ´rivoluzione´ is etymologically equivalent to the English term ´revolution´ in its specific sense of radical overturn or in the sense of ¨constitutional change¨[34] as was used by the Italian historian and statesman, Francesco Guicciardini. By the early sixteenth century, this Florentine historian, Guicciardini was writing of a change in government as ´rivoluzione´.[35] It shows why the anti- and pro-Medicean Revolutions in Florence in the years 1494, 1512 and 1527 were all called *´rivoluzione´*. In a general sense, *rivoluzione* was a ´return to a starting point´, and it is in this sense that the banishment of the Medici in 1494 could also mean a return to a more democratic regime, while its reinstatement in 1512 was a return to the regime of before 1494, and then its second banishment in 1527 a return to the regime before 1521.

The medieval concept of the term ´revolution´ shows it as mere mutations (mutation rerum, mutazioni) that re-establish pre-existing order through radical historical events. However, the distinctive character of the revolutions the aforementioned Latin and Italian words referred to is not merely that they are cyclical succession of phenomenon in the sense that the word ´revolution´ itself means to roll back, but they mainly indicate the dramatic changes at the time.

Moreover, the usage of the substantive ´revolutio´ as a technical term in astronomy beginning in the Latin Middle Ages serves to illustrate the clear sense in which the word was first accommodated in science. It was employed to illustrate the daily revolutions observed in the stars and in the sun, moon, and planet, and the orbital apparent motions of the planets. It appears emphatically in the title of Copernicus´s classic work *De Revolutionibus Orbium Coelestium* (On the Revolutions of the Celestial Spheres, 1543)

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[32] See Machiavelli, *´The Prince* Ch. 26, quoted in I.B Cohen, *Revolution in Science,* p.57

[33] Arthur Hatto, *´Revolution´: An Enquiry into the Usefulness of an Historical Term,* p. 503

[34] Francesco Guicciardini, *Storie Fiorentine,* dal 1378 al 1509 ed. Roberto Palmarocchi (Bari: Tipografi-Editori-Libra, 1931), chap. 2, pp. 20-21

[35] Francesco Guicciardini, *Opere.* ed. Emanuella Lugnani Scarano. (Turin: Unione Tipografico-Editrice, 1970) p. 81

and also appeared in various places in Galileo´s dialogue *On the Two Chief World Systems,* 1632.

Evidently, the varying sense of the cyclical and radical use of the words ´revolution in science´ could be found in the recurrent distinction usually made between ´rotation´ and ´revolution´. ´Rotate´ comes from the Latin verb ´rotare´ meaning to turn, or to swing around. Here rotation is used to refer to the turning of a body on its axis and revolution as the motion in a circuit along closed path or orbit. However, the two words were used interchangeably in Renaissance and late seventeenth century period. In this case the primary astronomical meaning of revolution was the circular motions of the heavens and its astrological signification of the way such motions affect or even determine the course of men´s lives and of the state. Consequently, in the renaissance context, the notion of ´revolution´ is more typified by the physical motions of physical images and objects, like the sun and clock towers of Renaissance buildings, than it is purely intellectual metaphor.

1.1.3 REVOLUTION AS A CONCEPT OF ´ABRUPT CHANGE´ IN THE ENLIGHTENMENT PERIOD

It was not until the American Revolution of 1776 and French Revolution in 1789 that a new meaning came to predominate the term ´revolution´ as a breach of continuity or a secular change of real magnitude. Its usage ever since has commonly implied what I. Bernard Cohen (1976) describes as,

> *a radical change and a departure from traditional or accepted modes of thought, belief, action, social behaviour, or political or social organisation.*[36]

This explanation of revolution depicts the concept of a change that is sudden, radical, and complete, often accompanied by violence or at least the exercise of force. Such

[36] I. Bernard Cohen, ¨The Eighteenth-Century Origins of the Concept of Scientific Revolution¨, *Journal of the History of Ideas*, 1976, 37(2), p. 258.

fundamental change has a dramatic character that usually enables observers to discern that a revolution is taking place or has just done so. For instance, the English ¨The Great Rebellion¨ of 1640-60 could not be termed a ¨revolution¨ until 1826-27 by analogy with the French Revolution of 1789.[37] In its own century the English Revolution was referred to as ¨The Great Rebellion¨ and ¨The Civil War¨ as reflected in Clarendon´s *History of the Rebellion and Civil Wars in England*[38]. Christopher Hill wrote on the English Revolution,

> *A great revolution took place¨ during ¨the decades 1640-60...comparable in many respects with the French Revolution of 1789.*[39]

In the enlightenment context ¨Revolution¨ refers to basic upheaval, radical break, profound change, and new beginning. These new meaning, evidently, bring some bits of confusion and ambiguity about the actual significance of the term ´revolution´ not only to science but to political events. The reason for such ambiguity is that the older sense of ¨revolution¨ as a cyclical phenomenon, a kind of return and repetition still remain. Notwithstanding this ambiguity, the writers on science in the eighteenth century developed the notion of revolutionary scientific events, comparable to political events and usually with the work of a single individual like Copernicus, Descartes, Newton etc. Consequently, the term *´The Scientific Revolution´* has become the name commonly given today to the particular scientific revolution (or set of revolutions) of the sixteenth and seventeenth centuries, by means of which modern science was established, and often associated with such figures like Copernicus, Vesalius, Bacon, Descartes, Galileo, Kepler, Harvey, Huygens and Newton.

The above illustrations denote two prevalent senses in which the concept of revolution has been used, namely:

1. The technical sense (astronomical) and
2. General sense (Political)

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[37] Arthur Hatto, *´Revolution´: An Enquiry into the Usefulness of an Historical Term,* p. 504
[38] Edward Clarendon, Earl of. 1888. *The* H*istory of the Rebellion and Civil Wars in England begun in the year 1641.* 6 vols. Oxford: Clarendon Press. (Culled from Bernard I. Cohen, *Revolution in Science*. p. 71)
[39] Christopher Hill, *The Century of Revolution, 1603-1714.* 2nd ed. (London: Sphere Books, 1972) p. 165

François Pomey (1691) in *Le Dictionaire Royal* made two separate entries for the term ´revolution´. They are *´Tour´*[40] meaning circuit or rotation and *´Changement d´ état´*[41] meaning overturning of the state or change of state. These entries indicate that in a technical sense, ´revolution` refers to the traditional motion of circularity and the going around of the heavenly bodies. In this case the notion is not only used as a purely intellectual metaphor but was exemplified in definite physical images and objects like the daily apparent motion in revolution of the celestial sphere like sun, stars and moon. While in the general sense, ´revolution´ is devoted to political change, change in general, and even the advance of time and the vicissitude of fortune.

The clear objective of these separate entries of Pomey would be to emphasize that it was in the socio-political sphere that talk of revolution as a successful uprising and overturning became common. In this sense a revolution is a successful revolt, ´revolution´ being an achievement or product term whereas ´revolt´ is a process term. Christopher Hill justifies the origin of this common concept of revolution when he writes that,

> *Conventional wisdom has it that the word ´revolution´ acquired its modern political meaning only after 1688. Previously it had been an astronomical and astrological term limited to the revolution of the heavens, or to any complete circular motion.*[42]

The fully modern conception of revolution as involving a break from the past in the sense of an abrupt, humanly-made overturning rather than a natural-overturning, depended on the linear, progressive conception of history that originated in the Italian Renaissance or at least the Protestant Reformation. Arthur Hatto demonstrated that from the bare factual history of ´revolution´ as a political term it is clear that its origin has to be sought not in France but in Italy, where the first revolutions of the epoch occurred.[43] However, the radical connotation of revolution as a political term gained strength during

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[40] François Pomey, *Le Dictionaire Royal* (Lyon: Molin, 1691) p. 839
[41] Ibid.
[42] Christopher Hill, *A Nation of Change and Novelty: Radical Politics, Religion and Literature in Seventeenth-Century England* (London: Routledge, 1990) p. 82
[43] Arthur Hatto, *´Revolution´: An Enquiry into the Usefulness of an Historical Term,* p. 509

the two seventeenth-century English revolutions of the 1640s and the Glorious Revolution of 1688.

The import of this modern concept with root in the Italian Renaissance is to illustrate that the notion of ´abrupt change´ of ´revolution´ is very reflective of the prevalent rejection of the idea of cosmic determinism at the period. This is because it is only within the context of cosmic determinism that the cyclical notion of ´revolution´ could be justified and in that way the meaning of revolution would just be mere changes or ordinary overturn rather than a radical and sudden departure from the past. It is on this basis that one can establish the difference between the cyclical and radical notions of revolution as ´abrupt change´.

Eventually, the modern conception gained its strength in the eighteenth century, and became practically dogma among the champions of the scientific Enlightenment. In the early eighteenth century in France, the term ´revolution´ had pure political definition and was being used often, though not in an explicit way, to mark significant developments at the time. By the mid eighteenth century it was obvious that Alexis-Claude Clairaut (1749), Diderot, D´Alembert et al (1751) sometimes applied the term to scientific developments, including Newton´s achievement but also Descartes´ rejection of Aristotelian philosophy.[44] And then by the end of the century several French authors were referring explicitly to one or another revolution in the sciences.[45]

1.2 SCIENTIFIC REVOLUTION AS A DUAL SENSE ´PHILOSOPHICALLY GENERAL´ AND ´HISTORICALLY UNIQUE´ CONCEPT

Floris Cohen (1994) did remarkable analysis of the concept of scientific revolution by clearly distinguishing between notions of the ´*Scientific Revolutions* and *The Scientific*

[44] I. Bernard Cohen, *Revolution in Science.* pp. 216-220

[45] Ibid. See also Le Marquis de Condorcet. *Sketch for a Historical Picture of the Progress of the Human Mind.* Trans. June Barraclough (New York: The Noonday Press, 1955; Hyperion reprint, 1979, Westport, Conn.: Hyperion Press); Jean-Etienne Montucla. *Histoire des mathématiques.* 2 vols. (Paris: Chez Ch. Ant. Jombert, 1758), and in the revised edition, 4 vols. (Paris: Chez Henri Agasse, 1799)

Revolution˝[46]. The term ´Scientific Revolutions´ which is *generic* stands for a *philosophical* idea about the on-going process of science. He explains it thus,

> *It signifies the idea that scientific discovery generally proceeds in a convulsive sort of way....Scientific revolution are taken to occur with a certain frequency, or even regularity; there is nothing unique about them.*[47]

This concept of scientific revolutions emerged during the 1960s and 1970s at a period when the historiography of science came to maturity primarily with important works on the Scientific Revolution. Thomas Kuhn published *The Copernican Revolution* in 1957 and *The Structure of Scientific Revolutions* in 1962, adding the important ¨Postscript—1969¨ to the second edition of 1970. Both Thomas Kuhn and Paul Feyerabend challenged received views of science and made talk of revolution and incommensurability central to history and philosophy of science. They asserted that major conceptual changes lay in the future of the various sciences as well as in their past. Therefore, no science of any particular epoch is inherently privileged than another. Feyerabend, introduced the term ´incommensurable´ in his "*Explanation, Reduction and Empiricism*"[48] , while Kuhn reiterated that there have been many scientific revolutions both small and large occurring in scientific specialty areas, with even very few members, though outsiders (non-members of that scientific community) might see those transformations as very normal and cumulative progress. As such, scientific revolutions are not quite highly distinctive developments even though there are deep conceptual changes.

In contrast, the term ´Scientific Revolution´ is *specific*. It stands for a *historical* idea about one concrete episode in the past of science. According to Floris Cohen,

> *It signifies the idea that there has been a period in history, which is hard to date with precision but which almost always is*

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[46] H. Floris Cohen, *The Scientific Revolution: A Historiographical Inquiry,* p. 21

[47] Ibid.

[48] Paul Feyerabend, "Explanation, Reduction and Empiricism", in *Scientific Explanation, Space, and Time*, Minnesota Studies in the Philosophy of Science, Vol. 3, eds. H. Feigl & G. Maxwell, (Minneapolis: University of Minneapolis Press, 1962) pp. 28–97

> *meant to include the first decades of the 17th century, when a dramatic upheaval occurred in science.*[49]

This concept indicates that there is existence of scientific revolution as highly distinctive development. For instance, works like *The Origin of Modern Science: 1300-1800* (Herbert Butterfield, 1949), *Scientific Revolution: 1500-1800* (Hall, 1954) *and Études Galiléennes* (Koyré, 1939) are some of such works that are characterized by their grand narratives of the science of the early modern period as highly distinctive development.

Since the middle of the 20th century, the frequency of revolutions and accumulations of historical data have produced an outpouring of studies on revolution from varying viewpoints. Therefore, in order not to be buried under the mass of material or lost in the confusion of differing conceptions, it is necessary to select a definition which can be focused on the scientific revolution. In doing this, the above analysis of the etymology of revolution has demonstrated that its modern use as a sudden and surprising change invariably neglects the political implications of the meaning of rolling forward or backward to a starting point, as illustrated in the Greek and medieval origin, and plays down the decisive part played by astronomical and astrological conceptions in its semantic development.

Various works on the scientific revolution have sought to give account of its development along the dual sense of the concept and such attempts have precipitated into two basic traditions, which will be carefully traced and discussed.

1.3 EXPANSION OF THE CONCEPT

There was tremendous rise and subsequent rapid spread of the concept of the ´Scientific Revolution´ during the periods between 1924 and the 1960´s. Two major factors are responsible for this development. Firstly, this concept was particularly forged as an analytical tool for the study and understanding of the emergence of modern science as a

[49] H. Floris Cohen, *The Scientific Revolution: A Historiographical Inquiry,* p.21

historical issue. The other was the establishment of the history of science as a professional academic disciple which occurred as a result of the fresh academic opportunities offered by the evolving articulations of the new concept of the Scientific Revolution. It was within the first decades of the twentieth century that a genuinely historical debate over the nature and the causes of the changes in the sixteenth-seventeenth-century science flourished.

In 1924 Edwin Arthur Burtt published *The Metaphysical Foundations of Modern Physical Science*. His philosophical thesis analyses how the human spirit has been read out of the cosmos at large through the advent of modern science. It makes a paradoxical representation of how the autonomy of the human mind was downgraded and banished by the same atomic universe it created through modern science. The thesis provides a framework for an overview of drastically novel ideas, mostly those in the mathematical and the corpuscularian mode, from Copernicus to Isaac Newton (1642-1727), but with much emphasis on Newton.

Alexandre Koyré, in *Études Galiléennes* (1939) coined ´Scientific Revolution´ and applied it as an analytical tool for grasping the essence of the rise of modern science. He analyses the concept in very restricted sense as the deep ramifications of Galileo´s novel mathematically idealized treatment of motion. Here, Galileo´s work was interpreted as a sort of Platonic intellectual transformation. Also, one need to read together Koyré´s *La revolution astronomique* (1961) and his *Newtonian Studies* (1965) to get an adequate picture of the expanded meaning he gave to the concept in later years. In the *Galileo Studies* he worked out the physic-mathematical current in early modern science, while in the *Newtonian Studies* adequate consideration was given to the empirical and experimental current with deliberate appreciation of the Democritean conception of the atomic structure of reality.

In *The Origins of Modern Science: 1300-1800* (1949), Herbert Butterfield, a British political historian, wrote a comprehensive summary of what we now term the Scientific Revolution. In the *Origins* Butterfield applied the revolution label not only to the Scientific Revolution and to several of its components but also to ¨The Postponed

Revolution in Chemistry¨[50], as if it were a delayed component of the Scientific Revolution. One could see in this work a clear divide between inner and outer Scientific Revolution. The inner Scientific Revolution runs across the various scientific adventures from Copernicus to Newton and was effectively distinguished from an outer Scientific Revolution which he superficially and rapidly surveyed in a technically undemanding way. Likewise, the anti-whiggism which he had advocated in his *The Whig Interpretation of History* (1931), after being imported from political history, became a major constraint on the new historiography of science, especially in the Anglophone world. Above all, it was his *Origins* that suggested to many readers that there had been several scientific revolutions and not just one single enormous one.

Subsequently, A. Rupert Hall, a full-fledged historian of science who worked from primary sources, published his *The Scientific Revolution* (1954). In this moderately technical survey that runs from 1500 to 1800, Hall treats the creation of modern science at the hands of, mostly, Copernicus, Galileo, Descartes, Newton, and Antoine Lavoisier (1743-1794) as the gradually emerging triumph of rationality. The organization of the book is more diffuse than those previously listed, partly because it gave ample attention to such non-mathematical disciplines as chemistry and the life sciences. Later on, many other scholars spoke of the Scientific Revolution, the achievements of the period from Copernicus to Newton, including such luminaries as Kepler, Galileo, Bacon, Descartes, Huygens, Boyle, and Leibniz.

Long before these scholars and many of their contemporaries formally recognized the rise of modern science as a legitimate historical problem, scientists and philosophers were already writing on the nature of the modern science. Such works include Ernst Mach´s *The Science of Mechanics* (1883)[51] and William Whewell´s *History of the Inductive Sciences* (1837)[52] and *The Philosophy of the Inductive Sciences* (1840)[53].

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[50] ¨The Postponed Revolution in Chemistry¨ is a chapter title in Herbert Butterfield´s *The Origin of Modern Science.* In it he illustrates how the new foundation of chemistry was laid by the works of Robert Boyle, Joseph Priestley, Joseph Black, Henry Cavendish and Antoine Laviosier. See Herbert Butterfield, *The Origins of Modern Science 1300-1800,* pp. 203-221

[51] Ernst Mach. *The Science of Mechanics: A Critical and Historical Account of Its Development,* trans. Thomas. J. McCormack 4th ed (Palm Springs, USA: Watchmaker pub., 2010[1919]). Original German version *Die Mechanik in ihrer Entwickelung historisch-kritisch dargestellt.* (Leipzig: Brockhaus, 1883)

[52] William Whewell, *History of the Inductive Sciences, from the Earliest to the Present Time.* 3rd ed. 3 vols. (London: Parker, 1857)

According to Whewell, scientific progress is dependent upon the ability of men of genius to formulate clear ideas and apply them to distinct facts. When this is done science flourishes and there is an Inductive Epoch. It is possible to have preludes and sequels to the Inductive Epochs and, since science is sometimes stagnant, we also find Stationary Periods. The Middle Ages is the prime example of a Stationary Period between the era of Greek science and the rise of modern science.

However, Continuity theorists such as Pierre Duhem (1906), John Herman Randall (1940), Alistair C. Crombie (1959), Marshall Clagett (1959), and more recent historians such as Peter Dear (2001) have pointed out very major difficulty in speaking of ¨the Scientific Revolution.¨[54] This difficulty lies in locating the alleged sharp break of modern science from medieval and Renaissance practices that discontinuity historians like Alexandre Koyré and Thomas S. Kuhn had illustrated. According to the continuity theorists, when examined closely in their own cultural context, all the supposed revolutionaries are found to have had one foot in the old traditions and to have relied heavily on the work of predecessors.

Consequently, the debate has since remained on how did this vast enterprise of modern science get its start? What were the unique elements in the Western tradition that stimulated its creation and rapid growth? Did science emerge because of a mutation in the intellectual life of Europe or through a long development process? Does its origin and growth depend upon external factors, such as socio-political and economic conditions, or upon factors from within science? These are questions that have perplexed historians for years. For more than half century now, historians attempting to answer them have turned to the histories of science, economics, religion, intellectualism, psychoanalysis, political ideology, art and the occult, and sociology. For many historians, ´the Scientific Revolution´ now describes a topic area rather than a

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[53] William Whewell, *The Philosophy of the Inductive Sciences, Founded upon Their History.* 2nd ed. 2 vols. (London: Parker, 1847)

[54] See Pierre Duhem. *Études sur Léonard de Vinci: Ceux qu´il a lus et ceux qui l´ont lu.* 3 vols. Paris: Hermann, 1906; 1913 (2nd impression, Paris: De Nobele, 1955); John. H Randall, *The Making of the Modern Mind.* (Boston: Houghton-Mifflin, 1940), 1st published in 1926; Alistair C. Crombie. *Medieval and Early Modern Science* (Garden City, NY: Doubleday, 1959); Marshall Clagett, *The Science of Mechanics in the Middle Ages.* (Madison: University of Wisconsin Press, 1959); Peter Dear. *Revolutionizing the Sciences: European Knowledge and Its Ambitions, 1500-1700* (Princeton: Princeton University Press, 2001)

clearly demarcated event. Invariably, the concept of Scientific Revolution has remained what Margaret J. Osler has called the ´single most unifying concept in the history of science´.[55]

Various attempts by historians and philosophers of science to find out what was characteristically new about modern science as distinct from previous systems of natural philosophy have precipitated into varying theories which can also be regarded as theses of the scientific revolution. The theses include The Kuhnian thesis by Thomas S. Kuhn, Shapin thesis—Stephen Shapin, A. Mark Smith—Smith thesis, David C. Lindberg—Lindberg thesis, Edgar Zilsel—Zilsel/Craftsman thesis, Boris Hessen—Hessen thesis, Robert K. Merton—Merton thesis, Alexandre Koyré—Koyré thesis, Pierre Duhem—Duhem thesis, Herbert J. Butterfield—Butterfield thesis, Joseph Needham—Needham thesis, Frances Yates—Yates thesis, Richard S. Westfall—Westfall thesis, The Continuity thesis—Alistair C. Crombie, The Hall thesis—A. Rupert Hall, The Ben-David thesis—Joseph Ben-David, The Popkin thesis—Richard Popkin, The Mandrou thesis—Robert Mandrou, The Burtt thesis—Edwin A. Burtt and the Eisenstein thesis—Elizabeth Eisenstein. A good number of these theses have been given comprehensive analysis in various works on the historiography of the Scientific Revolution.[56]

1.4 TWO TRADITIONS OF ACCOUNT OF THE SCIENTIFIC PROGRESS

Various works of philosopher-scientists of the late Enlightenment period illustrated well-articulated interest in the history of science but in a way of giving general account for how science progresses. Science was clearly shown as a revolutionary affair and the kind of conception of the birth of early modern science was one that is at once systematic, analytical and broadly interpretive its own right.

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[55] Margaret J. Osler ed., ¨The Canonical Imperative: Rethinking the Scientific Revolution¨, in *Rethinking the Scientific Revolution* (Cambridge: Cambridge University Press, 2000) p.3

[56] H. Floris Cohen´s *The Scientific Revolution: A Historiographical Inquiry* (1994) is the first most comprehensive and full-length historiography of the Scientific Revolution. Unlike other historiographies, he employed his analysis of the works of the historians of the Scientific Revolution as an occasion for pressing forward the inquiry into the nature and causes of the Scientific Revolution and not just to record their conclusions. See also George Basalla ed. *The Rise of Modern Science: Internal or External Factors*. (Lexington, Massachusetts: Heath, 1968); and Maria L.R. Bonelli & William R. Shea (eds.*). Reason, Experiment, and Mysticism in the Scientific Revolution* (NY: Science History, 1975)

1.4.1 PHILOSOPHICAL OVERVIEW OF THE SCIENTIFIC ADVANCEMENT

In *The Critique of Pure Reason* (1787) Immanuel Kant discusses the definitive way to turn metaphysics into science. He demonstrated that in its actual stage metaphysics displays the ´mere groping in the dark¨[57] characteristics of a non-secure science. Generally, the ´concerns of Reason´ that had acquired ¨the secure pace of a science¨[58] are logic, mathematics, and the empirical sciences. Then he goes on to illustrate this how mathematics after being turned into an established and indubitably secure science by the Greeks set the stage for the empirical sciences to achieve the status of a secure science. A field of thought gains the secure pace of science when it passes from the stage of aimless observations to active interrogation of its subject material through conscious experimentation. It is this revolution in mode of thought that gave such figures like Francis Bacon, Galileo Torricelli and Stahl the prominence in the big picture of the modern science. The reason was because of their key discoveries that enabled the empirical sciences to move on from the groping stage to the secure pace of mature science. They also inspired others to follow the right track of achieving genuine science.

August Comte´s *Positive Philosophy* (1853) is another pioneer attempt to discuss how true scientific enterprise emerges. It argues that the history of each science could be divided into three successive stages. Each branch of knowledge passes successively through three different theoretical conditions: the Theological, or fictitious; the Metaphysical, or abstract; and the Scientific, or positive.[59] In this overall developmental process the theological and the metaphysical have a function of their own, which is more or less to usher in the positive stage, to which every science should aspire. This evolutionary development is governed by an accumulation process whereby mere augmentation of a thing or things produces a change of quality, of characteristics and conversely this qualitative change produces a quantitative one. Therefore each successive stage or sub-stage in the evolution of the human mind necessarily grew out of the preceding one, and this depicts the function of the principle of lawfulness.

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[57] Immanuel Kant, *The Critique of Pure Reason,* trans. J. M. D Meiklejohn (New York: Dover, 2003) p. xxiv . The first and second editions were published as German as Kritik der reinen Vernunft in 1781 and 1787 respectively.

[58] Ibid., pp. xix, 15. In page 15, he refers to such science as a *´science whose roots remain indestructible.´*

[59] Auguste Comte, *The Positive Philosophy of Auguste Comte*, trans. Harriet Martineau (New York: Calvin Blanchard, 1855[1853]), pp. 25-26

Consequently, Comte describes the 17th-century Revolution in Science as marking the onset of the positive stage of science.

Whereas, Auguste Comte had argued that the ´principle of lawfulness´ (the description of phenomena) governs the whole of thought, the French chemist and philosopher of science, Emile Meyerson suggests that this was not the whole of thought. He argues that Comte ¨rigorously condemned all attempts to know anything beyond the law¨.[60] But it is anomalous to assume that if the law explains phenomenon it is useless to go beyond it. This is because in the attempt to understand a phenomenon we do not just apply the ´principle of lawfulness´ but the ´principle of causality. Hence, it is in that portion of science devoted to explanation that we ought to see the principle of causuality play a most conspicuous part.[61] Science, he says, attempts equally to explain phenomena. This explanation consists in the identification of antecedent and consequent. His empirical study of scientific theories thus proposes two innate principles of reason. The first principle of reason leads us to expect the regularity of natural events. We expect to find that the relationship between conditions and property behaviour in nature remains constant. He wrote that,

> *Our acts are performed in view of an end which we foresee; but this foresight would be entirely impossible if we did not have the absolute conviction that nature is well ordered, that certain antecedents determine and will always determine certain consequences.*[62]

The second innate principle leads us to expect identities between the antecedent and consequent of a change, and this underlies the success of scientific laws. Thus, he wrote that mechanistic or atomic theories would always be accepted because the human mind is always satisfied when it recognises them as valid, or as having even a chance of appearing as such.[63] Therefore the principles of reason are factual rather than normative.

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[60] Émile Meyerson, *Identity and Reality*, trans. Kate Loewenberg (New York: Dover, 1962). The original version in French was published in 1908 as Identité et réalité. (Paris: F. Alcan), I quote from the reprinted version published by the Muirhead Library of Philosophy (Routledge: London, 2002) p.48

[61] Ibid.

[62] Ibid., p. 19

[63] Ibid., p. 91

This implies that the acceptance by the seventeenth-century scientists of the theories of the mechanical philosophy is a clear illustration of the timeless psychological processes that transcended any particular historical context.

The principal aim of this work is not to do a study of scientific inductions, what the above illustrations intent to achieve is just to showcase the context under which initial study on the advancement of science was based. However, the illustrations of mathematics as completed science in the works of Kant and Comte, coupled with the influence of Comte´s positivism, generated increased interest on the part of philosophers in mathematics and of mathematicians in philosophy.

The French Idealist philosopher, Léon Brunschvicg, in *Les étapes de la philosophie mathématique* (The Stages in the Philosophy of Mathematics)*,* sets out the principal stages of philosophical reflection on mathematics. What fundamentally concerns him here is the problem of truth. He writes in the preface that he aims to resolve this problem by ´a meditation on the discipline which has employed the greatest scrupulousness and subtlety in its search for the truth´.[64] Towards the end of his work, he reiterates that mathematics represents one of the most powerful and lasting achievements of the human genius. It reveals to us the capacities of the human intellect, and should be as much a foundation for our knowledge of the mind as it is for the natural sciences. Therefore, ´the activity of the mind has been free and productive only since the epoch when mathematics brought to mankind the true standard of truth´.[65]

This particular epoch was the period between sixteenth-seventeenth-century when such figures like Galileo and Kepler orchestrated the mathematization of nature which became the defining feature of the early modern science. Such historical defining role of mathematics in the emergence of the early modern science was later to be given another perspective by a one-time student of Brunschvicg who had earlier listened to his lectures at Sorbonne. This student was Alexander Koyré and his conception of the Scientific Revolution of the 17th century was confined basically on the works of Galileo and Descartes, who developed the mathematical foundation of the early modern science.

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[64] Léon Brunschvicg. *Les étapes de la philosophie mathématique,* revised ed. (Paris: Blanchard, 1972) p. xi. First published in 1912

[65] Ibid., p. 577

1.4.2 HISTORICAL OVERVIEW OF THE SCIENTIFIC IDEAS IN EARLY MODERN SCIENCE

Alexandre Koyré´s *Études Galiléennes* (Galileo Studies*)* projected a coherent Platonist-idealist view into the account of the early modern science which eventually became the pioneer historical overview of scientific ideas in the course of the 17th Revolution in Science. Koyré is recognised to have been the first to coin the term ´Scientific Revolution in its current meaning. The *Galileo Studies*[66]*,* a 1978 translation from Koyré ´s original 1939 French version, discusses the development of Galileo´s theories of motion and their impact on the scientific world. He lists its intellectual achievements as the geometrization of space and the subsequent dissolution of the cosmos which allowed the universe to be broken into its constitute parts and the substitution of the concrete space of the pre-Galilean physics with the absolute space of the Euclidian geometric system. The historicity of Koyré account lies in the fact that he tied his notion of the revolution in the science of the 17th century with the work of Galileo, one its major propounders.

Central to Koyré account of Galileo achievement was his introduction of mathematics to physics which lead to genuine geometrization of space and the overthrow of the impetus theory. Galileo was heavily influenced by the thought of Plato which made him to side with ´Platonian ´mathematicism´ against Aristotelian empiricism with its claim that real physical bodies have no geometrical forms´.[67] Koyré notes that the classical concept of motion developed by Descartes, Galileo and Newton shows motion as a state in time, and also, that bodies have a set inertia. These fundamental achievements refuted three essential facts central to the Aristotelian physics. The first is that natural motion did not exist. Second, motion is not the consequence of the nature of the body. Third, none of such nature could bring it to rest. However, the way Koyré greatly emphasized the importance of mathematics in the Galilean achievement shows his understanding of physics as truly the incarnation of mathematics—indicating why the language of mathematics really expresses the essence of reality.

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[66] See Alexandre Koyré, *Galileo Studies,* trans. John Mepham (Hassocks: The Harvest Press, 1978)
[67] H. Floris Cohen, *The Scientific Revolution: A Historiographical Inquiry,* p.78

Another mathematician by training, Eduard Jan Dijksterhuis reiterated the view of the mathematization of nature as the defining feature of early modern science. His *The Mechanisation of the World Picture (1950)* was written with the intent of surveying the way in which the mechanistic conception of the world came into being. It began by first describing the impact of the mechanistic conception in the time of Newton. He writes,

> *It was this conception that first led to the methods of research and treatment that have caused the great flourishing of physical science...of which we are reaping the fruit in our own day: experiment as the source of knowledge, mathematical formulation as the descriptive medium, mathematical deduction as the guiding principle in the search for new phenomenon to be verified by experimentation.*[68]

Dijksterhuis attempts to record the development over time of those particular ideas in the history of mechanics that ultimately were incorporated into Newtonian mechanics. Hence, he made a delineation of the obstacles that obstructed advances in science during each period of scientific development, including, in particular, those obstacles leading to the adoption of the mechanistic conception in the time of Newton. In order to articulate the incremental development of the history of physical science during antiquity he describes six major factors, and explains why each of them fell short of the requirements needed to promote classical science. Such factors include: ancient mathematics, corpuscular theories, Platonism, Aristotelianism, Stoicism and Neo-Platonism.

This study will not pretend to analyse all these factors one after another. The important fact that could be extracted from the above analysis is that Dijksterhuis´s emphasis on the common hindrance which affected the success of each historical period depicts his believe in continuity in science. Invariably, the hindrance created the need for a mechanistic conception to advance the study of science and nature which could not

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[68] Eduard Jan Dijksterhuis, *The Mechanization of the World Picture* (London: Oxford University Press, 1961) p. 3. The original Dutch edition was *De mechanisering van het wereldbeeld* (Amsterdam: Meulenhoff, 1950).

materialise until the time of Newton. However, Dijksterhuis concept of continuity has not been acceptable by some scholars.

For instance, H. Floris Cohen (1994) tried to demonstrate that Dijksterhuis was not quite the advocate of ´continuity´ he appeared to be. He argued that Dijksterhuis abandoned continuity when he came to Copernicus´s De Revolutionibus. Thus,

> *...despite the [Dijksterhuis´s] protestations of continuity and despite organizing his book so that the period of early modern science is made to begin with Copernicus, the attentive reader leaves the book with the impression that in the past of science we find one unique break, which was occasioned in the main by the Archimedean Galileo and by Kepler, the Platonist and Pythagorean—the first two scientists truly to mathematized nature.*[69]

What Cohen failed to say here is that Dijksterhuis´s survey of the history of science found fault with the science of both Galileo and Kepler. While discussing Galileo, Dijksterhuis wrote that, ¨...in Galileo´s work, verification by experiment sometimes appears to be of secondary importance because it may be regarded as somewhat superfluous if the preceding reasoning seemed convincing; thus only purely mental experiments remain or the experiments are only described without being performed.¨[70] In discussing the new elements of Kepler´s work a similar fault is found. Dijksterhuis explained that Kepler´s new method does not deviate greatly from the old system, it is only different.[71] Hence, he actually maintained his continuity thesis because at the time of the scientific activities of these scientists human thinking had not reached independence with a completely functional mechanistic conception.

Even while Dijksterhuis discusses Newton´s scientific achievements, he does not say that a complete and useable mechanistic conception of the world was achieved. He sees this state of scientific investigation having to wait for those that followed Newton.

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[69] H. Floris Cohen, *The Scientific Revolution: A Historiographical* Inquiry, p. 69
[70] E. J. Dijksterhuis, *The Mechanization of the World Picture*, p. 345
[71] Ibid., p. 322

Dijksterhuis treatment of the historic ideas of the early modern science on their particular propounders during the period mirrors the changing scientific mentalities put forth by Herbert Butterfield in *The Origin of Modern Science* (1949).

Butterfield had published his work a year before the publication of Dijksterhuis´s in which, as a ´general historian´ than a ´historian of science´, demonstrated the importance of understanding the achievements of the early modern science only in the historical context of the era. His historical survey of the emergence of the scientific ideas in the early modern science lends huge sense of historical importance to the concept of Scientific Revolution. He portends that the novelty and magnanimity of the achievements of such figures like Galileo, Bacon, Copernicus, Newton, Harvey and Boyle could only be appreciated by defining them within the context these scientists lived and worked. The transformations they achieved were ones that required a different kind of thinking-cap, a transposition in the mind of the scientist himself.[72]

A. Rupert Hall is also one of such early historians to establish a historical overview of the account of the science of the early modern period. Unlike Butterfield, he is a full-blown historian of science. However, he recognises Butterfield, Alexandre Koyré, Joseph Needham and Charles Singer as his mentors. His principal objective was to illustrate that ´there was no unique reason for the development of science in early modern Europe, since one is free to argue that every feature of the European civilisation was a contributing factor´.[73] What made the science that developed in Western Europe between 1500 and 1800 so unique was the overall rational character which marks it throughout. His objective was more to discuss the rational nature of the Scientific Revolution as opposed to the various brands of mysticism, magic, superstition, and the like, which early modern science conquered and gradually out-grew. The importance of Hall´s work is that it has served to showcase the predominate tendency among historian in trying to identify one factor or another as the cause of the scientific revolution. The two predominant structures of account of the causes of the scientific revolution include the positivist and historicist models.

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[72] Herbert Butterfield, *The Origins of Modern Science 1300-1800*, p.17
[73] A. Rupert Hall, *The Revolution in Science 1500-1750* (London: Longman, 1983[1954]) p. 36

1.5 THE POSITIVIST MODEL

The positivist model of the scientific revolution account is not symmetrical to Positivism in philosophy. It represents the principal account of the scientific advancement during the 19th to early 20th century. This model includes the accounts of the scientific advancement by William Whewell (1794-1866), Isidore Auguste Marie Francois Xavier Comte (1798-1857), Pierre Humbert (1891-1953), Gaston Bachelard (1884-1892), Johann Christian Poggendorff (1796-1877) and Henri Louis Bergson (1859-1941). It would rather be regarded as general account of the scientific advancement than *thesis* of the Scientific Revolution. Moreover, it was concerned with the demonstration of the natural science as the progressive discovery of naïvely realistic truth about the external world. Likewise, its principal aim was to indicate how ´scientific theory offers accurate reference to or portrayal of independent reality´.[74]

Such account of the scientific advancement comes from the belief that the seventeenth century, employing the methods of Bacon and Galileo, had produced firm and permanent foundations of science, which might require adaptation and minor restructuring but no major reconstruction. This type of account tries to state categorically that the genuine science was born in the early modern period, and as such, other natural practices prior to this period cannot be accounted as science in the actual sense of the term ´science´. This explains why most accounts of this nature repudiate the ancient and medieval sciences since both of them permitted metaphysical claims to knowledge of the natural realities.

For Auguste Comte, the era at which the final overthrown of the predilection for metaphysical speculation in the previous sciences is that time ´when the human mind was astir under the precepts of Bacon, the conceptions of Descartes, and the discoveries of Galileo´ [75] He goes further to argue why this period was actually the period marked the triumph of positive science. He wrote,

> *Then it was that the spirit of the Positive philosophy rose up in opposition to that of the superstitious and scholastic systems*

[74] Jarrett Leplin ed., *Scientific Realism*. (Berkeley: University of California Press, 1984) pp. 1-2
[75] Auguste Comte, *The Positive Philosophy,* p.29

> *which had hitherto obscured the true character of all science. Since that date, the progress of the Positive philosophy, and the decline of the other two, have been so marked that no rational mind now doubts that the revolution is destined to go on to its completion.*[76]

Comte´s contempt for metaphysics was later criticized by William Whewell (1794-1866) who insisted that there is in Galileo, Kepler, Gassendi, and the other fathers of mechanical philosophy, as much of metaphysics as in their adversaries of the previous era of science. Whewell pointed clearly that,

> *Physical discoverers have differed from barren speculators, not by having no metaphysics in their heads, but by having good metaphysics while their adversaries had bad, and by binding their metaphysics to their physics, instead of keeping the two asunder.*[77]

Whewell had earlier given a positivist account of the scientific revolution whereby he had stated that science advances by progressive generalization from bare facts to general truths. Older truths are always modified by subsequent discoveries and are made fixed part of the body of knowledge. Therefore, ´the earlier truths are not expelled but absorbed, not contradicted but extended; and the history of each science, which may thus appear like a succession of revolutions, is, in reality, a series of developments´.[78]

The difference in Whewell account is that he presented a conception of science, ultimately Kantian in inspiration, according to which ideas supplied by the mind interact with factual data supplied by the sense in a dialectical process that leads to scientific

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[76] Ibid.
[77] William Whewell, *The Philosophy of the Inductive Sciences, Founded upon Their History.* 2nd ed, vol. 1. (London: Parker, 1847) p. x
[78] William Whewell, *History of the Inductive Sciences, from the Earliest to the Present Time.* 3rd ed, vol. 1 (London: Parker, 1857) p.8

knowledge.[79] In the case of Comte, he believed that positive science limits itself to relations among visible features of the world.

However, Whewell handled the whole body of science and its advancement more as a resounding success story that would not be totally acceptable to those who have witnessed the sudden shift in historical consciousness orchestrated by the historians of science in the 20th century. Eventually, the rise in awareness regarding the importance of history in the understanding of science culminated in two dynamic narratives within the historicist model of the scientific revolution

1.6 THE SOCIOLOGIST NARRATIVE

The sociologists' account of the scientific revolution arose from the growing awareness in the early half of the 20th century of the need to consider the body of a scientist´s work as an indissoluble part of its social, economic, and political context. This has been called the contextual approach to the account of the scientific progress. With this approach the objective of the cultural studies of science has been, mostly, to define the context and not just the content of the scientific works. It is rather a ´more or less´ search for the causes of progress in science, especially during the early modern period.

The American sociologist, Robert K. Merton, is the main pioneer of the sociology of science. His doctoral thesis which was defended in 1935 greatly contributed to the strong historical underpinnings of the many studies he devoted since then to sociological aspects of the scientific enterprise. His thesis *Science, Technology and Society in Seventeenth-Century England,* which was later published in 1938, demonstrated how Puritanism unintentionally provided social and cultural support for the science emerging in 17th-century England. He used massive amount of statistical and historical data to support his cautiously drawn conclusions that Puritanism provided a system of values and beliefs which fostered the development of seventeenth-century English science.

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[79] David C. Lindberg, ¨Conceptions of the Scientific Revolution from Bacon to Butterfield: A preliminary sketch¨, in *Reappraisals of the Scientific Revolution* eds. David Lindberg & Robert S. Westman (Cambridge: Cambridge University Press, 1990) p.11

However, the force of Merton argument seems to be weakened by the fact that he focused his attention upon the relationship between religion, science, and technology in England alone. Could not his argument have been more plausible if he had identified other parts of Europe where such Protestant ethic stimulated the scientific progress? The absence of the Protestant ethic did not either prohibit the progress of science in the pre-Reformation Italy. What insight, then, does the account of the support of Puritanism to science and technology in England bring to the whole idea of the Scientific Revolution in early modern period?

However, by systematically studying a particular national culture he facilitated the acceptance of his conclusions. In fact, the peculiar factor that made Merton´s work a classic of the sociology of science is that he avoided the error of over generalisation and unsupported account covering the whole scope of European science. Rather, he gathered and examined the existing, relevant data in the critical period of one society, and while affirming the possibility of peculiar causal connection in other societies he feels certain to have revealed the source of seventeenth-century English scientific activity by linking together Puritanism, technology, and science

Merton´s argument that interacting socio-economic and religious forces incited on the growth of science in England was inspired by Boris Hessen thesis. From June 29 to July 3, 1931, the Second International Congress of the History of Science and Technology met in London. A large Soviet delegation, headed by the eminent Communist theorist Nikolai I. Bukharin, came to present the Marxist explanation for the development of science. Professor Boris Mikhailovich Hessen presented an extraordinary paper titled ¨*The Social and Economic Roots of Newton´s ´Principia´*¨.[80] In the paper he claimed that Newton´s great masterpiece of mathematical physics, the *Principia,* was a product of seventeenth-century England´s commercial and industrial activity and the social system associated with it. He asserted that all the subjects handled in the three books of the *Principia* derive from technological issues that had come up during preceding decades of the century as a result of the needs of incipient capitalism.

[80] Boris Hessen, ¨The Social and Economic Roots of Newton´s ´Principia.¨ in *Science at the Cross Roads: Papers presented to the International Congress of the History of Science and Technology Held in London from June 29th to July 3rd, 1931, by the Delegates of the USSR,* 2nd ed. (London: Cass, 1971) pp. 149-212. First published in 1931

Most of the scientific activities of the sixteenth and seventeenth centuries have their root in the technical needs of Europe´s newly emerging bourgeoisie. For instance, the development of the merchant capital created a set of quite distinct problems in several areas of technology: transportation over water, the mining industry, and arms production. Some of the technical needs in these areas include ¨an increase in the tonnage capacity of vessels and in their speed ¨methods of ventilating the mines,¨ and ¨the stability combined with least weight of the firearm¨.[81] Hessen later formed with Henryk Grossman the celebrated classical Marxist historiography of science. This is due to the fact that their work displays a specifically Marxist approach. Gideon Freudenthal and Peter McLaughlin (2009) affirmed that they conceptualize science as one kind of labor within the system of social production. Their discussions of the social context and the cognitive content of science are modelled on Marx´s analysis of the labor process.[82]

However, Hessen has been severely criticised for his distortion of historical facts to fit his ideological mold. Nevertheless, his work has led more judicious historians and sociologists of science to consider the social and economic components of what might first appear to have been problems within the strict domains of science. Edgar Zilsel, an Austrian philosopher/scientist, the author of popular paper on the *Sociological Roots of Science,*[83] adopted a more moderate economic-deterministic approach in his researches. He propounds the idea that the early capitalistic society broke down the ancient barriers separating the scholar from the craftsman, or what George Basalla (1986) identified as the ´man of formal knowledge´ from the ´man of practical knowledge´[84]

From antiquity through the Middle Ages, the philosopher and the priest were socially superior to the metallurgist, potter, ship-builder, or other craftsman. On the different extremes the scholar excelled in logic, speculative thinking, and mathematics while the craftsman has a special knowledge of the material objects. Hence, theory and practice

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[81] d., pp. 158, 161, 164

[82] Gideon Freudenthal & Peter McLaughlin eds., ¨Classical Marxist Historiography of Science: The Hessen-Grossmann-Thesis¨, in *The Social and Economic Roots of the Scientific Revolution*, Boston Studies in the Philosophy of Science, 278 (Boston: Springer, 2009) p.1

[83] See Edgar Zilsel, ¨The Sociological Roots of Science,¨ *The American Journal of Sociology,* 1942, 47 (4), 544-562

[84] George Basalla ed., *The Rise of Modern Science: Internal or External Factors* (Lexington, Massachusetts: Heath, 1968) p. x

were separated for centuries until the needs of an emerging capitalistic society joined them together to produce modern science.

Another sociologist whose work is very central to the social historiography of science is Joseph Ben-David. In his *The Scientist´s Role in Society*[85] he sought to identify ´how and when´ was the ´role´ of the modern scientist established in European society? As such, his work tends to shift the focus from the emergence of modern science to the emergence of the role of the modern scientist. Of course, the larger question remains whether or not the intellectual basis of modern science must necessarily precede the creation of the social role of the modern scientist?

All these illustrations of the rise of modern science reviewed here have been based on *external* causes. External factors (social, economic, religious, artistic etc.) have been advocated as the true stimuli of scientific progress thereby treating scientific ideas as if they do not have a life of their own. However, this idea has been attacked and rejected by some *internalists* who believe that the history of science is purely an intellectual history, such that though the general cultural, social and economic setting may exert an influence on science they do not determine the direction and rate of growth of scientific thought. Such internalists like Alexandre Koyré and A. Rupert Hall would argue that it is no more meaningful to search for the economic and social roots of Newton´s *Principia* than it is to seek the economic and social roots of Kant´s *Critique of Pure Reason.* Therefore, what the sociologist of science can only do is an attempt at an understanding of the specific social conditions which made possible the pursuit of science. What such scholar cannot do is to explain scientist´s thoughts in terms of their social environment.

1.7 CONVENTIONALIST NARRATIVE

The conventionalist narrative also known as the social-constructivist account of the scientific advancement has to do with the increasing application to the history of science

[85] See Joseph Ben-David, *The Scientist´s Role in Society: A Comparative Study* (Englewood Cliffs, N.J.: Prentice Hall, 1971)

of the categories of social history and psychological analysis. It grew out from the moderately relativist conception of the scientific endeavour by Thomas Kuhn´s *Structure of Scientific Revolution* in which he demonstrated that science not only progresses by the fixed criteria of science but also by other attendant social-cultural factors. Kuhn actually sought to demonstrate that historical and logical evidence showed that new conception of objectivity, rationality and progress are needed, and that this new conception was what he attempted to provide. His target for his own account of science was to demonstrate the virtue of importing interpretive resources beyond simple logical relations and a rather simple empiricist epistemology. This is why he emphasised the importance of scientific *practices*, most of which proceed on the basis of acquired expertise rather than explicit methodological rules. His thesis will be treated fully in section 2.12

1.8 EVALUATION AND CONCLUSION

The historiography of the scientific revolution has received all kinds of scholarly analyses which are usually characterized by sharp oppositions between old and new, external and internal, continuity and discontinuity, inductive and conventional. These dichotomies reflect the historiographical tendencies operative since the 1920s, which are generally characterized by the search for causes to explain the rise of the modern science. Such explanations have most commonly taken the form of establishing continuities (in some cases discontinuities) with currents of thought prior to the Scientific Revolution. These currents include the medieval Aristotelianism, Renaissance Aristotelianism, Humanism, Neoplatonism, Hermetism, Skepticism and Copernicanism. Another broad category of explanations links the Scientific Revolution to religious currents like Puritanism, Protestantism and Catholicism.

Frances Yates´s *Giordano Bruno and the Hermetic Tradition* (1964) even went further to link it to the hermetic and natural magic traditions. More still, other attempts tend to explain it within the context of the commercial/Marxist capitalism of the early modern European history. There are also attempt to compare the fate of science in early-modern Europe with the fate of science in other civilizations like ancient Greece, pre-1600 China and the medieval Islamic civilization. All these historicist account of the

scientific revolution have really revolutionized the empiricist philosophy of science and our general notion of science.

The next chapter will discuss, in detail, the ten principal historicists' accounts of the scientific revolution to illustrate how their concern for a shift, from the traditional ways of relying solely on the content of scientific beliefs and methods for the justification of scientific claims, to the veritable consideration of the context of their development, broadens our notion of the scientific progress.

Finally, it is important to note here that these *theses* are drawn from the authors' different works written specifically on the Scientific Revolution. This forms the basis on which they are called theses of the Scientific Revolution unlike the positivist model (see section 1.5) that dwelled solely on the analysis of the scientific advancement. It is the historical character of their works that made them to be grouped under the historicist model of the scientific revolution irrespective of the school of thought they belong.

CHAPTER TWO

2.1 HISTORICIST ACCOUNTS OF THE SCIENTIFIC REVOLUTION

The concept of *the* Scientific Revolution of the sixteenth and seventeenth centuries achieved its own historiographical dominance in the period after the World War II. However, it has been demonstrated that even before this period the works of Martha Ornstein in 1913, Alfred North Wihtehead in 1923, E. A. Burtt in 1925, John Herman Randall Jr. in 1926, Preserved Smith in 1930, and J. D. Bernal in 1939 had all pressed forward with the concept of *the* Scientific Revolution as an event of major significance for the creation not only of modern science but of the modern world.[86] It was not until the early 1940s and the 1950s that the concept of *the* Scientific Revolution was considered as a major historiographical concept. In the *Revolution in Science,* I. B. Cohen identified the works of Alexandre Koyré, Herbert Butterfield, and A. Rupert Hall as the pioneers to inaugurate ´the Scientific Revolution´ as a historiographical concept.[87]

The attempts by historians and philosophers of science to treat the ´Scientific Revolution´ as a historiographical concept, beginning from the early 1940´s, have been the crucial factor in making the Scientific Revolution one of the most unifying concepts in the history of science. Unlike the historic approach to the historiographical study used by Koyré, Butterfield and Hall, the subsequent innovative works by Joseph Agassi and Thomas Kuhn, especially Kuhn, were instrumental in making the concept of ´Scientific Revolution´ one of the central focuses in the historiography of science. As a historiographical concept, the ´Scientific Revolution´ has brought comprehensive insights valuable not just to the understanding of science but also to the writing of the history of science. Generally, the historiography of science is regarded as the study of the history and methodology of the sub-discipline of history, known as the history of science. This study includes all its disciplinary aspects and practices such as methods,

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[86] Betty Jo Teeter Dobbs, ¨Newton as Final Cause and First Mover¨, in *Rethinking the Scientific Revolution*, ed. Margaret J. Osler. (New York: Cambridge University Press, 2000) p. 28

[87] I. Bernard Cohen, *Revolution in Science.* p. 22

theories and schools, and also the study of its own historical development or what might be called the history of history of science.

In the course of this chapter two of the major terms that will be recurrent are historiographical and historical. It is important, then, to make a clarification of the sense in which the two terms are used. Historiography refers to the writing of history. Therefore, historiographical and historical do not have the same meaning. Galileo or Newton´s historical significance derives from who he was and what he did. His historiographical significance derives from the great attention that has been paid to him by historians of science. Hence, historiographical controversies are conducted by historians while historical controversies are conducted by important people in history.

Most pragmatically oriented historiographies of science usually fall into the mistake of focusing on ´scientists´ circumstantial attempts to fix beliefs without discussing the scientific importance of the beliefs in the first place.[88] In this context the historian had only to tell the success story of discovery, with its consequent value judgements upon both the results and the methods of past science as either progressive or erroneous. This approach implied the treatment of past science on the basis of being steps towards either the best science now known, or as deviations from it. Such comparatively straightforward way of writing the history of science came from the belief in natural science as the progressively discovery of naïvely realistic truth about the external world.[89] The triumphalist attitude of evaluating past science by the precepts of the modern science has, sometimes, led historians of science to engage in pointless exercises of identifying the progress of science with the progress of any imaginable historical event, and at times remain mute about crucial aspects of the development of science.

Joseph Agassi (1963) criticises what he describes as the uncritical acceptance, on the part of historians of science, of two incorrect philosophies of science historiography. These are the inductive approach and conventionalist approach. The ¨inductivist¨

[88] See Renan Springer De Freitas, ¨What happened to the Historiography of Science?¨, *Philosophy of the Social Sciences*, 2002, 32(1), 92-106

[89] Mary Hesse, *Revolutions and Reconstructions in the Philosophy of Science* (Sussex: Harvester Press, 1980) p. xv

historian of science supposedly starts with present-day textbooks and approaches the past with a view to allocating credit for the findings codified there. And sometimes blames are unleashed on those whose efforts could be regarded as impeding or having impeded scientific progress at a time. The ¨conventionalist,¨ since he adopts the view that we prefer the simple theory to the less simple one, not a true theory to a false one, is distinguished for accepting ¨a new criterion of graded valuation to replace the old inductivist criterion which divides theories into the good and the bad.¨ Agassi categorised this approach as that according to which scientific theories are mathematical pigeonholes for classifying facts.[90] Although the conventionalist approach seem to have some improvement over the inductivist, he asserts that the Popper´s critical philosophy of science, provides a possible remedy which should guide historians of science

However, the arguments over which of the approaches best serves as the proper method for the study of the history of science are sometimes complicated by the fact that accurate demarcation is not usually made between three important factors. The first is a *criterion of interest* for selecting past scientific works for discussion in the historiography of science. The second factor is a *criterion of importance* for rating the significance of particular scientific findings, and thirdly, a *criterion of merit* for assessing the worth given a piece of scientific work. It is difficult to make a clear cut demarcation among the factors because a rather unimportant finding may be of great historical interest if it involves some conceptual or methodological innovation. In this case the first and second criteria are intertwined. Likewise, in the issue of merit: a man who makes a very important finding may deserve little credit as scientist if he stumbles upon it unwittingly while a man who makes a very unimportant finding may deserve substantial credit as scientist if he had to deploy substantial talent in arriving at it.

Nevertheless, Agassi´s *Towards an Historiography of Science* (1963) and Thomas Kuhn´s *The Structure of the Scientific Revolutions* (1962) are two exemplars of such works that treated in a very philosophical way the question of approach to the historiography of science. Kuhn considered the nature of science as evident in its

[90] Joseph Agassi, *Towards an Historiography of Science* (The Hague: Mouton & Co. 1963; the facsimile reprint is used in this work, Middletown: Wesleyan University Press, 1967) p. v

history (not just in its historiography) in comprehensive and systematic fashion. Agassi complimented such view by demonstrating the reciprocity that should exit between the historiography of science and its philosophy, sociology and formalism. The importance of these two works indicates why the early Sixties of the 20th century could be referred to as the period when the explicit presentation of the Historiography of Science was made. It was in this period that very innovative attempts were made in modelling an adequate approach to the historiography of science. It also explains why one could find Gerb Buchdal (1965) reporting of ¨A Revolution in Historiography of Science¨[91] making reference to the innovative studies of Thomas Kuhn and Joseph Agassi. Gerd´s work therefore suggested that these two writers had inaugurated the sub-discipline by distinguishing clearly between the history and the historiography of science.

It is very insightful to see how the emergence of the historiography of science occurred within the context of the treatment of the ´Scientific Revolution´ as a historiographical concept. This means that the concept of the scientific revolution generated the essential elements that constitute the basics of the historiography of science. Notwithstanding the controversies regarding the issue of methodology in the historiography of science, the fact remains that its course content have their substances drawn from the crucial constituents of the ´Scientific Revolution´. The constituents would be treated according to their different presentations by various authors to see how they actually demonstrate a veritable philosophy of the scientific development and the significance of their impact on the history and philosophy of science. They will be discussed under the following categories; ´discontinuist´ historiography of Koyré, ´continuist´ historiography of Duhem, ´periodization´ historiography of Butterfield and Hall, ´territorist´ historiography of Needham and Merton, marxist historiography of Hessen, hermeticist historiography of Yates and sociologist historiography of Kuhn and Shapin. The reason for this taxonomy is primarily to aid easy study of the different issues they treated. It is not absolutely exclusive since there are interpositions of themes in virtually all the theses.

[91] See Buchdahl Gerd, ¨A Revolution in Historiography of Science¨, in *History of Science*, 1965, 4, pp. 55-69

2.2 ´DISCONTINUIST´ HISTORIOGRAPHY OF THE KOYRÉAN THESIS

The ´Scientific Revolution´ was first developed as an analytical tool for the study of the scientific advancement of the 16th and 17th century by Alexandré Koyré. Steven Shapin asserted that Koyré is widely known to have coined the term ´Scientific Revolution´ in 1939 to describe this epoch.[92] This French historian of Russian origin is generally recognised for his ´philosophical´ interest in the history of science. In the *Galileo Studies* where he demonstrated his thesis of the ´Scientific Revolution´ he cited charitably the enormous influence the works of Pierre Duhem, Émile Meyerson, Ernst Cassirer and Leon Brunschvicg made on his understanding of the history of science. Although Koyré is best known as a philosopher of science, he started out as a historian of religion. In fact, much his originality rested on his ability to ground his studies of modern science in the history of religion and metaphysics. His root in metaphysics seems to have come from his earlier studies in Germany. In Göttingen, Germany (1908-11), he studied under Edmund Husserl and David Hilbert. Whereupon Husserl did not approve his dissertation, he left for Paris to study from 1912, notably under Henri Bergon and Léon Brunschvicg.

Alexandre Koyré (Aug. 1892 – Apr. 1964) thesis of the ´Scientific Revolution´ is illustrated in his conviction that it was not the experimental or empirical nature of Galileo´s and Newton´s discoveries that actualised the Scientific Revolution of the 16th and 17th Centuries. He asserted that it is rather a shift in perspective, a change in theoretical outlook toward the world. In the introduction to his *Galileo Studies* he argued that,

> *The study of the evolution (and the revolutions) of scientific ideas... shows us the human mind at grips with reality, reveals to us its defeats and victories; shows us what superhuman effort each step on the way to knowledge of reality has cost, effort which has sometimes led to a veritable ´mutation´ in human intellect, that is to a transformation as a result of which ideas which were*

[92] Steven Shapin, *The Scientific Revolution* (Chicago: University of Chicago Press, 1996) p. 2; See also I. Bernard Cohen, *Revolution in Science.* p.390

> *´invented´ with such effort by the greatest of minds become accessible and even simple, seemingly obvious, to every schoolboy.*[93]

Koyré´s idea of the mutation of human intellect is greatly derived from Gaston Bachelard´s concept of *epistemological obstacle* and *epistemological break*. He cited Gaston Bachelard´s *Le nouvel espirit scientifique*[94] (The New Scientific Spirit) in his ´Au l´aurore de la science moderne. La jeunesse de Galilée (1) published in the *Annales de l´Université de Paris* 10 (1935), pp. 540-41. It was this article that later became the introduction to the *Etudes galiléenes* (Galileo Studies). And then in the 1939 volume, he added Gaston Bachelard´s *La formation de l´ esprit scientifique. Contribution à une psychanalyse de la connaissance objective*[95] acknowledging both works for the idea and term ´mutation´.

Bachelard´s studies of the history and philosophy of science in *Le nouvel esprit scientifique* (¨The New Scientific Mind¨, 1934) and *La formation de l´esprit scientifique* (The Formation of the Scientific Mind¨, 1938) were based on his vision of historical epistemology as a kind of psychoanalysis of the scientific mind, or rather of the psychological factors in the development of sciences. He was critical of Auguste Comte´s positivism, which considered science as continual progress. To Bachelard, scientific developments such as Einstein´s theory of relativity demonstrated the discontinuous nature of the history of sciences. Such models like the Comte and Émile Meyerson´s which framed scientific development as continuous seemed simplistic and erroneous to Bachelard. Hence, he used his concept of ´epistemological break´ to underline the discontinuity at work in the history of science.

It is this idea of break that informs the basis from which the scope of Koyré´s thesis was developed. This notion of ¨epistemological rupture´ developed by Bachelard and later re-interpreted by Alexandre Koyré was to be used by Thomas S. Kuhn to develop his theory of the paradigm shifts as we shall see in sections 2.12.1 and 2.12.5. When

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[93] Alexandre Koyré, *Galileo Studies*, p. 1

[94] See Gaston Bachelard, *Le Nouvel Espirit scientifique* (Paris: Presses Universitaires de France, 1934); *The New Scientific Spirit*, trans. A. Goldhammer (Boston: Beacon Press, 1985)

[95] See Gaston Bachelard´s, *La formation de l´ esprit scientifique. Contribution à une psychanalyse de la connaissance objective* (Paris: Vrin, 1993 [1938])

Bernard Cohen recommended Koyré to Kuhn, he read Koyré ´s *Etudes Galiléennes* and ¨loved them. I mean, ¨ as he testified later, ¨this was showing me a way to do things.¨[96] Koyré´s impact on the development of the history of science is well attested by Kuhn later. ¨Within a decade of their [Etudes] appearance,¨ wrote Kuhn, ¨they and his subsequent work provided the models which historians of science increasingly aimed to emulate. More than any other scholar, Koyré was responsible for … the historiographical revolution.¨[97]

Koyré strongly criticized what he called the ¨positivist¨ notion that science should only discover given phenomena, the relations between them and certain laws that would help to describe or predict them. For Koyré the central constituent of science is theory. That is an aspiration to know the truth of the world, of uncovering the essential structures from which phenomena and the basic laws relating to them arise. He was suspicious of scientists´ claims to prove natural or fundamental truths through experiments. He argued that these experiments were based on complicated premises, and that they tended to prove the outlook behind these premises, rather than any real truth. He repeatedly critiqued Galileo´s experiments, claiming that some of them could not have taken place, and therefore brought into question the results that Galileo claimed and which modern historians of science had hitherto accepted. Stromholm Per (1975) argued that for Koyré it was not observation and experiment that were the driving forces in Galilean science but unaided reason bursting the fetters of experience.[98] Koyré even went on to argue that the inclined plane experiment, which was meant to demonstrate the law of free fall, was an accumulation of sources of error and inexactitude.[99]

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[96] Thomas Kuhn, *The Road Since Structure: Philosophical Essays, 1970-1993, with an Autobiographical Interview,* eds. James Conant & John Haugeland (Chicago: University of Chicago Press) 2000 p. 285

[97] Thomas Kuhn, ¨Alexandre Koyré and the history of science,¨ *Encounter*, 1970, p. 67

[98] Per Stromholm, ¨Galileo and the Scientific Revolution,¨ *INQUIRY: An Interdisciplinary Journal of Philosophy* (London: Routledge, 1975), p. 345

[99] Alexander Koyré, *Metaphysics and Measurement: Essays in Scientific Revolution.* (London: Chapman and Hall, 1968) p. 64

2.2.1 PHILOSOPHICAL PURPOSES OF AN ANALYTICAL TOOL

Koyré coined the term ¨Scientific Revolution´ as an analytical tool to illustrate the disparity that exists between the science that prevailed before the 16th and 17th Centuries with that which existed afterward. He aimed to show, through the study of the history of science, the changes in the way human beings reason. For him the mind has a history. In virtually all his writings he continued to distinguish several revolutions in science. These revolutions include the Greek creation of the idea of the Cosmos; the revolution of Galileo and Descartes, and the 20th century revolution of Einstein and Bohr. He characterised the Scientific Revolution as a ¨mutation¨ of the human intellect, a ¨profound intellectual transformation¨ of which classical physics is ¨both the expression and the fruit¨.[100] The ´birth of early modern science was not just the emergence of a number of new statements about nature; not even such fundamental propositions as the principle of inertia or Newton´s second law marked the transition in their own right´.[101] Their very discovery and subsequent adoption could only be accounted for in the framework of the larger transition, which Koyré described as fundamentally new overall conception of *motion.*

Koyré´s analysis of conceptual changes dwelled on the historical mutation from the Aristotelian conception to that of classic physics. He argued that after Galileo, space was no longer a concrete space, in which objects occupy their given place, but rather the abstract space of Euclidean geometry. Koyré would dedicate most of his work to the history of the intellectual revolution that led to modern science. He regarded this revolution as a slow process, which for him began as early as the fourteenth century, when the early Italian humanist, such as Petrarch, started to display a lack of interest in Aristotelian scholastics.[102] For him, the Renaissance prepared Galileo´s and Descartes´ revolution which later led to Newton´s physics. He recapitulated this revolution primarily as an intellectual change, which brought about a mutation in aims, values and worldview.

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[100] Alexander Koyré, *Études Galiléennes*, 3 vols. (Paris: Hermann, 1939). For the quote used here see vol. 1, pp. 5-6, of the 1939 edition or p. 1 of Mepham´s translation in *Galileo Studies*)

[101] H. Floris Cohen, *The Scientific Revolution: A Historiographical Inquiry,* p.75

[102] Alexandre Koyré, ´La pensée moderne´ [1930] quoted in Alexandre Koyré *Etudes d´ histoire de la pensée scientifique*. (Paris: Presses Universitaires de France, 1966), p. 19.

His analysis of this mutation has generally centred on Galileo, Plato and Newton. However, his lectures series delivered at the Johns Hopkins University in 1953, which was later published as *From the Closed World to the Infinite Universe,*"[103] treated on the rise of early modern science and the change of scientist´s perception of the world during the period from Nicholas of Cusa and Giordano Bruno through Newton. In this work, he argued that the world itself changed.

Initially the Aristotelian and medieval world had the earth at its centre, enclosed in concentric spheres, on which the planets were carried. This world was ontologically differentiated. In such world the heavenly spheres were incorruptible and moved circularly and eternally, whereas the sub-lunar world was corruptible, and its motions were rectilinear. What scientific revolution achieved was the substitution of this Aristotelian-scholastic world with an open and infinite universe, in which there is no ontological difference between celestial and terrestrial bodies, and consequently the same physics applies to heaven and earth. Therefore, in this new infinite universe, the earth lost its central place. Consequently,

> *Movement ceased to be regarded as a goal-oriented process in our heterogeneous, finite Cosmos; largely through the work of Galileo and Descartes, movement henceforth came to be regarded as a value-neutral state of bodies on their way through the homogeneous infinity of Euclidean, geometrized space.*[104]

Koyré identifies this huge transformation as an intellectual change to indicate that the scientific advancement of that period could not have taken place if an even wider framework of new conception of the universe at large was not established in the mind of these scientists. However, he maintained that the scientific revolution had not only implemented a dramatic change of worldviews, but also a change in questions and methods. For him, the post-Galilean world is a mathematical world. As such the objective of the post- Galilean science is to measure, rather than to establish qualitative

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[103] See Alexander Koyré, *From the Closed World to the Infinite Universe* (Baltimore: John Hopkins Press, 1957)
[104] H. Floris Cohen, *The Scientific Revolution: A Historiographical Inquiry,* p.75

difference among things as did the Aristotelian-scholastic science. What the koyréan thesis sought to establish, in essence, was that the revolution of the early modern science was in the minds of sixteenth and seventeenth-century Europeans. In fact, the revolution ¨changed the very framework and patterns of our thinking.¨[105] It not only changed man´s approach to the nature but also changed the world itself.

2.2.2 GALILEO AND THE ARISTOTELIAN PHYSICS.

The scope of what Koyré termed ´the Scientific Revolution of the 17th century´ in the *Galileo Studies* was confined in its usage, solely, to the activities of Galileo and Descartes. Galileo was the first scientist to realize the idea of a mathematized physics while Descartes was the first to think up, in a systematic way, a world consisting of nothing but bodies moving through infinite space in accordance with the principle of inertia. However, in the *Newtonian Studies* he incorporated a third actor, Isaac Newton, who completed the revolution circle by unifying the corpuscular philosophy of Gassendi, Roberval, Boyle and Hooke with the panmathematism of Galileo and Descartes.[106]

Koyré emphasis on the ´mutation´ the human mind underwent on its way to achieving the modern science of mechanics was to capture the immensity of the ingenuity employed to overcome the intellectual hurdles posited by the Aristotelian natural motion. The Aristotelian natural theory asserted that all heavy terrestrial bodies had a natural motion towards the centre of the universe. This implies that motion in any other direction was violent motion because it contradicted the ordinary tendency of a body to move to what was regarded as its natural place. Such motion depended on the operation of a mover. Therefore, a body would keep in movement only so long as a mover was actually in contact with it, imparting motion to it steadily. Once the mover stops to prompt the movement of the body it falls straight to the centre of the earth which is its resting place.

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[105] Alexander Koyré *From the Closed World to the Infinite Universe,* p. v

[106] Alexandre Koyré, *Newtonian Studies* (Chicago: University of Chicago Press, 1965) p.12

In its own right, the Aristotelian theory does not sound stupid because it corresponds in a self-evident manner with most of the data available to common sense. However, there are facts which cannot square well with it even when analysed on the common-sense level. For instance, on the common-sense level the Aristotelian theory imply that an arrow ought to have fallen to the ground the moment it lost contact with the bow-string. Naturally, it should be so since neither the bow-string nor anything else could impart a motion which would continue after the direct contact with the original mover had been broken. Therefore, this theory cannot make a logical claim on how an arrow fired into the wind could be carried forward by the reaction of the air.

The Aristotelian theory of natural motion held sway for centuries before the advent of the Scientific Revolution not because its inconsistencies were not noticed but because there was no immediate alternative since the colossal intellectual system to which it was a part gained hold on medieval scholastic thought. Nevertheless, the Aristotelian teaching carried such an intricate dovetailing of observations and explanations which was hard for the human mind to escape from. Reconstructing the deficiencies of the Aristotelian motion meant dismantling the whole natural philosophy on which it was built. The cosmos of the Aristotelian natural philosophy is ´a finite and hierarchically ordered, therefore qualitatively and ontologically differentiated universe.[107]

The Parisian terminists who were the first men in the middle ages to launch great attack on the Aristotelian theory were also conscious of the fact that this colossal issue was involved in the task. Such men like Jean Buridan and Nicholas of Oresme pointed to alternative interpretation that would eliminate the need for the Intelligences that turned the universe. This alternative was contained in the impetus physics of the Parisian tradition. The impetus theory conceives motion as the effect of a force contained within the moving body. Koyré highlighted the importance of this theory in creating the first departure from Aristetolianism. He stated that impetus physics makes it possible to separate the body´s motion from the idea of the goal, towards which it is directed, and makes it possible to isolate the moving body from the rest of the Universe.[108]

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[107] Ibid., p. 7
[108] Alexander Koyré, *Galileo Studies,* p. 70

The theory of impetus takes motion to be the effect produced by a cause internal to the moving body. Impetus could then be identified as an efficient cause producing motion as its effect. With the impetus theory the Parisian terminists especially Giordano Bruno sought to replace Aristotle´s close and finite world with an open and infinite universe and this involved the rejection of the notion of ´natural´ and ´violent´ motions. In some ways, this impetus-dynamics helped the Parisian terminists to displace the Aristotelian dynamics. The theory was able to refute some of the arguments of Aristotle. ´Yet it was not able to meet all of them; still less was it able to carry the structure of modern science.´[109]

Similarly, the Galilean physics rejected the notion of the ´natural´ and ´violent´ motions. This physics maintained that a motion never reveals nor expresses the nature of a body. Motion does not affect the moving body in itself and is only possessed by the moving body in relation to something other than itself. For Galileo, gravity or ´heaviness´ is the only natural property of bodies and is also the only natural source of motion. This implies that since gravity or heaviness is a universal natural property of all bodies, it is what produces in all bodies a *natural* motion in a downwards direction. As such fall is a natural and universal motion. However, Galileo does not take gravity as a natural quality of bodies. Though gravity refers to something in reality which he was not capable of mentioning, he restated that it does not constitute the ´nature´ of bodies neither is it one of their essential properties. It is rather an empirical property than a theoretical property of bodies. Its empiricity is derived from common sense. As such it is just a name assigned to ´downwards tendency´ of natural bodies. Galileo identified the essence of bodies as their mathematical properties. Koyré summaries thus,

> *It can be seen that in Galileo´s view (as in Descartes´, and for the same reasons) what constitutes the essence of bodies, or of matter, that which we cannot think of them as being without, and consequently that without which they could not exist, are their mathematical properties.*[110]

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[109] Alexandre Koyré, ¨Galileo and the Scientific Revolution of the Seventeenth Century¨, in *The Philosophical Review* (Ithaca: Duke University Press, 1943) p.342

[110] Alexander Koyré, *Galileo Studies*, p. 179

In the actual reality the mathematical idea Galileo propounds does not designate any essential quality of bodies. It should be noted that he was not discussing real bodies as we definitely observe them in the real world. The bodies to which he makes such mathematical attributes are geometrical bodies moving in a world without resistance and without gravity. The type of world implied here is that boundless emptiness of Euclidean space which Aristotle had regarded as unthinkable by his strong rejection of the existence of a vacuum. Herbert Butterfield reiterated that even the ´Aristotelians regarded ´such´ a complete void as impossible, and said that God Himself could not make one´.[111] For Koyré, this ingenious effort of Galileo in establishing a different wider framework to account for the local motion needed a ´veritable mutation in human thought´. Therefore, The Scientific revolution of the seventeenth century was without doubt such a mutation.[112] The ´mutation´ that Koyré had in mind here was a product of the geometrization of space and the dissolution of the cosmos, both contained in the principle of inertia, first stated by Galileo and fully articulated by Descartes.

2.2.3 KOYRÉ´S INTERNALIST APPROACH

In almost all his major works on the scientific revolution Koyré used a very unique mechanism. This mechanism consisted in discussing the scientific revolution of the seventeenth century by first identifying and analysing the content of its major constituents before attempting an explanation of its historical occurrence. The reason for this method was because of his priority in showing the changes in the way human being reason through the study of the history of science. In this way, he tried to distinguish active science (scientific inquiries) from applied science. His approach is largely successful search for legitimation of the new science than its applicability.

He writes thus,

> *I do not see what the scientia activa has ever had to do with the development of the calculus, nor the rise of the bourgeoisie with*

[111] Herbert Butterfield, *The Origins of Modern Science 1300-1800,* p.16
[112] Ibid., p. 1

> *that of the Copernican, or the Keplerian, astronomy. And as for experience and experiment—two things which we must not only distinguish but even oppose to each other—I am convinced that the rise and growth of experimental science is not the source but, on the contrary, the result of the new theoretical, that is, the new metaphysical approach to nature that forms the content of the scientific revolution of the seventeenth century, a content which we have to understand before we can attempt an explanation (whatever this may be) of its historical occurance.*[113]

What Koyré demonstrated here is a total disapproval of any explanation of scientific thought that threatened to undermine the autonomy of its internal development as a process guided above all by an inherent logic all its own. This does not mean that he is totally against the externalist explanations in the history of science. Such externalist explanations investigate, mainly, the social-cultural conditions that made the emergence of early modern science possible. However, he sought to reject such unguided social reductionism of the scientific ideas. In a similar vein, Mary Hesse also criticised such reductionism. She argued that a proper historical perspective neither involves uncritical accumulation of ever minor writing of forgotten figures, nor is it necessarily vitiated by the imposition of our standards of rationality on an alien age.[114]

The imposition of our standards of rationality to other historical periods is, perhaps, what defines the efforts by some authors to create continuous link between the science of the sixteenth and seventeenth centuries with those before them. However, Koyré illustrated that the arguments for the historical continuity depreciate the ´decisive mutation.´[115] There is no logical justification in establishing continuity between the medieval physics of the Parisian precursors of Galileo with the classical physics issuing from the thought of Galileo and Descartes.[116] Contrary to the appearances of historical continuity demonstrated by Pierre Duhem, Koyré argued that the precursor and inspirer of classical physics was neither Buridan nor Nicole Oresme. This is because the

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[113] Alexander Koyré, *Newtonian Studies*, p.6
[114] Mary Hesse, *Revolutions and Reconstructions in the Philosophy of Science,* p. 20
[115] Alexander Koyré, *Galileo Studies*, p.3
[116] Ibid

medieval physics operated on a different terrain unlike the classical physics which operated on a terrain that could be defined as Archimedean. If any precursor of Galileo is to be mentioned then, it has to be Archimedes not Buridan or Oresme. However, thanks to the ambitious works of Pierre Duhem many insightful scientific progresses are now known of the medieval scientific thought.

2.3 ´CONTINUIST´ HISTORIOGRAPHY OF THE DUHEM THESIS

Pierre Maurice Marie Duhem (Jun.1861 - Sept.1916) strongly defended a thesis of continuity between medieval and early modern science. In arguing for the absence of abrupt discontinuities between medieval and early modern science he highlighted the positive role played by religion in the development of science in the Latin West and the cumulative nature of the history of physics. His work in the field of medieval science was originally prompted by his research into *The Origins of Statics* (1905–06) in which he first makes case for the existence of the medieval science. In the preface to the work he states thus,

> *the mechanical and physical science of which we are well within our rights proud in modern times flows, by an uninterrupted series of scarcely sensible improvements, from the doctrines professed in the heart of the schools of the Middle Ages; the intellectual revolutions alleged have not been, most often, but slow and long-prepared evolutions; the self-proclaimed renaissances but reactions frequently unjust and sterile; the respect of tradition is an essential condition of scientific progress.*[117]

It was while writing *The Origins of Statics* in 1904 that Duhem came across an unusual reference to a then-unknown medieval thinker, Jordanus de Nemore. Jordanus de Nemore was recognised by Ferrari as the pioneer scientist to determine the apparent

[117] See Pierre Duhem, *Les origines de la statique*, 2 vols., (Paris: Hermann, 1905–06). See the English Translation, Pierre Duhem, *The Origins of Statics,* trans. Grant F. Leneaux, Victor N. Vagliente, and Guy H. Wagener (Dordrecht: Kluwer, 1991)

weight of a body posed on an inclined plane thereby claiming the invention for such geometer of the 13th Century for him. Duhem pursuit of this reference, and the subsequent research to which it led, has been widely acknowledged to have created the field of the history of medieval science. Thereafter came the three-volume *Etudes sur Léonard de Vinci*[118] and the ten-volume *Le Système du monde*[119], in which his thesis of the continuity of late medieval and early modern science was fully displayed.

2.3.1 THE CONTINUITY THESIS

From 1906 to 1913, Duhem delved deeply into his favourite guide for the recovery of the past science. This guide was the scientific notebooks of Leonardo de Vinci. He published a series of essays uncovering De Vinci´s medieval sources and their influences on the modern age. The third volume of Duhem´s *Etudes sur Lèonard de Vinci* gained a new subtitle, Les précurseurs parisiens de Galilée (the Parisan precursors of Galileo), announcing Duhem´s bold new thesis that even the works of Galileo had a medieval heritage. He argued that in the 14th century a number of natural philosophers at the University of Paris had laid the groundwork for the early modern science. Their teachings were gradually received in Italy, where, in the 16th century, they came under attack from orthodox Aristotelians with a strongly Averroist inspiration. It is this reinforced Aristotelianism that Galileo engaged in battle. Galileo achievement was the recovery and, at a later stage, elaboration of the science already created in Paris two and a half centuries earlier. While reviewing the historical accomplishment of Galileo he stated thus,

> *When we see the science of Galileo triumph over the stubborn Peripatetic philosophy of somebody like Cremonini, we believe, since we are ill-informed about the history of human thought, that we are witness to the victory of modern, young science over medieval philosophy, so obstinate in its mechanical repetition. In truth, we are contemplating the well-paved triumph of the science*

[118] See Pierre Duhem, *Études sur Léonard de Vinci: Ceux qu´il a lus et ceux qui l´ont lu.* 3 vols. 2nd imprint, Paris: De Nobele, 1955. First published in 1906

[119] See Pierre Duhem, *Le système du monde: Historie des doctrines cosmologiques de Platon à Copernic. 10 vols.* (Paris: Hermann, 1913-1959)

> *born at Paris during the fourteenth century over the doctrines of Aristotle and Averroes, restored into repute by the Italian Renaissance.*[120]

Duhem presents the Galilean dynamics here as a continuous development out of medieval dynamics. He had demonstrated this by making reference to Jordanus Nemorarius attempt to determine the apparent weight of a body posed on an inclined plane years before that of Galileo. He also recovered the late medieval theory of impetus, tracing it from John Philoponus´ criticism of Aristotle to its mature statements in the fourteenth century works of John Buridan and Nicole Oresme: "The role that impetus played in Buridan's dynamics is exactly the one that Galileo attributed to *impeto* or *momento*, Descartes to 'quantity of motion,' and Leibniz finally to *vis viva*. So exact is this correspondence that, in order to exhibit Galileo's dynamics, Torricelli, in his *Lezioni accademiche*, often took up Buridan's reasons and almost his exact words".[121] Duhem then sketched the extension of impetus theory from terrestrial dynamics to the motions of the heavens and earth:

> *Nicole Oresme attributed to the earth a natural impetus similar to the one Buridan attributed to the celestial orbs. In order to account for the vertical fall of weights, he allowed that one must compose this impetus by which the mobile rotates around the earth with the impetus engendered by weight. The principle he distinctly formulated was only obscurely indicated by Copernicus and merely repeated by Giordano Bruno. Galileo used geometry to derive the consequences of that principle, but without correcting the incorrect form of the law of inertia implied in it.*[122]

Duhem could not proof with actual facts that Galileo had direct access to the studies of Buridan and Oresme. However, he insinuated that the means of transmission of the medieval ideas to modern science could be found in the availability of the works of

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[120] Pierre Duhem, *Études sur Léonard de Vinci: Ceux qu´il a lus et ceux qui l´ont lu, vol III, Les précurseurs parisiens de Galilée,* p. vi, quoted in Pierre Duhem*, Essays in History and Philosophy of Science*, edited and translated with Introduction by Roger Ariew and Peter Barker. (Indianapolis: Hackett, 1996) p. 193

[121] Pierre Duhem*, Essays in History and Philosophy of Science*, p.194

[122] Ibid., p. 196

Albert of Saxony which were reprinted during the sixteenth century. These works could be the possible link to Galileo. There is possibility that he might have had access to them since he had once used the phrase Doctores Parisienses referring to the popular name with which the Parisian Doctors, Buridan and Oresme are known. Therefore, based on evidence including references to certain unusual doctrines and the particular order in which the questions were arranged, Duhem conjectured that Galileo had consulted George Lokert's compilation of Albert of Saxony, Themo Judaeus, and others, and also the works of the Dominican Domingo de Soto.[123]

2.3.2 THE ROLE OF THE PARIS TERMINISTS.

The terminism of the fourteenth century was a reaction against the formalism of John Duns Scotus which has to do with his claim of the non-qualitative property responsible for individuation. The ´subtle doctor´ as was nicknamed had demonstrated his realist inclination about universal by calling the extra-mental universal the ¨common nature¨ (natura communis) and the principle of individuation the ¨haecceity¨ (haecceitas) of all realities. Paul Spade (1994) described this common nature in Scotus as that which is ¨indifferent¨ to existing in any number of individuals.[124] But it has extra-mental existence only *in* the particular things in which it exists, and in them it is always ¨contracted¨ by the haecceity. In this way the common nature *´humanity´* exists in both Mr A and B, while both are made different individuals by their *haecceitas* which is non-repeatable.

The terminists opposed this formalism of Scotus, and taking as their motto pluralitas non est ponenda sine necessitate (plurality is not to be posited without necessity), made a veritable destruction of metaphysical notions of the Scotus´s formalism. Terminism is usually equated with nominalism. But though the Paris terminists were all nominalists in their logic, making extensive use of Ockhams´ *logica moderna,* they rejected the nominalist analysis of motion in natural philosophy and developed realist views of their own. They rather devoted themselves consistently to investigating the physical causes of

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[123] Pierre Duhem, *Études sur Léonard de Vinci: Ceux qu´il a lus et ceux qui l´ont lu,* pp. 582–83

[124] Paul Vincent Spade, *Five Texts on the Mediaeval Problem of Universals* (Indianapolis: Hackett Publishing Company, 1994) pp. 57-113

motion; introducing the concept of impetus and quantifying the forces and resistance involved in the natural movements of bodies.[125] These Paris terminists included Jean Buridan, Albert of Saxony and Nicole Oresme.

2.3.2.1 JEAN BURIDAN

Jean Buridan is regarded as the most influential Parisian philosopher of the fourteenth century. He is best known for his development of the concept of impetus as a cause of projectile motion and of the acceleration of falling bodies. His most famous work is the *Summulae de dialectica* (Compendium of Dialectic), a text of astonishing breadth and originality aimed at redeeming the older tradition of Aristotelian logic using the new, terminist logic of ´moderns´ such as Peter of Spain and William of Ockham. In it, Buridan redeems the older medieval tradition of Aristotelian logic through the newer, terministic logic that had gradually replaced it. Due to the accessibility of the work to masters and students alike, it became extremely popular at Paris and in newly-founded universities like Heidelberg, Prague, and Vienna.

2.3.2.2 NICOLE ORESME

Nicole Oresme showed greater competence in mathematics than Buridan. He applied the Mertonian techniques which were earlier developed by the nominalists in Oxford for the discussion of both terrestrial and celestial motions. The Mertonians were highly imaginative in their treatment of kinematical problems, but did so in an abstract mathematical way, generally without reference to the motions actually found in nature. These Mertonians were the members of the Merton College at Oxford, and the major contributors to this new natural philosophy were Walter Burley, Thomas Bradwardine, William of Heytesbury, and Richard Swineshead.[126] Oresme´s work, in fact, provided some basis for the development of modern mathematics and science. He contributed to

[125] Wallace William, ¨The Philosophical Setting of Medieval Science¨, in *Science in the Middle Ages*, ed. David C. Lindberg (Chicago: University of Chicago Press, 1978) p. 113
[126] Ibid., p.112

the development of geometrical methods of summing series and integrating linear functions. He also adumbrated some of the concepts of analytical geometry.

The works of these Paris terminists spread throughout Western Europe and continued to shape the European thought well into the Renaissance. As these works were mainly commentaries and critiques of the Aristotelian natural philosophy it meant that the Master would teach Aristotle by reading and explaining their works to the class, and by that means paved way for their works to make big impact. It is for this reason that pioneer historians of medieval science, such as Duhem, spoke of the Paris terminists as the ¨Parisian precursors of Galileo.¨[127]

2.3.3 CONTINUITY THESIS EXPANDED

Duhem´s target had been to challenge the historiography of science that depicts the medieval period as a time of intellectual and cultural desolation, and such works of historians like Voltaire and Condorcet who denigrated the impact of the middle ages on science. Condorcet´s history of science strived to show that the ancient achievement, such as it was, fell before barbarian invasions and the triumph of Christianity. For him, the triumph of Christianity was the signal for the complete decadence of philosophy and the science.[128]

The astounding discovery of the rich scientific heritage of the Parisian school and its exposition in Duhem´s work echoed the danger of such negligence of the medieval science. This is because the history of scientific development does not follow a sporadic process; rather it is subject to the law of continuity. And it is in this regard that the great discoveries are almost always the fruit of slow and complex preparation, which is pursued in the course of the centuries. The awakening created by the continuity concept of Duhem led to massive subsequent works that sought to provide details of medieval

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[127] Pierre Duhem, *Études sur Léonard de Vinci,* p. 583

[128] Marquis de Condorcet, *Sketch for a Historical Picture of the Progress of the Human Mind,* ed. Stuart Hampshire, trans. June Barraclough (London: Weidenfeld & Nicolson, 1955) p. 76

scientific achievements and uncovering the ¨germs of later scientific discoveries¨[129] in the works of medieval masters.

In *The History of Science and the New Humanism*[130], George Sarton, argued that science was first introduced to Western Culture in the 12th century during the Arabic-Latin translation movement. It was later introduced again in the 17th century during what became known as the ¨Scientific Revolution¨. The first occurrence was when a number works, predominantly those by Aristotle, were translated from Arabic into Latin and thus became known in the West for the first time. The major developments brought by this movement were however stagnated during the Renaissance. The Renaissance humanism had put more emphasis on form over fact and adored ancient authorities over empirical investigation. The humanists' revival of Platonism neglected the epistemic importance of experience which was visible in the Aristotelian thought that was made popular during the translation movement. Even though the disposition to experiment in the Aristotelian thought is bit defective and not that tangible to guarantee productive experimentation in the sense of the modern science, his thought was marked throughout by the awareness of the epistemic importance of experience. This awareness was totally lacking in the humanist´ Platonism. Likewise, the humanists were almost like the scholastics in their great regard for authorities. Hence, Sarton´s idea that science had to be introduced to Western culture twice was due to the first appearance of science being swept away by Renaissance humanism before science had to be re-introduced again in the 17th century.

He states thus,

> *It does not follow, as so many ignorant persons think, that the medieval activities were sterile….The Middle Ages were pregnant with many ideas which could not be delivered until much later. Modern science, we might say, was the fruition of medieval immaturity. Vesalius, Copernicus, Galileo, Newton were the happy inheritors who cashed in*.[131]

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[129] Lynn Thorndike, *History of Magic and Experimental Science,* 8 vols. (New York: Columbia University Press, 1923-1958), Vol. 4. p. 612

[130] See George Sarton, *The History of Science and the New Humanism* (New York: Henry Holt, 1931)

[131] George Sarton, *Introduction to the History of Science*. Vol. 3. (Baltimore: Williams & Wilkins, 1947) p.91

Unlike the usual claim that the Middle Ages were notable for the decline in scientific activities the sympathisers of the continuity thesis argued that it was the Renaissance and not the medieval period that cause stagnation to the scientific progress. The Australian mathematician and historian of science, James Franklin (1982), claims that the Renaissance was in face a period when thought declined significantly, bringing to an end a period of advance in the late Middle Ages. Just like Sarton he argues that the twelfth century was the ¨real, true and unqualified renaissance.¨[132] The reason is that the rediscovery of ancient knowledge, which the later Italian humanists claimed to themselves, was actually accomplished in the 12th century. Edward Grant (1996), also complimented this view by arguing that the origins of modern science lie in the Middle Ages[133], and was due to a combination of four factors. They include the Translation into Latin of Greek and Arabic scientific texts in the twelfth and thirteenth centuries; the development of universities, which were uniquely Western and used the translations as the basis of a science curriculum; the adjustments of Christianity to secular learning and the transformation of Aristotle´s natural philosophy.

Generally, the emphasis of these continuity theses on the importance of the medieval science has centred mainly on the medieval activities within the European environment thereby leading to a Eurocentric conception of the Scientific Revolution. Arun Bala argued on the contrary. In *The Dialogue of Civilizations in the Birth of Modern Science*[134], he claimed that the activities of the middle ages that yielded to the triumph of the Scientific Revolution should be sought in the foreign multicultural influences on Europe within the medieval period. For instance, Islamic science gave the first exemplar of a mathematical realist theory with Alhazen´s *Book of Optics* in which physical light rays travelled along mathematical straight lines. The swift transfer of Chinese mechanical technologies in the medieval era shifted European sensibilities to perceive the world in the image of a machine. The Indian number system, which developed in close association with atomism in India, carried implicitly a new mode of mathematical atomic thinking. And then the heliocentric theory which assigned central status to the

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[132] See J, Franklin, ¨ The Renaissance Myth¨, *Quadrant*, 1982, 26(11), 51–60

[133] See Edward Grant, *The Foundations of Modern Science in the Middle Ages: Their Religious, Institutional, and Intellectual Contexts* (Cambridge: Cambridge University Press, 1996); See also Grant, E., *Sourcebook in Medieval Science* (Cambridge, Mass: Harvard University Press 1974)

[134] Bala, Arun, *The Dialogue of Civilizations in the Birth of Modern Science*. (New York: Palgrave Macmillan, 2006)

sun, as well as Newton´s concept of force acting at a distance, were rooted in ancient Egyptian religious ideas associated with Hermeticism.

The continuity theory has been very instrumental in development in the studies of the medieval science. However, most of the studies have not been able to prove in very satisfying way how the science of the early modern period was a continuation of its medieval predecessor. Evidently, the two sciences have not operated within the same framework. The cosmology within which the medieval science was developed does not provide the mechanism that facilitated the activities of the early modern science. Still, studies on the medieval science have brought up many crucial issues which the historiography of science could not neglect without losing its central focus. Notwithstanding the wonderful insights brought by the continuity theory, ´majority of scholars on the ´Scientific Revolution´ still hold to the traditional view that it occurred in the 16th and 17th centuries.[135]

2.3.4 INHERENT WEAKNESS OF THE DUHEM THESIS

The Duhem thesis has been acknowledge by historians of science as the foundation of what has been turned into an area of specialization in the historiography of science in its own right—the history of medieval science. With his studies on the origins of statics (1905-1906), on the mechanical tradition linked to Leonardo da Vinci (1906-1913), and on cosmology from Plato to Copernicus (1913-1958), he founded single-handed the history of medieval physics.[136] Perhaps, this explains why Duhem´s work in the history and philosophy of science has been viewed by Lowinger (1941) as an attempt to defend the aims and methods of energetics.[137] Duhem´s works pointed to many interesting adumbrations of the three centuries before the ´Scientific Revolution´. However, their peculiar weakness has been the consistent evaluation of the performance of the Parisian terminists against the yardstick of the achievements of such scientists like Galileo,

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[135] See Peter Dear, *Revolutionizing the Sciences: European Knowledge and its Ambitions, 1500-1700* (Princeton: Princeton University Press, 2001); Howard Margolis, *It Started with Copernicus* (New York: McGraw-Hill, 2002); Richard S, Westfall, *The Construction of Modern Science: Mechanisms and Mechanics* (New York: John Wiley and Sons, 1971. Reprinted version Cambridge: Cambridge University Press, 2009[1977])

[136] Roberto Torretti, *The Philosophy of physics* (Cambridge: Cambridge University Press, 1999) p.242.

[137] See A. Lowinger, *The Methodology of Pierre Duhem* (New York: Columbia University Press, 1941)

Descartes, Kepler, Newton etc even when the activities of the two groups do not match in some cases. For instance, he knew that the Parisians had written in manuscripts and their tracts were produced too early to benefit from the invention of printing. In the face of seeming irreconcilability between the two periods he conjectured that Galileo might have consulted George Lokert's compilation of Albert of Saxony, Themo Judaeus, and others, and also the works of the Dominican Domingo de Soto where he could have gotten access to the Parisian studies.

Duhem´s latter works in which the continuity theory was developed seem very distanced from his earlier works in the history of science. His previous work had three main features: it assumed that physics was completely independent of metaphysics—the separability thesis[138]—or could easily aspire to be so. It focused on the historic justification of his own thermodynamic approach to physics, and ignored the Middle Ages entirely. All three were now abandoned. In his later works beginning from the *Origins of Statics* he increasingly focused on the mutual relations of physics and metaphysics in practice. One has to take into account Duhem´s previous stand on the history of science to understand most of the tension that arise from his continuity thesis.

While reviewing Duhem´s *The Origin of Statics,* R. N. D. Martin (1996) illustrated that historians who wish to judge Duhem´s work have to consider how far Duhem came to clarify his new position and what resources he may have had to defend it.[139] The next generation of historian of science, led by Alexandre Koyré and Anneliese Maier, constructed elaborate metaphysical justification for the repudiation of continuity thesis. Two themes divide Koyré's historical work from that of Duhem. The Koyréan thesis presents histories of science in which metaphysics plays a primary role in explaining scientific change and it espouses a historiography that gives a central place to the concept of revolution. Medieval thought and early modern science are judged to be different in kind as well as in content.

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[138] Roger Ariew, ¨The Duhem Thesis¨, in *The British Journal for the Philosophy of Science* (Oxford: Oxford University Press, 1984) p. 314

[139] See R. N. D. Martin, book review of Pierre Duhem, The Origins of Statics: The Sources of Physical Theory, translated from the French by Grant F. Leneaux, Victor N. Vagliente and Guy H. Wagener, with a Foreword by Stanley L. Jaki, Boston Studies in the Philosophy of Science, 123. Dordrecht: Kluwer Academic Publishers, 1991. Pp. xxxvi + 593, *The British Journal for the History of Science*, 1996, 29, p. 362

At the start of his essay on *Void and infinite space in the 14th century*, Koyré quotes a passage from Duhem that has become infamous: "If we were obliged to assign a date to the birth of modern science, we would undoubtedly choose 1277, when the Bishop of Paris solemnly proclaimed that a multiplicity of worlds could exist, and that the system of celestial spheres could, without contradiction, be endowed with straight line motion."[140] Koyré rejected Duhem's date for the birth of modern science; he remarked that Duhem even gave another date elsewhere, corresponding to Buridan's impetus theory being extended to the heavens. He dismissed it by arguing that "it is as false as the first date".[141] For Koyré, the introduction of Platonic metaphysics, the mathematization of nature, marks a break with the Aristotelian Middle Ages.

2.5 PERIODISATION OF THE SCIENTIFIC REVOLUTION

The traditional account of the scientific revolution usually centres its interpretation of the scientific advancement of the early modern period on the achievements of such elite figures like Copernicus, Kepler, Galileo, Descartes and Newton. In this context limits of space, time and theme are inevitably placed to demarcate the scope within which the transformations wrought by these men were achieved. However, as a periodization, the Scientific Revolution has grown increasingly complex. As it has attempted to take account of new research and alternative perspectives, new additions and changes have been made. Since the institution of the ´Scientific Revolution´ as a major historiographical concept, beginning from the 1960s, a number of sub-periodizations have been generated by more narrow research topics, usually from a more focused topical theme or from a narrower chronological period. Some of these sub-periodizations include The Copernican Revolution, the Galilean Revolution; the Keplerian Revolution; the Cartesian Synthesis; and not least, the Newtonian Revolution and the Newtonian Synthesis. Understood as an historical periodization, which is periodization defined by geographical, chronological and topical element, the Scientific

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[140] Pierre Duhem, *Études sur Léonard de Vînci*, vol 2. p. 411, quoted in Alexandre Koyré, "Le vide et l'espace infini au XIVe siècle," *Etudes de l'histoire de la pensée philosophique*. (Paris: Gallimard, 1961) p.37 The essay was originally published in 1949 but was later included in his work on the Studies of the history of the philosophical thinking.

[141] Ibid.

Revolution refers to European developments extending over periods of at least 80 to 300 years. These developments involve changing conceptual, cultural, social, and institutional relationships involving nature, knowledge and belief.

Many scholars do not agree on the exact dates of the scientific revolution. Various historians of science now consider the term ¨Scientific Revolution¨ as very problematic.[142] Some have reduced or entirely denied the earliest years of the Scientific Revolution, usually associated with what had been long known as the ´Copernican Revolution´. Some argued that if there was a Copernican Revolution, then it began and ended in 1610 with the work of Galileo and Kepler. Other scholars, emphasizing the development of key conceptual elements, have the opinion that the key period of the Scientific Revolution was 1610-1660. Some others, specializing in social institutional elements, have suggested that the period after 1660 was more crucial, as it was then that scientific periodicals and state-sponsored science emerged. The question is: have there been other comprehensive revolutions? Recent scholars have suggested the existence of a ¨second scientific revolution¨ in the institutional structure of the sciences in the decades around 1800. On this same period authors like Thomas Kuhn (1962), identifies a multidisciplinary revolution in the ¨Baconian sciences¨(chemistry, electricity, magnetism, heat, etc). Likewise, it has been illustrated that there was a general revolution in the sciences in the decades around 1900.[143] In fact, the issue of the periodization of the scientific revolution has shifted historiographically across chronological, geographic, thematic, and methodological boundaries.

Two English men, Herbert Butterfield (1900-1979) and A. Rupert Hall (1920-2009), have been very outwithstanding in handling this problem of periodization and prompting its diverse analysis within the historiographical context. The former is generally recognised as having introduced the expression ´the Scientific Revolution´ into historical discourse while the latter has been a vigorous opponent of attempts at monocausal explanation and one-sided interpretation of the Scientific Revolution.

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[142] For illustration of the relevant issues see Steven Shapin, *The Scientific Revolution* (University of Chicago Press, 1996), pp.1-4; David C. Lindberg, "Conceptions of the Scientific Revolution from Bacon to Butterfield," in *Reappraisals of the Scientific Revolution,* eds. David C. Lindberg & Robert Westman (Cambridge University Press, 1990), pp. 1-26; and A. Rupert Hall, "Retrospection on the Scientific Revolution," in *Renaissance and Revolution: Humanists, Scholars, Craftsmen and Natural Philosophers in Early Modern Europe,* eds. J. V. Field and Frank James (Cambridge University Press, 1993), pp. 239-250)

[143] See I. Bernard Cohen, *Revolution in Science*, chapter 6

2.5.1 THE BUTTERFIELD THESIS

Six decades ago the British historian Herbert Butterfield (Oct. 1900 – Jul. 1979) started a stir by arguing that the emergence of modern science between 1600 and 1700 ´outshines everything since the rise of Christianity and reduces the Renaissance and Reformation to the rank of mere episode, mere internal displacements, within the system of medieval Christendom´.[144] The Scientific Revolution of the seventeenth century marked a watershed in Western Civilization and Modern Thought. It challenged Christian revelations, altered the world view of philosophers, permeated university curricula, established new literary genres, and suggested new approaches for economic, political, and social theorists. The idea that there was something called ¨the scientific revolution¨ was popularized by Butterfield in *The Origins of Modern Science* (which has been his only work on the topic) published in 1949.

Unlike the 19th century historians who claimed that the great changes that ushered Europe into the modern age were the Reformation and the Renaissance, Butterfield argued in *The Origins of Modern Science* that the major breakthrough were in the paired advance of scientific conceptualization and factual discovery that began in the 16th century. It was this double advancement that led to the ´Revolution´ in science which overturned the authority not only of the middle ages but of the ancient world—it did not only result to the eclipse of scholastic philosophy but also the destruction of Aristotelian physics. He identified the Scientific Revolutions as the upheaval in science during the period between 1300 and 1800. Though the period of the scientific revolution has been popularly associated with the sixteenth and seventeenth centuries he recognised that it reached ¨back in an unmistakably continuous line to a period much earlier still.¨[145]

The long duration assigned to the scientific revolution gives rise to serious doubt on what significance dating its start from 1300 holds for him? One could see that the whole historical survey in his work centred entirely on the period between Copernicus and Newton while describing the scientific revolution. His account of the period was mainly the 16th and 17th achievements in astronomy and mechanics, which for him hold the strategic place in the whole movement. However, his major reason in putting the date so

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[144] Herbert Butterfield, *The Origins of Modern Science 1300-1800,* p. 7
[145] Ibid.

early could be to incorporate the era of the impetus physics which he claimed was the starting point of the scientific revolution. He wrote,

> *A particular development of ideas which was already taking place in the later middle ages has come to stand as the first chapter in the history of the transition to what we call the scientific revolution.*[146]

This first stage was started by that school of thinkers who as far back as the fourteenth century were challenging the Aristotelian explanations of motion. They were able to put forward an alternative doctrine of ´impetus´ which though was imperfect in itself but represented a major step to the final break from the authority of the Aristotelian physics. Just like Duhem, he identified his group of thinkers as Jean Buridan, Albert of Saxony and Nicholas of Oresme. However, these men could not achieve such final break because of their resort to ´verbal subtleties´ and ´excessive straining of language´ to resolve the complicated issues involved in the Aristotelian intricate dovetailing of observations and explanations. It was on this aspect that the modern law of inertia triumphed though on a total different framework. Butterfield argues thus,

> *...the modern law of inertia is not the thing you would discover by mere photographic methods of observation—it required a different kind of thinking-cap, a transposition in the mind of the scientist himself; for we do not actually see ordinary objects continuing their rectilinear motion in that kind of empty space which Aristotle said could not occur, and sailing away to that infinity which also he said could not possibly exist; and we do not in real life have perfectly spherical balls moving on perfectly smooth horizontal planes—the trick lay in the fact that it occurred to Galileo to imagine these.*[147]

The actual transformation occurred in Galileo´s thought of mathematical ways to formulate things and his idea of geometrical bodies moving in a world without resistance and without gravity. Such thought requires a ´transposition in the mind´, ´new thinking-cap´ which has to do away with the framework of the older system of

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[146] Ibid., p. 14

[147] Ibid., 17

ideas—therein lays the major triumph of the scientific revolution. It did not just stop there, the extension of the date to 1800, illustrates that the revolution in chemistry which started with Robert Boyle(1627-1691) and subsequently culminated in the achievement of Antoine Lavioser (1743-1794), who maintained that weight was conserved through the course of chemical reactions even those involving gases, are included in this historical period.

It could be asserted that the notion of scientific revolution popularized by Butterfield was an analysis of the concept already developed by Edward Burtt in the *Metaphysical Foundations of Modern Science*(rev. ed. 1932), and more deeply by Alexandre Koyré in *Études Galiléennes*(1939) and *From the Closed World to the Infinite Universe* (1957). Also some influence of the continuity thesis of Duhem could be seen in his work. However, his concept of the scientific revolution offered a framework with which to contrast our accounts of ancient and medieval science and within which to develop the story line leading to modernity. His thesis helped narrowed the internal versus external divide that often appear on the narratives of scientific progress by tying the very content of the questions that provide the agendas of the sciences to the material conditions and social practices of the various disciplines. In fact, the Butterfield thesis presented a picture of the development of the scientific disciplines that overcomes the separation of history of ideas from history of social structures and interests. In doing so, he has stretched the date to include the 18th century for the benefit of the Enlightenment and the revolution in chemistry.

2.5.2 HISTORICAL OVERVIEW AND `WHIGGISHISM´ OF THE *ORIGINS*

The structure of his *Origins,* however, contradicts his historical theory in *The Whig Interpretation of History* (1931) and has often been criticized as the most classic example of whiggishness in the historiography of science. In *The Whig Interpretation of History* he had criticized the Whiggish history because it twists the past to see it in terms of the present, to squeeze the contending forces of such periods like the mid-17th century into those which remind us of ourselves most and least, or to imagine them as struggling to produce our wonderful selves. He wrote that ¨Whiggishness¨ is too handy a ¨rule of thumb… by which the historian can select and reject, and can make his points

of emphasis."[148] Therefore, he argued that the historian must seek the ability to see events as they were perceived by those who lived through them. However, *The Origins of Modern Science* appears to be typical of such whiggish history as a result of its emphasis on the canonical set of subjects in the scientific revolution by considering the achievements of such canonical individuals like Copernicus, Tycho, Kepler, Galileo, Vesalius, Harvey, Descartes, Boyle, and Newton, with their predecessors. Another important work that followed the traditional histories of the Scientific Revolution which customarily focus on a list of canonical individuals who explored a canonical set of subjects is Rupert Hall´s *The Revolution in Science, 1500-1750.*[149]

2.6 ALFRED RUPERT HALL—HALL THESIS

Alfred Rupert Hall (Jul. 1920 – Feb. 2009) account of the progress of the early modern science is one of the pioneer works that made visible the dilemma in exact periodization of the scientific revolution. His earliest effort to address the challenges generated by Butterfield´s *Origins* is contained *The Scientific Revolution, 1500-1800: The Formation of the Modern Scientific Attitude* (1954). The title provides a useful label for the changes in approach to the natural world, the new institutions, and the power that new knowledge generated. The book's range and its accessibility made it a landmark, opening up the history of science for a new generation.

Just like Butterfield, he placed science at the centre of modern Western culture and pointed to the scientific revolution as the great moment of change, the point at which both science and the West broke free from medieval stasis and commenced their steady progress. This movement was motivated by certain crucial principles which also inform the new attitude towards nature. The basic principles of this new attitude were that "the only sort of explanation science could give must be in terms of descriptions of

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[148] Butterfield, Herbert. *The Whig Interpretation of History* (London: G. Bell, 1959 [1931]) p. 10

[149] See A. Rupert Hall, *The Revolution in Science, 1500-1750* (New York: Longman, 1998); first published in 1954; see also, Richard S. Westfall, *The Construction of Modern Science: Mechanisms and Mechanics* (Cambridge: Cambridge University Press, 2009)

processes, mechanisms, interconnections of parts," and that "the only realities were matter and motion."[150]

These principles stood in sharp contrast to the medieval world view, inherited from Aristotle, which explained things in organic, teleological, and animistic terms. Equally important is the fact that adherents of the "new philosophy" married theoretical abstraction to rigorous empirical observation, unlike their forebears who had seen philosophical inquiry and empirical practice as unrelated endeavours. Hall thesis of the scientific revolution is more a historical overview albeit concise, and is also somewhat more technical. However, the purported intimidating mastery of the technicalities of Hall´s work seems quite hard to be accepted in the face of various inconsistencies that could be found in his work. It is, for example, a very serious error to assert that "Kepler's discoveries might have been expressed in the terms of the geostatic system."[151]

Of course, none of Kepler's laws can be expressed in a geostatic system, nor can his theory of planetary distances, etc. Likewise, it makes little sense to claim on the one hand that "Galileo concedes that the motions of the heavenly bodies are perfectly circular", but "to the question: how and by what are the planets moved? Galileo returned no answer."[152]

And on the other hand that "Galileo, it is clear, was far more confident of the truth of the mechanical principle that bodies possess the property of inertial rotation on a perfect circle."[153] Finally, Newton's proof of the law of equal areas is of course not carried out "with the aid of the parallelogram of forces"[154] since there is only one force involved (namely gravity).

Hall makes the Scientific Revolution start around 1500 because that was when, in his view; European science began to cut loose from the Greek heritage for the first time. His account started with the description of science in 1500, emphasizing both the power of the Aristotelian system and the slow emergence of challenges to it, such as impetus theory. These challenges were limited in scope and ambition, and they remained so

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[150] A. Rupert Hall. *The Scientific Revolution, 1500-1800: The Formation of the Modern Scientific Attitude.* 2nd ed. (Boston: Beacon Press, 1966) p. xvii

[151] A. Rupert Hall´s *The Revolution in Science, 1500-1750,* p. 122

[152] Ibid., p. 126

[153] Ibid., p. 131

[154] Ibid., p. 316

throughout the sixteenth century. By stretching the stronghold of the Aristotelian system till the sixteenth century Hall meant to demonstrate that neither Copernicus nor Vesalius was a revolutionary, though their ideas and discoveries later inspired others who were. It was in the new mechanics and the new astronomy of the early seventeenth century that the taints of various brands of mysticism and magic of the previous sciences were conquered and modern science emerged. The unique character of this transformation which his account seeks to underscore is the rational nature of the Scientific Revolution.

2.6.1 SCIENTIFIC REVOLUTION AS MAINSTREAM OF RATIONAL SCIENTIFIC DEVELOPMENT

The course of the scientific revolution was marked by what Hall illustrated as the organized, conscious and rational response to the ubiquitous challenge of Nature.[155] In *From Galileo to Newton, 1630—1720* (1981), the revolution in physics initiated by Galileo and culminated in Newton´s achievements was not recounted as mere narrative. Hall, rather, sought to characterise the nature of the changes initiated into the spirit and ideas of science by these scientists. The distinguishing feature of the Scientific Revolution, he argues, is its rational character. It was during the first quarter of the seventeenth century that the force of scientific ideas began to act. With the appearance of the Galileo´s *Dialogues on the Two Chief Systems of the World* (1632) a new structure of thought was established. Hall argued that it is no exaggeration to describe [Galileo´s mechanics]...as the beginnings of exact science which consciously set itself to proceed by other ways than those of the past.[156]

The new scientific tradition would act as process of purification of all forms of mysticism, magic and superstition from nature. This true scientific tradition ´invariably opposed the magical view of nature, the view that events are governed by spirits or demons or other unknowable forces not obeying the normal laws of cause and effect.[157] In fact, the critical feature of seventeenth-century science was that it embraced new or revived ideas, and this was achieved by such academic professionals like Galileo,

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[155] A. Rupert Hall. *The Scientific Revolution, 1500-1800: The Formation of the Modern Scientific Attitude,* p.365
[156] Ibid., p.91
[157] A. Rupert Hall, *From Galileo to Newton* (New York: Dover, 1981[1963]) p.25

Kepler, Cavalieri, Wallis, Newton, Hooke, Leibniz, Huygens, and other like Harvey, Fermat, Descartes, or Hevelius.[158] Hall´s abhorrence to the irrationality of metaphysics ascribes to the vicious generalization that all of primitive science was to be found wholly in the realm of the occult, or , more specifically, in magical activities. In fact, Hall is just one of a small army of science historians who abhor the irrationality of metaphysics mixed up with modern science. Kant´s *Critique of Pure Reason* had illustrated that such ´corrupt nature´ of metaphysics has to be purified before it could turn into science.

However, historians like Barnes have demonstrated the generic relation of religion and magic, and revealed the origins of science as proceeding primarily from everyday secular and common place activities.[159] E.A Burtt´s *The Metaphysical Foundations of Modern Physical Science* (1924) and Frances Yates´ *Giordano Bruno and the Hermetic Tradition* (1964) also illustrated in a very analytical way the metaphysical underpinnings and implications of the scientific accomplishments of such figures like Kepler, Galileo and Newton. Maybe it was Hall´s objection to such tendency in introducing ´irrationality´ to the scientific realm, as these works have insinuated, that made him to make no mention of Burtt or *The Metaphysical Foundation* in his *The Scientific Revolution, 1500-1800.*

The enormous controversies that the rationality of science has generated, often, have to do with the identification of rationalism with `mathematical realism´[160] in the early part of the twentieth century by philosophers of science. It also later came to mean same for the historians of science. However, the historians conflated empiricism and Baconian experiment with mathematical realism, which they traced to Plato, the Pythagorean tradition, the Mertonian scholastic tradition, or something arising for the first time with

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[158] Ibid., p.28

[159] Harry Elmer Barnes, ¨The Historian and the History of Science¨, in *The Scientific Monthly* Vol II. (1919), p.113 quoted in Diane Elizabeth Davis Villemaire, *E. A. Burtt, Historian and Philosopher: A Study of the Author of the Metaphysical foundations of Modern Physical Science.* (Dordrecht: Kluwer 2002) p.169

[160] Mathematical realism is a modern version of what in traditional philosophy is sometimes called transcendental realism—the view that there is no essential distinction to be drawn between reality in itself and the ensemble of phenomena. This concept gained popularity at least in the epistemological circles where Karl Popper´s influence was dominant. However, when considered in the light of recent findings in physics, this kind of realism proves difficult to sustain, even in its fallibilist form. Cf. Bernard D´Espagnat, *Reality and the Physicist,* trans., J. C. Whitehouse. (Cambridge: University of Cambridge, 1990 [1982]) p. 18. It was originally published in French as *Une incertaine réalité* in 1985. See Chapters 4-6 of the book.

Galileo.[161] The insistence by some historians in identifying rationality with science has been somehow prompted by the ´concept of the Scientific Revolution´ itself and its mechanism of interpreting the past scientific heroes as if their thought patterns were basically like our own, even when they did not see their achievements the way we do. Betty J. Dobbs writes

> *I think the problem arises somewhat in this fashion: we choose for praise the thinkers that seem to us to have contributed to modernity, but we unconsciously assume that their thought patterns were fundamentally just like ours. Then we look at them a little more closely and discover to our astonishment that our intellectual ancestors are not like us at all: they do not see the full implications of their own work: they refuse to believe things that are now so obviously true; they have metaphysical and religious commitments that they should have known were unnecessary for a study of nature.*[162]

Dobbs demonstrated that judging the achievements of the 16th and 17th century scientist based the standard of the rationality created by the modern mind will not offer us a clear view of the nature of the science those scientists practised. Our understanding of the scientific revolution has been fed with such mix between rationalism and mathematical realism that we might be tempted to think that the scientifically rational is that which is mathematically real. This tendency explains why authors like Thomas Kuhn and Frances Yates has been criticized as propagating irrationalism in science with the former´s treatment of the interplay of sociological factors in the scientific progress and the latter linkage of alchemy to Newton physics.

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[161] Diane Elizabeth Davis Villemaire, *E. A. Burtt, Historian and Philosopher: A Study of the Author of the Metaphysical foundations of Modern Physical Science.* p.172

[162] B.J. Dobbs lecture at the 1993 Annual Meeting of the History of Science Society quoted in B. J. Dobbs, *Newton as Final Cause and First Mover, Isis,* 1994, 85: 640-41

2.6.2 CHANGE OF DATE

The extension of the end of scientific revolution to 1800 in the earlier work was later reduced to 1750 in Hall´s *The Revolution in Science 1500-1750.* In the preface to the work he gives reason for the reduction in date.

> *I now conclude my story near the middle of the eighteenth century. [Because] When Newton died the great creative phase of the scientific revolution was already finished, though its acceptance and assimilation were still incomplete. Therefore I now omit the successor phases of the eighteenth century in which the science of chemistry and electricity received their first coherent forms.*[163]

In the earlier work the date was stretched to include the purported emergence of ´rational´ chemistry, biology, and electrical science during the eighteenth century. It was Hall insistence in demonstrating the rational character of scientific revolution that guaranteed the need to include the early history of electrical and magnetism in the former account.

Hall´s change of the date demonstrates the general problem in making a definite chronological scheme for the Scientific Revolution. The dilemma is how to account for a Scientific Revolution within the seventeenth-century physical science where a complete revolution in mathematical science has been identified to stand beside an incomplete degree of progress in the experimental branches. Thomas Kuhn elaboration of the two basic sciences (Classical and Baconian) of this period indicated that complete mathematization in the Baconian tradition was delayed till the nineteenth century.[164]

Agreeing with Koyré (who had identified mathematization of nature as the crux of the revolution), Kuhn argued that ´if one thinks of the Scientific Revolution as revolution of *ideas,* it is the changes in these traditional, quasi-mathematical fields which one must seek to understand´.[165] The classical and Baconian science did not merge till the 19th century when the barriers between the mathematical and the experimental approaches to

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[163] A. Rupert Hall, *The Revolution in Science 1500- 1750*, p. vii

[164] Thomas S. Kuhn, *The Essential Tension* (University of Chicago Press: Chicago, 1977) pp. 41-42

[165] Ibid., p. 41

science finally broke down. Before then the Baconian science which was mark more by experimentation existed only as craftship. This implies that a complete historical symmetry cannot be established between even the mathematical and experimental departments of physics. Hall, therefore, concluded that it would not be surprising then that even greater historical asymmetries should exist between the mathematical and the chemical, geological and biological science, where the ´Baconian´ features of evolution are even more marked than in experimental physics.[166]

However, it was not just the revolution in thought that occurred during the sixteenth and seventeenth centuries as there were other important historical things which happened to the sciences during the period. These were factors that yielded to the integration of crafts knowledge with scholarly literary culture in the European early modern period. Those factors like the rise of Capitalism, Renaissance and Reformation were instrumental to the establishment of an experimental or technology based science in Europe which eluded other crafts based civilizations like China and India at the time. The British biochemist, Joseph Needham, illustrated the lack of an experimental or technology based science in traditional China in terms of the lack of prestige of craftspeople and the lack of integration of crafts knowledge with scholarly literary culture.

2.7 ´TERRITORIST´ HISTORIOGRAPHY OF THE NEEDHAM THESIS

Joseph Terence Montgomery Needham (Dec. 1900 – Mar. 1995) was a British biochemist but has wide recognition for his pioneer works in bringing the history of science and technology in China into the scholarship of the Scientific Revolution. His first major work on the theme, *The Grand Titration: Science and Society in East and West* (1969), heralded the initial studies in cross-cultural history of science. With this work another dimension was brought to the controversy surrounding the Scientific Revolution—the issue of its geography. His thesis appears to address the question: Can the location of scientific endeavour make any difference to the conduct of science? [167]

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[166] A. Rupert Hall, *The Revolution in Science 1500- 1750*, p.149

[167] David N. Livingstone, *Putting Science in Its Place: Geographies of Scientific Knowledge* (Chicago: University of Chicago Press, 2003) p. 1

Between the first and fifteenth centuries the Chinese were technologically far in advance of Europe and it was not until the scientific revolution of the Renaissance that Europe drew head. The viable question that Needham thesis sought to investigate was: What were the inhibiting factors in their civilisation which prevented the rise of modern science in Asia? The Scientific Revolution was given a classic formulation with his question on, ¨Why did modern science, the mathematization of hypotheses about Nature, with all its implications for advanced technology, take its meteoric rise only in the West at the time of Galileo?¨, ¨Why had not modern science developed in Chinese civilisation...?¨[168] Another issue was even added to make the larger problem more interesting. It was noted that ¨between the first century B.C and the fifteenth century A.D., Chinese civilisation was much more efficient than occidental in applying human natural knowledge to practical human needs.¨[169]

2.7.1 CHINESE CONTRIBUTIONS TO SCIENCE AND TECHONOLOGY

The Chinese had invented paper, gunpowder, the compass, astronomical coordinates and instruments and the astronomical clock. They made technological advances in the use of animal power (harness, stirrup, wheel-barrow), water power (crank, driving-belt), iron and steel (bridge building), textile (simple flyer), immunization and nautical instruments (rudder). Hence, it is very surprising that the modern science did not emerge in the Chinese soil given the numerous ancient and medieval Chinese technological achievements far ahead of those of the medieval and Renaissance West. Besides, numerous observational and natural history records in astronomy and the earth and biomedical sciences were made in Europe until much later. The big question remains: is: why did not modern science develop in China?

In two essays Needham addresses the question of why modern science did not develop in China. These two essays are reprinted in Needham's book *The Grand Titration: Science and Society in East and West* (Chapters 5 and 6). Needham's argument, in part, is as follows: there is an "antagonism between manual and mental work which has run

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[168] Joseph Needham, *The Grand Titration: Science and Society in East and West* (London: Allen & Unwin, 1969) p. 16

[169] Ibid., p. 190

through all ages and all civilizations."[170] He argued that it was only the merchant class that could bring together such Greek *praxis* and *theoria*, or the corresponding Chinese *shu* and *hsueh*. He states that,

> *...there cannot be much doubt that the failure of the rise of the merchant class to power in the State lies at the basis of the inhibition of the rise of modern science in Chinese society.*[171]

One of the major contrasts Needham made between the Chinese and Western science was that the Chinese was mainly practical oriented. The Taoist tradition had much empirical observation of natural phenomena, and even the logical and rational thought of the neo-Confucian tradition were largely confined to the challenges of establishing and maintaining social order and cohesion.

> *It was not that there was no order in nature for the Chinese, but rather that it was not an order ordained by a rational personal being, and hence there was no conviction that rational personal beings would be able to spell out in their lesser earthly languages the divine code of laws which he had decreed aforetime. The Taoists, indeed, would have scorned such an idea as being too naïve for the subtlety and complexity of the universe as they intuited it*.[172]

Generally, there was not any conscious interest in studying nature as it had occurred in the European history, and subsequently there was no vivid combination of rationalized thought with an interest in nature. In fact, China did not develop modern science and an industrial society for three reasons which are mainly intellectual, philosophical and social.

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[170] Ibid., p. 187

[171] Ibid. p. 186

[172] Joseph Needham & Wang Ling (王玲), *Science and Civilisation in China: Introductory Orientations*. Vol. 1 (Cambridge: Cambridge University Press, 1954) p. 581

2.7.2 SCIENTIFIC AND TECHONOLOGICAL STAGNATION IN CHINA

The reasons for the Chinese scientific and technological stagnation are intellectual, philosophical and most importantly political and social. Intellectually, the Chinese technical achievements lacked the essential elements of science, such as scientific explanations or mathematical proofs. Their mathematical concepts were algebraic, not geometric. Chinese mathematical thought was always deeply algebraic, not geometrical[173], and it is in this regard that it lacked the capacity to bring such transformation as witnessed in Galileo´s application of mathematical hypotheses to Nature.

Philosophically, the Chinese didn't have a mechanical view of the world. For them, every phenomenon was connected with everything else according to a hierarchical order (a perfect copy of their political system). Moreover, the Taoists distrusted reason and logic as well as precisely formulated abstract codified laws due to the tyranny of the politicians of the School of Legalism. Also, for them the cosmic order of things was inscrutable. Hence, Needham argued by quoting a letter written by Einstein to a friend, that

> *The development of Western Science has been based on two great achievements, the invention of the formal logical system (in Euclidean geometry) by the Greek philosophers, and the discovery of the possibility of finding out causal relationship by systematic experiment (at the Renaissance). In my opinion one has not to be astonished that the Chinese sages have not made these steps. The astonishing thing is that these discoveries were made at all.*[174]

Moreover, the most important reasons for the stagnation were political and social. For Needham, there is a fundamental correlation between science and `democracy' (liberalism). In China, bureaucratic feudalism (in Marxist terms, the Asian production mode) controlled the whole country for more than 2000 years. It was a top-down power structure. Imperial power was exercised through an extremely elaborate civil service,

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[173] Joseph Needham, *Science in Traditional China* (Hong Kong: Chinese University Press, 1981) p.10

[174] Francis Bacon, *Novum Organum,* Book 1, aphorism 129; quoted in Needham, J., *The Grand Titration: Science and Society in East and West*, p. 62

`the mandarinate'. ¨To become a mandarin, a man had to be an expert in the writings of Confucius and, for much of Chinese history (more than 1000 years) he had to pass very difficult examinations in these ancient writings.¨[175]

All lords were swept away except one, the emperor, who ruled and collected taxes through a gigantic bureaucracy. This bureaucratic system prevented the rise of a merchant class. The powerful were opposed to free enterprise and destroyed regularly the merchants through excessive regulation and heavy taxation (with a cut for the mandarins). The only possibility for individual investment was land. All other economic sectors (iron and steel, salt) were nationalized for the well-being of one man, the despot. Jared Diamond traced the problem of this bureaucratic system to the geographical situation of China.

In *Guns, Germs and Steel*[176]*,* Jared Diamond, postulates that the lack of geographic barriers in much of China (essentially a wide plain with two large navigable rivers, and a relatively smooth coastline) led to a single government without competition. At the whim of a ruler who disliked new inventions, technology could be stifled for half a century or more. In contrast, Europe's barriers of the Pyrennes, the Alps, and the various defensible peninsulas (Denmark, Scandinavia, Italy, Greece, etc.) and islands (Britain, Ireland, Sicily, etc.) led to smaller countries in constant competition with each other. If a ruler chose to ignore a scientific advancement (especially a military or economic one), his more-advanced neighbours would soon usurp his throne. However, James Morris Blaut had criticized Diamond´s *Guns, Germs, and Steel* for reviving the theory of environmental determinism. He described Diamond as an example of a modern Eurocentric historian.[177] This kind of Eurocentric determinism is very visible in the Needham thesis which does not appear to have made an independent study of the Scientific Revolution. His views represent ´a highly selective precipitate of assorted portions of the literature on the subject´[178] which make the reader to wonder at times if his thesis is, really, about the ¨Scientific¨ rather than about the ¨Industrial¨ Revolution.

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[175] John Marks, *Science and the Making of the Modern World* (Oxford: Heinemann, 1983) p. 224

[176] See Jared Diamond, *Guns, Germs and Steel: The Fates of Human Societies* (New York: W. W. Norton, 1997) Chap. 16

[177] James M. Blaut, *Eight Eurocentric Historians* (New York: The Guilford Press, 2000) p. 228

[178] H. Floris Cohen, *The Scientific Revolution: A Historiographical Inquiry,* p. 444

Needham's rather romantic identification of Daoism with the Chinese scientific spirit is questionable, given Lao Tzu and Chuang Tzu's opposition to technological innovations. In fact the exception that proves the rule, so to speak, for Needham's thesis is the ancient Mohist School of Chinese philosophers. Their work focuses on optics and mechanics and has many features more resembling Western science than any other Chinese school. Their ethics which was a strange mixture of extreme utilitarianism and Christian-like universal love also had odd resemblances to Western philosophy. Mohists also developed logic, something that no other indigenous Chinese sect did. Their philosophy was only studied again after Buddhism spread in China.

> *The Mohists had no deductive geometry (though they might have developed one), and certainly no Galilean physics, but their statements often give a more modern impression than those of most of the Greeks. How it was that their school did not develop in later Chinese society is one of the great questions which only a sociology of science can answer.*[179]

The Mohists were craftspeople, military engineers, and Mo Tzu himself may have been a former slave and is very likely to have worked as a wheelwright. When the empire was consolidated around 200 BCE the independent role of the Mohist sects as military engineering consultants and defensive mercenaries to various small warring states was eliminated and Mohism disappeared, along with Chinese understanding of Mohist logic and science.

2.7.2.1 WHY SCIENTIFIC REVOLUTION DID NOT HAPPEN IN CHINA

Needham emphasized that the triumph of the Scientific Revolution in the West was because of the other great events that characterized the European environment at that time. He strived to demonstrate that the Scientific Revolution is inextricably bound up with the Renaissance, Reformation, and the rise of Capitalism. These three events formed together the peak landmarks in the underlying process of the dissolution of feudalism and the rise of capitalism from the 15th through the 18th centuries. Therefore,

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[179] Joseph Needham, *The Grand Titration: Science and Society in East and West,* p. 224

Needham concluded that, ¨To ask why modern science and technology developed in our society (Europe) and not in China is the same thing as to ask why capitalism did not arise in China, why was there no Renaissance, no Reformation, none of those epoch-making phenomena of that great transition period of the fifteenth to the eighteenth centuries.¨[180] He later asserted that the more one knows about the Chinese civilization, the more odd it seems that modern science and technology did not develop there. Perhaps, this is explained by the fact that Chinese science got along without dichotomies between mind and body, objective and subjective, even wave and particle. In the West, the dichotomies between mind and body were entrenched in scientific thought by the time of Plato. Galileo, Descartes, and others carried them into modern times to mark off the realm of physical science from the province of the soul, and it formed the basis of liberty on which the secular innovators acted.

However one of the major questions Needham´s thesis failed to address was whether the merchants indeed began to get more closed off in the Ming Dynasty (1368–1644), at the same time that the scientific drive seemed to weaken? Or were there other factors at play? To confuse the issue further, in recent years a number of strong scholarly works have tracked many new examples of dynamic commercial and economic enterprise in the Qing period (circa 1644–1911), during China's last dynasty, when China appeared to be dramatically "falling behind" in scientific energy. The debate is far from over.

Those who might want to pursue these questions further, whether to rethink them fundamentally or to tie them more firmly to Needham's own magnum opus, will surely find no better point of entry than the recent review essay by Professor Nathan Sivin, a leading historian of Chinese science. Published in *China Review International* in 2005, Sivin's essay focused on Needham's *Science and Civilisation: The Social Background, General Conclusions and Reflections* wherein he gave a poignant and nuanced overview of Needham's work as a whole.

Sivin is by no means convinced that "the Needham Question" needs asking anymore after so many years, for he feels—along with many other scholars—that "to explain what did not happen is about as rigorous as fiction." Yet when he steps back and looks at all the contributions which have sought to give explanations for what happened to Chinese science, Sivin concludes that "Needham's are the most thoughtful and the best

[180] Ibid., p. 176

informed," even if ultimately "none has reshaped our understanding." If we seek certainties about the long hiatus within Chinese science, we are likely to be disappointed: "What did happen was the emergence of early modern science in Europe. It is Europe that needs to be understood."[181] Consequently, the theory of environmental determinism of the scientific revolution generated by the Needham thesis has led to various ´scholarly nationalist works´[182] on theme, among which is Robert Merton´s *Science, Technology & Society in Seventeenth-Century England.*

2.8 MERTON THESIS: PURITANISM AND THE RISE OF MODERN SCIENCE

Robert King Merton (Jul. 1910 – Feb. 2003) was famous American sociologist. The Merton thesis originated from Robert Merton´s arguments in a doctoral dissertation which was originally titled, ¨Sociological Aspects of Scientific Development in Seventeenth-Century England. The dissertation was concluded in 1936, and a revised version of it appeared in 1938 as a monograph in George Sarton´series, *Osiris*, with the new title, ¨*Science, Technology and Society in Seventeenth-Century England.* It was his erudite demonstration of the connections between religion and the rise of modern science that launched the historical sociology of science. The Merton Thesis has two distinct parts. Firstly, it says that the changes in the nature of science were due to an accumulation of observations and better experimental technique. Secondly, it proposes that the popularity of science in England in 17th Century, and the religious demography of the Royal Society (English scientists of that time were predominantly Protestants or Puritans) can be explained by a correlation between Protestantism and the values of the new science. He illustrated, specifically, that the English Puritanism and German

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[181] See Nathan Sivin, ¨Joseph Needham. Science and Civilisation in China: The Social Background, General Conclusions and Reflections, Vol 7, Part 2¨, in *China Review International*, 2005, 12: 297-307, See also, Nathan Sivin, ´Why the Scientific Revolution Did not Take Place in China- Or Didn´t it? The Edward H. Hume Lecture, Yale University, *Chinese Science,* 1982, 5: 45-66

[182] See Mario Biagioli,¨Scientific Revolution, Social Bricolage, and Etiquette,¨ in *The Scientific Revolution in National Context,* ed. Roy Porter and Milukás Teich (Cambridge: Cambridge University Press, 1992) pp. 11-54; David C. Goodman, ¨The Scientific Revolution in Spain and Portugal,¨ in *Scientific Revolution in National Context,* pp.158-77; John Henry, ¨The Scientific Revolution in England,¨ in *Scientific Revolution in National Context,* pp. 178-209; Daniel Banes, ¨The Portuguese Voyages of Discovery and the Emergence of Modern Science,¨ *Journal of the Washington Academy of Science,*1988, 28: 47-58; Noel Coley, ¨Science in Seventeenth-Century England,¨ in *The Rise of Scientific Europe,* eds. Goodman and Russell, pp. 197-226; R. Hooykaas, *Humanism and the Voyages of Discovery in 16th Century Portuguese Science and Letters* (Amsterdam: North Holland, 1979)

Pietism were significant causes in the development of the scientific revolution of the 17th and 18th centuries. Hence, he attributes the connection between religious affiliation and sustained interest in science to a strong compatibility between the values of ascetic Protestantism and those associated with modern science.

Merton states thus;

> *¨The coincidence of such distinguished men of religion as ZWINGLI, LUTHER, CALVIN, KNOX, MELANCHTHON AND BEZA; of such dramatic and lyric poets as SPENSER, MARLOWE, SHAKSPERE AND JONSON; of such scientists as BOYLE, WREN, WALLS, HOOKE, NEWTON, HALLEY and FLAMSTEED cannot readily be attributed to the chance concurrence of individuals biologically endowed with predispositions toward special fields of activity. The more plausible explanation is to be found in the combination of sociological circumstances, of moral, religious, aesthetic, economic and political conditions, which tended to focus the attention of the geniuses of the age upon specific spheres of* endeavor.¨[183]

Merton statement implies that the explanation for the great activities of these geniuses of that century has to be sought in the external factors (socio-economic, moral, religious, aesthetic and political situations) which in large measure account for the marked development of science and for the ´direction of interest into specific departments of inquiry.´[184] However, the Merton thesis has been criticized on its two basic parts. This criticism is focused, firstly, on its insufficient consideration of the roles of mathematics and mechanical philosophy in the scientific revolution. The second criticism is on its arbitrary distinctions and statistical inaccuracies supporting his purported connection between Protestantism and the rise of science. Merton seem to

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[183] Robert K. Merton, *Science, Technology and Society in Seventeenth-Century England,* (New York: Howard Fertig, 2001[1938]) p. 5; The original version was first published in 1938 as volume IV, part 2 of *Osiris: Studies on the history and philosophy of science, and on the history of learning and culture.* (Burges: St. Catherine Press, 1938) 4(2), 360-632. See p. 364

[184] Robert K. Merton, ¨Science, Technology and Society in Seventeenth-Century England¨, *Osiris,* p. 365

have handled both science and religion as essentially homogeneous entities, as if throughout the course of the eventful century no significant changes had occurred in either of them. Also, the rise of the English science was explained exclusively through the Puritan ethic, whereas in reality the work pretended to demonstrate that not only was there mutual relationship between the two, there were other factors which might as well have been equally or perhaps even more important in accounting for the phenomenon of the scientific change.

2.8.1 ´MERTON REVISITED´

Merton had nowhere in the book claimed to explain, or had explained in fact, the rise of early modern science. He did not argue that the English Calvinist theology generated scientific innovation. He merely claimed, with many qualifications, that ´Puritans shared certain clusters of values that encouraged worldly endeavour, of which inquiries into Nature were a part´.[185] Perhaps, it was ignorance of this fact that had led to numerous criticisms of the Merton thesis, and which Gary Abraham sought to clarify in *Misunderstanding the Merton Thesis.*[186] It was Alfred R. Hall´s *¨Merton Revisited¨* that actually brought the Merton thesis into the focus of an explanation of the Scientific Revolution. Hall faulted the Merton thesis for its limitation of the rise of modern science to the case of England thereby making the account incapable of explaining the scientific revolution in its entirety, as it was supposed to have done.

Of course, this was not what Merton set out to do—to explain the Scientific Revolution in its entirety which will in this case involve all the prominent figures and the canonical subjects. He, however, sought to explain the rise of the science within the English context. In trying to make the Merton thesis a good account of the Scientific Revolution, Hall implied that it should have incorporated the conceptual overhaul accomplished by Galileo and Kepler and many others, and not just the bogus emphasis Merton made throughout his work of the Baconian aspect of early modern science.

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[185] Nathan Sivin, ed., *Joseph Needham: Science and Civilisation in China* (Cambridge: University of Cambridge Press, 2000) VI(6) p. 9

[186] Gary A. Abraham, ¨Misunderstanding the Merton Thesis: A Boundary Dispute between History and Sociology¨, in *Isis* (Chicago Journals, Chicago: University of Chicago Press, 1983) 74(3), 368-387

Hall´s disagreement with the Merton thesis is understood by his rejection of any attempt at ´external´ explanation of events in the history of ideas. In fact, Hall agreed more with the intellectualist approach of Alexandre Koyré in *Études Galiléennes* (1939). Hence, he asserted that ´Merton summed up one epoch, that of the socio-economic historian, Koyré opened another, that of the intellectual historian.´[187]

In *Lilley revisited: or Science and Society in the Twentieth Century* (2009) Vidar Enebakk, argued that Merton thesis was not the only target of attack in Hall´s ´Merton Revisted´. There was another explicit target, and this was Sam Lilley´s *Essays on the Social History of Science* (1953).[188] Precisely, Hall refuted such sociological interpretation of science because it sustains the Marxist historiography of science which typifies a form of social reductionism or extreme externalism.

However, Steven Shapin dismissed such criticism by illustrating that Merton's claims were ¨not to imply that the discoveries of Newton, Boyle or other scientists can be directly attributed to the sanction of science by religion. Specific discoveries and inventions belong to the internal history of science and are largely independent of factors other than the purely scientific.¨[189] Hence, he affirms that it is, indeed, a plausible hypothesis that our present-day language of ¨internal¨ and ¨external¨ factors, as well as the validation of an overwhelmingly ¨internalist¨ historiography of scientific ideas, actually originated from Merton. Nevertheless, the Merton thesis´s illustration of viable interaction of socio-economic and religious forces as having incited the growth of science in England has some inspiration from Boris Hessen´s *The Social and Economic Roots of Newton´s ´Principia´*(1931)

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[187] Alfred Rupert Hall, ¨Merton Revisted, or Science and Society in the Seventeenth-Century¨, *History of Science,* 1963, 2 , p.10

[188] See Vidar Enebakk, ¨Lilley Revisited: or Science and Society in the Twentieth Century¨, in *British Journal of History of Science* (Cambridge: Cambridge University Press, 2009) 42(4), pp. 563-4

[189] Steven Shapin, ¨Understanding the Merton Thesis¨, in *Isis.* (Chicago: University of Chicago Press, 1988) 79, p. 594

2.9 MARXIST HISTORIOGRAPHY OF BORRIS HESSEN THESIS

The Marxist Historiography of the Science was first inaugurated by Boris Hessen thesis of the Scientific Revolution which establishes the European ´development of merchant capital, international maritime relationships and heavy (mining) industry´[190] as factors that prompted the rise of the early modern science. At the Second International Congress of the History of Science and Technology which met in London in 1931, Professor Boris Mikhailovich Hessen (Aug. 1893 – Dec. 1936) presented a paper titled ¨*The Social and Economic Roots of Newton´s ´Principia´*. In the paper he claimed that Newton´s great masterpiece of mathematical physics, the *Principia,* was a product of seventeenth-century England´s commercial and industrial activity and the social system associated with it. He stated thus,

> *In this paper we shall present a radically different view of Newton and his work. We aim here to apply the method of dialectical materialism and Marx's conception of the historical process to an analysis of the genesis and development of Newton's work within the context of the period in which he lived and worked.*[191]

The point of departure of Hessen´s arguments is the correlation between problems in economics, technology and science in the time up to Newton. Certain economic needs were correlated with certain technological problems like ballistics, mining and maritime, which in turn are correlated with the fields of scientific study. He continued.

> *Consequently, we shall first investigate the historical demands presented by the emergence and development of merchant capital. Then we shall consider what technical problems were posed by the newly developing economy and what complex of physical problems and knowledge, essential for solving these technical problems, they generated.*[192]

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[190] Boris Hessen, "The Social and Economic Roots of Newton's 'Principia'", in *Science at the Cross Roads*, with a preface by Joseph Needham and an introduction by P.G. Werskey. (London: Cass, 1971[1931]) p. 155

[191] Ibid., pp.149-50

[192] Ibid., p. 153

Hessen's "The Social and Economic Roots of Newton's Principia" formulates three theses. The first of which concerns the relation of economic and technological developments in the early modern period and the relation of these two to the emergence of modern science: Theoretical mechanics developed in the study of machine technology.

The second thesis draws the converse conclusion: In those areas where seventeenth-century scientists could not draw on an existing technology (heat engines, electric motors and generators) the corresponding disciplines of physics (thermodynamics, electrodynamics) did not develop. And the third thesis concerns the ideological constraints placed on science in England at the time of the "class compromise" or "Glorious Revolution" (1688): Because of this compromise Newton drew back from fully endorsing the mechanization of the world picture and adapted his concept of matter so as to be able to introduce God into the material world. He concluded by reiterating the particular point that he has wanted his thesis to underscore. He remarks,

> *We come to the conclusion that the scheme of physics was mainly determined by the economic and technical tasks which the rising bourgeoisie raised to the forefront. During the period of merchant capital the development of productive forces set science a series of practical tasks and made an imperative demand for their accomplishment.*[193]

Hessen noted that the further development of trade—merchant capital—depended on improved transport. Naturally, water was the most efficient means of transport for goods. Hence, the economic development at the time set the following technical problems for transport.

1. To increase the tonnage capacity of vessels and their speed,
2. To improve the floating qualities of ships,
3. To develop means for better navigation,
4. To improve the construction of canals and docks.

[193] Ibid., p. 167

The efforts to resolve the technical problems 1, 2 and 4 were what later gave rise to the scientific studies in hydrostatics and hydrodynamics while no.3 involved the development of chronometers and was also correlated with studies in mechanics. In fact, Hessen thesis provided a classical Marxist twist to the factors that provided major boost to the rise of early modern science than had done Merton´s thesis on Puritanism and science. And for the period throughout the 1930s and 1940s the Hessen thesis provided a platform unto various theses in same direction were created.

2.9.1 CLASSICAL MARXIST HISTORIOGRAPHY OF SCIENCE

Classical Marxist historiography of science (2009) is the title designated by Gideon Freudenthal and Peter McLaughlin to illustrate the core Marxist approach to the historiography of the Scientific Revolution and the methodology of the historiography of science inaugurated by the similar works of Boris Hessen and Henryk Grossmann. The classical marxist historiography of science captures what they called ´The Hessen-Grossmann-thesis. Boris Hessen's "The Social and Economic Roots of Newton's 'Principia'" (1931) and Henryk Grossmann's "The Social Foundation of Mechanistic Philosophy and Manufacture" (1935) are the classic programmatic examples of Marxist historiography of science.[194] Even though these works were produced independently Gideon and Peter saw it reasonable to conjoin the two theses because ´both scholars were working within the same intellectual tradition with the same conceptual tools on the same topic´. Besides, while many Marxists have contributed to the historiography of science, Hessen's and Grossmann's work displays a specifically Marxist approach: they conceptualize science as one kind of labour within the system of social production. However, works like these has been criticised as negative paradigm of externalism because their explanation of scientific thought undermine the autonomy of its internal development as a process guided above all by an inherent logic all its own

[194] Gideon Freudenthal & Peter McLaughlin, eds., ¨Classical Marxist Historiography of Science: The Hessen-Grossmann-Thesis¨, in *The Social and Economic Roots of the Scientific Revolution*, Boston Studies in the Philosophy of Science (Boston: Springer, 2009) 278, p. 1

2.10 HERMETICIST HISTORIOGRAPHY OF FRANCES YATES THESIS

Dame Frances Amelia Yates (Nov. 1899 – Sept. 1981) was a noted British historian. She taught at the Warburg Institute of the University of London for many years. Among her major works are ´Giordano Bruno and the Hermetic Tradition´ (1964) and ´The Rosicrucian Enlightenment´ (1972) in which she illustrated the Hermeticist reinterpretation of the Scientific Revolution. In the Rosicrucian Enlightenment, she made important statement on the hermetic tradition and the new science. She noted how Elias Ashmole, charter member of the Royal Society, had written of the hermetic John Dee and the Rosicrucian Michael Maier in his *Theatrum chemicum* and how Newton, a later member of the Royal Society, owned and read not only Ashmole´s alchemical collection but also the same Rosicrucian material to which Ashmole had referred. She wrote thus,

> *Now it would have been clear to the attentive reader of Ashmole´s Theatrum that this work was ´Rosicrucian´ in sympathy, that it was in fact a kind of continuation of Michael Maier´s revival of English alchemy in the German Rosicrucian Movement.*[195]

She illustrated that behind the great exoteric movement typified in Newton's achievements in mathematics and physics was another exoteric movement that has root in Rosicrucian alchemy. She maintained that the Rosicrucian movement of ´Magia, Cabala, and the Alchemy must have tinged the new science.

According to her, various influential Renaissance philosophers were greatly influenced by the Hermetic corpus of writing. Consequently, through the Rosicrucian manifestoes of 1614-1615, the advent of new knowledge was proclaimed all over Europe by the Rosicrucian movement, and thus prepared the European mind for the Scientific Revolution. Among great scientists, she discussed in detail were, Kepler, Descartes,

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[195] Francis Yates, *The Rosicrucian Enlightenment.* (London: Routledge & Kegan Paul, 2010 [1972]) p.250

Newton and Bacon. She demonstrated Kepler´s immersion in the Hermetic atmosphere of the court of Rudolf II in Prague and Newton's efforts in alchemy.

Rosicrucianism was described as a Paracelsian current in hermetism that was more given to scientific curiosity. She highlighted that it was through Rosicrucianism that hermetic tradition became an antecedent of modern science. Therefore, the seventeenth-century science could be seen as a mathematical and mechanical manifestation of the same impulses expressed in magical and animist philosophies of nature in the preceding century.[196]

This thesis tends to show that the Scientific Revolution was not so much the beneficial triumph of rational thought about nature, but rather the agent chiefly responsible for the destructive handling of nature, whose consequences we find ourselves facing in the late 20th century. Hence, the rise of modern science cannot be dissociated from its relations to hermeticism. However, some historians of the Scientific Revolutions disagree on the significance of the Yates thesis, especially on its affirmation on the Rosicrucian motivations in Newton's science.

2.11 STEVEN SHAPIN´S VIEW OF THE SCIENTIFIC REVOLUTION

Steven Shapin´s ¨*Scientific Revolution*¨ started with the provocative that ¨There was no such thing as the Scientific Revolution.¨[197] However, he ended up telling the usual stories about great characters of scientific traditions such as Copernicus, Galileo, Bacon, Descartes, Boyle, Hooke, Huygens, and Newton. Nevertheless, the book is very significant in two important respects. The first pertains to its organization. It is organized around three key questions: What was known?[198]; how was it known[199]; and what was the knowledge for?[200] Shapin suggests that ´The Scientific Revolution´ was a

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[196] Brian P. Copenhaver, ¨Natural magic, hermetism, and occultism in early modern science¨, in *Reappraisals of the scientific revolution*, eds. David C. Lindberg & Robert S. Westman (London: Cambridge University Press, 1990) p. 261

[197] Steven Shapin, *The Scientific Revolution,*p. 1

[198] Ibid., p.15

[199] Ibid., p.65

[200] Ibid., p. 119

period in which new answers to these questions were forged. The second significance of the book is a bit more substantive. Shapin believes that the key figures of the revolution were a heterogeneous lot, divided over many issues and practices. Perhaps, this is a dimension of the history of this period which other historians have tended to ignore. Most importantly, he stresses the continuity of seventeenth century science with its medieval past. The new ideas in science, he says, were situated in a wide cultural context and were closely related to religious, political, and economic changes. But then, he was not only interested in this context, he sought to x-ray what people actually did when they practiced science, and who these people were. Nonetheless, Shapin' s notion of the scientific revolution could be capitulated under five major issues. These issues reflect the basic concepts that underlie what appeared to be his rejection of the existence of such thing as the scientific revolution.

They include:

1. Mechanism
2. Objectivism
3. Methodology
4. Impartiality
5. Altruism

These factors will be clearly explained so as to show the vital illustrations they reflected on his concept of scientific revolution.

2.11.1 MECHANISM

This is a framework which emerged during the late fifteenth century to the early seventeenth century. It is the preference of modeling the natural world, explicitly, ´on the characteristics of a machine.´[201] Before this period, nature was considered as an animated entity whose elements have the character of striving to achieve their natural ends. This concept explains the natural motion on the basis of animistic and teleological

[201] Ibid., p. 30

interpretations. For instance, such interpretation would describe the tendency of a stone to fall at the centre of the earth on the basis that it is in the nature of the stone to do so.

On the contrary, the concept of mechanism is the preference to reconstruct the natural world in an artificial way by employing mechanical means. It strived to reconstruct nature, wholly, on concrete or tangible interpretations. This preference was motivated by the desire to explain and model physical realities in terms of artifacts. Therefore, the interpretation of matter and motion of physical realities were made in terms of size, shape and position.

Most importantly, the preference of mechanism over naturalism was on the basis that the latter was not intelligible and accurate. But then, Shapin emphasized that mechanism does not reflect much intelligence than naturalism. This is because mechanism also failed to give a perfect representation of nature with mechanical interpretations as it claimed. Based on this, it is not justifiable to place the superiority of one over another.

2.11.2 OBJECTIVITY

In science, objectivity is often bounded up with questions about the truth and referential character of scientific theories. The claim of objectivity affirms that the view provided by science is an accurate description of the facts of natural world as they are. The implication of this claim is that the view provided by science is one achieved by reliance upon non arbitrary and non-subjective criteria for developing, accepting and rejecting the hypotheses and theories that make up the view. Likewise, it demonstrates that the truth character of the scientific theories stands independent of the influence of the scientist that discovered and developed them. Therefore, they are wholly objective.

However, Shapin illustrated that this claim was construed by the science practitioners of the early modern period. They believed to have achieved relative confidence in their accounts of what the real underlying structure of the natural world was like. It is against this background that they caricatured as unscientific and subjective any account of nature that is not construed on the exact form of the natural facts as they are in

themselves. In other words, a perfect account of the structure of the natural world should not be influenced by religious, political, economic or social motives. But then, Shapin emphasized that this claim cannot be true since the pure pursuit of objective truth by disinterested human beings is not possible.

2.11.3 METHODOLOGY

The crucial factor at the centre of the controversy for the authentic pattern of practicing science is the problem of method. Shapin shows with clear elucidation that this controversy was even acute during the early modern period. For him, it is unfortunate that such period should be acclaimed as the era of the scientific revolution. It is not logical that an era that is marked by heterogeneity and even the contested status of the natural knowledge should be observed or portrayed as the period at which the best method of doing science emerged.

He indicated that just as seventeenth-century moderns diverged about the proper construal and philosophical role of experience, so they differed on questions of *method* to be employed in making natural philosophical knowledge.[202] According to Shapin,

> *¨Method was meant to be all. Method was what made knowledge about the natural world possible and powerful, even though prescriptions for that proper method varied greatly¨*[203]

Moreover, it was generally believed that methods could be devised for mechanical guidance to inquirers since ´the uninstructed senses were apt to deceive.´[204] Such methods were accepted to be the key to providing the discipline necessary for understanding nature.

Nevertheless, Shapin maintained that the corpuscular, mechanical and mathematical interpretations were just choice-patterns adopted to carry out the project of the

[202] Ibid., p. 90
[203] Ibid., p. 90
[204] Ibid., p. 30

objectification and mechanization of nature. But then, these methods could not even satisfy, efficiently and effectively, the problem-field they were deployed to treat. Besides, they are often dominated by the principles developed in the Aristotelian natural philosophy. And so, the seventeenth century science is, simply, a continuity of its medieval past.

2.11.4 IMPARTIALITY

Scientific judgement is usually referred as unbiased. It does not have the imprints of subjective and socio-cultural factors. This implies that the truth and objectivity of the scientific knowledge are correct and impartial. Hence, the judgement or postulation about scientific facts or theories is devoid of interference of the cultural, social or economic interests of the context within which an individual scientist works. In this regard, the scientist speaks impartially when he presents scientific facts or theories. As such, he presents, in an objective sense, the truth-character of the scientific facts or theories.

However, Shapin stressed, strongly, that even the science of the early modern period had some influences from its medieval past. Likewise, there were great influences of other historical events. Therefore, the new ideas in early modern science were all situated in a wide cultural context, and they were closely related to religious, political, and socio-economic changes.

Of course, ´no body of culture is able to wholly reject its past´.[205] And so, the distancing of the modern science from its ancient and medieval past was more of a rhetorical stance than a reality. In fact, the picture of science that accompanied this rhetoric needs to be rejected. The new science has been inaccurately portrayed as something that is not subject to the various social forces that influence all other human institutions. Even the modern's rhetoric about methodology was a myth. Shapin grants that such myths ´may have real historical functions´ to both justify the new science and distinguish it from other practices.[206] But as far as he is concerned, science no longer needs this facade.

[205] Ibid., p. 67
[206] Ibid., p. 95

Modern science has an integrity that is not threatened by social analyses, for it is a reliable source of knowledge, despite the fact that it is as affected by social factors as its pre-modern predecessors were.

2.11.5 ALTRUISM

Shapin emphasized here that science can hardly stand independent of the social or historical context in which it is practised. The structure of the scientific knowledge bears some resemblance to the cultural context within which it emerged. The interplay between the progress of the scientific knowledge and the religious, social and political changes in Western Europe is a typical example. The principles of science are often utilized to restructure the patterns of religious, social and political institutions. In like manner, the changes in the religious and social political structures also influence the progress of science.

Therefore, science is a contingent, diverse, and at times, deeply problematic product of interested, morally concerned, and historically situated individuals.

2.11.6 THE ANTHROPOCENTRISM OF THE ARISTOTELIAN NATURAL PHILOSOPHY

The anthropocentrism of the Aristotelian natural philosophy centers on the fact that all natural motion has developmental character.[207] The basic natural elements like earth, water, air and fire have their unique natural motions. As such, natural motion always tends to natural place**.**[208] Shapin stated thus:

> *Bodies naturally moved so as to fulfill their natures, to transform the potential into the actual, to move toward where it was natural for them to be. Aristotelian physics was in that sense*

[207] Ibid., p. 29
[208] Ibid., p. 29

> *modeled on biology and employed explanatory categories similar to those used to comprehend living things.*[209]

This implies that all natural motions have natural motives attached to them. However, the overthrow of this naturalistic physics began with Galileo's interpretation of his observation of the dark spots on the surface of the sun. Galileo demonstrated clearly that these spots are not far from the surface of the sun. They are either contiguous to it or separated by interval so small as to be quite imperceptible. Initially, the Aristotelian natural philosophy made distinctions between the physics of the heavens and of the earth by attributing mutability and decay to the components of the earth and immutability and perfection to the components of heaven. Consequently, the rejection of the traditional physics of motion was on the basis of its teleological and animistic features. It was disparaged as absurd and unintelligible.

Nevertheless, Shapin reiterated that the rejection of the Aristotelian physics on the basis of unintelligibility was not logical. This is because the mechanical physics does not prove more intelligible either. For instance, what superior intelligibility can one discover in mechanism which speaks of the matters of facts and their physical causes when the causes which these matters of facts testify to are not visible and accessible to the senses?

2.11.7 MECHANIC—CORPUSCULARIANISM

The centre point of mechanical physics is the interpretation of the structure of the natural world on its resemblance to the physical artifacts. Of course, the naturalistic interpretation had been denigrated and rejected on the basis that it conceded teleological motives to the natural elements. Invariably, the destinies of those elements belonged naturally to them. But then, the mechanical interpretation sought to shift these destinies to the control of the forces that can be manipulated and regulated so that the true nature of these elements can be studied and known.

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[209] Ibid., p. 29

Eventually, the method that was employed to the study of nature was the reinterpretation of well-known observations in terms of the physical motion and interactions of corpuscles. Therefore, all sensory appearances, including color, taste, and even weight was explained in terms of the size, shape, position, and motion of the elementary corpuscles of base matter. To attribute other qualities to the elementary atoms will be to resort to occultism.

The error of mechanic-corpuscularianism is that it goes to the extreme of trying to explain the mechanism of the corpuscles in a realm that could not be observed, and also to attribute to them properties which, intrinsically, they do not possess. For instance, the sweetness of a pineapple juice could be explained on the basis of the shape or size of the corpuscles whereas there is no visible observation which shows that such properties belong to them. Therefore, the lack of adequate mechanical interpretations for all physical realities makes it illogical to say that the mechanic—corpuscularianism was more intelligible and accurate than the naturalistic account.

2.11.8 SCIENTIFIC REVOLUTION AS METHODOLOGICAL DYNAMISM

The goal of all the philosophers, both mechanical and natural, had been, implicitly or explicitly, the production and extension of true or probably true knowledge. The only difference can be on the procedure or modality of the search for this truth. Each method is really authentic in as much as it offers adequate explanation to the problem field it is deployed. Thus, it is quite implausible to talk of the ¨essence¨ of the scientific revolution in just one historical era like the early modern period. Besides, this period had the most heterogeneous and even contested status, of the scientific knowledge.

Therefore, Shapin maintained that what was ¨really new¨ and ¨really important¨ in the seventeenth century was the mathematization of the study of motion and the destruction of the Aristotelian cosmos. But then, he stated thus,

> *¨Despite widespread contemporary professions of a natural ¨fit¨ between mechanism and mathematically expressed physical regularities or laws did not depend on belief in their mechanical causes. That is to say, although the mathematization of natural*

> *philosophy was certainly an important feature of seventeenth-century practice, professions of a constitutive relation between mechanism and mathematics remain problematic¨*[210]

This is to show that there were contestations on the efficiency of the mathematically formulated binding laws of nature. Some philosophers of science argued in its favour, while others doubted that such mathematical representations could capture the contingencies and the complexities of real natural processes. Shapin quoted Francis Bacon and Charles Boyle to have said that mathematical accounts worked very well when nature was considered abstractly and less well when it was addressed in its concrete particularities. Hence, he concluded that, though in traditional accounts fundamental changes in mathematical physics constitute the ¨essence¨ of the Scientific Revolution, the culture of physics and the mathematical sciences is not coextensive with ¨early modern science¨.

2.12 THOMAS S. KUHN— KUHNIAN THESIS

The originality of Kuhn's book titled *¨The Structure of Scientific Revolutions¨* lies precisely in the refined manner in which he brought together all kinds of previously wide-apart ideas on the historical growth of science and made them merge both with one another and with a number of ingredients of his own making so as to yield a smoothly appealing account of the revolutionary character of science. Kuhn demonstrated that there were scientific revolutions and they are responsible for the rapid advancements achieved in modern science. These advancements had not been uniform, but had followed normal and revolutionary phases. Hence, he tried to recapitulate the dynamic nature of the activities that go on among the scientists before and after revolutions, and the factors that make these activities progress through revolutions.

The major factor in Kuhn's illustrations of the scientific revolution is the concept of the paradigm. Paradigms are the universally recognized scientific achievements that for a time provide model problems and solutions to a community of practitioners. They

[210] Ibid., p. 58

determine the legitimate problems and also deploy the tools with which they are solved. In other words, the paradigm is the shared belief which the practitioners of a science field have on the how the natural world is like. And so, it determines the problems, methods, and solutions within the given field.

This common belief makes the adherents to be fully committed as they confidently employ the tools to the problems with the assurance that it provides all the possible explanation needed in this field. But then, when the paradigm proves incapable of providing solution to certain problems in some acute cases, a period of crisis begins and eventually ends with a revolution.

Therefore, scientific revolutions are those non-cumulative developmental episodes in which an older paradigm is replaced in whole or part by an incompatible new one. And so, the progress of the scientific advancement cannot be a uniformed process. Rather, it is a process with both normal and revolutionary phases. Consequently, the above illustrations imply that an adequate knowledge of Kuhn's concept of the paradigm is tantamount to having clear understanding of his concept of the scientific revolutions. Thus, it will be to understand properly what a paradigm means.

2.12.1 WHAT IS PARADIGM?

In the simplest form, paradigm is an accepted model or pattern. An accepted model or pattern shows a uniform or particular way of doing something. Likewise, the acceptance that is involved implies a conviction or belief in the effectiveness of the model or pattern that has been accepted. The accepted model acts like a guide or standard against which possible problems or puzzles can be resolved. This illustration is just an attempt to capture the ordinary sense of what a paradigm is.

According to Kuhn, paradigm provides the legitimate problems for a given science field, and the tools for solving those problems. It is largely a promise of success discoverable in selected, and still incomplete, examples. Hence, it posits a number of selected problems and offers the tools that at given time provide the solutions to the

problems. As such, it is able to sustain the confidence and adequate commitment of its adherents by focusing attention to small range of relatively esoteric problems.

The scientist who is guided by a particular paradigm is not just doing an undefined work. He knows the problem he is treating and at the same time has anticipation of what the result will be with the tools he deploys to solve the problems. In following this pattern, the paradigm forces the scientist to investigate in some part of nature, in detail and depth. Hence, paradigms help scientific communities to *bound* their discipline by offering them the capacity to create avenues of inquiry, formulate questions, select methods with which to examine questions, and define areas of relevance

However, it happens that at some critical times the problems which ought to be solved by known rules or procedures deployed by the paradigm resists repeated trials of the most capable members of the group within whose competence it falls. Likewise, particular instruments that had been used before to solve usual problems fail to perform in anticipated form. Such situations imply the existence of crisis in that particular science field.

The period of crisis leads to what Kuhn called ´extraordinary investigation´ from which emerges new set of commitments to another paradigm. Consequently, there is a shift from one paradigm to another—an occurrence known as paradigm shift.

In conclusion, paradigm can be described as a mix-up of theoretical and methodological belief that permits selection, evaluation and criticism in scientific research. The complex sense in which the term ´paradigm´ was employed to elaborate a coherent account of consensus formation in critical moments in the scientific progress has been the major source of its criticism and to the kuhnian thesis as a whole. Its usage has often ranged from ¨a concrete scientific achievement¨[211] to a ¨characteristic set of beliefs and preconceptions.¨[212] The set of beliefs has sometimes include instrumental, theoretical,

[211] Thomas Kuhn, *The Structure of Scientific Revolutions* (Chicago: University of Chicago Press, 1996) p. 11
[212] Ibid., p. 17

and metaphysical commitments together.[213] However, Kuhn acknowledged his critics´ complaint that he had used the term *paradigm* ambiguously.

Responding to this criticism in *The Essential Tension* (1977) Kuhn introduces two new terms to stand for the two of the most important sense of *paradigm: exemplars* and *disciplinary matrices.*[214] Exemplars are concrete problem solutions, accepted by a scientific group as, in a quite usual sense, paradigmatic. They are the types that appear at the end of chapters in science texts, in laboratory exercises, and on examinations. The exemplars are very important to teaching students of science how to use theories to solve problems, and such students become scientist by recognizing and imbibing the tacit knowledge implicit in the exemplars.

Kuhn refers to the *disciplinary matrices* as symbolic generalizations, models, and exemplar.[215] It is important to note that it is in this second, more inclusive sense of *paradigm* that Kuhn employs in many of his more challenging and controversial claims about science. Therefore, most of Kuhn elaboration of *paradigm* in consensus formation in science should be understood in this notion of disciplinary matrices.

2.12.2 THREE PHASES OF THE SCIENTIFIC ENTERPRISE

Kuhn used the concept of the paradigm to make distinctions between three phases of the scientific advancement. The first phase describes the period of science in which there were no coherent traditions, but only a disarray of incompatible theories aim at explaining physical realities. He called this phase the pre-paradigm phase. The second phase described the emergence of mature science which has all the characteristics that make a field of study scientific. It was this phase that he tended to illustrate as the proper history of science. For Kuhn, this second phase which is called normal science captures the whole scope of the scientific enterprise. Lastly, sporadic failures of efforts within the normal science lead the third phase which is referred to as the revolutionary science. This period of science refers to the durations of transformation in a scientific

[213] Ibid., pp. 39-42
[214] Thomas Kuhn, *The Essential Tension,* pp. 297-298
[215] Ibid., p. 297

field. Hence, it does not capture the full nature of the scientific enterprise, even though it is an essential ingredient that determines the dimension of the scientific progress.

2.12.3 PRE-PARADIGM PHASE

This is the prehistoric period of science, in which there was no consensus on any particular theory, though the researches that were carried out could be regarded as scientific in nature. This phase was characterized by several incompatible and incomplete theories. Making reference to the radical change brought by Newton's work which marked the beginning of the new science, Kuhn commented thus:

> *¨No period between remote antiquity and the end of the seventeenth century exhibited a single generally accepted view about the nature of light. Instead there were a number of competing schools and sub-schools, most of them espousing one variant or another of Epicurean, Aristotelian, or Platonic theory¨.*[216]

This shows that this phase was more or less, the prehistoric antiquity of science in which there were competing schools of thought geared towards giving varying explanations on certain physical phenomena. Thus, it proceeded without proficient standard against which achievements could be measured. According to most philosophers of science, this phase of science does not qualify as science per se. Besides, we simply beg the question if we talk about ´science´ as though it always existed.

2.12.4 NORMAL SCIENCE

The second phase is the normal science in which puzzles are solved within the context of the dominant paradigm. Normal science embraces all the normal activities of the

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[216] Thomas Kuhn, *The Structure of Scientific Revolutions,* p. 12

community of scientists when there is no crisis. As long as there is general consensus within the discipline, normal science continues. Its activities are those premised on the assumption of knowing what the world is like, and the eagerness to defend this assumption. There is common belief on the standard set of problems and the methods to be used in solving them. And so, the choice of supporting observation and experiment is guided by the shared belief.

In normal science, scientific research is carried out on the assumption that only certain sorts of circumstances will arise. The scientist, conveniently, apply a particular piece of apparatus in a particular way because he anticipates a particular form of solution for a result.

Normal science has a peculiar role. According to Kuhn, this role consists in the actualization of the success promises implicit in an accepted model. The success promises are discoverable in selected and still incomplete examples. There are three ways by which this role is achieved. They are stated as follows:

1. Extension of the knowledge of those revealing facts illustrated by the paradigm.
2. Increasing the proximity between the realities of those facts with the predictions of the paradigm.
3. Further articulation of the paradigm itself.

The aforementioned patterns by which the normal science performs its role show that it is highly enclosed within itself. In fact, it is dogmatically structured. It does not seek for novelty neither does it has the disposition to incorporate any form of novel phenomena within it. For Kuhn, this peculiar characteristic of the normal science shows why the changes in paradigms bring about drastic transformations which transfigure the world of the scientist.

In summary, normal science is the scientific research which deals mainly on the articulation of those phenomena and theories already supplied in the paradigm. But then, over some period of time, progress in normal science may reveal anomalies; facts which are difficult to explain within the context of the existing paradigm. Usually, while

these anomalies are resolved, in some cases they may accumulate to the point where normal science becomes difficult and where weaknesses in the old paradigm are revealed. This leads to a period of crisis, of which, when adequate efforts employed at resolving them fail, it yields to the third phase called the revolutionary science.

2.12.5 REVOLUTIONARY SCIENCE

This is the phase in which the underlying assumptions of a scientific field are reexamined and a new paradigm is established. After the new paradigm's dominance is institutionalized, scientists return to normal science, solving puzzles within the new paradigm. A science may go through these cycles repeatedly, though Kuhn notes that it is a good thing for science that such shifts do not occur often or easily. Hence, it is incorrect to view science solely from this revolutionary phase since it does not capture the exact nature of the scientific enterprise. He reiterated that neither science nor the development of knowledge is likely to be understood if research is viewed exclusively through the revolutions it occasionally produces.[217]

2.12.6 THE ROLE OF ANOMALIES IN SCIENTIFIC DISCOVERIES

An anomaly is discovered when the paradigm-induced expectation within a particular area of the scientific research fails to be actualized. Its occurrence leads to a period of crisis which is intensified with the despair on the effectiveness of the paradigm. Eventually, it results to the loosening of the rules of normal science. And then, greater attention is focused on the area in which the anomaly has occurred so as to resolve it.

The vital importance of the anomalies in the scientific research is that they facilitate the emergence of scientific discoveries. They perform this role by the inducement of extraordinary research. Extraordinary research begins when the scientists try to resolve,

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[217] Thomas Kuhn, ¨Logic of Discovery or Psychology of Research¨, in *Philosophy of Science*, eds. Curd, M & Cover, J. A (New York, London: W. W. Norton & Company, 1998) p. 14

by other means, problems that have defied the application of the tools deployed by the current paradigm.

During this period of crises, the paradigm does not hold much force on the scientists. Rather, they are guided more by individual experience and skills acquired during the time of commitment to the paradigm.

Consequently, individual scientists begin to encounter novel phenomenon which the commitment to paradigm obstructed them from seeing. Hence, discoveries commence with the awareness of anomalies, and the consequent exploration of the area at which they occur. This extended exploration results to the adjustment of the paradigm theory, which makes the anomaly become a normal phenomenon.

Most importantly, Kuhn has shown that the transition from one paradigm to another is not a simple event which receives the approval of all scientists. The fact is that the debates that take place among the opposite groups during the period of crisis ensue from strong polarized ends. Each group tries to defend their stand from the frontiers offered by their respective paradigms. Nevertheless, scientists learn to see nature in a different way when the new fact discovered has been recognized as truly scientific.

2.12.7 THEORY OF INCOMMENSURABILITY

Kuhn argued that in scientific revolutions it is not only the scientific theories that change but the very standards by which scientific theories are judged, so that the paradigms that govern successive periods of normal science are *incommensurable.*

The thesis of incommensurability is based on the fact that vocabulary used in some given theory is semantically dependent on that theory. As such, the terms of successor theories have different meanings. Hence, comparison between the theories cannot be as straightforward, or rather; there cannot be fully adequate translation of terms between theories. This thesis responds to the traditional view which proposes that since new paradigms are born from old ones, they incorporate much of the vocabulary and

apparatus that the traditional paradigm had previously employed, though these elements are employed in different ways

Theories are incommensurable when they share no common measure. Normally, paradigm provides the puzzle-solutions in a given science field. As such, it is the measure upon which puzzle-solutions are developed. This implies that puzzle-solutions developed in different eras of normal science will be judged by comparison to differing paradigms, and in that case, they lack a common measure. Three important issues are deducible from the incommensurability thesis.

1. There is no common measure because the methods of comparison and evaluation often change.
2. Observational evidence cannot provide a common basis for theory comparison, since perceptual experience is theory- dependent.
3. The fact that the language of theories from different periods of normal science may not be inter-translatable presents an obstacle to the comparison of those theories.

Consequently, Kuhn reiterated that successive theories are incommensurable (which is not the same as incomparable) in the sense that the referents of some of the terms which occur in both are a function of the theory (and belongs exclusively to it) within which those terms appear. Hence, there is no neutral language available for purposes of comparison. Nonetheless, translation is in principle possible. But to translate another's theory is still not to make it one's own. Therefore, the incommensurability thesis implies that scientists of rival theory who are converted to adopt a new theory practice a totally different new science with totally new foundation

2.12.8 IMPLAUSIBILITY OF THE FALSIFIABLITY THEORY

The philosophy of science of Sir Karl Raimund Popper (1902—1994) illustrated that the, ¨criterion of the scientific status of a theory is its falsifiability, or refutability, or

testability.[218] Contrasting the Einstein theory of relativity with the Marxist and Freudian theories, he illustrated that the superiority of the Einstein theory is that it ran a serious risk of refutation by predicting the result of an observational test before the test was made. It was this success that led to its overthrow of Newton's theory of gravity. Therefore, Popper shows that the genuineness of a scientific theory lies in its possibility of being refuted by observation and experiment. According to Imre Lakatos:

> *Popper's distinction lies primarily in his having grasped the full implications of the collapse of the best-corroborated scientific theory of all times: Newtonian mechanics and the Newtonian theory of gravitation. In his view virtue lies not in caution in avoiding errors, but in ruthlessness in eliminating them. Boldness in conjectures on the one hand and austerity in refutations on the other.*[219]

However, Kuhn insisted that this kind of kind of philosophy of science, as Popper demonstrated, does not reflect the actual nature of the intricate events which bear on history of science. Besides, no process yet disclosed by the historical study of scientific development resembles at all the methodological stereotype of falsification by direct comparison with nature.[220] Philosophy of science ought to describe the ways scientist actually behave, and the way that science has evolved over time. It is in this regards that Popper's philosophy of science lacks credibility. Consequently, the falsifiability theory does not show the real structure of the scientific progress.

According to Kuhn, the concept of falsifiability is unhelpful for understanding why and how science has developed as it has. In the practice of science, scientists will only consider the possibility that a theory has been falsified if an alternative theory is available which they judge more credible. If there is not, scientists will continue to adhere to the established conceptual framework. If a paradigm shift has occurred, the

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[218] Karl Popper, ¨Science: Conjectures and refutations¨, in *Philosophy of Science*, eds. Curd, M & Cover, J. A(New York, London: W. W. Norton & Company, 1998) p. 7

[219] Imre Lakatos quoted by John Worrall & Gregory Currie, eds., *The Methodology of Scientific Research Programmes* (Cambridge: Cambridge University Press, 1980) Vol.1, p. 8

[220] Thomas Kuhn, *The Structure of Scientific Revolution,* p. 77

textbooks will be rewritten to state that the previous theory has been falsified. This implies, then, that the aim of practicing scientists is not to call into question Newtonian mechanics or the laws of thermodynamics, but to see whether they can solve problems by using accepted theories in conjunction with other assumptions and models. Therefore, the failure to solve a science puzzle, with an accepted theory, at the time of normal science is considered the fault of the scientist using the theory and not the theory itself. However, it is only during periods of crisis do scientists deliberately question the received theories of their day and attempt to refute them.

Kuhn concluded that if falsifiability was the criterion for distinguishing science from pseudoscience, then, genuine science as it is done most of the time, being normal and not extraordinary, would be improperly classified as pseudo-scientific.[221] However, Kuhn´s view of the scientific advancement has been criticized by Philip Weiner. He sees Kuhn´s view as an important logical problem in the philosophy of science. He argued that current scientific theories do not ¨destroy¨ previous theories, ¨if ´destroy´ means eliminating them completely along with their confirmatory evidence,¨ but rather they ¨correct¨ them by situating them in a larger explanatory context.[222] For Weiner, a logical continuity exists between the data of the previous theory and the more precise data and enlarged framework of the current theory; hence, a current theoretical ¨explanation is part of the cumulative growth of scientific explanations.¨[223]

2.12.9 QUINTESSENCE OF SCIENTIFIC REVOLUTIONS

The above illustrations of Kuhn's view of scientific revolution demonstrate clearly why Kuhn has stressed that the progress of science do not follow uniform pattern, but has normal and revolutionary phases.

Interestingly, the essence of the scientific revolutions as he has shown is that the consequent shifts in paradigms bring about tremendous transformations of the world within which scientific work is done. It results to detailed and deep understanding to the natural phenomena, and also makes chance for further articulation of this understanding.

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[221] Curd, M. and J. A. Cover eds., *Philosophy of Science* (New York, London: W. W. Norton & Company, 1998) p. 68

[222] Philip P. Weiner, ¨Review, The Copernican Revolution,¨ *Philosophy of Science,* 1958, 25, p. 298

[223] Ibid.

Kuhn´s final approach to scientific development was through the analysis of three scientific revolutions: the shift from Aristotelian to Newtonian physics, Volta´s discovery of the electric cell, and Planck´s black-body radiation research and quantum discontinuity. From these examples, Kuhn derived three characteristics of scientific revolutions. The first is holistic. According to Kuhn, a scientific revolution´s ¨central change cannot be experienced piecemeal …Instead, it involves some relatively sudden and unstructured transformation in which some part of the flux of experience sorts itself out differently and displays patterns that were not visible before.¨[224] This implies that scientific revolutions are all-or-none events. The second characteristic of scientific revolutions is the manner referents change after a revolution. Kuhn argued that ¨the distinctive character of revolutionary change in language is that it alters not only the criteria by which terms attach to nature but also, massively, the set of objects or situations to which those terms attach.¨[225]

The third feature involves ¨a central change of model, metaphor, or analogy—a change in one´s sense of what is similar to what, and of what is different.¨[226] These three characteristics of the scientific revolutions signify that it is not just the knowledge of the world that changes after a revolution but also the knowledge of the words used in science. Kuhn summaries what I tend to call the quintessence of the scientific revolutions thus,

> *The central characteristic of scientific revolutions is that they alter the knowledge of nature that is intrinsic to language itself and that is thus prior to anything quite describable as description or generalization, scientific or everyday …. Violation or distortion of a previously unproblematic scientific language is the touchstone for revolutionary change.*[227]

Finally, the advancement of the scientific knowledge through revolutions does not reflect a decline or rise in standards of science. Rather, it reflects the changes which are

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[224] Thomas Kuhn, ¨What are Scientific Revolutions?,¨ in *The Probabilistic Revolutions: Ideas in History,* eds. L. Kruger, L. J. Daston & M. Heidelberger (Cambridge, MA: MIT Press, 1987), vol. 1 p. 9
[225] Ibid., p. 19
[226] Ibid., p. 20
[227] Ibid., p. 21

necessitated by the paradigm shifts. Hence, Kuhn illustrated that since a paradigm shift means complete abandonment of an earlier paradigm, and there is no common standard to judge scientific theories developed under different paradigms, there can be no sense in which theories developed after a scientific revolution can be said to add cumulatively to what was known before the revolution. Only within the context of a paradigm can we speak of one theory being true or false.

2.13 KUHN AND SHAPIN THESES IN CLOSE PERSPECTIVE

Both concepts seem to have been deeply structured with reliance on some sticky issues already illustrated in previous historiographies of science, even though they strived to present their own unique account of the Scientific Revolution. It is quite remarkable how both concepts sought to make precise analysis or resolution to the different striking issues demonstrated in the new historiography of science. These new historiographies sought to address certain irreconcilable issues inherit in the ´Great Tradition of the historiography of the Scientific Revolution[228] which chronicles the developmental lines for the sciences as ¨successive increments¨.[229] Thomas Kuhn's *´The Structure of Scientific Revolutions´* and Steven Shapin´s *´Scientific Revolution´* followed the tune of the new historiography. This explains why both books commenced with references to names like Alexandre Koyré, and Herbert Butterfield. Kuhn mentioned Koyré´s name, in particular, and goes on to say that

> *Seen through the work that result, works perhaps best exemplified in the writings of Alexandre Koyré, science does not seem altogether the same enterprise as the one discussed by writers in the older historiographic tradition. By implication, at least, these historical studies suggest the possibility of a new image of science. This essay aims to delineate that image by making explicit some of the new historiography's implications.*[230]

[228] H. F. Cohen, *The Scientific Revolution: A Historiographical inquiry*, p.122
[229] Thomas Kuhn, *The Structure of Scientific Revolution,* p. 2
[230] Ibid., p. 3

It implies that new historiographies sought to demonstrate that the concept of ´development-by-accumulation´[231] assign to the scientific advancement by the older historiographical tradition has proved very problematic in achieving its functions. Hence, the new historiographies had sought to demonstrate explicit failures of the older tradition by attempting to display the historical integrity of that science (early modern science) in its own time. Issues that are discussed boarders on the impact of humanism, Aristotelianism, Hermeticism and Neo-Platonism; the influence of Old magic and Alchemy, debates on rationality of early modern science, continuity with the medieval past, mathematization and mechanism; unrest in European culture and institutions, etc

Shapin comments,

> *As our understanding of science in the seventeenth century has changed in recent years, so historians have become increasingly uneasy with the very idea of ¨Scientific Revolution.¨ Even the legitimacy of each word making up that phrase has been individually contested. Many historians are now no longer satisfied that there was any singular and discrete event, localized in time and space that can be pointed to as ¨the¨ Scientific Revolution. Such historians now reject even the notion that there was any single coherent cultural entity called ¨science¨ in the seventeenth century to undergo revolutionary change.*[232]

The above citations show that both concepts were guided by the view that the reality of the Scientific Revolution was meditated by social circumstances, and the body of knowledge that proceeded from it has imprints of the some sociological factors that surrounded its participants.

In order to understand the underlying factors surrounding varying views in these two concepts it is necessary to resort to our earlier clarifications in section 1.2 between the terms ´Scientific Revolutions´ and the Scientific Revolution. ´Scientific Revolutions´ is a generic term. It stands for a *philosophical* idea about the on-going process of the

[231] Ibid., p. 2
[232] Steven Shapin, *The Scientific Revolution,* p. 3

scientific enterprise. It implies the idea that scientific discovery usually proceeds in a very radical way that is somewhat frequent. This view demonstrates that the advances in sciences take place in leap, and are not just small incremental additions. The term ´Scientific Revolution´ is a bit *specific*. It stands for a *historical* idea about one significant episode in the past of science, particularly the 17th century.

Shapin´s view is more in line with the description of the second term, and this shows why he wrote more as a historically-minded sociologist. Thus, he tends to demonstrate the nature of the scientific knowledge as both historically situated and a process which is socially driven. For Kuhn, Scientific Revolution did not occur once and for all, in the seventeenth centuries. It is an essential phase of science, which also aids its progress. Hence, Kuhn's view is mostly demonstrated in line with the first term. As such, he was more focused on underscoring the predominant factors responsible for why scientist that worked together, and were totally commitment to common belief at one point, get to differ at another.

Most importantly, both theses of the scientific revolution have their points of convergence and divergence on issues of the objectivity of the scientific truth, impartiality of scientific judgement and the issue of method upon which the rationality of Scientific Revolution is contested.

2.13.1 SCIENTIFIC OBJECTIVITY

The image of science as objective has a lot to do with our society's general high regard for science as an institution and for scientific method as a way of knowing. Traditionally, science is thought to provide views of the world that are objective in at least two different sense of the term. In one sense, objectivity is bound up in questions about the truth and referential character of scientific theories. In this sense, the claim of objectivity of science demonstrates that the account of the world as provided is an accurate description of the objects in the world and the relations among them as they really are. In the second sense, objectivity has to do with modes of inquiry. The claim of objectivity in this sense demonstrates that the account of the world provided by science

was arrived at by methods that rely on non-arbitrary and non-subjective criteria for developing, accepting, and rejecting the hypotheses and theories that make up that view.

Shapin emphasized that the claim of objectivity in science in the second sense is illogical due to the impropriety of treating ideas as if they floated freely in conceptual space.[233] The objectivity of the first sense is also contested. He illustrated that the science practitioner of the early modern period constructed such claim because they believed to have achieved relative confidence in their accounts of what the real underlying structure of the natural world was like.[234] But then, the mechanically explanation that was used to denigrate the Aristotle ´animistic´ physics, absolutely, failed in its function to give logical *match* between how the world was and how we experienced it.[235] In fact, the idea of science as an entity that emerges outside cultural and social context cannot be plausible since the ´Scientific Revolution´ is never a history of free-floating concepts. Besides, the relations between the scientific changes of the seventeenth century and changes in religious, political, and economic patterns are nonnegotiable. As such, the claim for the pure pursuit of objective truth of science by disinterested human beings cannot be true.

For Kuhn, the claim of objectivity in science does not do justice to the intricate dynamism inherent in the nature and unique advancement of science. The issue of arbitrariness, compounded of personal and historical accident cannot be wholly ruled out of science. He states,

> *An apparently arbitrary element, compounded of personal and historical accident, is always a formative ingredient of the beliefs espoused by a given scientific community at a given time.*[236]

This implies that the processes by which theories are tested, justified, or judged involves critical and complex situation which are often rectified, only, by the arbitrary elements of participating members. And so, the objectivity of the scientific truth which ensues

[233] Ibid., p. 4
[234] Ibid., pp. 50-57
[235] Ibid., p. 55
[236] Thomas Kuhn, *The Structure of Scientific Revolutions,* p. 4

from this exercise cannot be true in the ´objective sense´. He had enumerated five characters of a good theory to include, Consistency, Accuracy, Scope, Simplicity, and Fruitfulness. However, he maintained that they are insufficient to determine the decisions of individual scientists.[237] Hence, scientific truth is objective to the extent that arguments are based on the objectivity or rationality of shared values applied by proponents of rival paradigms at the time of theory choice.

The views of Kuhn and Shapin seem to illustrate, using David Bloor´s words, ´that scientific knowledge is *whatever scientists take to be* knowledge.´[238] They demonstrate that knowledge of natural reality is mediated by social circumstance, and this mediation requires empirical investigation. However, both of them were not intending to return to the absolute scepticism of David Hume. Neither are they trying to favour a kind of truth relativism. They sought to address some truth-questions of scientific advancement by focusing on the social relations. Nevertheless, the most confusing issue of Kuhn's view on objectivity is his insistence that the shared values such as accuracy, scope, etc are fixed and permanent features of science, while at the same time maintaining that these values can never determine the outcome of scientific revolutions. It implies that the epistemic values of science cannot be given any rational justification. In other words, he denies any objective progress of science. Science, he maintains, never progressed by virtue of some shared and binding algorithm of choice. Probably, the problem of induction could have been solved if there had been any philosophical justification for the epistemic values of science. Therefore, as long as science has not produced an algorithm able to dictate rational, unanimous choice, scientists would have no alternative but to supply subjectively what the best current list of objective criteria still lacked.

2.13.2 THE PROBLEM OF METHOD

The problem of method has been at the heart of the controversy of what determines a genuine science. Also, it has been the determining factor to the different dimensions of

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[237] Thomas Kuhn, *The Essential Tension,* p.325
[238] David Bloor, *Knowledge and Social Imagery*, p. 5

progress made in science. The problem of method received adequate analysis in Paul Feyerabend´s *´Against Method´* (1975) in which he illustrated science as an essentially anarchistic enterprise. However, he maintained that it is such anarchism that is more likely to encourage progress than its law-and-order alternatives.

Shapin argued that the seventeenth century witnessed the most turbulent quest for a coherent, universal, and efficacious set of procedures for making scientific knowledge than any other period in history science. And so, it is quite ridiculous to situate the origin of the scientific method in this period, and to refer to the changes wrought in those scientific beliefs and practices as ´revolutionary´. For Shapin, the goal of every scientist is to produce and extend true, or probably true, knowledge. Of course, both the natural and mechanical philosophers had, implicitly or explicitly desired to produce and extend such knowledge. Thus, it sounds unreasonable to differentiate or place the superiority of the one over another on the basis of intelligibility or accuracy.

Like Shapin, Kuhn reinstated that the scientific advancement does not reflect any upgrade of scientific method. The Aristotelian dynamics is no less scientific nor more the product of human idiosyncrasy than its Newtonian counterpart. Out-of-date theories are not in principle unscientific because they have been discarded.[239] Consequently, what differentiated various schools was not one or another failure of method—they were all ¨scientific¨—but because of their incommensurable ways of seeing the world and of practicing science. This is because the meaning variance which inevitably occurs wherever two theories differ makes it impossible that any valid logical comparison can be made between them. As such, the reductionist model whereby old theory is logically derivable from the theory that replaced it cannot depict the true nature of science. It means that each method is correct inasmuch as it satisfy the specific field to which it is deployed.

However, as Shapin tried to use the discussion on method to soft peddle the noise about the radical nature of the changes on the scientific knowledge of the seventeenth century, Kuhn illustrated that therein lies the essence of the scientific revolution. For Kuhn, the radical nature of the transition from one paradigm to another lies on the fact that the scientist resumes his work in a totally different way and with totally new method.

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[239] Thomas Kuhn, *The Structure of Scientific Revolutions,* p. 3

Therefore, the advancement of the scientific knowledge through revolutions does not reflect a decline or rise in standards of science. Rather, it reflects the changes which are made necessary by the paradigm shifts.

2.13.3 IMPARTIALITY OF SCIENTIFIC JUDGEMENT

Both Shapin and Kuhn emphasized that the judgement or postulation about scientific facts or theories without the interference of the cultural, social or economic interests of the context within which an individual scientist works is quite misleading. Kuhn stated that such view emanated from the model which seeks to express an analogy between scientific theory and pure mathematical system. This is a model that has its origin in the twentieth-century philosophy of science. He maintained that since there is no set of universal rules for choosing between rival theories, cognitive values that determine the choice of a particular theory are ultimately a matter of subjective preference that transcends rationality.[240] Hence, this explains why non rational psychological and social factors must play a vital role in determining which theory wins the allegiance of the community.

For Shapin, the permanent crisis of European institutions during the early modern period affected attitudes toward knowledge in general, and it affected attitudes to natural knowledge most specially. The development of the modern scientific worldview is a historically situated process that has strong link to the shifts in culture and society which took place in response to changing intellectual agendas, political commitments, and religious beliefs. Likewise, the continuity of the modern science from its medieval past cannot be denied. Even Kuhn illustrated that men like Galileo and Descartes, who laid the foundation for seventeenth-century mechanics, were raised within the Aristotelian scientific tradition, and it made essential contributions to their achievement.[241] Moreover, Shapin demonstrated that the ancient past was not transformed into the ¨modern world¨ at any single moment.[242] The upheaval at the early

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[240] Curd, M. and J. A. Cover, eds. *Philosophy of Science*, p. 84
[241] Kuhn, T. S., *The Essential Tension,* p. xiii
[242] Shapin, S., *The Scientific Revolution,* p. 7

modern science was just a continuation of the medieval recipe of the ancient natural philosophy.

The implication of Shapin and Kuhn views on impartiality is that scientific knowledge should not be treated as true and justified belief. One should rather treat knowledge as a ´natural phenomenon´ which enjoys a special authority in society. The danger in this perspective is that it makes scientific knowledge a mere construction of the scientists. As such, it implies that knowledge is ´whatever people take to be knowledge´.[243]

Consequently, this might lead to a situation whereby what we study are mere idiosyncratic beliefs of individuals and not the objective truth of natural realities. In that case, the aim of science must have been defeated. On the contrary, Kuhn illustrated that the element of arbitrariness which play role in theory choice does not, however, indicate that any scientific group could practice its trade without some set of ´objective´ shared criteria of choice. Hence, he does not undermine the objectivity of science; rather, he seeks to demonstrate the imports of psychology, sociology and history on science.

Niiniluoto commented thus,

> *The acceptance of scientific evidence and the link between scientific evidence and conclusions depend on the standards of scientific inference and method adopted in the relevant scientific community—and such standards have varied in the history of science. But ...this partial influence of social factors does not imply that scientific practice is not generally reliable for generating true or truthlike theories.*[244]

Therefore, the illustrations that both concepts made on impartiality is that the findings of the scientist about nature have strong ties to his standing in the cultural and political milieu of which he is a part. And so, impartiality cannot be totally ruled out of science, although what distinguishes different scientific epochs is the type of method that is accepted and used at a particular time.

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[243] Bloor, David, *Knowledge and Social Imagery*, p.5

[244] Ilkka Niiniluoto, *Critical Scientific Realism* (Oxford: Oxford University Press, 1999) p. 259

2.13.4 POINTS OF SIMILITUDE AND DIVERGENCE

Although Shapin rejected the reality of such thing as the scientific revolution, his analysis of the advancements in science does not draw any overt conflict with Kuhn's description of the structure of the scientific revolutions. Kuhn was rather concentrated on giving a description of what goes on in the sciences at times of theory choice and Shapin was interested in showing that the progress from the medieval to the modern science did not follow any ´logically supreme model´. In fact, it is obvious that both concepts, like the other historicist accounts, were deployed as ways of restructuring the overt misconceptions of the nature of scientific advancement developed against the backdrop of logical positivism and logical empiricism.

Both differed in their approach to analyzing the scientific revolutions, but the truth is that they were together on the recognition that there were great transformations in science during the early modern period. Therefore, it shows that they approved the fact that there are peculiar characteristics which distinguished this period from all others. Most importantly, their reliance on the ideas of some previous historicist accounts of the scientific revolution helped to give shape to their unique ways of presenting their respective views

Moreover, both of them recognized scientific revolutions as those profound scientific researches that resulted to great transformations in science. But then, Kuhn reiterated that neither science nor the development of knowledge is likely to be understood if research is viewed exclusively through the revolutions it occasionally produces. This is because scientific revolutions do not capture the whole story of what normal scientific practices means.

Finally, both concepts tried to create a balance between the sociologists and rationalists view of scientific revolution by illustrating that the rational justifications of the scientific knowledge should be contextually situated. The reason is that there is a social dimension in cognitive processes. It explains why Shapin contested that the preference of mechanism to naturalism on the basis of unintelligibility and inaccuracy is illogical; while Kuhn maintained that the shift from one paradigm to another does not imply a decline or rise in standards of science.

2.14 EVALUATION AND CONCLUSION

Various philosophers and historians of the *Scientific Revolution* have divergent opinions on the scope of its subjects, methodology, duration and even the nature of its fundamental aim. The only unifying feature that stands out in virtually all of their accounts is the new image of science that resulted from the activity of the scientific revolution. This science has displaced the earth from the centre of the universe and made of the universe a gigantic machine quite independent of human feelings and needs. Some of the accounts showed it overthrew the Aristotelian natural philosophy of scholasticism, substituting a search for precise mathematical regularities confirmable by experiment. In fact, the *Scientific Revolution* created modern consciousness and its science. In Hermeticism*, Rationality, and the Scientific Revolution* (1975)[245], Rossi argued that it substituted a new view of the universe as a machine for the older Greek and Roman views of the universe as divine being or readable book. It also proposed that people could improve their lot by the application of reason and experiment rather than by prayer and devotion.

As in all other history writing disciplines one could see that the major tension that has generated the differences in this historiography has mainly been between the reasons and causes of the Scientific Revolution. This tension arises between the rational and causal accounts of the event due to the controversy on how much explanatory force to attribute to each. Such tension has led us to see how Duhem maintained that the cause of the event has to be identified in the prior scientific events proceeding from the medieval period. The argument of the continuity thesis as discussed in the section 2.3.1 illustrates that the casual considerations possesses more explanatory force to demonstrate the continuous development of the Galilean dynamics from the medieval dynamics. This type of argument seem to have offered insight to why Steven Shapin (section 2.11) made an outright negation that there was no such thing as the Scientific Revolution.[246] He implied that since there was continuous progress of the seventeenth-century science from its medieval past it is, therefore, irrational to talk of a revolution in

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[245] See Paolo Rossi, ¨Hermeticism, Rationality, and the Scientific Revolution¨, in *Reason, Experiment, and Mysticism in the Scientific Revolution,* eds. M. Bonelli and W. Shea N (New York: Science History Publications) 1975

[246] Steven Shapin, *The Scientific Revolution,* p. 1

the science of that period. However, the revolutionists (see sections 2.2.1, 2.5.1, 2.6.1, and 2.12) showed that the seventeenth-century science had significant changes compared to the medieval and ancient science. The science of the sixteenth and seventeenth century was totally different from its predecessors in method, scope and structure.

The account of the scientific progress presented by Kuhn and Koyré suggests a new image of science that is dynamic. Science does not progress cumulatively as argued in the traditional account whereby it proceeds from experimental facts to theories. This positivist notion implies that science discovers given phenomena, the relations between them and certain laws that would help to describe or predict them. Hence, the accumulation of the experimental facts brings science closer at each stage to the objective truth of the realities in the world. However, arguments from the defenders of the historical knowledge of science show that the purported experiments are usually based on complicated premises, and they tend to prove the outlook behind these premises, rather than any real truth. Kuhn argued that, ¨…scientific research is inherently circular, that it does not proceed from experimental facts to theories, but that facts and theories are provided together, in more or less inchoate form, by scientific orientations¨.[247] He went further to state that, hence, science progress ¨by a series of circular attempts to apply different orientations or points of view to the natural world.¨[248] One of Kuhn´s innovations was to stress the social nature of science. Science is practised by community of scientists, not by isolated men and women. Hence, in order to understand working science one must understand the scientific community and its shared norms, which together constitute normal science.

The principal implication in the analytical study of the scientific revolution as a historiographical concept is that it makes science to be understood within the framework of a larger conception of how things in the universe cohere. If science is to be pursued in its own right as the traditional accounts of the scientific revolution portend, science is unlikely to survive indefinitely. This is because the basis of its

[247] Thomas Kuhn, MIT MC240, box 3, folder 11, ¨Evidence and explanation¨, p. 16; ¨MIT MC 240¨ refers to the Thomas S. Kuhn papers, at the Institute Archives and Special Collections, MIT Libraries, Cambridge, MA, quoted in James A. Marcum, *Thomas Kuhn´s Revolution: An Historical Philosophy of Science,* (London: Continuum, 2005) p. 33
[248] Ibid., p. 17

pursuits provided within a particular age tends to be minute and unstable. As a historiographical concept science is better understood in the context of the bigger picture that prompts, nurtures, and sustains its progress. Consequently the analysis of the *Scientific Revolution* as a historiographical concept yielded to the historical epistemology of scientific knowledge. Even though, etymologically, science was taken to have the same meaning as epistemology, the image of science presented in the traditional account of the *Scientific Revolution* presents science as being couched in the epistemology of radical empiricism—the theory that all knowledge is derived from the senses. However, the historicist historiography questions and, in most cases, rejects radical empiricism as the epistemological nucleus of science thereby highlighting the relevance of the wider framework in which scientific activities take place. Science is fundamentally recognized as a human activity and the context of its progress is made to incorporate the broader conception of the cosmos which prompted it in the first place.

This new image of science created in the new historiography of science refutes the old image of science that was accepted in the old philosophy of science chiefly in the guise of coarse Positivism cum Logical Empiricism and to some extent the Popper´s Falsificationism. When tested against the historical record, the image of science in the old philosophy of science, which stems from textbooks and the old history of science (mere chronology of scientific data), is wholly falsified. The result from such juxtaposition shows a science in which theories are fitted to facts and not vice versa. Science becomes an activity of groups rather than achievement of solitary individuals. In its resort to historical sources, the new historiography seeks to establish a larger platform for the context of discovery. This larger platform included attention to the dynamics of the scientific process as much as to the logic of results, concern with the semantics as well as the syntactics of scientific utterances, and recognition that there are definite limits to what can be reconstructed logically in terms of rules and criteria.

Therefore, the nature of the scientific development that emerges is one that is both continuously cumulative as well as revolutionary. Such model of scientific development supersedes the ´naive cumulative´ model presented in Logical Empiricism and the ´wanton revolutionary´ model argued in Falsificationism. I call it wanton revolutionary model because the falsification theory of the scientific development focuses solely on the occasional moments of the scientific progress rather than the usual manner in which

science is done outside such periods. The new historiography of science, however, reiterates the historical insight that science is not a process of discovering an objective mirror of nature, but of elaborating subjective paradigms subject to empirical constraints. It therefore elaborates a new image of science which approves of the fact that basic assumptions shape scientific progress. It is not surprising though why most historians and philosophers of science that emphasized the historical nature of the scientific revolution have become more influential than scientists themselves in shaping notions of science´s method and process.[249]

[249] See Nicholas Wade, ¨Thomas S. Kuhn: Revolutionary theorist of Science¨, *Science.* 1977, pp. 143-5

SECTION II

SCIENTIFIC CLAIMS AND PROGRESS:

CHAPTER THREE

3.1 ´SCIENTIFIC REVOLUTION´ AND THE TRADITIONAL CLAIMS OF SCIENCE

The philosophical developments in the historiographical revolution treated in the previous chapter are largely intricate reactions to the traditional claims of science. Koyre´s illustrations, in the *Etudes Galiléennes* (Galileo Studies) on Galileo achievements, were to show that science does not necessarily prove natural truths through experiments (Section 2.2). The development of scientific truth is not the driving force that motivates scientific advancement. Besides, truth and falsity are irrelevant to solving empirical problems in science.[250] The scientific revolution of the seventeenth century was basically profound changes in the very framework and patterns of thinking of that era. This perspective does not entail outright denial of truth-seeking activity in science. For instance, nobody doubts the reality of the motion of fall. It rather questions the justification of scientific truth in relation to scientific progress—does the way in which science has advanced justify the authority of its truths?

Francis Yates, Steven Shapin and Thomas Kuhn questioned the nature of scientific rationality and in what ways it determined the scientific progress of the early modern science. However, Rupert Hall reiterated that the very defining character of the seventeenth century science was its organized and rational response to the ever-present challenges of nature (Section 2.6.1). The scientific tradition of that period set the demarcation between science and pseudo-science. The fields of mysticism, magic and superstition are, thus, not fit to be counted as areas of scientific knowledge. What Hall´s failed to tell us is on which platform the standard of rationality he meant was

[250] Larry Laudan discussed the irrelevance of truth and the falsity to solving a problem. See Larry Laudan, *Progress and its Problems*. (London: Routledge & Kegan Paul, 1977) p. 24

established. Was the standard of rationality based on or just same thing as the mathematical interpretation of reality expounded in the works of such achievers like Galileo, Kepler, Newton, and Huygens? He had posited these men as having consciously established the new beginnings of an exact science from the ´irrational´ way of those of the past. However, mathematical interpretation of reality alone cannot account for all the intricate concepts and beliefs that determined the change of attitude to nature in the early modern period. Hall agreed with this when he noted that ¨mathematical science could not explain things by revealing the structure of reality and its inner logic, it could only give the possibility of predicting future results from stated antecedents.[251]

To understand how science works and the character of its progress a larger framework of beliefs, other than mathematical realism could guarantee, was required. Mathematical realism entails the belief that numbers exist as objects, and it assumes mathematical knowledge to be on a par with that of logic. The ontological claim that runs through mathematical realism is that numbers are abstract object associated with certain concepts. However, mathematical objects are usually thought as abstract objects that are non-spatiotemporal and causally inert. It is therefore difficult to understand how we can have knowledge of them.[252] This shows that mere identification of rationality with mathematical interpretation of reality is implausible, besides it excludes the other basic principles, like mechanism and experimentation, which also determined the unique and differentiating character of the seventeenth century science from its predecessors. Hall´s description of scientific revolution as mainstream of rational scientific development largely shows the predominant tendency of mingling the question of scientific rationality with the issue of its progress.

Larry Laudan (1977) had illustrated that ¨for a long time, many have taken the rationality and progressiveness of science as an obvious fact or a foregone conclusion.¨[253] Such presumption emanated from the outright recognition of the

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[251] A. Rupert Hall, *The Revolution in Science* 1500-1750, p. 11

[252] See Gottlob Frege (1959) *Die Grundlagen der Arithmetik,* translated by J L Austin as *The Foundations of Arithmetic* (Oxford: Blackwell); Michael Dummett, *Frege Philosophy of Mathematics.* (Harvard: Harvard University Press, 1991)

[253] Larry Laudan, *Progress and its Problems*, p. 2

traditional scientific claims such as rationality, truth, objectivity, and realism as binding on science. And it could be traced to the intertwinement of the scientific progress with scientific rationality in the falsificationism of Karl Popper and also inductive logic of Rudolf Carnap.

Inductive logic set out to define the probabilities of different theories according to the available total evidence. It means that if the mathematical probability of a theory is high, it qualifies as scientific; if it is low or even zero, it is not scientific.[254] Carnap´s work on probability and inductive logic were connected with the liberation of empiricism as a part of which he abandoned the verification principle. The idea was to replace the black-and-white notion of verifiability with more subtle tones of confirmability. Carnap sought a notion of probability suitable for this purpose, the frequency notion of probability not being thought suitable. He called the new kind of probability logical or inductive probability. Such kind of probability is used in giving an exact numerical value for the degree of confirmation which bodies of evidence confer upon scientific hypotheses. ¨Inductive logic¨, by which Carnap means any system of inference in which conclusions do not hold with deductive necessity, is essentially the rules whereby these logical or inductive probabilities are assigned to conclusions. Carnap´s Inductive logic eschews the ´either or´ distinctions between science and pseudoscience by providing a continuous scale from poor theories with low probability to good theories with high probability. Bringing the lessons of Carnap´s inductive logic into the question of the scientific progress will demonstrate that science progress when good theories replace poor theories as they are by all indications the more rational, true and objective ones.

In *The Logic of Scientific Discovery* (1959), Popper argues, on the contrary, that the mathematical probability of all theories, scientific or pseudoscientific, given any amount of evidence is zero.[255] However, a theory is ´scientific´ if it designates in advance a crucial experiment (or observation) which can falsify it, and it is

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[254] Imre Lakatos, ¨Science and Pseudoscience¨, in *Philosophy of Science*, Curd, M & Cover, J. A eds., (New York, London: W. W. Norton & Company, 1998) p.22

[255] Karl Popper, *The Logic of Scientific Discovery* (New York: Routledge, 2010), pp. 374-78. This claim is elaborated in the Appendix vii. This book was first published as *Logik der Forschung* in 1934, and the first English translation was published in 1959 by Hutchinson & Co.

pseudoscientific if it does not specify such a ´potential falsifier´. As Popper puts it, ¨the criterion of the scientific status of a theory is its falsifiability, or refutability, or testability¨.[256] Invariably, genuinely progressive theories are those which have the capacity to explain and predict a larger range of facts than their rival, and scientific progress can occur only when one *testable* theory succeeds another. Larry Laudan summaries this positivist view this way,

> *A science progresses just to the extent that later theories in a domain can predict and explain more phenomena than their predecessors did. Since the seventeenth century, the sciences—at least the natural sciences—have done just that.*[257]

The prospective explanatory and predictive range of a theory determines its progressiveness. By discarding all the *discredited* lawlike statements associated with the earlier theory and correctly predicting those unexplained and unpredicted phenomena which its predecessor did not embrace a good scientific theory facilitates genuine progress in science.

In very obvious way, the theories of confirmationism and falsificationism illustrate the traditional scientific claims to include rationality, truth, objectivity and realism. In fact, these four claims define the unifying character of any genuine science. Let´s see how these claims have been traditionally defended in relation to scientific progress, and the responses from the historiographies of scientific revolution.

3.2 SCIENTIFIC RATIONALITY

One of the important traditional trademarks that various theories of scientific advancement have bequeathed on our understanding of science has been the idea of rationality. Science has often been conflated with rationality. Rationality, customarily

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[256] Karl Popper, *Science: Conjectures and Refutations*, p.7
[257] Larry Laudan, *Science and Relativism,* p. 3

defined as giving reasons for actions or for holding beliefs, is truly the sophist servant of desire. Rationality comes closer to being scientific when the desire is to aim at objective truth. In philosophy of science, questions about what would constitute scientific rationality, are usually discussed in the context of theory choice. Scientific rationality is normally treated in such questions as ¨What are the appropriate standards for evaluating scientific theories, and how do scientists adopt them¨? However, scientific reasoning is not just about theory choice since there are other kinds of scientific reasoning like analysis of experimental data. Besides, reasoning in science is sometimes practical as in the scientists´ decision on what research programs to pursue and what experiments to perform.

Conflation of rationality with scientific progress finds its justification by the belief that the epistemic goal of science (truth) is chiefly determinant in the process of theory choice. The epistemic goal defines the normative standards by which a scientist´s practice conforms to scientific rationality. Hence, the traditional question of rationality in science involves, ´what is the nature of reasoning by which individual scientists accept and reject conflicting hypotheses´? But then, Scientific rationality not only involves individuals, it also involves groups, for we can as well ask whether scientific communities are rational in their collective pursuit of the aims of science. However, most relativists like Kuhn and Feyerabend raise serious doubts as to whether scientists are in fact rational, that is, whether they conform to normative standards of individual and group rationality.

The two dominant theories of scientific rationality, confirmationism and falsificationism mainly illustrate that rationality is a rule-governed process, and that scientific progress is cumulative. However, relatively few theorists have offered theories according to which data drawn from the history of science somehow *constitute* or *are evidential for* the concept of rationality. Such theories are known as historicist theories of scientific rationality. The major difference between the two traditional theories and the historicist theories is that the former view scientific rationality as unchangeable over time, while the latter see scientific rationality to be changing over time. This difference gives clue to the divergent notions of cumulativity and the revolutionary progress of science by the two groups respectively. The immutability of scientific rationality will be discussed under the notion of formal rationality, and then its mutability as informal rationality.

3.2.1 FORMAL RATIONALITY

Proponents of formal rationality as represented in logical positivism and critical rationalism view scientific rationality as immutable, meaning that it does not change over time. This immutability is very implicit in all genuine science through different periods of its development. The two main theories that expound this view of scientific rationality are confirmationism and falsificationism. Confirmationism drives from Rudolf Carnap´s discussion on Inductive Logic. According to this view, scientists should accept theories that are probably true, given the evidence. However, Popper maintained with his critical rationalism that we do not use evidence to prove theories. We use it to criticise theories. Likewise, we decide what evidence to acquire by looking at our best theories and what evidence would allow us to say that a particular event is explained by one theory but not another. Critical rationalism, therefore, illustrates that scientific theories, and any other claims to knowledge, can and should be *rationally criticized,* and (if they have empirical content) can and should be subjected to *tests which may refute them.* In other words, Popper´s theory of scientific rationality has its foundation in critical rationalism. Falsificationism shows that scientist should reject theories that make false predictions about observable and replace them with theories that conform to all available evidence.

The two theories mentioned above are regarded as standard conception of scientific rationality. They will be briefly discussed to show how they have sought to account for scientific progress. The discussion will enable us to see in what ways the historiographies of scientific revolution have truly brought transformation to our understanding of science and how they have impacted greatly on the evolution of the trends in Philosophy of Science.

3.2.1.1 CONFIRMATIONISM

In the *Logical Foundations of Probability* (1950) Carnap Rudolf rejects a statistical frequency basis for probability in favour of a logical relation between two statements or propositions. Its central tenets are that all inductive inference is probabilistic, that the required concept of probability derives from logical relations between evidence and

hypotheses, and that inductive inferences are therefore analytic. Probability "is the degree of confirmation of a hypothesis (or conclusion) on the basis of some given evidence (or premises)."[258] Furthermore, all principles and theorems of inductive logic are analytic, and the entire system is to be constructed by means of symbolic logic and semantic methods. This means that the author confines himself to the formalistic procedures of word and symbol systems. The resulting sentence or language structures are presumed to separate off logic from all subjectivist or psychological elements.

The probability of a statement is the degree of confirmation the empirical evidence gives to the statement. For example, the statement “the score is five” receives a partial confirmation by the evidence; its degree of confirmation is one sixth. Carnap devoted himself to giving an account of the probability as a degree of confirmation. The philosophically most significant consequences of his research arise from his assertion that the probability of a statement, with respect to a given body of evidence, is a logical relation between the statement and the evidence. Thus it is necessary to build an inductive logic; that is, a logic which studies the logical relations between statements and evidence. Inductive logic would give us a mathematical method of evaluating the reliability of a hypothesis. In this way inductive logic would answer the problem raised by David Hume’s analysis of induction. Of course, we cannot be sure that a hypothesis is true; but we can evaluate its degree of confirmation and we can thus compare alternative theories.

In spite of the abundance of logical and mathematical methods Carnap used in his own research on the inductive logic, he was not able to formulate a theory of the inductive confirmation of scientific laws. In fact, in Carnap’s inductive logic, *the degree of confirmation of every universal law is always zero*. However, Carnap tried to employ the physical-mathematical theory of thermodynamic entropy to develop a comprehensive theory of inductive logic, but his plan never progressed beyond an outline stage. His works on entropy were published posthumously.

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[258] Rudolf Carnap, *Logical Foundations of Probability*. (Chicago: University of Chicago Press, 1962[1950]), p. v; See also Rudolf Carnap, ¨On inductive Logic¨, *Philosophy of Science*,1945, 12(2) p. 72

The confirmationist account of scientific progress implies that scientists are ´confirmation agents´ that operate roughly as follows. Scientists start with hypotheses that they use to make predictions about observable phenomena. If experiments or other observations show that the predictions are true, then the hypotheses are said to be confirmed. A hypothesis that has received substantial empirical confirmation can be accepted as true, or at least as empirically adequate.[259]

3.2.1.2 FALSIFICATIONISM

The term ¨falsifiable¨ does not mean something is made false, but rather that, if it is false, it can be shown by observation or experiment. Falsificationism is a rival account of the processes involved in scientific research as earlier demonstrated by inductivism. Inductivism holds that science proceeds from observation to theory, beginning with observations derived from experiments, and extrapolating from these to general laws. Falsificationism suggests that science proceeds in the opposite direction, beginning with scientific theories or ¨conjectures¨, and then conducting experiments and eliminating those theories that are falsified by results. Invariably, scientific progress results from the continued cycles of conjectures and refutations.

Falsificationism exploits an important logical point: falsifying instances are more significant than confirming instances. If we have a general law, and conduct an experiment that confirms it, then we still do not know whether the law is true. It remains a live option, but nothing more. If, on the other hand, our experiment contradicts the theory, then we have discovered that the theory is false. Unexpected experimental results are far more significant than expected results. Falsificationism, thus, rejects the logical positivist demarcation criterion of verifiability (or confirmability) by demonstrating that empirical theories cannot be verified but falsified. In *The Logic of Scientific Discovery*, Popper argued that scientists should not aim for confirmation, but should operate as the following sort of *falsification agents.* Scientist use hypotheses to

[259] See Carl G. Hempel, *Aspects of scientific explanation* (New York: The Free Press, 1965); Hempel, C. G., "Studies in the Logic of Confirmation." *Mind, 54,* 1945; See also Franz Huber, ¨Hempel´s Logic of Confirmation¨, in *Philosophical Studies,* 2008, 139: 181-189, for analysis of Hempel´s conditions of adequacy for any relation of confirmation

make predictions, but their primary aim should be to find evidence that contradicts the predicted results, leading to the rejection of hypotheses rather than their acceptance.

For a theory to be considered falsifiable or empirical it must divide ¨the class of all possible basic statements unambiguously into the following two non-empty subclasses.¨[260] These two classes are: 1) the class containing all the basic statements that are inconsistent with the theory (or which it rules out, or prohibits) and 2) the class containing all the basic statements allowed or permitted by the theory. The former class is the important one for falsificationism and is dubbed the class of ¨potential falsifiers¨ by Popper. Thus, the class of potential falsifiers must not be empty if a theory is to be falsifiable.[261] In addition to being falsifiable; a scientific or empirical theory must be consistent, since from any inconsistent system all possible statements may be derived. Hence, he wrote that ¨agreement upon the acceptance or rejection of basic statements is reached, as a rule, on the occasion of *applying* a theory; the agreement, in fact, is part of an application which puts the theory to the test.[262]

Scientific progress, therefore, occurs when one *testable* theory succeeds another, and such theory is able to retain the successes of its predecessor and provided correction for its mistakes. In this way, falsificationism not only demonstrates the continuity within science it also demonstrates scientific rationality as the ´super-standard´ which demarcates genuine science from non-science and pseudo-science.

Popper presents ´falsifiability´, and not verifiability (or confirmationism), as the distinguishing mark of scientific theories. He was apparently fond of referring to ´the soaring edifice of science´, an indication that scientific knowledge is *cumulative.*
However, falsificationism has lots of inherent problems which provoke various philosophical questions demanding for clarification. For instance, assuming falsificationism is true, how can we rationally distinguish between a highly ¨corroborated¨ theory and a new theory? Even if corroboration is different from confirmation in that it is only ¨backward-looking¨, how can it be rationally justified?

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[260] Karl Popper, *The Logic of Scientific Discovery,* pp. 70, 96
[261] Ibid., p. 95
[262] Ibid., p. 88

Since the main motive of this work is not to discuss the intricate problems involved in the divergent views between falsificationism and confirmationism on the nature of scientific theories, It will not go into analysis of the debates that ensued from the deficiencies in both theories. Our interest in this part of the work is to understand the fundamental issues that spurred the various reactions in the historiographies of scientific revolution as regards the question of scientific rationality. The principal reaction to such question would be recapitulated as informal rationality.

3.2.2 INFORMAL RATIONALITY

Informal scientific rationality was clearly depicted in the works of those proponents of the revolutionary advancement of science, like Kuhn and Feyerabend. This view of scientific rationality claims that standards of rationality change over time. Such standards are mutable. They change with the change of scientific beliefs. In fact, no standard or method in science is insulated from the periodic changes that occur in science. Hence, it is not logical to accept the existence of super scientific standards which survive the revolutions in sciences, and consequently permit continuity within science. Neither are there such standards which demarcate genuine science from pseudo-science. Most critics of this view of scientific rationality have often tagged it as irrationalistic and predominately heretical conception of the scientific rationality.

The most interesting thing about the informal scientific rationality is that it provides for methodological pluralism in science unlike the methodological monism that is implicit in formal scientific rationality. In order to understand this view of science rationality, one must also understand the distinction between methodology and meta-methodology. In the parlance of the history and philosophy of science, a methodology for scientific rationality is a theory of rationality: it tells us what is rational and what is not in specific cases. Thus, the rule ¨Always accept the theory with the greatest degree of confirmation¨ would count as (part of) a methodology. On the other hand, a meta-methodology provides us with the standards by which we evaluate the theories of rationality that constitute our methodologies (be it falsifiability or confirmability). Informal scientific rationality is, primarily, defined by the meta-methodology. It accepts the claim that a good theory of rationality must fit the history of science. Invariably, the

best theory of rationality is the one that maximizes the number of rational episodes in the history of science (subject to some filtering out of sociologically infected episodes). This tendency to define scientific rationality by appealing to history of science is generally denoted as historicism.

3.2.2.1 HISTORICIST THEORY OF SCIENTIFIC RATIONALITY

Thomas Kuhn´s (1970) work effects three major great changes in the study of scientific rationality. First, it brought history to the fore. This is, in fact, the most important aspect of the transformation he brought, though following a path already established by Alexandre Koyré and Herbert Butterfield. The vital revelation of *The Structure of Scientific Revolutions* is that a respectable theory of *rational* scientific procedure must conform to the greater part of actual scientific procedure. Unarguably, scientists do their work in the context of groups of various sizes, from the research teams in their own laboratories to community of scientists working on similar projects, and to the overall scientific community.

Scientists operate within the context of a wider community with shared societies, journals, and conferences. Therefore the question of the rationality of science can be raised for groups as well as individuals: What is it for a group of scientists to be collectively rational, and are such groups generally rational? Second, instead of assuming that scientific theories were the units of rational evaluation, *The Structure of Scientific Revolutions* was based on a unit that could persist through minor theoretical changes. Hence, it could distinguish between revisions and wholesale rejection. Kuhn called this unit ¨the paradigm¨. This unit is subsequently identified as the research programme, the research, the global theoretical unit etc. as one could find in the historicist theories of scientific rationality by Imre Lakatos and Larry Laudan. Third, the work highlighted the real problems that historically conscious accounts of rationality face: when all is said and done, there may be no trans-historical rule for rational scientific procedure. For Kuhn, scientific change—from one ´paradigm´ to another—is

a mystical conversion which is not and cannot be governed by rules of reason and which falls totally within the realm of the *(social) psychology of discovery.*[263]

It is at this extreme that historicism most times descends into triviality, as the Marxist historiography of the scientific revolution has been accused of. In such situation scientific explanations are viewed as social events, speech acts, which take place in a certain social context. For instance the Hermeticist and Puritan reinterpretation of the scientific revolution tend to focus on the complex social interactions that inevitably surround and infuse the generation of scientific knowledge. Hence, ´instead of looking at scientific theories as abstract objects, historians examine how science changes, revealing the human dimension of science.´[264] Steven Shapin wrote thus,

> *If we want ultimately to understand the appeal of mechanical metaphors in the new scientific practices* (referring to the science that ensued from the events of the scientific revolution)*...we shall ultimately have to understand the power relations of an early modern European society whose patterns of living, producing, and political ordering were undergoing massive changes as feudalism gave way to early capitalism.*[265]

Traditionally, scientific rationality was structurally construed on appeal to mechanical metaphors in science. Such metaphors alludes that the physical realities contain ´matters of fact´ which exhibit some regularities that can be properly represented in theories. These theories represent the laws of nature derived from a number of facts. Nature was like a clock: man could be certain of its effects, of the hours shown by its hands; but the mechanism by which these effects were produced, the clock-work, might be various.[266] This type of scientific reasoning shows that theories are confronted with facts; and one of the central conditions of scientific reasoning is that theories must be supported by

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[263] Imre Lakatos, ¨Falsification and the Methodology of Scientific Research Programmes,¨ in *Criticism and the Growth of Knowledge,* eds. Imre Lakatos & Alan Musgrave (Cambridge: University of Cambridge Press, 1970) p. 93

[264] Thomas Hardy Leahey, *A History of Psychology,* 6th ed. (New Jersey: Pearson) 2004[1980], p. 14

[265] Steven Shapin, *The Scientific Revolution*, p. 33

[266] Steven Shapin, ¨¨Pump and Circumstance: Robert Boyle´s Literary Technology, ¨ in *The Scientific Revolution*. ed. Marcus Hellyer (Oxford: Blackwell, 2003) p. 76

facts. However, any genuine scientist can easily demonstrate today that there can be no valid derivation of a law or nature from any finite number of facts. Isaac Newton claimed to have deduced his laws from the ´phenomena´ provided by Kepler. He even boasted not to be uttering mere hypotheses: ¨hypotheses non fingo¨ (I feign no hypothese).[267] He himself thought that he proved his laws from facts. But this was false, since according to Kepler, planets move in ellipses, but according to Newton´s theory, planets would move in ellipses only if the planets did not disturb each other in their motion. We know that planets do that. This is why Newton had to devise a perturbation theory from which it follows that no planet moves in an ellipse.

History of science, therefore, shows that it is implausible to base the justification of scientific rationality on the mechanical metaphors. It means another platform for such justification has to be sought. But then, if scientific rationality does not derived from those mechanical metaphors it means that the structure of the early modern science was absolutely not different with its predecessor. In fact, it is one of the more profound ironies of the history of thought that the growth of mechanical science, through which arose the idea of mechanism as a possible philosophy of nature, was itself an outcome of the Renaissance magical tradition.[268]

3.2.2.2 HISTORY AND SCIENTIFIC RATIONALITY

The major insight the theses of scientific revolution in the previous chapter proffer is that a comprehensive theory of scientific rationality is lacking in the traditional conception of scientific progress. Rationality itself has a history and it is constituted by that history. They imply that in our way up from the dark, from man´s first stumbling experiments with artefacts to its most sophisticated instruments of listening to the

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[267] The passage occurs in the final General Scholium of Newton´s *Principia* (1687). The English translation by Francis Motte (1729) states it thus, ¨Hitherto we have explained the phenomena of the heavens and of our sea by the power of gravity, but have not yet assigned the cause of this power…I have not been able to discover the cause of those properties of gravity phenomena, and I frame no hypotheses [*hypotheses non fingo*]; for whatever is not deduced from the phenomena is to be called an hypothesis; and hypotheses whether metaphysical or physical, whether of occult qualities or mechanical, have no place in experimental philosophy¨. Culled from Toni Vogel Carey (2012) ¨Hypothese Non Fingo¨, in *Philosophy Now*, 20-23, p.20

[268] Francis Yates, *The Rosicrucian Enlightenment* (London: Routledge & Kegan Paul, 2010[1972]), p.150

rumblings of remote galaxies, our species *homo sapiens* has reached out into its environment and moulded through its praxis the complex cognitive apparatus that many today take as given. But the unfolding of history at every stage entered into and decisively shaped the scientific and philosophical thought process itself. There are no non-contextual, ahistorical norms. Nor is there any need for any. There is no truth standing above history or beyond history. History is all there is. There is nothing in any of this that should undermine our confidence in scientific rationality. Quite the contrary! The fact that our canons of rationality are historically forged should not make us conclude that they are groundless, but should highlight for us how well grounded they actually are. This is for the reason that they represent the embodiment of centuries of striving, of trial and error, of continuous refinement of our cognitive apparatus. Definitely, scientific knowledge has its base in this process.

Historicity does not imply irrationality, arbitrariness, groundlessness, discontinuity, incommensurability, deconstruction or hyper-reflexivity. It most certainly does not rule out differential assessment of conflicting claims to knowledge, of rival theories and paradigms. Rather it requires it. The historical process by which our embodied knowledge and our criteria for what is to count as knowledge have come to us has been one marked by constant differential assessment of alternatives and continual testing of alternative methods of differential assessment of alternatives. It is to the test of this embodied experience, socio-historically evolved, that we bring every new experience and move our own thinking and even the history of ideas onward. Generally, controversies on the nature of scientific rationality are motived by its implicit justification of scientific truth.

3.3 SCIENTIFIC TRUTH

The discussion in sections 3.2.1, 3.2.1.1 and 3.2.1.2 shows how the traditional model of science tie the grounds for asserting the truth of a hypothesis to our observational experience. Such empirical nature of the ¨scientific method¨ informs their conviction that science gives us a true account of the universe. It exposes a simple-minded understanding of scientific methodology that is monistic. According to this methodology, a scientist develops a hypothesis by inductive inference from a number of

discrete observations or from inferences based on other ´true´ theories. Good scientific hypotheses entail particular observational consequences. Scientists confirm the truth or falsity of their theories by testing—looking for the occurrence of the predicted observational consequences. Theories should have evidence that supports them. But even if the evidence supports a theory today, tomorrow, new evidence may cause the theory to be revised just as it had been the case with Newton´s theories of mechanics and universal gravitation. For a couple of centuries all the evidence seemed to show Newton´s theories explained the universe precisely and were deemed ´true´. But in the late 19th century evidence started to accumulate that disturbed scientists. They were discovering phenomena Newton´s theory did not account for. It was in explaining how these new pieces of evidence, as well as other ideas, fit into a more comprehensive theory that Albert Einstein made his mark. And Newton´s theory which had appeared to be ´true´ for so long was finally shown to be ´untrue´. Eventually, Einstein´s theory became the new ´truth.´

Obviously, there are problems with saying a scientific theory is a true theory, partly because we run into the problem of determining which theories are true, and deciding whether a term in a scientific theory actually refers to a target. Instead, science uses a range of representational vehicles, e.g. models of familiarity, like Bohr´s, and abstract mathematical models. In other words, it is not adequate to analyse scientific data using solely a linguistic medium.

3.3.1 LINGUISTIC AMBIVALENCE

Past scientific theories may appear false if we analyse scientific data linguistically to see if what is being described actually is connected to any physical reality. However, if we recast the superceded theory as a sort of model, we may notice that the theory, in essence, was structurally parallel to a current theory. A good example of this could be the Carnot cycle of Sadi Carnot. In a Carnot cycle, an engine accepts heat energy from a high-temperature source, or hot body, converts part of the received energy into mechanical (or electrical) work, and rejects the remainder to a low-temperature sink, or cold body. The greater the temperature difference between the source and sink, the greater the efficiency of the heat engine. Nicolas Léonard Sadi Carnot (1796 – 1832)

sought to answer two questions about the operation of heat engines: ¨Is the work available from a heat source potentially unbounded? ¨, and ¨Can heat engines in principle be improved by replacing the steam with some other working fluid or gas? ¨
In his *Réflexions sur la Puissance Motrice de Feu* [1824/1988] (¨Reflections on the Motive Power of Fire) he arrived to the conclusion that the production of motive power was due ¨not to actual consumption of caloric but to its transportation from a warm body to a cold body.¨[269] Likewise, ¨In the fall of caloric, motive power evidently increases with the difference of temperature between the warm and cold bodies, but we do not know whether it is proportional to this difference.¨[270]

Carnot originally formulated his theorem on the basis of the caloric theory of heat which was later discarded as an incorrect concept, but in essence his theorem was found to be correct if the notion of heat (distinguished as *chaleur* from *calorique* by him)[271] was identified with a form of a mechanical energy, as enunciated by such heat theorists like Count Rumford (known as Sir Benjamin Thompson). After examination of Carnot´s work, R. Clausius (1850) and such physicists like W. Thomson (Lord Kevin) were able to modify the Carnot theorem and enunciate the second principle of thermodynamics when systems undergo cyclic processes. Hence, according to the Clausius principle, by R. Clausius, it is impossible to transfer heat from a colder to a hotter body without converting at the same time a certain amount of work into heat at the end of a cycle of changes.
Carnot thought heat was a fluid of sorts. He was wrong, linguistically, but his ´fluid´ was enough like that of kinetic energy that it mattered little. In other words, the issue of ´truth´ should not matter much as regards the efficiency of one theory over rivals. Duhem wrote thus,

> *It quite naturally happens that those who believe too much in their own theories do not sufficiently believe in the theories of*

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[269] Sadi Carnot, ¨Reflection on the Motive Power of Fire,¨ in *Reflection on the Motive Power of Fire by Sadi Carnot and other Papers on the Second Law of Thermodynamics by É. Claperyron and R. Clausius. Ed.* Mendoza, E. (New York: Dover, 1988[1960]) p.7
[270] Ibid., p. 15
[271] In Carnot´s theory, there appears the notion of *calorique,* which is distinctive from *chaleur.* He did not clarify its true nature, but it is safe to assume it is a quantity associated with heat transfer and equivalent to entropy or, more precisely, calortropy as the heat theory of Count Rumford suggest.

> *others. Then the dominant idea of these condemners of others is to find fault with the theories of the latter and to seek to contradict them….They are doing experiments only in order to destroy a theory instead of doing them in order to look for the truth.*[272]

However, this leaves us with another problem: Should we restrict science´s goal to seeking theories that are solely ¨empirically adequate¨[273] while rejecting the linguistic representation medium entirely? Or can scientific theories, in some cases ´fit´ reality, which means, they are ´true´?

The conception that observation serves as the independent foundational justification for our theoretical claims has been shown to be wrong. Observation is not independent of theory at all. All observations are dependent on some theory at some level. Observation alone is never enough and no matter how strong the evidence, science can never prove a theory true with certainty as we have seen in the overthrow of the Newtonian theory by Einstein theory. Eventually, there are other sources of evidence beyond the strictly observational that indicate truth. These additional sources of evidence do not rely on asserting a ¨match¨ between the claims made by the theory and the world itself. Instead, this evidence comes from an evaluation of the internal coherence of the theory itself. Evaluating a hypothesis becomes a two-step process: We want to know whether the hypothesis is ´empirically adequate´—is it consistent with our observations. Second, we want to know whether the hypothesis has certain ´virtues´ we think correlate with its being ´likely to be true´. These virtues include: Simplicity, Generality, Fecundity, Entrenchment, and Testability. This shows that scientific advancement through time does not move closer and closer to a correct (true) characterization of the natural world.

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[272] Pierre Duhem, ¨Physical Theory and Experiment,¨ in *Philosophy of Science*, eds. Curd, M & Cover, J. A (New York, London: W. W. Norton & Company, 1998) p. 258

[273] Van Fraassen´ constructive empiricism argued that ´science aims to give us theories which are empirically adequate; and acceptance of a theory involves as belief only that it is empirically adequate. See Bas C. Van Fraassen. ¨Arguments concerning Scientific Realism¨, in *Philosophy of Science*, eds. Curd, M & Cover, J. A (New York, London: W. W. Norton & Company, 1998) p. 1069; see also Bas. C. van Fraassen, *The Scientific Image.* (Oxford: Oxford University Press, 1980) p. 12

3.4 SCIENTIFIC OBJECTIVITY

The view of scientific objectivity as one achieved by reliance upon non arbitrary and non-subjective criteria for developing, accepting and rejecting the hypotheses and theories that make up the whole view of science is derived from an initial factor. Such factor deals with the affirmation that science provides accurate description of the facts of the natural world as they really are. Precisely, this notion is derived from the conviction of the science practitioners of the early modern period that they have construed accurate accounts of the real underlying structure of the natural world. Hence, it implies that such accurate description of the facts in the natural world provides us knowledge of nature that is uninfluenced by the scientists.

Precisely, the accounts of the scientific revolution by various authors in the previous chapter have shown that the pure pursuit of objective truth, by ´disinterested individuals, in science is not only implausible but incorrect. Robert Merton (1938) demonstrated the role of puritanism in the rise of modern science. The Marxist historiography of scientific revolution by Hessen (1931) instigated that the development of Newton´s ´ *Principia´* had its root in the economic demands of the period. Frances Yates (1964, 1972) insisted that hermeticism must have influenced the developments in the physics of the seventeenth-century science and that alchemical influences were particularly important in relation to the development of the mathematical approach to nature.[274] For Joseph Needham (1969) the social transformation wrought by capitalism, renaissance and reformation motivated the rise of the early modern science in Europe.

Most traditional accounts of science repose the objectivity of science on their conviction that its method is purely objective. Objectivity is granted based on the theory-neutral nature of the observational data and the necessary nature of the logical relationship between hypotheses and their observational consequences. In this case, objectivity is attributed to the scientists to the extent that he or she follows the scientific method. Shapin insisted that it is incorrect to justify scientific objectivity based on the objectivity of scientific method.

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[274] Francis Yates, *The Rosicrucian Enlightenment,* p. xii

He states that,

> *Historians and philosophers of science have traditionally paid far too much attention to formal methodological pronouncements, often taking such statements at face value as adequate accounts of what past practitioners actually did when they went about making, assessing, and distributing scientific knowledge. In fact, the relation between any body of formal methodological directions and concrete natural philosophical practice in the seventeenth century is deeply problematic.*[275]

In order to understand the actual identity and the worth of such formal methodology, like Bacon´s method, we also need to understand the context under which the justification for such methods is made. It means that we should have a more vivid picture of what a range of modern natural philosophers actually *did* when they set about securing a piece of knowledge.

3.5 SCIENTIFIC REALISM

Scientific realism is the philosophical position that ´the picture which science gives us of the world is a true one, faithful in its details, and the entities postulated in science really exist: the advance of science are discoveries, not inventions´.[276] Science at the very least gives us knowledge about the true structures of the world. Science is more than a tool to ¨save the phenomena¨, and grants real insight into the truth of the universe. Scientific realism asserts that the objects of scientific knowledge exist independently of the minds or acts of scientists and scientific theories are true of the objective (mind-independent) world. The reference to knowledge points to the dual character of scientific realism. On the one hand it is a metaphysical (specifically, an ontological) doctrine, claiming the independent existence of certain entities. On the other hand it is an epistemological doctrine asserting that we can know what individuals

[275] Steven Shapin, *The Scientific Revolution,* pp. 94-95
[276] Bas. C. van Fraassen, *¨Arguments Concerning Scientific Realism*,¨ p. 1065

exist and that we can find out the truth of the theories or laws that govern them. As a philosophical position, it is often framed as an answer to the question ¨how is the success of science to be explained¨? The argument mainly use to answer such question is popularly known as the ´miracle argument´.[277]

3.5.1 THE MIRACLE ARGUMENT

The miracle Argument has its origin from Putnam´s claim in *Mathematics, Matter and Method* (1975) that realism ´is the only philosophy that does not make the success of science a miracle´.[278] Hence the argument for realism is usually referred to as the ´miracle argument´ or ´no-miracles argument´. This argument often starts with the widely accepted premise that the best theories in science are extraordinarily successful: they facilitate empirical predictions, retrodictions, and explanations of the subject matters of scientific investigation, often marked by amazing accuracy and intricate causal manipulations of the relevant phenomena. How can one explain this success of the scientific theories? The main explanation that the realists give is that our best theories are true of a mind-independent world of entities, properties, law and structures. It, therefore, means that if these theories are not actually true the fact that they are so successful would be, indeed, miraculous. Consequently, given the choice between a straightforward explanation of success and a miraculous explanation, any reasonable mind would prefer the non-miraculous explanation going by the fact that our best theories are approximately true. Invariably, this account of scientific success claims definitive status for the unobservable entities apparently talked about by scientific theories.

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[277] For detailed studies on the miracle argument see Brown, J. R., ´The Miracle of Science´, *Philosophical Quarterly,* 1982, 32: 232-244; Boyd, R. N., ´What Realism Implies and What it Does Not´, *Dialectica,* 1989, 43: 5-29; Lipton, P., ´Truth, Existence, and the Best Explanation´, in *The Scientific Realism of Rom Harré,* ed. A. A. Derksen (Tilburg: Tilburg University Press, 1994); Psillos, S., *Scientific Realism: How Science Tracks Truth* (London: Routledge, 1999) ch. 4; Barnes, E. C., ´The Miraculous Choice Argument for Realism´, *Philosophical Studies,* 2002, 111: 97-120; Lyons, T. D, ´Explaining the Success of a Scientific Theory´, *Philosophy of Science,* 2003, 70: 891-901; Busch, J., ´No New Miracles, Same Old Tricks´, *Theoria,* 2008, 74, 102-114; and Frost-Arnold, G., ´The No-Miracles Argument for Realism: Inference to an Unacceptable Explanation´, *Philosophy of Science,* 2010, 77: 35-58

[278] Putnam, H. *Mathematics, Matter and Method* (Cambridge: Cambridge University Press, 1975) p. 73

Scientific realism grants the ontological status of unobservables. Even though we cannot see electrons with our naked eyes (we only observe what electrons do and identify them with by such characteristics) the fact that scientific theory affirms its existence means that it really exist, since the ´acceptance of such scientific theory involves the belief that it is true´. This implies then that the theoretical statements of science are, or purported to be, true generalized descriptions of reality.[279] Scientific realism strongly affirms the ontological status of the unobservable facts. Van Fraassen (1998) summaries scientific realism thus,

> *Science aims to give us, in its theories, a literally true story of what the world is like; and acceptance of a scientific theory involves the belief that it is true.*[280]

The term ´literally´ that Fraassen uses in this definition should be understood as means of distinguishing the position of the logical positivist, conventionalist and instrumentalist from that of the scientific realist since the former groups have the view that science is true if ´properly understood´.[281] They believe that science only offer useful tools to help understand the phenomena we observe but does not give literal true story about the things in the world.

The general approach that the scientific realists adopt to explain how science works is causal oriented. This casual approach argue that the goal of science is to penetrate the causal structure of reality and discover the laws of nature not just to invent it as the non-revisionary scientific anti-realism might claim. Therefore, the knowledge of the world that science gives us is objectively and scientifically true since science not only gives us the true picture of reality but also the causal explications of how reality is composed.

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[279] Brian Ellis, *Rational Belief Systems* (Oxford: Blackwell, 1979) p. 28

[280] Bas C. Van Fraassen. *¨Arguments Concerning Scientific Realism¨,* p. 1066; see also Bas. C. van Fraassen, *The Scientific Image.* p. 8

[281] Bas C. Van Fraassen. *¨Arguments Concerning Scientific Realism¨,* p. 1067

3.5.2 CUMULATIVITY OF SCIENTIFIC PROGRESS

Since scientific theories capture the nature of the objects in the world as they are in themselves, such realists as Richard Boyd and Hilary Putnam argue that for any science to be regarded as mature and well-developed its later theories should entail at least approximations to their predecessors.[282] For the realist, science all through history moves closer and closer to a correct characterization of the natural world. The only sorts of changes this position regard as really progress in the history of science are those that have advanced in a cumulative manner. They are the changes that have really contributed to the growth of knowledge. In fact, from the origins of modern science in the works of Copernicus, Galileo, and Newton in the sixteenth and seventeenth centuries, till the logical empiricists of the twentieth century; scientific progress has been viewed as an evolutionary process of uncovering truth in the physical world.

The logical empiricists of the twentieth century represent the final school of thought that supported scientific realism and the evolutionary development of science. As the name, "logical empiricist" implies, this movement combined induction, based on empiricism, and deduction in the form of logic. Carl Hempel, one of the later advocates of logical empiricism, in *Philosophy of Natural Science* (1966) argued against those who "deny the existence of 'theoretical entities' or regard theoretical assumptions about them as ingeniously contrived fictions."[283] Although Hempel recognized that many theoretical entities and processes cannot be directly observed (e. g. gravity cannot be observed; we only observe the effects of gravity), as a scientific realist he believed that a theory well-confirmed by experiment translated to a high probability that the entities and processes of the theory really did exist.

Because of his belief in scientific realism, Hempel was also convinced that science evolved in a continuous manner. New theory did not contradict past theory: "theory does not simply refute the earlier empirical generalizations in its field; rather, it shows that within a certain limited range defined by qualifying conditions, the generalizations

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[282] See Boyd, Richard, ¨On the Current Status of Scientific Realism¨, in *The Philosophy of Science*, Richard Boyd, Philip Gasper & J.D. Trout eds., Massachusetts: Mass. Institute of Technology Press, 1991 pp.915-222. See also Boyd, Richard (1973). ¨Reason, Underdetermination and a casual theory of evidence.¨ *Nous,* 7:1-12 and Putnam, Hilary (1978). *Meaning and the moral sciences.* London: Routledge.

[283] Carl G. Hempel, *Philosophy of Natural Science*, p. 79

hold true in fairly close approximation."[284] ¨New theory is more comprehensive; the old theory can be derived from the newer one and is one special manifestation"[285] of the more comprehensive new theory. Nevertheless, the difference between the continuity thesis of scientific advancement argued by the logical empiricists and that of historicists like Duhem and Shapin, is the affirmation of the historical determinacy of scientific rationality by the latter.

The logical empiricists would agree, for instance, that Newtonian physics is a special case of, and can be derived from, Einsteinian physics. The logical empiricist's conception of scientific progress was thus a continuous one; more comprehensive theory replaced compatible, older theory. Each successive theory's explanation was closer to the truth than the theory before. It was the truth, and the prediction and control that came with it, that was the goal of logical-empirical science.
The notion of scientific realism held by Newton led to the evolutionary view of the progress of science. The entities and processes of theory were believed to exist in nature, and science should discover those entities and processes. The course of nineteenth- and twentieth-century science eventually threatened the idea of scientific realism. Particularly disturbing discoveries were made in the area of atomic physics. For instance, Heisenberg's indeterminacy[286] principle, according to historian of science Cecil Schneer, yielded the conclusion that "the world of nature is indeterminate. The behavior of the particle is uncertain and therefore the behavior of the atom is an uncertainty."[287] Thus at the atomic level, "even the fundamental principle of causality fail[ed]."[288]

Despite these problems, it was not until the second half of the twentieth century that the preservers of the evolutionary idea of scientific progress, the logical empiricists, were seriously challenged. Although Thomas Kuhn was not the first critic of traditional views of science (as one could see from the perspective of the historiographical revolution

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[284] Ibid., 76
[285] Ibid.
[286] According to Stephen Toulmin, the "foundations of the classical picture suddenly disintegrated" between 1890 and 1910 when "all the axioms of nineteenth-century physics and chemistry [then] revealed themselves as no more than working assumptions, which were sound only if not pressed too hard."" See Stephen Toulmin and June Goodfield, The *Architecture of Matter* (Chicago: University of Chicago Press, 1962), p. 270
[287] Cecil J. Schneer, *The Evolution of Physical Science*, p. 364.
[288] Ibid., pp. 358-9

treated in chapter two), his work held the most important implications about the rationality of science.[289]

Kuhn resorted to the history of science to show that it was ¨implausible¨ to say that theory is approaching truth. There is no linear advancement of theory toward truth. He states thus,

> *Newton´s mechanics improves on Aristotle´s and …Einstein´s improves on Newton´s as instruments for puzzle-solving. But I can see in their succession no coherent direction of ontological development. On the contrary, in some important respects, though by no means in all, Einstein´s general theory of relativity is closer to Aristotle´s than… to Newton´s.*[290]

Kuhn´s statement indicates that Einstein´s theory is not merely a more complex version of Newton´s. Einsteinian theory heads in its own direction; there is ¨no coherent direction of ontological development¨. This statement encompasses Kuhn´s conviction that there is ´Revolution´ in science. In order to find a replacement of the idea of progress toward the truth in science, he advocated on the need for a goal to guide science which will avert the traditional tendency of speaking about single hypotheses or theories being ¨well tested¨ or ¨confirmed¨ or even ¨corrigibly falsified.¨[291] Such tendency inform the underlying motive of justifying the progress of science toward the truth.

3.6 NATURALISTIC APPROACH OF THE KUHIAN ´PARADIGM´

The naturalistic approach to the account of scientific progress was first initiated by Thomas Kuhn. He did this by way of a historicist attempt to elaborate an historical account of the scientific revolution where he envisioned history of science informing

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[289] Stephen Toulmin & June Goodfield, The *Architecture of Matter*, p. 270

[290] Thomas Kuhn, *The Structure of Scientific Revolutions*, p. 206

[291] Larry Laudan, *Science and Relativism,* p.70. Laudan describes the Relativist view of theory change (as represented in Kuhn) to consist that ´single hypotheses are never tested in isolation but are always tested as parts of larger complexes or wholes´

philosophy of science as an historical philosophy of science rather than the history and philosophy of science. In his view, the relationship between them is asymmetrical. Instead of analysing scientific theories as abstract objects, he sought to describe how the hidden worldview, or ´Weltanschaung´ shared by practitioners of the scientific enterprise conditions theory choice which invariably determine how science changes.

Prior to 1950 history of science was a discipline practised mostly by eminent scientists, who generally wrote heroic biographies or sweeping overviews of the discipline, often for pedagogical purposes. This earlier history of science focused on, according to Kuhn, ¨the development of science as a quasi-mechanical march of the intellect, the successive surrender of nature´s secrets to sound methods skilfully deployed.¨[292] The kind of history of science that was developed by the likes of E. J. Dijsterhuis, Anneliese Maier, and Alexander Koyré was simply more than chronicling science´s theoretical and technical achievements. The important contribution from such system of history writing was the recognition of institutional and historical factors in the practice of science.

Kuhn, rather, argued that mere chronicling of major themes and figures does not offer an accurate perspective of how the worldviews and changes in worldviews occur in science. It is the worldviews that facilitate the theoretical and technical achievements being chronicled. Therefore, adequate analysis of what the worldviews are, how they work and motivate scientific progress contributes immensely to understanding the real nature of the scientific achievements. He looked into the ´Weltanschauung´ shared by the members of the scientific community to show how it works and how it changes over time. He did this by means of an articulated elaboration of the cyclical nature of science history (see figure 1 below). Therefore, to understand working science we must understand the scientific community and its shared norms, which together constitute what he described as *normal science.*

[292] Thomas Kuhn, "The history of science," in *International Encyclopedia of the Social Sciences*, ed. D. L. Sills (New York: Free Press, 1968) 14, p. 75

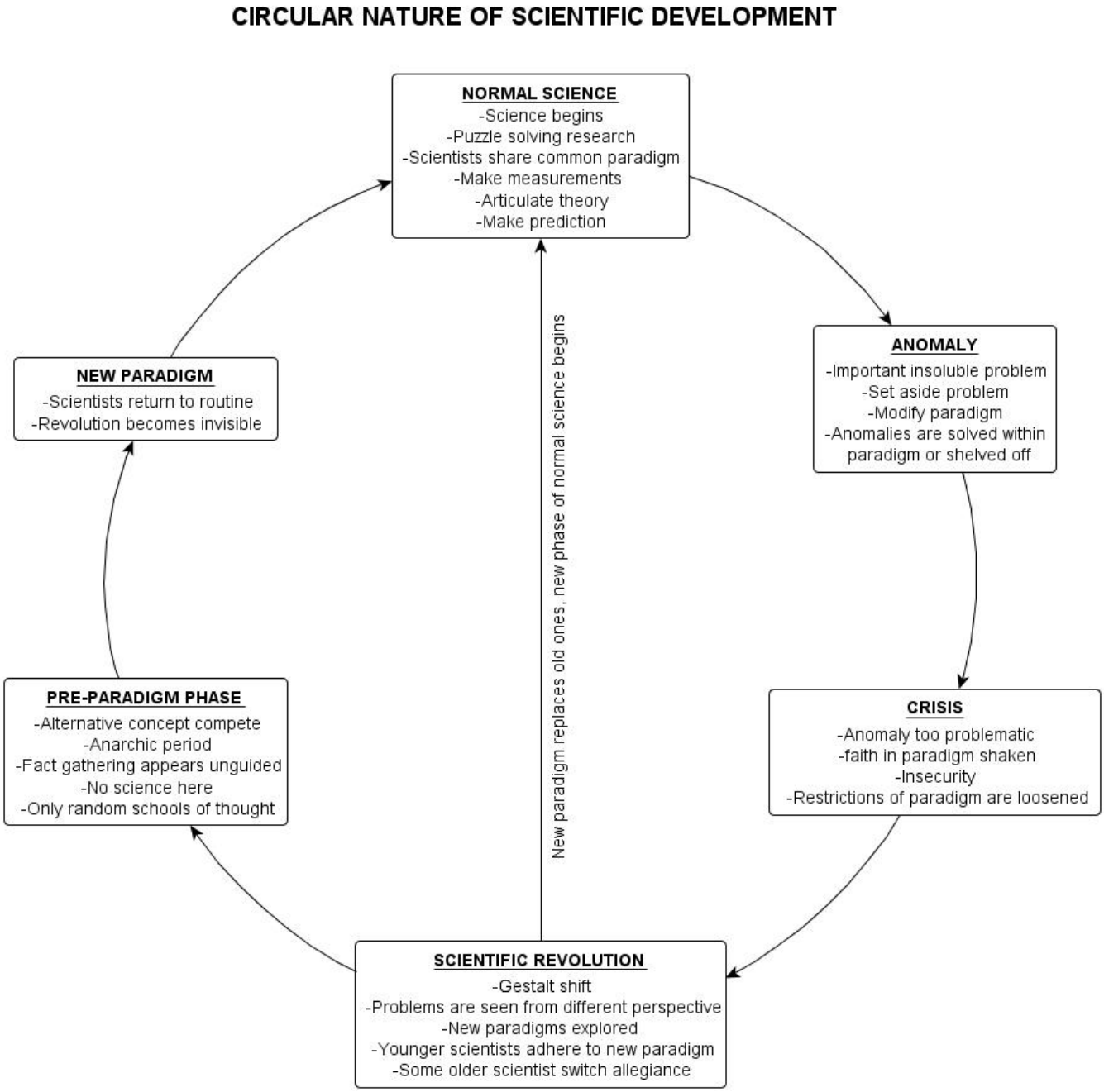

Figure 1: Scientific disciplines, once they have emerged from the pre-paradigmatic stage, undergo periods of "normal science" which allow them to obtain a high degree of precision and progress rapidly. Normal science is dependent on the adoption of a universally accepted paradigm which defines research problems for the scientist, tells him/her what to expect, and provides the methods that he/she will use in solving them. However, in the course of research, scientists inevitably stumble upon anomalies which the paradigm is unable to explain. If the paradigm repeatedly fails to explain the

anomaly, a crisis ensues and alternative theories develop. Eventually a competing theory proves relatively successful in explaining the anomaly and it replaces the old paradigm. This replacement is Kuhn's "scientific revolution." Initially, the scientific community resists the replacement, but with time the success of the new paradigm gains enough support to win out.

According to Kuhn, the adoption of a new paradigm necessarily establishes the creation of new research problems, methods, and expected results. The scientists within the discipline thus see the world in a different way than it "was" under the old paradigm. Once the old paradigm is replaced and the revolution has ended, normal science re-emerges only to await the discovery of new anomalies. Kuhn, therefore, argued that science does not progress toward a predetermined goal but, like evolutionary change, one theory replaces another with a better fit between theory and nature vis-à-vis competitors. Kuhn believed that his use of the Darwinian metaphor was the correct framework for discussing science´s progress. But he felt no one took that metaphor seriously. This negligence was actually what led to the view of scientific progress as a continuous increase in a set of accepted facts and theories. Kuhn sought to correct such anomalous view of the scientific progress by arguing for an episodic model in which periods of such conceptual continuity in normal science were interrupted by periods of revolutionary science. The unusual emphasis on a conservative attitude distinguishes Kuhn not only from the heroic element of the standard picture but also from Popper and his depiction of the scientist as incessantly attempting to refute his or her most important theories.

This conservative resistance to the attempted refutation of key theories means that revolutions are not sought except under extreme circumstances. The Falsificationism of the Popper's philosophy had required that a single reproducible, anomalous phenomenon be enough to result in the rejection of a theory.[293] Kuhn's view is that during normal science scientists neither test nor seek to confirm the guiding theories of their disciplinary matrix. Nor do they regard anomalous results as falsifying those theories. It is only speculative puzzle-solutions that can be falsified in a Popperian

[293] Karl Popper, *The Logic of Scientific Discovery* (London: Hutchinson) 1959, pp. 86–7

fashion during normal science.[294] Rather, anomalies are ignored or explained away if at all possible. It is only the accumulation of particularly troublesome anomalies that poses a serious problem for the existing disciplinary matrix. A particularly troublesome anomaly is one that undermines the practice of normal science. For example, an anomaly might reveal inadequacies in some commonly used piece of equipment, perhaps by casting doubt on the underlying theory. If much of normal science relies upon this piece of equipment, normal science will find it difficult to continue with confidence until this anomaly is addressed. A widespread failure in such confidence Kuhn calls a 'crisis'[295]

Also, Kuhn used the theory of incommensurability to demonstrate that comparison between theories will not be as straightforward as the standard empiricist picture would have it, since the standards of evaluation are themselves subject to change. This sort of difficulty in theory comparison is an instance of what Kuhn called ´incommensurability´(see section 2.12.7 for detailed description of the term). This Suggest that ´the competition between paradigms is not the sort of battle that can be resolved by proofs.´[296] Many scientists and philosophers have attacked Kuhn on the basis that his theory is too cynical, implying as it does that scientific theories are simply temporarily useful utilities for explaining things. This attack comes from the fact that they would like us to believe that they are discovering abstract truth. Historicist account of the scientific advancement has made us to see that this is simply not the case. Science provides us with the best current explanation for things, not with truth.

Kuhn ´s naturalistic approach to scientific advancement was well criticized by his colleagues in the history and philosophy of science. In 1965, a special symposium on Kuhn's SSR was held at an International Colloquium on the Philosophy of Science that took place at Bedford College, London, and was chaired by Sir Karl Popper The symposium led to the publication of the symposium's presentations plus other essays, most of them critical, which eventually appeared in an influential volume of essays that by 1999 had gone through 21 printings. Kuhn expressed the opinion that his critics' readings of his book were so inconsistent with his own understanding of it that he was

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[294] Thomas Kuhn, "Logic of Discovery or Psychology of Research?", in *Criticism and the Growth of Knowledge*, eds. I. Lakatos & A. Musgrave (London: Cambridge University Press, 1970) p. 19

[295] Thomas Kuhn, *The Structure of Scientific Revolutions*, pp. 66–76

[296] Ibid., p. 148

"...tempted to posit the existence of two Thomas Kuhns," one the author of his book, the other the individual who had been criticized in the symposium by "Professors Popper, Feyerabend, Lakatos, Toulmin and Watkins."[297] From Kuhn's recollection, he felt that the reviews of Structure were good.[298] His chief concern was the tag of irrationalism. "I was not saying, however", stated Kuhn later, "that there aren't good reasons in scientific proofs, there are good but never conclusive reasons."[299]

Notwithstanding the numerous controversies that trailed and still trail the Kuhnian Structure of Scientific Revolution our major concern here is its innovation in stressing the social nature of science. Science is practised by communities of scientists, not by isolated men and women. Even though, the adequacy of Kuhn´s specific historical model is still unresolved, he established without doubt the urgency for the study of science to incorporate historical, social, and personal influences lying outside scientific methodology. It is no doubt that Kuhn led a historiographic revolution in the history and philosophy of science.

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[297] Thomas S. Kuhn, ¨Reflections on my Critics¨, in *Criticism and the Growth of Knowledge,* eds. Imre Lakatos & Alan Musgrave (Cambridge: Cambridge University Press, 1970), p. 231

[298] Thomas Kuhn, *The Road Since Structure: Philosophical Essays, 1970–1993, with an Autobiographical Interview* (Chicago: University of Chicago Press) 2000, p. 307

[299] Sigurdsson, S., "The nature of scientific knowledge: an interview with Thomas Kuhn," *Harvard Science Review*, Winter issue, 1990, p.21

CHAPTER FOUR

4.1 THEORETICAL MODELS OF THE ´HISTORICIST´ HISTORIOGRAPHY

The choice of only the major historicist historiographies has been to highlight their concern for a shift, from the traditional mode of relying solely on the content of scientific beliefs and methods as the basis for justification of scientific claims, to the veritable consideration of the context of their development. Such approach not only holds great insights for genuine understanding of science, it has also influenced the development of the philosophy of science. It demonstrates that the very plausible way to make comprehensive narrative of the scientific progress is to understand the context of its development as well as the situations that inform the formation and choice of scientific theories.

J.D. Bernal clearly illustrated in the four volumes of his *Science in History*[300] the stimulus given to (and the limitation placed upon) discovery and invention by pastoral, agricultural, feudal, capitalist, and socialist systems, and conversely the ways in which science has altered economic, social, and political beliefs and practices. His attempt was to illustrate the mutual relations of science and society throughout history. Certainly, if the nature of the scientific claims is to be well accepted the interplay between science and the wider culture has to be given definite consideration. Pyenson & Sheets-Pyenson (1999) demonstrated that if we wish to understand why things changed in early modern science, not just describe how they changed, we have to look to the historical context out of which they arose.[301]

The highlights on the socio-cultural, economic and political influences on science do not imply its unsuitability as a genuine device for the accurate study of physical world;

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[300] See John Desmond Bernal, *Science in History.* 4 vols (Cambridge, Mass: M.I.T Press, 1971[1954]). In the second and fourth volumes he highlighted clearly the mutual interplay with the socio-cultural influences and science. The second volume, *Sciences in History: The Scientific and Industrial Revolution* commenced with the work of the Renaissance and continued with a discussion of the stimulus given to scientific development by emerging seventeenth-century capitalism. It concluded with industrial revolution and the way in which science and technology changed the whole nature of human society. In the fourth volume, *Science in History: The Social Sciences: Conclusion* he gave a bold Marxist outline of the history of the social sciences and of the social and political tendencies in the contemporary period.

[301] See Lewis Pyenson & Susan Sheets-Pyenson, *Servants of Nature: A History of Scientific Institutions, Enterprises and Sensibilities* (London: Fontana, 1999)

rather they serve to weigh the value judgment of its claim. It all centres on the logical implications of adopting the scientific processes and norms of the 16th and 17th century's science, which include mechanism and materialism, mathematical natural philosophy, and experimentalism, as functional parameter for the justification of the validity of the objectivity, truth, realism and rationality of scientific knowledge. (See sections 3.2.2, 3.2.2.1 and 3.2.2.2). In most cases, the truth, objectivity and rationality of science are hinged on the processes by which theories are tested, justified, or judged. The processes are believed to certify the validity of the objectivity or truth of good theories that were chosen over the poor or less effective ones. The reason is that those processes are taken to be governed by a set of criteria shared by the entire group of scientists competent to judge. Likewise, they do not, or at least need not, involve subjective or social factors at all. But most surprisingly, no scientist or philosopher of science has claimed to possess either a complete or an entirely well-articulated list of the criteria that govern those processes. It therefore, indicates that to explain why particular men made particular choices at particular times we must go beyond the list of shared criteria to the social context and characteristics of the individuals who make the choice.

> *Other factors relevant to choice lie outside the sciences. Kepler´s early election of Copernicanism was due in part to his immersion in the Neoplatonic and Hermetic movements of his day; German Romanticism predisposed those it affected toward both recognition and acceptance of energy conservation; nineteenth-century British social thought had a similar influence on the availability and acceptability of Darwin´s concept of the struggle for existence.*[302]

The above citation from Kuhn´s *The Essential Tension* (1977) shows that every individual choice between competing theories (as in the case of Kepler´s choice of Copernicanism over Ptolemy´s) depends on a mixture of objective (stipulated criteria) and subjective or extra-scientific factors. There are various works that strongly

[302] T. S. Kuhn, *The Essential Tension,* p. 325

illustrated the role of hermeticism in the thought of Bacon and Newton.[303] Even if we do not accept wholly the claims which these historicist theses make on the authority of the scientific claims they have one indisputable lesson to offer not just to the understanding of science but to general epistemology as well. John Henry summarises it thus,

> *...If we wish to achieve as full an understanding as possible of the Scientific Revolution we need to consider not only the role of natural philosophizing, and of the various technical considerations relevant to any aspect of scientific knowledge, but also religion, theology, politics, economics, metaphysics, methodology, rhetoric and, above all, the complex interplay between all these factors.*[304]

The cultural studies of science in the historicist model disapprove the claim that scientific knowledge has the capability to transcend any socio-cultural and political influence. They illustrate that such understanding of science drives from the belief in the internal consistency and self-sufficiency of science which has been proven to be false. The historicist overview of the Scientific Revolution is not particularly debates about its success or validity; they are, invariably, explicit appraisal of the scientific claims and its value judgement. Virtually all the historicist accounts attested to the success of western science of the early modern period and designated such figures like Galileo, Kepler, Descartes, Boyle, Huygens and Newton etc. as its heroes.

Alexandre Koyré illustrated that the study of this epoch shows us what superhuman effort each step on the way to knowledge of reality has cost, effort which has sometimes led to the veritable ´mutation´ in human intellect.[305] In the introduction to the *The Revolution in Science 1500-1750* Rupert Hall argued that though no less part of a world-

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[303] See Frances Yates, *Giordano Bruno and the Hermetic Tradition.* Chicago: University of Chicago Press, 1964; Betty Jo Teeter Dobbs, *The Foundations of Newton´s Alchemy,* Cambridge: Cambridge University Press, 1975; Paolo Rossi, *Francis Bacon: From Magic to Science,* trans. Sacha Rabinovitch, Chicago: University of Chicago Press, 1968; Brian Vickers ed. *Occult and Scientific Mentalities in the Renaissance,* Cambridge: Cambridge University Press, 1984.

[304] John Henry, *The Scientific Revolution and the Origins of Modern Science,* 2nd ed. (New York: Palgrave, 2002) p.109

[305] Alexandre Koyré, *Galileo Studies*, p. 1

view than any scientific system of the past, modern science differs markedly from any of them.[306] Modern science was unique due its rational way of establishing the factual knowledge of the external world through observation and experiment. Even Kuhn showed that it was precisely from the period of the scientific revolution that the sciences began to exhibit a single generally accepted view about the nature. According to Butterfield, the scientific revolution outshines everything since the rise of Christianity and reduces the previous historic events of the Renaissance and Reformation to the rank of mere episodes.[307]

One of the predominant issues historicists theses press forth is the incorrectness of subsuming the success of the scientific revolution as a logical justification for the validity of the scientific claims. In fact, the success of the scientific revolution lies in the fulfilment of the socials functions that have characterized early modern science ever since Francis Bacon proclaimed the idea of the dominion over nature by man through the application of science. The historicist historiography of the scientific revolution mostly used two major theoretical models to illustrate the principal frameworks on which the acclaimed success of the scientific revolution hinges. It is on the basis of such frameworks that they demonstrate the implications of a unilateral justification of the traditional claims of science.

These models include the physico-mathematical current and contextualism. However, both frameworks suggest that the success of the early modern science does not provide ample justification for establishing a platform that would clearly distinguish the authority of its claims from those of its predecessors.

The Shapin and Duhem theses would argue that the mathematical framework on which the scientific achievements of Kepler, Galileo and Newton are traceable to the ancient and medieval periods.

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[306] Rupert Hall, *The Revolution in Science 1500-1750*, p.4
[307] Herbert Butterfield, *The Origins of Modern Science 1300-1800,* p. 9.

According to Shapin,

> *Seventeenth-century confidence in the basic propriety and power of a mathematical framework for natural philosophy had ancient warrants.*[308]

The mathematization of nature was one of the prominent features which characterised the scientific revolution. Historians and philosophers of science show that most modern natural philosophers turned to Pythagoras (ca. 570 – 490 BCE), and particularly to Plato (ca. 427-347 B.C.), to legitimate a mathematical treatment of the world. In mathematics Plato´s name is attached to the Platonic solids. In the *Timaeus* there is a mathematical construction of the elements (earth, fire, air, and water), in which the cube, tetrahedron, octahedron, and icosahedron are given as the shapes of the atoms of earth, fire, air, and water respectively. The fifth Platonic solid, the dodecahedron, is Plato´s model for the whole universe. Unlike atomists such as Theophrastus of Eresus (ca. 371 BC – ca. 287 BC), Leucippus of Miletus (fl. 480 BC- ca 420 BC) and Democritus of Abdera (ca. 460-ca. 370 BC) who based their physical theories on crude analogies of the constituent element of the world, the novelty of the mathematical Platonism lies in the proposition of precise geometrical account of the shapes of the primary bodies and the reduction of the changes that take place between them to mathematical formulae.[309]

The mathematical Platonism later became transformed in the hands of Euclid, Archimedes, Eratosthenes, Heron, Menelaus and Diophantus. Euclid virtually invented classical (Euclidean) geometry as we know it. Archimedes was best known for his military innovations like his siege engines and mirrors to harness and focus the power of the sun, as well as levers, pulleys and pumps (including the famous screw pump known as Archimedes´ Screw, which is still used today in some parts of the world for irrigation). Likewise, he produced formulas to calculate the areas of regular shapes, using a revolutionary method of capturing new shapes by using shapes he already understood.

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[308] Steven Shapin, *The Scientific Revolution,* p.58

[309] G. E. R. Lloyd, *Early Greek Science: Thales to Aristotle* (New York, London: W. W. Norton, 1970) p. 77

Subsequently, the mathematical formulations by Euclid and Archimedes exerted enormous spell over the minds of such thinkers like Kepler and Galileo through whose combined efforts the mathematization of nature was totally realized and subsequently led to the dethronement of the Aristotelian physics. However, there is doubt regarding the legitimacy of mathematical ¨idealizations¨ in the explication of physical nature as it actually was, and if mathematical representations could capture the contingencies and the complexities of real natural processes.[310]

These problems will be discussed under the physico-mathematical current of the scientific revolution to see how the historicists´ theses weigh the plausibility of the mathematization of nature and its justification of the traditional claims of science.

4.2 PHYSICO-MATHEMATICAL CURRENT

During the ´Age of Reason´ which started in the wake of the Renaissance there was unprecedented explosion of mathematical and scientific ideas across the 17th Europe. Coming on the heels of the ´Copernican Revolution´ of Nicolaus Copernicus in the 16th Century, scientists like Galileo Galilei, Tycho Brahe and Johannes Kepler were making equally revolutionary discoveries in the exploration of the Solar system. Such effort culminated in Kepler´s formulation of the mathematical laws of planetary motion. Central to the flourishing of the mathematics in this period was the invention of the logarithm by John Napier of Merchiston (1550 – 4 April 1617).

This significant mathematical development was instrumental to the performance of such complex calculations needed for most scientific innovations wrought by Kepler and Newton. Mathematics later underwent transformation in the hands of some French Mathematicians like René Descartes (1596 -1650), Pierre de Fermat (1601 – 1665) and Blaise Pascal (1623 – 1662). Descartes, who is sometimes considered the first of the modern school of mathematics, developed analytic geometry which made possible the plotting of the orbits of the planets on a graph, as well as lay the foundations for the later development of calculus and much later multi-dimensional geometry. Fermat

[310] Steven Shapin, *The Scientific Revolution,* p. 59

formulated several theorems which greatly extended our knowledge of number theory, as well as contributing some early work on infinitesimal calculus. Blaise Pascal is most famous for Pascal´s Triangle of binominal coefficients, although similar figures had actually been produced by Chinese and Persian mathematicians long before him.

The mathematization of nature by which the scientific revolution triumphed was culminated in the development of infinitesimal calculus, with its two main operations: differentiation and integration, by Isaac Newton (1642 -1727) and Gottfried Leibniz (1646 – 1716). The German mathematician, Leibniz, is said to have invented the calculus independently but did not apply it to the real world as Newton did, who for the rest of his life was unwilling to share the credit with Leibniz. Though there is controversy about who among the duo first revolutionized mathematics completely with the development of the infinitesimal calculus, the fact remains that calculus of some sort is used extensively in everything from engineering to other fields like economics, medicine and astronomy.

4.2.1 THE SYNTHESIS OF MECHANICO-CORPUSCULARISM WITH MATHEMATICS

Among all the scientists who worked for the mathematical interpretation of physical realities Newton is designated as the hero by whom the mathematization process started by Galileo was perfectly accomplished. Newton ingenuity lies in establishing mathematical formulations of the regularities observable in nature for the expansion of the scope of casual mechanical explanation. This move was informed by the view that it is within this framework that the merging of the terrestrial and celestial physics could be established as against their initial separation in the Aristotelian physics.

Aristotelian physics made distinction between the terrestrial and celestial physics. In the terrestrial realm (below the orbit of the Moon), each body has a rightful place and must move naturally (up or down) toward the earth depending on its material composition. In the celestial realm (at or beyond the orbit of the Moon), each body is made of quintessence, a perfect and unchanging element. Each must move at a constant speed in perfect circles.

Newton´s revolutionary view of falling bodies brought about the joining together of the physics of the terrestrial and celestial realms into one simple package. The Newtonian synthesis argue that all bodies, regardless of size, shape, constitution, colour, texture generate and respond to gravitational forces in the same way. The power of gravity … was not limited to a certain distance from the earth but this power must extend much farther than was usually thought.[311] The Earth pulls on and is pulled by an apple (a terrestrial body) in the same way it influences and is influenced by the Moon (a celestial body), since ¨whatever draws or presses another is as much drawn or pressed by that other¨.[312] It means that if one object A exerts a force $\mathbf{F}_A$ on a second object B, then B simultaneously exerts a force $\mathbf{F}_B$ on A, and the two forces are equal and opposite: $\mathbf{F}_A = -\mathbf{F}_B$[313]

As the perfect circles of the Aristotelian physics gave way to the ellipses of the Newtonian physics the distinction between terrestrial and celestial matter evaporated. Newton´s eventual success depended on both observational evidence and the use of mathematically-expressed laws, marking a new combination of observation and the mathematization that came to define modern physics and modern science more generally.[314]

The ingenuity of the Newtonian physics is exemplified in the fit between mechanism and mathematics. For Newton, gravity was an action at a distance; two masses acted on one another despite the fact that empty space lay between them. Defined as a change in motion, Newton's conception of force was a mechanical, causal agent that acted either through contact or through action at a distance. He built a corpuscular theory with a new

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311 Richard Westfall, *Never at Rest; A Biography of Isaac Newton*. (Cambridge: Cambridge University Press. 1983) p. 154

312 Isaac Newton, *The Mathematical Principles of Natural Philosophy*, trans. Andrew Motte (London: Benjamin Motte. 1729 [1687]) Vol.1, Book 1. p. 20. This volume contains the addition of the Laws of the Moon´s motion according to Gravity by John Machin. Available at: http://books.google.es/books?id=Tm0FAAAAQAAJ&printsec=frontcover&hl=ca&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false Last accessed 15th December, 2012

313 D. Halliday, R. Resnick, & K. S. Krane, *Physics*, 4th ed. (Wiley, New York, 1992), Vol. 1. p. 83

314 Gary Hatfield, ¨Was the Scientific Revolution Really a Revolution in Science?¨, in *Tradition, Transmission, Transformation*, proceedings of two conferences on Pre-Modern Science held at the University of Oklahoma, eds. F. Jamil Ragep & Sally P. Ragep (New York; Leiden: E.J. Brill, 1996) p. 489

focus on forces that could be mathematically described. For him, corpuscles are units of mass and his introduction of the laws of mechanics was to explain their motion.

> *Certainly a mechanical view of the world was in principle amenable to mathematization, and a number of mechanical philosophers vigorously insisted on the central role of mathematics in the understanding of nature.*[315]

This mathematical tendency is closely related to the mechanical philosophy pursued by Descartes (1596 – 1650), Pierre Gassendi (1592 – 1655), and Robert Boyle (1627 – 1691). Boyle accepted that a natural world whose corpuscles were conceived to be variously sized, shaped, arranged, and moved demanded, in principle, for mathematical treatment. Robert Boyle´s *Sceptical Chymist*[316]*,* consisted of a sustained polemic against the Aristotelian concept of an element and the Paracelsian concept of a principle. What Boyle offered in their place was mechanical philosophy.

Like the Ionian philosophers, Aristotle believed in four elements, while the alchemist Paracelsus and his followers believed there were three elements, or as they called them, principles: sulphur, mercury, and salt. Boyle argued that the Aristotelian element and Paracelsian principle do not exist. What does exist is the qualitatively neutral matter of the mechanical philosophy, divided into particles differentiated only by size, shape, and motion. Boyle´s corpuscular theory of matter included the void to explain diffusion and other gas properties. His air-pump was developed in part to test the question of ´vacuum´ which was widely disputed in the seventeenth century.

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[315] Steven Shapin, *The Scientific Revolution,* pp. 57-58

[316] Robert Boyle, *The Sceptical Chymist: or Chymico-Physical Doubts & Paradoxes* (London: F. Cadwell, 1661). In this masterpiece, Boyle posited the hypothesis that matter consisted of atoms and clusters of atoms in motion and that every phenomenon was the result of collisions of particles in motion. See Robert Boyle, *The Sceptical Chymist.* (New York: Dover, 2003)

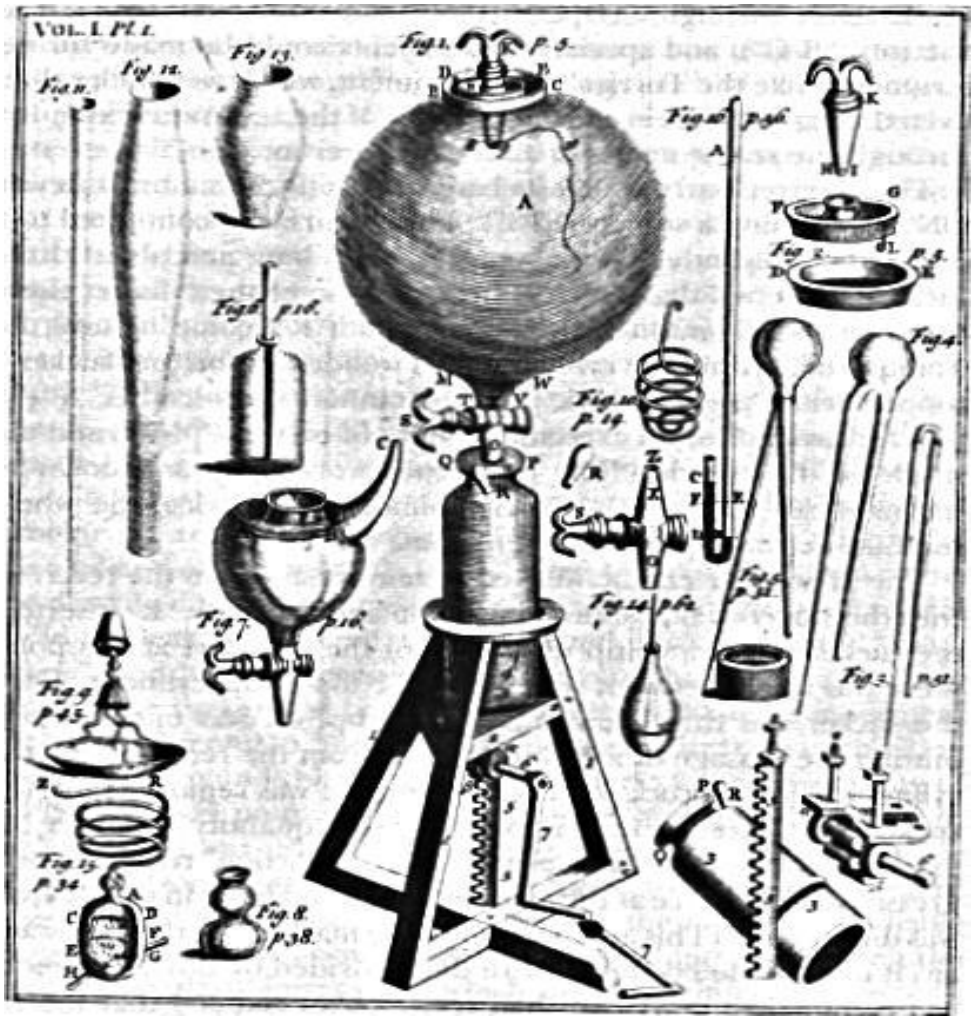

Fig. 2. Boyle's air pump was an advance over Von Guericke's spheres in that it provided a glass receptacle into which candles, mice, and other objects could be placed for experimentation. Air was ratcheted out from a cylinder and piston attached through a stopcock to the receptacle. After each cylinder of air was evacuated, the stopcock was closed and the ratchet and piston reset.

The existence of a ¨void¨, what we now call a vacuum, was earlier expounded in Descartes´ mechanical philosophy of corpuscularism. Descartes thought everything physical in the universe to be made of tiny vortices of matter. Like the ancient atomists, Descartes claimed that sensations, such as taste or temperature, are caused by the shape and size of tiny pieces of matter. The main difference between atomism, and Descartes´s concept was the existence of the void. For him, there could be no vacuum, and all matter was constantly swirling to prevent a void as corpuscles moved through other matter. Another main distinction between Descartes´ corpuscularism and classical atomism is Descartes´ concept of mind/body duality, which allowed for an independent realm of existence for thought, soul and most importantly God.

Unlike Descartes´ corpuscularism, the Gassendi´s system was without atheistic undertones, and was much closer to classical atomism. He was particularly intrigued by the Greek atomists, so he set out to purify atomism from its heretical and atheistic philosophical conclusion.[317] In a close analysis of Democritus´s system, Gassendi credited the ancient philosopher with a deterministic cosmology based on mechanical motion: The motion of the atoms, their percussion and repulsion, is the cause of all things, and things have to happen necessarily as they have happened because of this motion.[318] According to Koyré,

> *By introducing Democritean atomism as the fitting ontology for the new science, Gassendi, more than anybody else, had broken up the Aristotelian ontology of substance and attribute.*[319]

Gassendi formulated his atomistic conception of mechanical philosophy partly in response to Descartes´. He particularly opposed Descartes´ reductionist view that only purely mechanical explanations of physics are valid, as well as the application of geometry to the whole of physics.[320] However, the final form of corpuscularism that came to be accepted by most English scientists after Robert Boyle was a conjoined system of Descartes and Gassendi theories. Boyle´s corpuscular philosophy drew on both Gassendi and Descartes, and validated corpuscularism in the English scientific community in the late seventeenth century.[321]

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[317] See Eduard Jan Dijksterhuis, *The Mechanization of the World Picture* (Oxford: Oxford University Press, 1961)

[318] Gassendi, ¨Ethics,¨ in *SP*, *Opera,* 2: 834, quoted in Lisa T. Sarasohn, *Gassendi´s Ethics: Freedom in a Mechanistic Universe.* (Ithaca: Cornell University Press, 1996) p. 136

[319] Alexandre Koyré, ¨Gassendi et son temps,¨ in idem, Études d´histoire de la pensée scientifique. Ed. R. Taton. Paris: Presses Universitaires de France, 1966, quoted in H. Floris Cohen, *The Scientific Revolution,* p. 83

[320] See Antonio Clericuzio, *Elements, Principles and Corpuscles: A Study of Atomism and Chemistry in the Seventeenth Century* (Dordrecht: Kluwer, 2000) pp. 35-74. In the chapter two he discusses Spirit, Chemical Principles and Atoms in France in the first half of the seventeenth century.

[321] See Marie Boas Hall, *Robert Boyle on Natural Philosophy: An Essay with Selections from His Writings.* (Bloomington: Indiana University Press, 1965) pp. 281-82, and Robert H. Kargon, ¨Walter Charleton, Robert Boyle, and the Acceptance of Epicurean Atomism in England,¨ *Isis.* 1964, 55: 184-92

According to Sarasohn,

> *The Baconian tradition, with its repudiation of Aristotelian natural philosophy, made English thinkers sympathetic to the mechanical philosophy, with its close ties to atomism. English exiles during the Civil War period ... associated with Gassendi and Descartes. They became the conduit for atomistic ideas to cross the English Channel.*[322]

Corpuscularism preserved as a dominant theory throughout the 17th and 18th centuries, and particularly as an idea that some of the properties that objects appear to have are artefacts of the perceiving mind. Though similar to atomism it maintained that atoms were indivisible and corpuscles could in principle be divided. It also retained its link with alchemy in the work of scientists such as Robert Boyle and Isaac Newton in the 17th century. For instance, it was used by Newton to develop his corpuscular theory of light.

The above discussion shows the classical view that the mechanical picture of a matter-and-motion universe implied a mathematical conception of nature. Feingold quotes Boyle to have noted that the stress was upon the practical aspects of mathematics, especially those having to do with surveying and fortification, and it fed into the gentry´s current infatuation with mechanical devices as ¨artificial miracles¨ and with experimental displays valued ¨for their novelty or prettiness¨.[323] But even if there was a fit between mechanism, corpuscularism and mathematics the important question remains, how much of the mechanical philosophy was mathematized? For instance, Boyle´s original reports of experiments with the air-pump showed he excused his eschewal of physical generalization in part because this would have, he wrote, ¨require[d] more skills in mathematics than I pretend to.¨[324]

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[322] Lisa T. Sarasohn, *Gassendi´s Ethics: Freedom in a Mechanistic Universe,* pp. 170-71

[323] Mordechai Feingold, *The Mathematicians´Apprenticeship: Science, Universities and Society in England, 1560-1640* (Cambridge: Cambridge University Press, 1984) pp. 193-95

[324] Robert Boyle, *Some Considerations Touching the Usefulness of Experimental Natural Philosophy.* Second Tome, 1671, p. 425, quoted in Steven Shapin, *A Social History of Truth: Civility and Science in Seventeenth-Century England.* (Chicago: University of Chicago Press, 1994) p.313

If mathematics was acclaimed as the most proficient tool of reaching the true reality, what proper place did its notions of certainty and precision occupy in the practice of those experimentalists like Galileo, Kepler, Boyle, Newton etc in the early modern science? The answer to this question will demonstrate the bases of the historicists' critiques of the justification of scientific truth and objectivity from the notion of mathematical realism. Although the combination of mathematical science and corpuscularian conception of nature proved quite fertile ´neither the mathematical exactitude of Kepler´ s laws of planetary motion nor the quantitative rigor of Galileo´s laws of falling bodies proved derivable by means of he explanatory tools accepted in the corpuscularian world-view.[325] For Needham, mathematical reductionism of the scientific revolution is what gives prominence to mechanism over organic materialism which in his view should be overcome because ´such reductionism has reached its limits´.[326]

4.2.2 SCIENTIFIC TRUTH: METAPHYSICAL OR PROGRAMMATIC?

The claim for the viability of scientific truth could also be traced to mathematical Platonism. This aspect of Platonism is a metaphysical view that there are mathematical objects and they are independent of intelligent agents and their language, thought, and practices. It suggests that the natural world is made up of mathematical objects. They exist in this manner independent of their perception by human beings. Their nature has been made in mathematical forms because the ´Supreme Intellect´ who made them thinks mathematically and conceives of physical relations mathematically. This perception of physical reality defined the mathematical physics of Galileo and Kepler, which affirms that mathematical relations and quantities are really part of nature itself. This position has also been identified as Pythagorean.[327]

The brain behind the formulation of this kind of Platonism as we now know it is Gottlob Frege, who in his *Foundations of Arithmetic*[328] maintained that the language of

[325] H. Floris Cohen, *The Scientific Revolution: A Historiographical Inquiry,* p. 512
[326] Ibid., p. 465
[327] Rupert Hall, *The Revolution in Science 1500-1750*, p.286
[328] See Frege, G. *The Foundations of Arithmetic.* Trans. J L Austin (Oxford: Blackwell, 1959)

mathematics purports to refer to and quantify over abstract mathematical objects. Accordingly, a great number of mathematical theorems are true. But a sentence cannot be true unless its sub-expressions succeed in doing what they purport to do. This implies that there exist abstract mathematical objects which these expressions refer to and quantify over. Just like many other forms of Platonism it should be noted that mathematical Platonism is very distinguished from the view of the historical Plato. As we have seen from the earlier illustrations from his *Timaeus* Plato believed at first that mathematics would be the key to Thought. However, in his *Meno*[329], we see a Plato who has abandoned mathematical aids and embarked on his own quest with the Ideas. Such tremendous shift suggests that Plato´s famous ¨mathematical examples¨ were illustrations rather than central to his arguments.

Although Plato revered mathematics, he did so for its alleged ability to train the mind to receive the Forms (the higher dimension of the world) rather than as a means of gaining understanding of the physical world. Perhaps, this explains the bases for the difficulty in making neither completely logical description of how the mathematical-expressed-physical-regularities depended on the belief in the mechanical causes nor a comprehensive demonstration of the ways in which the mechanical philosophy was mathematized in the period of the early modern science.

It is not surprising that there was no experiment showing how Galileo´s mathematical laws of fall could be obtained in the physical world of concrete matter. Such law only pertained to ideal bodies moving in a frictionless environment. This raises doubt on whether Galilean physics was in essence addressed to the mathematical ideal or the concretely and physically real as the mechanico-corpuscularism pretends it was. Perhaps, it could be that the nature of the scientific truth that ensues from our knowledge of the world is a programmatic one. In that case, the Galilean mathematical theory of fall becomes true and represents an objective view of moving things if all motions only take place in a frictionless environment, which we know is not feasible. Assuming that the mathematical picture of the universe does not answer the questions that non-mathematical philosopher asked and vice versa, how could the success of the

[329] M, Jane Day, *Plato´s Meno in Focus* (London: Routledge, 1994); See also G. M. A, Grube, *Plato Five Dialogues* (USA: Hackett, 2002) pp.75-80. When asked if a given triangle can be inscribed in a given circle, the geometer chose to proceed hypothetically knowing that a rigorous mathematical proof is impossible

early modern science provide the justification for the viability of scientific truth? The above discussion already shows that physico-mathematical current does not provide demonstrable description of natural processes any better than its Aristotelian counterpart on whose defeat its success hinges.

Newtonian mathematical physics and scientific truth

Steven Shapin illustrated that Isaac Newton´s *The Mathematical Principles of Natural Philosophy* argued convincingly that the world-machine followed laws that were mathematical in form and that could be expressed in the language of mathematics.[330] His physico-mathematical approach serve to homogenise the platonic idea of mathematical construction of reality, which inspired Galileo and Kepler, with the Democritean conception of its atomic structure, which was transformed in the hands of Gassendi and Boyle. Shapin, summarised the Newtonian programme thus,

> *The gravitational force that bound the universe together was, to be sure, mathematically describable. It was even offered as a model for a practice whose end was the lawful characterization of the mathematical regularities of nature—laws (as Newton said) ¨deduced¨ from the actual observed behavior of bodies.*[331]

Newton asserted an indefinitely sized universe united only by the identity of its fundamental contents and laws as against the finite universe with qualitatively differentiated regions of space the Aristotelian and ancient Greek physics suggested. In this indefinitely sized universe there is no qualitative physical distinction between heavens and earth, or any of their components, such that astronomy and physics become interdependent and united because of their common subjection to geometry. This view re-echoes the perspective of mathematical Platonism about the existences of abstract mathematical objects by illustrating that all natural processes take place on a fabric of abstract time and space. In such homogenized world, abstract bodies move in an

[330] Steven Shapin, *The Scientific Revolution,* p. 61
[331] Ibid., p. 62-63

abstract space. Hence, a proper knowledge of such a universe becomes itself objective. The independent existence which the mathematical Platonism assigns to mathematical objects is meant to substantiate an analogy between mathematical objects and ordinary physical objects. Just as electrons and planets exist independently of us so do numbers and sets. And just as statements about electrons and planets are made true or false by the objects with which they are concerned and these objects' perfectly objective properties, so are statements about numbers and sets.

4.2.3 MATHEMATICAL CONCEPTUALISATION AND PHYSICAL REALITY

The major philosophical difficulty which the physico-mathematical current has not been able to surmount regards it incapability of guaranteeing a mathematical description of all natural processes. For instance, how does mathematics define the sweet taste of an orange in relation to the nature of its corpuscles? The issue of the relationship between mathematical explanation and the world of reality reminds us of the Platonic distinction between the world of ideas or pure forms and the world of reality. The debate about the relation between scientific explanations, particularly mathematical explanations was revived during the fifteenth and sixteenth centuries following the Copernican Revolution in Astronomy. One interpretation of Copernican theory was that it was only a computational device designed to save the appearances of planetary motion, though Copernicus as a committed Pythagorean, claimed physical truth for his theory.

Copernicus did not demonstrate mathematically how his system is truer than the Ptolemaic system. Besides, his system ´was not more accurate than Ptolemy´s until drastically revised by Kepler more than sixty years after Copernicus´s death.¨[332] The astronomical theory of Ptolemy was more accurate because it fitted well with the Aristotelian physics and was consistent with existing scientific explanation of earth´s motion and other terrestrial phenomena. However, in the triumph of Pythagoreanism during this period, Copernicus was strongly supported by Johannes Kepler (1571-1630) and Galileo Galilei (1596-1650).

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[332] T. S. Kuhn, *The Essential Tension,* p. 323

The triumph was because of the application of mathematical apparatus to explain vital aspects of the planetary motion, like retrograde motion and so on. In this case the Copernican theory was the simpler since it required only one circle per planet while Ptolemy´s require two. The basis on which judgments of the triumph of heliocentricism does not have do with its truth. The idiosyncrasy of Kepler and Galileo, and their shared scientific values were determinants of such scientific advancement. Because Galileo believed that the universe and the world of nature were ruled by mathematical relations and principles, he maintained that the scientific study of nature must be aimed at those aspects of nature which undergo quantitative variations. He thus came to establish a distinction between ´primary qualities´ and ´secondary qualities´ in the subject matter of physics.

The issue, here, is not if the science of the seventeenth century was successful or not, our concern is whether its success provides ample justification for its claims. The above discussion on the Copernican revolution showed that the Copernican theory of astronomy was not ´truer´ that Ptolemy´s. In fact, the scientific knowledge that ensues therefrom cannot be said to be wholly true and objective. Besides, Koyré (1957) and Dijksterhuis (1961) illustrated that the methodological maturity of science is located in the seventeenth century and it does not involve any obvious stipulation against the invocation of the supernatural. If we have to consider why physics (which provided the fertile ground for the triumph of mathematics) was so successful in the early modern period we have to learn from its rich experience over the centuries. In this way, one can track the changing ontologies and laws from Aristotle through Buridan and Oresme to Copernicus and Galileo and hence to Descartes, Huygens, Hooke, Newton et al, as the gradual reduction of ´primitives´ in the ontologies of motion and their replacement by the material implications which we now know as Newton´s laws of motion.

4.3 THE ´INNER LOGIC´ ARGUMENT

The physico-mathematical reductionism of the scientific revolution nurtured the assumption that science fully provides knowledge of the world that is true, objective, real and rational, and nothing less. Even among the historicist model this perspective finds ground among those who argue that the history of science is the history of the

inner intellectual logic of science. This internalist notion attributes simple conceptual, intellectual and cognitive essence to science. It maintained that the development of ideas following their own internal logic was the central element in the foundation of modern science.[333] Schuster summarised the classical view of internalism:

> *Internalists believed that scientific ideas and methods are autonomous, unfolding through the internal dynamics of rational thought and procedure alone, with social and economic circumstances at best affecting the timing or direction of research and at worst hindering progress.*[334]

This classical view of internalism demonstrates that scientific beliefs are stabilized only from inside the scientific community, and this is enough to demarcate science from non-science. Its focus is on the cognitive character of theories than the context that motivated their formulation. The sociological and institutional factors that influenced scientist´s choice of a theory are out-rightly irrelevant. The important fact is that internal consistency of a theory constitutes its cognitive value. Theory choice is conditioned only by the criteria that permit the acceptance of good theories over bad ones, or most effective over less effective ones. The vital factors in the process of scientific advancement are totally *pure* ideas. In fact, the history of the scientific advancement is typically a ´history of ideas´.

The internalists believe that science, or possibly an individual sub-discipline within science, was a system of thought which was self-contained, self-regulating, and developed in accordance with its own internal logic. Internalist histories of science often focus on the rational reconstruction of scientific ideas and consider the development of these ideas wholly within the scientific world. The Internalist approach to the Scientific Revolution (also known as ´intellectual history´ of the Scientific Revolution) conceives the history of the emergence of the modern science as an intellectual enterprise largely independent from the socio-political context in which science was practised. It is concerned with the growth of particular scientific, often technical, ideas: with how

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[333] Richard S. Westfall, *The Construction of Modern Science: Mechanisms and Mechanics,* p. 2

[334] John Schuster, ¨Internalist and Externalist Historiographies of the Scientific Revolution,¨ in *The Encyclopedia of the Scientific Revolution*, ed. AppleBaum, W. (New York: Routledge, 2008) p. 334

certain ideas in a field of science arose, were influenced by or, in turn, influenced ideas in other fields of science (or occasionally philosophy). For instance, Dijksterhuis concentrated mainly on free fall and projectile motion to explain the impact of the transition from Aristotelian natural philosophy to early modern mechanics because, for him, it was with Galileo that a new period began in the history of man´s thinking about nature.[335] Lakatos identified the problem with this approach thus,

> *...in constructing internal history the historian will be highly selective: he will omit everything that is irrational in the light of his rationality theory.*[336]

Intellectual history seem very ´whiggish´ due to the fact that it selects and judges past event based on the standard of rationality established by the contemporary evaluators.
The standard introductory texts are Koyré´s, *Études Galiléennes* (1939) and *Newtonian Studies* (1965), Butterfield's *The Origins of Modem Science* (1949) and Hall's *The Scientific Revolution* (1954), all of which were almost exclusively concerned with the internal history of scientific ideas. However, among the ten historiographies treated in chapter two, Koyré particularly represented in a very outstanding manner the intellectual history of the Scientific Revolution (See section 2.2.3). It is as though he was saying that ´Copernicus begot Galileo, Galileo begot Newton, and Newton begot Modern Science´. Koyré´s aim was to trace the development of ideas over time in Science, and he was very good at it. He demonstrated in *Metapphysics and Measurement,* (1968) that the idea of the internal logic of science is certified by the theory-dependence of observation. Metaphysical ideas are considered the source and guideline of ´proper´ science, and in general, ideas are seen as much more important than experience or even a deliberately set-up experiment, unless we are referring to thought-experiments.[337] The belief in the importance of metaphysics drives from the fact that physics is the science of intrinsic quantities, and mathematics is the science of

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[335] Eduard Jan Dijksterhuis,Val en worp: Een bijdrage tot de geschiedenis der mechanica van Aristoteles tot Newton. (Groningen: Noordhoff) 1924, p. 284 quoted in H. Floris Cohen, *The Scientific Revolution: A Historiographical Inquiry,* p. 65

[336] I. Lakatos, ¨History of Science and Its Rational Reconstructions¨, *Proceedings of the Biennial Meeting of the Philosophy of Science Association*, 1970, p. 106

[337] Yehuda Elkana, ¨Alexandre Koyré: between the History of ideas and Sociology of Knowledge¨, *History and Technology,* 1987, p. 111

discrete and continuous qualities. Invariably, both physics and mathematics have metaphysics as their fundamental base.

Metaphysics and observation are very important in science, and well controlled experiment serves as the bridge between then. Hence, if one seeks to explain the scientific revolution, attention must be concentrated on the philosophical outlook of the scientist and far from speculative theories. It was not the empirical nature of Galileo´s and Newton´s discoveries that carried the scientific revolution of the 16th and 17th centuries, but a shift in perspective, a change in theoretical outlook toward the world—a ´mutation´ of the human intellect. In brief, the logical way to explain discoveries is by explaining their metaphysical background. Koyré appeared certain that mathematization of nature was at the centre of the ´decisive mutation´ during the 16th and 17th centuries. Thus, there is no logic in establishing historical continuity between the medieval physics of Buridan and Nicole Oresme and classical physics of Galileo and Descartes since ¨the search for a mathematical law of nature is not a medieval problem.¨[338]

4.3.1 EXTRA-SCIENTIFIC IDEAS

Koyré´s internalistic approach made it appeared as if he was absolutely against the influence of forces in the development of science. On the contrary, he accepted the influence of extra-scientific ideas. The Koyréan thesis (see section 2.2, 2.2.1 and 2.2.2) illustrated the role of non-testable general views about the world in the formulation of mathematical derivable and experimentally testable theories about the world. For him, scientific metaphysics influenced scientific theories. His internalistic approach became a paradigm for history of science as history of disembodied ideas, thereby heralding the distinction between the history of ideas and sociology of knowledge. At first sight it might appear Koyréan thesis is totally different from the general thesis of the historicist model. Such mistaken understanding of the Internalist approach of the Koyréan thesis is what gave the perception that the history of ideas is ´uninfluenced´ in contrast to the sociology of scientific knowledge propounded by other historicists.

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[338] Jean Celeyrette, ¨Bradwardine´s rule: A mathematical law?¨ in *Mechanics and Natural Philosophy before the Scientific Revolution.* Eds. Laird, W. R & Roux, S. (Dordrecht: Springer. 2008) p. 64

Koyré accepted that ideas are influenced. He was open to the influence of ¨extra-scientific¨ factors in science. His studies on Galileo and Newton attributed significant role to extra-scientific ideas in the development of science. Often, his works on both great scientists are labelled as pure history of ideas but his acceptance of the great role of metaphysics in science shows the contrary. We should not forget the impact of his researches on the German post-Reformation mystics on his view of science. Koyréan thesis is not absolutely opposite to the general thesis of the historicist model which consists in showing how the structure of scientific knowledge fits into history. Even though he resisted, mainly, from giving attention to socio-economic and institutional factors as did the Marxist and sociologist historiographies, he showed that the body of scientific knowledge has extra-scientific influence.

> *Alexandre Koyré redirected the historiography of scientific ideas for several generations. He actually was among the creators of the historical sociology of scientific knowledge, together with Emile Meyerson whose work he continued, with Robert K. Merton with whom he overlapped for some decades, and with Thomas Kuhn who, in a way, continues his work.*[339]

He identified the scientific revolution as the establishment of a new ¨metaphysics, ¨ or set of deep conceptual presuppositions for scientific thought. In the *Galileo Studies* (1939) he attributed Galileo´s success in founding the first version of classical mechanics to the fact that he worked within the correct sort of metaphysical framework—the Platonic metaphysics, which showed that the basic furniture of the world consists in mathematical objects, moved according to simple mathematical laws.

Just like Kuhn and Merton, he knows that important influences of problem-choice and other aspects of scientific processes are exercised by what is thought about sources, aims and kinds of legitimation of knowledge. Although he recognised mathematical principles as playing great roles in the works of Galileo and Newton, he showed that the vital factor was the metaphysics behind them. Such metaphysics are those statements

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[339] Yehuda Elkana, *¨Alexandre Koyré: between the History of ideas and Sociology of Knowledge¨*, p. 113

about the object of discussion—the world, society, the biological organism or the individual human being—which are untestable. Certainly, he was more interested in the body of knowledge than its image. But he showed with his illustrations that the body of knowledge which is built from the mathematical principles, invariably, mirrors the image of the extra-scientific ideas from which they emanate—in this case ´Platonic metaphysics´.

Koyré's illustration shows that ideas are influenced and science is not restricted only within the ´testable´. That a claim cannot be unambiguously verified or falsified (see confirmationism and falsificationism in sections 3.1.1.1 and 3.1.1.2) does not mean that no meaningful debate about its truth can be conducted. On the contrary many great scientific debates focused on metaphysical generalisations which were in principle untestable. For instance, Newton´s view that the world consists of discrete particles with central forces acting between them, or Faraday´s that the world is a continuum of forces, the quantity of which is conserved, or the view of the molecular biologists that with growing knowledge of the chemistry of life, the phenomena of evolution will be reducible to molecular biology, are exactly such ´untestable´ propositions.

Mathematics was highly appreciated because of its social status among the prominent scientist of that period. In fact, some historical studies would argue that the ´mathematization of nature´ which has been held as a *sine que non* for the Scientific Revolution, precisely, describes the changing social status of mathematical practitioners and concomitant changes in attitudes about the relevance and value of mathematics, in everyday life but also in the higher echelons of thought.[340] Precisely, the major difference there is among the internalists and externalists of the historicist model is that while the internalist considers extra-scientific ideas, the externalists focus on socio-economic and institutional factors. They all converge on the view that ideas are influenced.

[340] John Henry, ¨Ideology, Inevitability, and the Scientific Revolution¨, *Isis,* 2008, 99(3), pp. 554-555

4.4 EXTERNALISM

The externalists emphasised the importance of social and economic forces and downplayed any ´internal´ factors in the development and advancement of science. According to Schuster,

> *Externalists, especially of the Marxist school, held that content as well as the direction of scientific knowledge was shaped by technological pulls that ultimately depended upon economic and social forces and structures.*[341]

The reason for this emphasis is that, in the Marxist view, the methods and means of production are the fundamental factors underlying the structure of a society. Hessen states thus,

> *The method of production of material existence conditions the social, political and intellectual process of the life of society.*[342]

For the extreme externalist position, the ideas and directions of science are completely shaped by social forces. It implies that the ´inside´ of the scientific field is, using John Locke´s aphorism, a *tabula rasa* to be imprinted on by society at large. The origin of the externalist interpretation of the Scientific Revolution is traced to Boris Hessen´s *"The Social and Economic Roots of Newton's Principia¨*(1931). Recent studies have shown that Hessen motives for an externalist account of the Scientific Revolution were not completely academic.[343] At that time in the Soviet Union, the work of Albert Einstein was under attack by Communist Party philosophers; being supposedly motivated by bourgeois values—it was "bourgeois science¨[344], and should henceforth be banned. As a result of this, Hessen was more concerned with the connections between Newton´s *Principia* and the simultaneous development of the bourgeoisie and capital, and the

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[341] John Schuster, *¨Internalist and Externalist Historiographies of the Scientific Revolution¨*, p. 334
[342] B. Hessen, *The Social and Economic Roots of Newton´s ´Principia´*.(Sydney: Current Book, 1946) p.9
[343] H. Floris Cohen, *The Scientific Revolution: A Historiographical Inquiry* p. 331
[344] Loren R Graham, "The socio-political Roots of Boris Hessen: Soviet Marxism and the History of Science", *Social Studies of Science* (London: SAGE, 1985) p. 711

creation of technical problems that were then solved by the application of Newton´s work. From this he draws the conclusion that the bourgeoisie were largely responsible for the creation of Newton´s work, and the Newtonian achievement should be seen from the perspective of a man being in the right place at the right time.

Hessen´s paper at the Second International Congress of the History of Science, convened in London in 1931, was a lobbying tactic. The Communist Party philosophers had no doubt about the accuracy of Newton´s theories, but Hessen thought that to demonstrate those theories as being motivated by bourgeois interest would justify the fact that scientific validity could exist whatever the motivations were for undertaking it. Nevertheless, there has been no study that gives evidence that Hessen paper succeeded in creating such effect in the internal Soviet philosophical battles over Einstein´s work. Even, Hessen´s paper was not able to achieve desired effect in his home country, although its wide effect in Western history of science is well noted.

Notwithstanding that his work has been severally tagged as ¨Vulgar Marxism¨[345], its insights on the relationship between society and science was, in its time, seen as novel and inspiring. It was a challenge to the notion that the history of science was the history of individual genius in action which had been the dominant view at least since William Whewell´s *History of the Inductive Sciences* in 1837. Most interestingly, the idea from Hessen´s thesis struck profound chords in the minds of a number of somewhat vaguely leftist scientists and sociologists among whose works include Robert Merton´s Science, Technology and Society in Seventeenth-Century Englang (1938), Edgar Zilsel´s *Sociological Roots of Science* (1942), Joseph Needham´s *Science and Civilisation in China* (1954), and J. D. Bernal´s *The Social function of Science* (1939) and *Science in History* (1954).

The emergence of a new wave of externalist studies has been related to the more general impact of postmodernism over the social sciences. Even if ‘nothing about this term is unproblematic´[346,] postmodernism is generally employed to define a cluster of thinkers who, during the 1970s and the 1980s, shared a sceptical position about the major foundations of Western thought and about the attainment of scientific truths. The

[345] Simon Schaffer, "Newton at the crossroads", *Radical Philosophy*, 1984, 37, p. 26
[346] B. McHale, *Postmodernist Fictions* (London: Routledge. 1987) p. 3

externalist approach at its extreme suggests that the scientists of the sixteenth and seventeenth centuries were vividly inspired and interested by problems which were suggested by socio-economic factors. This type of materialist historiography was widely seen as an aggressive attempt to devalue science by displaying its ´banausic´ (utilitarian) and practical origins. It was understood that to depict scientists as motivated by mundane and material concerns, to see the genesis of science more in craftwork than in philosophy, and to show that scientific concerns were animated more by the search for solutions to technological problems than by the disinterested quest for truth which *simply was denigration.*[347]

Perhaps a less polemic example of externalism is Bernal´s *Science in History* (1954) Bernal looks at art, medicine, government, trade, capital, engineering, and many other factors to demonstrate the principal motivators of scientific advancement. Unlike Hessen, he did not attempt to reduce the achievements of the great scientists to any forces or modes of production. For him, the drive that gave the scientific revolution its particular novelty was the dissolution of feudalism and the birth of merchant capitalism. This driving factors were not only visible in the scientific revolution there were present in the science of previous ages. According to Bernal,

> *The ¨flourishing periods [of science] are found to coincide with economic activity and technical advance. The track science has followed—from Egypt to ... England of the Industrial Revolution—is the same as that of commerce and industrial.*[348]

The transformation of science in any period in history coincides with its peculiar flourishing economic activity. Could this then signify that that any age without successful economic activity cannot witness tangible transformation of its science?

In a very practical sense, it is difficult to draw definitive line between the scope of the internalist and externalist approach since none of the historians of the respective approaches could insist that any of them either paints a wholly complete picture of the

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[347] Steven Shapin, ¨Discipline and Bounding: The History and Sociology of Science as Seen Through the Externalism-Internalism Debate¨, *History of Science,* 1992, 30, p. 339

[348] John D. Bernal. *Science in History.* p.47

scientific revolution or could be adopted exclusively. It can be seen that both internalist and externalist positions agree on two main points: Science has an ´inside´ and an ´outside´, and these two areas have minimal effect on each other. The ´inside´ of science consists of all of the ideas, theories and method, while the ´outside´ of science consists of the larger society.

Both approaches debate on which area determine the course of science. The primary factor affecting who became proponents of one side or another in the argument was the relative desirability of incorporating Marxist thinking into the process of scientific development. In other words, for scientists in the West, during the Cold War, anything that smacked of Marxism or Communism was to be avoided, while for scientists behind the Iron Curtain, the converse was the case. Steven Shapin suggested that neither of the approaches seems to have been properly established as valid or viable and it wasn't long before a professed eclectic approach became all the rage.[349]

Resuming the implication of the internalist and externalist debate

As various illustrations from the internalist-externalist debate has shown, internal historians of science do not deny the obvious truth that an activity carried on by a scientist living in a society has a valid social history. Likewise, external historians of science do not deny that the content of science is an essential part of the story. The internalist and externalist debate created a richer contextualization of scientific knowledge. Its result is a sub-discipline of history which is flourishing in its own terms, and which more generally is making a major contribution to our understanding of how and why science has become such an overwhelming feature of the Western culture. However, at heart of that debate is contained a basic question about the nature of science: what is the relationship between the producers and consumers of scientific knowledge? The answer to this question must, in some way, inform the method by which the history of science and technology is conducted. The question itself contains an entire host of philosophical questions: what is the nature of scientific truth? What

[349] Steven Shapin, *¨Discipline and Bounding: The History and Sociology of Science as Seen Through the Externalism- Internalism Debate¨,* pp. 345-51

does objectivity mean in a scientific context? How does change in scientific theories occur? Shapin wrote that

> *Treating externalism and internalism as theories of scientific change is the most coherent way to formulate them: scientific change proceeds (wholly/ mainly/partly, in response to intrinsic/extrinsic factors.*[350]

This formulation could serve to bring a lasting resolution to the complex historiographical issues in the ´Scientific Revolution´. One of the major impacts the internalist-externalist debate has brought to the historiography of science is that it has demonstrated that science does not have any ´immanent logic or rationality´, with a dynamic force, that guarantees scientific change. Some historically oriented philosophers like Lakatos, Laudan, McMullin, Shapere, and Toulmin had in their account of the scientific change demonstrated the role external-social and internal-cognitive factors play in science, but were more inclined to appealing to a historical notion of rational progress.

What differentiates the notion of rationality of the aforementioned philosophers with that of the historicist accounts of the scientific revolution is that they regard science as being globally rational. Their attempt is inversely contrary to the notion of the scientific rationality that the historicists' historiography would accept. Nevertheless, the arguments most of the theses of scientific revolution, treated in chapter two, highlighted in the internalist-externalist debate helps us to see their enthusiasm and interest in showing how science is historically or locally rational. This type of rationality is quite different from the historical notion of rational progress the aforementioned philosophers adopted. Likewise, it is quite distanced from the logical notion of rational inferential argued by the traditionalist accounts of scientific change. They, therefore, insist that if we must talk about rationality of the Scientific Revolution that rationality should be historical or contextual—situated in a particular time. Scientific knowledge does not have global rationality. The only way we can understand adequately scientific

[350] Ibid., p. 346

rationality is by employing the method of hermeneutic contextualism in discussing the science of any particular period and location

4.5 HERMENEUTIC CONTEXTUALISM

After the passionate debates of the 1950s and 1960s, most historians embraced an eclectic position combining 'externalist' with 'internalist' factors with the aim of explaining scientific change. Contextualism defines the externalists and internalists´ demonstration of what constitutes the ´insides´ of the sciences as mistaken. Schuster states thus,

> *Inside a science we do not find concepts or ideas or theories rattling around in a void. We find a social institution: People in social and institutional relations—the people being professional practitioners of that science.*[351]

It shows that science is not wholly created out of a continuum of ideas as internalist would suppose, neither is it wholly moulded by socio-economic forces as the externalist insist. Science is influenced, and in turn influences the larger society in which it is a part. The misleading image of science as having norms and processes that are non-contextual drives heavily from the appearance most textbooks have given of the physical sciences. These textbooks or their equivalent are mainly repository of the finished achievements of modern physical scientists. They contain few historical elements which attribute particular natural phenomena to the historical personages who first discovered them. Invariably, the image of science they present shows its important goal as mainly discovery. Hence, ¨to make a discovery becomes achieving one of the closest approximations to a property right that the scientific career affords.[352]

Nevertheless, many scientific discoveries, particularly the most interesting and important, are not the sort of event about which the questions ¨Where?¨ and, more

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[351] John Schuster, *The Scientific Revolution: An Introduction to the History and Philosophy of Science.* (University of Wollongong Press, 1995) p.215

[352] T. S. Kuhn, *The Essential Tension,* p. 166

particularly, ¨When? ¨ can appropriately be asked. To ask such question would be to demonstrate a fundamental inappropriateness in our image of discovery. But with the instrumentality of hermeneutics the historian could make fundamental conceptual readjustment of history so as to recapture the past or, conversely, of the past to develop toward the present. Just as the in the case of Kuhn, ¨the discovery of hermeneutics did more than make history seem consequential.[353]

An elaborated history of science would not only concentrate on the substance of science as knowledge but also on the activities of scientists as a social group. If one thinks of knowledge as having a separate existence from the people who use it, one almost inevitably ends ups espousing a kind of Platonism, placing primacy on some Form that exists independently of the physical world. Given the historical fact of scientific revolutions, it would be impossible to argue for an idealistic Platonism without ending up with a Whiggish history of ideas. Such were the case where mathematical Platonism and mathematical realism were deployed as stance justifying the truth, pure objective and scientific realism. However, as Richard H. Shryock stated,

> *We do not think that the history of science is sullied by the inclusion of social backgrounds, but neither are we convinced that scientific ideas are simply products of economic determinism. [The history of science] can be understood only in terms of a constant interplay between internal logic and environment.*[354]

The new hermeneutic contextualism, unlike externalists, recognise that scientific judgements about pertinent experimental or analytical results, or about correct theory, can sometimes only be understood in terms of the technical tradition within which they play a part, and may be insulated from wider social considerations. This is not tantamount to internalism since eclectic historians of science would argue (or assume) that in such cases the technical tradition itself is a socially constructed, or culturally

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[353] Ibid, p. xiii

[354] W. J. Bell, Jr, ¨Richard H Shryock: Life and work of a historian¨, *Journal of the history of medicine*, 1974, 29: 15-31, p. 23 quoted in Steven Shapin, *¨Discipline and Bounding: The History and Sociology of Science as Seen Through the Externalism- Internalism Debate*, p. 341

determined phenomenon, and that work within that tradition is affected by social interactions between the relevant specialists.[355] However, the question still remains if there is really any distinction between internalism and externalism in the historicist model of the scientific revolution. For Kuhn, the labels ¨internalist¨ and ¨externalist¨ no longer quite fit. The reason is that those who have concentrated primarily on individual sciences, e.g. Alexandre Koyré, Rupert hall etc., have not hesitated to attribute a significant role in scientific development to extrascientific ideas. What they have resisted primarily is attention to socio-economic and institutional factors as treated by such writers as B. Hessen, Robert Merton, Zilsel etc.[356]

4.6 THE ROLE OF HISTORY IN THE ´SCIENTIFIC REVOLUTION´

The Internalist-externalist debate brought philosophical insights to the role of history in the structure of scientific advancement. It changed the sort of epistemological questions that philosophers of science work on. The epistemological question for traditional philosophers was, "Why should one believe a given body of knowledge claims?¨[357] But now historically enlightened philosophers ask, "Why should one shift from one body of knowledge claims to another?¨[358] The answer to the latter question does not involve evaluative criteria as absolutes, when comparing a theory to the empirical evidence. It highlights the interplay of the both objective and subjective or extra-scientific factors.

As earlier mentioned in this work, the traditional account of the scientific development has the view of science as a repository of accumulated facts, discovered by individuals at specific periods in history. Given this traditional view of science, the historian therefore sees his/her main task as that of giving answer to the questions about who discovered what, where, and when. Even though the task seems straightforward, many

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[355] Steven Shapin makes a forceful plea for a historicist sociology of knowledge approach in 'Discipline and Bounding: The History and Sociology of Science as Seen Through the Externalism–Internalism Debate´, pp. 352-3; He also presents a manifesto for the application of sociology of knowledge to historiography in Steven Shapin, 'Social Uses of Science', in *The Ferment of Knowledge,* eds. G. Rousseau and R. Porter (Cambridge: Cambridge University Press, 1980), pp. 93–139.

[356] T. S. Kuhn, *The Essential Tension,* p. 32

[357] Thomas Kuhn, MIT MC240, box 23, folder 21, "Scientific development and lexical change," p. 12; ¨MIT MC 240¨ refers to the Thomas S. Kuhn papers, at the Institute Archives and Special Collections, MIT Libraries, Cambridge, MA, quoted in James A. Marcum, *Thomas Kuhn´s Revolution: An Historical Philosophy of Science*, p. 121

[358] Ibid.

historians found it difficult and doubted whether these are the right kinds of questions to ask concerning science's historical record. "The result of all these difficulties and doubts is a historiographical revolution in the study of science."[359]

This revolution changed the sorts of questions historians ask by revising the underlying assumptions concerning the approach to reading historical records. Rather than reading history backwards and imposing current ideas and values on the past, the texts and documents are read within their historical period, thereby maintaining their integrity. It is important to ask, what did science mean to the scientific revolutionaries? But one of the problems inherent in this question is that the revolutionaries rarely used the word science. Instead, they talked and wrote about natural philosophy or the philosophy of nature. Nature, to them, meant the natural world, that is, what was natural, what was not made by human hands.

I would suggest that using the expression the philosophy of nature was really a hangover from the medieval world. In other words, questions of science were subsumed under the study of philosophy, and since medieval man called the phenomenal world Nature, it was quite logical to refer to the study of Nature as the philosophy of Nature. Some works like *Epistemological and Political Implications of the Scientific Revolution* (1992) would argue that the Scientific Revolution should not be seen as a revolution *in* science, because there was nothing like our notion of science until it began to be forged in the Scientific Revolution out of previously distinct elements which includes the mathematization of nature with synthesis of mechanic-corpuscular philosophy.[360]

The historiographical revolution in the study of science's record had implications for how science is viewed and understood philosophically. One of such implications is that the dichotomy which traditional accounts seem to make between the ´context of discovery´ and the ´context of justification´ does not really hold in the historical analysis of the actual situations in which knowledge is gained, accepted, and assimilated. Kuhn wrote that rather than being elementary logical or methodological distinctions, which would thus be prior to the analysis of scientific knowledge, they now

[359] Thomas Kuhn, *The Structure of Scientific Revolutions*, p.3
[360] See Wilbur Applebaum, ´´Epistemological and Political Implications of the Scientific Revolution´, in *Science, Pseudo-Science, and Utopianism in Early Modern Thought,* ed. Stephen A. McKnight (London: University of Missouri Press, 1992), pp. 167 -202.

seem integral parts of a traditional set of substantive answers to the very questions upon which they have been deployed.[361]

Therefore, seeing that the efforts in the traditional analysis of scientific progress has failed to establish a stable and theory-neutral data or observations to justify theories—a search that has also eluded the traditional western philosophy for the past three centuries—the historiographical revolution offered that recourse to the history of science could be effective means to actualize that.

Having used the historicist model of the scientific revolution to illustrate that scientific claims are historically, and locally (Europe) determined, the next chapter will deal on the philosophical problem that ensues from this claim—How do we explain the universality of modern science? Is modern science really universal or Does it only have global extension?

[361] Thomas Kuhn, *The Structure of Scientific Revolutions*, p. 9

SECTION III

SCIENTIFIC PROCESSES AND UNIVERSALITY OF SCIENCE:

CHAPTER FIVE

5.1 UNIVERSALITY OF MODERN SCIENCE

The issue of the universality of modern science is largely tied to the justification of the traditional scientific claims on the basis of the ´scientific´ processes of the 16th and 17th centuries being more ´rational´ and ´objective´ than its predecessors. This justification drives from the fact that scientific processes of the early modern period are seen to be very progressive and their progressiveness provides the guaranty for the authenticity of their claims—a notion well supported by the ´miracle argument´ for scientific realism. Interestingly, the philosophical implications raised in the historicist´s appraisal of traditional scientific claims show that all ´sciences´ in history have similar innate character—to expand their scope in a way that their contents are truly ¨hardcore¨ of their statements. However, this is an ´ideal´ which no science has achieved since there are always factors (metaphysical, sociological and extra-scientist) that relativize their contents. The case is not different for modern science. In fact, the idea of universality comes in when scientific traditions are shown to advance without any link to the context within which they were cultivated. But then the peculiar traits that mark each science remain with it even when it has transcended various localities.

From the illustrations of the historicist model of the scientific revolution narrative we learn that in the development of human civilizations there was an Indian science, a Chinese science, a Greek science, a science in Arabic language, a science of European Christian Middle Age, a science of European Renaissance, a science called ´modern´, and then a ¨contemporary¨ science. Nevertheless, the asymmetrical characteristics of the debate between continuity vs. discontinuity, internalist vs. externalist, physico-mathematical vs. magico-mystical draw our attention not only to their philosophical insights on the progress of science but also the issue of the universality of modern science. How can we defend the universality of science when the practices of scientific

investigation, its products, and its norms are historically variant? Besides, scientific work is, sometimes, culturally variant even within the same field. For instance, high-energy physics, low-temperature physics, molecular biology, meteorology and paleontology are in many ways quite different epistemic practices across Europe, North America and Asia. Hence, how is modern science universal when its processes are explained by reference to the factors that can be found, and shown to be found, in particular localities?

In section 2.7.2.1 Needham argued that the epoch making events like Capitalism, Renaissance and Reformation were factors that guaranteed the occurrence of scientific revolution in Europe, and not china. If these three historical events were what provided the ingredients for the transformation of science in the 17th century Europe does it mean the 17th century China did not have a dynamic commerce that could have facilitated similar breakthrough with its already advanced astronomical science? And if those factors did not really constitute the intricate elements that engineered the advancement of the 17th century science from its medieval root what factors really made the logic of the early modern science appear more ´scientific´ than its predecessors? These questions bring us to another important one: Is there a basic difference in modes of thought—both in content and more especially in logic and formulation—between Western and non-Western societies? Or between ¨traditional¨ and ¨modern¨, ¨pre-scientific¨ and ¨science oriented¨, literate and non-literate, industrial and non-industrial, ¨developed¨ and ¨developing¨, etc.,? [362]

The dominant illustrations from the historicist analysis of the modern science traditional claims opine that there is no fundamental difference in mode of thought between modern Western and traditional non-Western societies. However, some important differences in the sciences of these societies can be accounted for without contradicting the view of the congenial similitude of their scientific practices. Although there are important national differences in the style, direction, standards, and goals of scientific work, it does not mean that different scientific cultures are self-enclosed or mutually

[362] See Robin Horton, & Ruth Finnegan (eds.), *Modes of Thought.* (London: Faber and Faber, 1973, p. 11

uncomprehending. Nor does it mean that the epistemically interesting differences in scientific cultures neatly map onto national, linguistic, or other culture boundaries.[363]

5.2 FACTS AND SCIENTIFIC STATEMENTS ABOUT NATURE

Generally, the controversy regarding the universality of modern science does not, typically, have to do with the actual constituents of scientific phenomena but rather, the propositions given to the account of those phenomena. No one doubts the motion of falling bodies to the centre of the earth. For instance, an Orange falls from its tree to the ground and not in an upward movement because of the active force that pulls it downward. Precisely, the question of universality of science arises from the nature of propositions given to account the fall of the orange and the values we attach to the motion of the fall of such orange. According to Cobern and Loving,

> *The question of universality does not arise over the phenomenon of falling. The question of universality arises over the fashion of the propositions given to account for the phenomenon of falling, the fashion of the discourse through which we communicate our thoughts about the phenomenon and the values we attach to the phenomenon – including the account offered by a standard scientific description.*[364]

The important fact reiterated here is that science consists of a body of knowledge about the world. However, this does not imply that scientific knowledge progresses steadily with the expansion of the accepted propositions that are given to account for the scientific phenomena. In the first place such understanding makes science appear as if its propositions capture wholly the true nature of physical things. This positivist understanding of science would maintain that the meaning of a scientific theory is exhausted by empirical and logical considerations of what would verify or falsify it. A

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[363] See Joseph Rouse, ¨What Are Cultural Studies of Scientific Knowledge?¨, *Configurations*, 1992, 1 (1), 1-22

[364] William W. Cobern & Cathleen C. Loving, ¨Defining ´Science´ in a multicultural world¨, *Reconsidering Science Learning,* eds. Eileen Scanlon, Patricia Murphy, Jeff Thomas & Elizabeth Whiteleg (London: RoutledgeFalmer, 2004) p.195

scientific theory, then, is a condensed summary of possible observations. Hence, scientific theories are built up by the logical manipulation of observations[365], and scientific progress consists in increasing the correctness, number, and range of potential observations that its theories indicate. It is such understanding of science that has given credence to the universality of modern science.

For the logical positivists, theories develop through a method that transforms individual data points into general statements. This indicates why positivists tried to develop a logic of science that would make solid the inductive process of moving from individual facts to general claims within the context of discovery.

They maintained this stance on the basis that the justification we have for believing a scientific theory is based on that theory´s solid connection to data. It is an empiricist reducibility thesis according to which all terms suited to describe actual or possible empirical facts are full definable by terms referring exclusively to aspects of immediate experience. However, if meanings are reduced to observations, there are many ¨synonyms,¨ in the form of theories or statements that look as though they should have very different meanings but do not make different predictions. In *An Introduction to Science and Technology studies* (2010), Sergio Sismondo, gave an example of such. He wrote that Copernican astronomy was initially designed to duplicate the (mostly successful) predictions of the earlier Ptolemaic system; in terms of observations, then, the two systems were roughly equivalent, but they clearly meant very different things, since one put the Earth in the centre of the universe, and the other had the Earth spinning around the Sun.[366]

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[365] See Alfred J. Ayer, *Language, Truth, and Logic,* New York: Dover, 2nd ed., 1952[first published 1936]. The reprinted version with a new introduction, London: Penguin, 2001 is used. In this work the concept underlying Ayer's discussion is the "principle of verifiability," which defines a statement as being "literally meaningful" only if it either is logically necessary ("analytical") or can be empirically verified as being either true or false. Under this definition, metaphysical statements are not literally meaningful, and so are properly part of theology rather than philosophy. See also, Rudolf Carnap, *Der Logische Aufbau der Welt.* Berlin-Schlachtensee: Weltkreis-Verlag. (English translation by Rolf A. George, *The Logical Structure of the World and Pseudo-problems in Philosophy.* Berkeley: University of California Press, 1967) By utilizing logic and radical reductionism, Carnap tried to show how one's knowledge of the world can be reduced to sense data and how our talk about the external world is built up from our immediate sense data.

[366] Sergio Sismondo, *An Introduction to Science and Technology studies.* 2nd ed. (West Sussex: Blackwell, 2010) p.2

In fact, many apparently meaningful claims are not systematically related to observations, because theories are often too abstract to be immediately cashed out in terms of data. Likewise, that a claim cannot be unambiguously verified or falsified does not mean that no meaningful debate about its truth can be conducted. On the contrary, virtually all the great scientific debates concerned ambiguous metaphysical statements. These debates focused on metaphysical generalisations which were in principle untestable.

Very good examples of such propositions are: Newton´s view that the world consists of discrete particles with central forces acting between them; Faraday´s view that the world is a continuum of forces, the quantity of which is conserved; and the view of the molecular biologists that with growing knowledge of the chemistry of life the phenomena of evolution will be reducible to molecular biology. More still, Newton´s assertion that the whole is simply the sum of its component parts provided the crucial foundation stone for his pivotal work on gravity. But from where did he get the idea? The assertion cannot, of course, be proved. As we could see in section 2.9 Boris Hessen went far to demonstrate that the rise of capitalism after the demise of European feudal society provided the underlying principles that fomented Newton´s *Principia.*

Consequently, it is as a result of the logical inconsistencies implicit in positivism that the Shapin and Kuhnian theses described such understanding of science is implausible (See sections 2.11, 2.11.2, 2.11.3, 2.12, 2.13.1, 2.13.3 and 2.13.4). Michael Reiss shared similar perspective thus,

> *It is not too much of a caricature to state that science is seen by many as the way to truth…. The advance of science then consists of scientists discovering eternal truths that exist independently of them and of the cultural context in which these discoveries are made….Truth is supposed to emerge unambiguously from experiment like Pallas Athene, the goddess of wisdom, springing nature and unsullied from the head of Zeus.*[367]

[367] Michael Reiss, ¨What is Science? Teaching Science in Secondary Schools¨, in *Reconsidering Science Learning,* eds. Eileen Scanlon, Patricia Murphy, Jeff Thomas & Elizabeth Whitelegg (London: RoutledgeFalmer, 2004) p.4

The understanding of science as a truth-seeking enterprise is traceable to its mathematical reductionism. However, the hypothetico-deductive methodology of Christian Huygens (1628 – 1695) suggested that science and mathematics were actually different fields, and could not be treated the same way. The distinction he made between the two was the idea of proof. He stated that mathematics and geometry could prove something beyond doubt, whereas science can never prove something emphatically. Science, merely, gives a probability that a certain finding is true. Although the facts from which scientific knowledge is constituted are derived from accurate observations and careful experiments that can be checked by repeating them, such knowledge is still conditioned by the experience and guiding principle of the community of the scientist that work it out. Besides other socio-cultural factors like the technological or economic needs (see sections 2.8, 2.9 and 2.9.1) of the society also affect the direction of the research whereby those facts are studied. But the fact that science and society are inevitably, and inexorably, intertwined does not necessarily require one to abandon all belief in the objectivity of science. Alan Chalmers writes thus,

> *The natural world does not behave in one way for capitalists and in another way for socialists, in one way for males and another for females, in one way for Western cultures and another for Eastern cultures.*[368]

In essence, the behaviour of the natural world is not ambiguous but our understanding of it may. A scientist´s *perceptions* of the natural world, as well as his or her interpretations of it, are conditioned by the aptitude of his or her senses and the culture that nurtured them. Therefore, there can be no single, universal, acultural science. The implication is that all sciences of various civilizations are tainted with unique ethnographic colourations which explain their usual identification within such civilization. But if science and its content are so ethnographically determined how can we explain the ´universality of modern science´?—a science whose presumed universal practice is still invisible, and often misunderstood in most locations in Africa, East-Asia and South-America? Why is it that in most parts of these locations one could find many scientists and students that are very good in mathematics and physics but lack the

[368] Alan Chalmers, *Science and Its Fabrication* (Minnesota: University of Minnesota Press, 1990) p. 112

appropriate measure on how to give practical solution to concrete local problems? How universal is modern science? Is universality the appropriate term to attribute to the concurrent presence of modern scientific practice in most localities of the world? Perhaps, we would have to accept that scientific knowledge is universal only in the sense that locomotives can move everywhere. They can move in all parts of the world, provided that the rail network has been built for them.[369]

5.3 ´STRONG LOCALISM´ THEORY

The non-restriction of the developmental character of scientific knowledge within particular locality provides the demarcation between the ´socio-cultural´ theory of the historicist model of the Scientific Revolution and the ´strong localism´ theory of various sociological studies of scientific knowledge. Both the strong localists/constructivists and most historicists treated in chapter two maintained that scientific research is a process of social production and certification, which must be understood in terms of social categories. However, the strong localists argued that locality determines the practice and outcomes of science, leaving a permanent imprint on them and limiting their applicability. According to David Livingstone,

> *Science is not to be thought of as some transcendent entity that bears no trace of the parochial or contingent. It needs rather to be qualified by temporal and regional adjectives. At one scale of operations, science is an ancient, Chinese, a medieval Islamic, an early modern, English, a Renaissance French, a Jeffersonian American, an enlightenment Scottish thing—or some modifying variant.*[370]

The localism theory demonstrates that scientific products are ´occasioned´ by the circumstances of their production. ´Occassioned´ here means that the circumstances of production are an integral part of the products which emerge.

Knorr-Cetina states thus,

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[369] Bruno Latour, *The Pasteurization of France,* trans. Alan Sheridan & John Law. (Cambridge, MA: Harvard University Press, 1993 [1988]) p. 226

[370] David N. Livingstone, *Putting Science in its place: Geographies of Science,* p.13

> *This contextual location reveals that the products of scientific research are fabricated and negotiated by particular agents at a particular time and place; that these products are carried by the particular interests of these agents, and by local rather than universally valid interpretations; and that the scientific actors play on the very limits of the situational location of their action. In short, the contingency and contextuality of scientific action demonstrates that the products of science are hybrids which bear the mark of the very indexical logic which characterizes their production....*[371]

Thus, we are not just referring to contextual factors which *influence* scientific work that in its core is non-contextual. For most of the historicists discussed in chapter two, although science is a form of social practice that takes place in some location and is performed by the people of that location, the social-cultural imprint on the outcomes of science does not limit its applicability. This explains why most of the theses showed how inter-exchange of scientific practices and outcomes between locations led to the scientific breakthrough of the early modern period. What are known as scientific breakthroughs build, whether this is acknowledged or not, on previous work and rest on a tradition of understanding, even when the effect of the breakthrough will be to undermine those understandings.[372] For instance, James Watson´s account of the discovery of the molecular structure of DNA, read in conjunction with the story of Rosalind Franklin´s contributions to that discovery.[373] The continuity thesis (see section 2.3.1) showed the influence of the medieval science on its modern counterpart. The Kuhnian, Shapin, Needham, Yates and Butterfield and Hessen theses showed constant extra-scientific influences and exchange of science outcomes between localities. Likewise, various tents of the Greek and Arabic science were shown to be instrumental to the development of some fields of modern science

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[371] K. D. Knorr-Cetina, *The Manufacture of Knowledge: An Essay on the Constructivist and Contextual Nature of Science* (Oxford: Pergamon Press, 1981) p.58

[372] Helen E. Longino, ¨Values and Objectivity¨, in *Philosophy of Science*, eds. Curd, M & Cover, J. A (New York, London: W. W. Norton & Company, 1998) p.175

[373] See Anne Sayre, *Rosalind Franklin and DNA.* (New York: W. W. Norton, 1975)

Nevertheless, the formulation of the ´strong localism´ theory drives from the response to the purported account of the *Western* modern science as the *Standard Account of science.* Virtually all the theses of the Scientific Revolution had based their discussion on the progress of science on the Ancient Greek and European culture. It implied that *Western* science was recognised simply as *science,* and even when Western scientists occasionally took note of non-Western indigenous knowledge of nature, that knowledge was distinctively labelled *ethnoscience*[374]. It does not mean that such ethnoscience does not have value—It, rather, does not qualify as Standard Account of science. But then, to tag the indigenous knowledge of nature as ethnoscience portrays a clear misunderstanding of the nature of science since all science is set in a cultural milieu. In this case, all science will be ethnoscience as we cannot validly distinguish a number of ethnosciences from a single international non-ethnoscientific science. Hence, in the 1990s, non-Western peoples and some scholars within the West began to formally and overtly resist this imperial Western attitude toward indigenous knowledge of nature. This movement was abetted by the programme for the social study of science, founded in the 1970s at Edinburgh[375], which argued that all science is socially contingent and culturally embedded. New epistemological perspectives such as multiculturalism[376], post-colonialism and postmodernism[377] rose to challenge the conventional Western wisdom on the relationship between science and culture. The Standard Account issue was also contested.

However, unlike the ¨Strong Programme´ of the social constructivist tradition at Edinburgh the historicist model suggests that the plausible means of accounting for the purported universality of science and ´delocalization of scientific knowledge` lies in the replication of equipment (*for experiment)*, the training of observes (*scientists)*, the circulation of routine practices and the standardization of methods and measures. When equipment, instruments, theories, statements, expressions of scientific laws and training

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[374] See Behrens, C.A, ¨The scientific basis for Shipibo soil classification and land use: changes in soil-plant associations with cash cropping¨, *American Anthropologist,* 1989, 91:83 -100 and Berlin, B. ¨Speculations on the growth of ethnobotanical nomenclature¨, *Language in Society,* 1972, 1:51-86

[375] See D. Bloor, and B. Barnes, *Scientific Knowledge. A Sociological Analysis.* (Chicago: University of Chicago Press, 1996)

[376] See D. Bloor, and B. Barnes, *Scientific Knowledge. A Sociological Analysis.* (Chicago: University of Chicago Press, 1996)

[377] See W. B Stanley, & N. W.Brickhouse, ¨Multiculturalism, universalism, and science education¨, *Science Education,* 1994, 78: 387- 98

are standardized, the same kinds of practices or units will become accepted as default options in multiple localities. Hence, all these procedures reiterates why scientific research is a process of social production and certification, which must be understood in terms of social categories.

5.4 UNIVERSALITY OF SCIENCE AS A PHILOSOPHICAL IDEA

The philosophical tradition of the ancient Greeks provided the basis for the epistemologically formulation of the universality of science. The ancient Greeks philosophers established the *logos* as the principle of rational thought, together with the requirement of intelligibility, which refers to the idea of *being.*[378] Their conception of the *Logos* strongly highlighted the role of mathematical thinking. This is because of the mathematical method of reasoning that overcomes the approximations of discourse in ordinary language. The mathematical thinking is also reflected in the Logos´ ability to serve as a model, because of its ideal objects that make possible to relate, through rigorous logical reasoning, the one and the multiple, the identical and the varied, by referring one to each other the elements of geometrical figures. Hence, the *logos* verifies always the validity of established meaning.

In other words, every utterance asks for its own criticism, thereby illustrating ´the formation of positivist thought in archaic Greece´[379] This internal criticism was later brought to full maturity in positivism and the Falsificationism of the logical positivists and logical empiricists. For instance, the Popper´s scientist is first and foremost sceptical, unwilling to accept anything as proven, and willing to throw away anything that runs contradictory to the evidence. For both positivism and Falsificationism, the features of science that make it scientific are formal relations between theories and data, whether through the rational construction of theoretical edifices on top of empirical data or the rational dismissal of theories on the basis of empirical data. Just like the *Logos,* these formalist pictures of science have analogous views about mathematics. Invariably, they depend on stereotypes of mathematics as a logical activity.

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[378] Jean Pierre Vernant, *Myth and Thought Among the Greeks* (London: Routledge & Kegan Paul, 1983) p. 341. First published in French in 1965 as Mythe et pensée chez les Grecs, Maspéro, Paris, 1965.
[379] Ibid., p. 343

Similar permanent criticism was also guaranteed in Descartes affirmation of the possibility of a universal doubt. With Descartes, doubt is founding of a knowledge that is to be, at the same time, and for this very reason, universal. This implies that the only true knowledge is that knowledge that, for every thinking subject, overcomes the obstacles opposed by doubt. In fact, Descartes´ *Meditations* showed his conviction in establishing a science that is certain and effective with geometrie. Therein he proposed to look back to the *ego cogito* as the first evidence eventually able to provide an absolute foundation to knowledge.[380] Hence, the science that is established by the doubting being is in all ramifications certain and universal. However, one important question needs clarification here: to what degree are scientific results and scientific theories acceptable to every human being? This aspect of the universality of science concerns the logical status of scientific theories and results and will be discussed as the epistemological aspect

5.5 EPISTEMOLOGICAL ASPECT OF THE UNIVERSALITY OF SCIENCE

The universality of science is, often, taken to derive from the universality of its methods and the way its results are shared. The natural sciences are considered universal because they follow the scientific method and their results can be shared and understood by different human beings. Many schools of science philosophy define these two properties as "intersubjectivity" and "testability of science." At the root of this concept is the idea that scientific results can be communicated in an unambiguous way and tested by anybody who wishes to do so. However, nowhere in the laboratory do we find the ´nature´ or ´reality´ which is so crucial to the descriptive interpretation of reality.
Karin D. Knorr-Cetina wrote thus,

> *In the laboratory scientists operate upon (and within) a highly preconstructed artifactual reality. It is clear that measurement instruments are the products of human effort, as are articles,*

[380] See René Descartes, *Meditations on First Philosophy*, translated by John Cottingham (Cambridge: Cambridge University Press, 1996) first published 1641

> *books, and the graphs and print-outs produced. But the source materials with which scientists work are also preconstructed. Plants and assay rats are specially grown and selectively bred. Most of the substances and chemicals used are purified and are obtained from the industry which serves the science or from other laboratories. The water which runs from a special faucet is sterilized. ´Raw´ materials which enter the laboratory are carefully selected and ´prepared´ before they are subjected to ´scientific´ tests.... the laboratory displays itself as a site of action from which ´nature´ is as much as possible excluded rather than included.*[381]

As far as simple, down-to-earth facts of science are concerned, the explanation of scientific methods and results seems to be relatively simple. However, when it comes to more sophisticated theories and results, the task becomes very prohibitive. Scientific theories and facts are often expressed in the kind of mathematical language or theoretical jargon that is far removed from the vernacular and outside the experience of ordinary sensual perception. To understand a scientific theory and thus to be able to test it, one must belong to a defined scientific community, master the language used by its members, and share the methodologies specific to that community. A way out of this dilemma is to state that scientific results are universally testable in principle. However, this statement does not solve the problem. The question remains how can this principle be realized? Finding an answer to it lies in showing how science is intertwined with society and not excluded from it as most historicist model of the Scientific Revolution have shown.

The discussion in section 3.4 showed how realism depicts the core epistemic justification of science universality. It has taken scientific theories to be generally fairly abstract. According to realist intuitions, there is no way to understand the increase in predictive power of science, and the technical ability that flows from that predictive

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[381] Karin D. Knorr-Cetina, ¨The Ethnographic Study of Scientific Work: Towards a Constructivist Interpretation of Science¨, *Science Observed: Perspectives on the Social Study of Science*, eds. Karin D. Knorr-Cetina and Michael Joseph Mulkay, London: Sage, 1983, p. 119

power, except in terms of an increase of truth. This implies that if science accumulates truths, it does so on a rational basis, not through luck, thereby justifying the universal obtainability of its results. However, the universality of science appears to be measured in terms of the trust we place in science. In the normal daily life, the layman hardly has direct contact with pure science. All he knows of science is its manifestation as technological product, and he usually trusts the workings of those products. For instance, when he presses an electrical bell and it does not ring, he does not blame the science of electricity, but rather he thinks that something has gone wrong with the wires or switches. This shows a manifestation of his confidence in the technology and, invariably, in the science that lies behind this technology.

If we accept this criterion, we can say that science is universal because our trust in technology is universal**.** But the fact remains that most people know almost nothing about the science upon which their technology is based, such that this kind of trust in technology can be equivocated with a magical view about the manner in which these products work. We can suppose that there is a spirit at work behind every instrument. In fact, we can compare this kind of trust with that which people place in religion and deities. Of course, science does not deal with values per se, but it contains values in the execution of scientific research and in the application of scientific knowledge. There are values **in** science and there are values **of** science. The search for truth in science imposes on the researcher a moral conduct, which is not unlike the moral conduct of a person in the broader society.

Invariably, the theories of inter-subjectivity and the testability of science (as we have seen in the Cartesian formula, Confirmationism and Falsificationism) do not prove the universality of science but rather point to its *potential*. Science disciplines are potentially intersubjective, and scientific methods are potentially testable. These two potentialities can be actualized only through conscious human effort, and their realization depends on various factors that are not dictated only by the logic of science itself. For example, we can decide in principle between any two rival theories by doing a suitable experiment, which is usually called a crucial experiment. But in practice, to be able to perform an experiment demands many prerequisites as Knorr-Cetina has shown in the above citation. One has to have access to relevant technologies—to be able to build the necessary instruments—and these technologies are not always accessible.

Historical science presents us with many examples of theories that have had to remain undecided because the relevant experimental technology or instrumentation is not available. The question of the speed of light—whether light travels at a finite speed or instantaneously—is only one example.

Thus, in its epistemological aspect, the universality of science expresses not a reality but rather an ideal. The potential for this ideal to become a reality depends on how much scientific knowledge human beings can possess. In other words, science is universal to the extent we want it to be universal.

5.6 THE SOCIAL ASPECT

The *functionalist* view of the Mertonian thesis illustrates that science served a social function, providing certified knowledge. Hence, as a social function each culture has peculiar axis on which it measures scientific development. The notion as to what constitutes science differs over time and between cultures.[382] Though certain principles, such as testability and repeatability, may be central to modern science, it is now widely held that the question ´What is science?´ can only be answered thus—it is that which is recognized as such by a scientific community. It is a recognition that reflects the values and goals which a scientific community upholds. For instance, the Needham thesis demonstrated that the organic sciences were being developed optimally within the Chinese culture at the time when the Western culture upheld the physical sciences as the paradigm of science. Perhaps, it was the quest for a science that has universal appearance that made the West to base more on the physical science due its mathematical stereotypes. Mayr wrote thus,

> *As everyone was willing to concede, the universality and predictability that seemed to characterize studies of the inanimate world were missing from biology. Because life was*

[382] See Hiatt, L. R. and Jones, R. ¨Aboriginal conceptions of the workings of nature¨, in R. W. Home (ed.) *Australian Science in the Making.* (Cambridge: Cambridge University Press, 1988) pp. 1-22; Brooke, J. H, *Science and Religion: Some Historical Perspective.* (Cambridge: Cambridge University Press, 1991)

> *restricted to the earth, as far as anyone knew, any statements and generalizations one could make concerning living organisms would seem to be restricted in space and time. To make matters worse, such statements nearly always seemed to have exceptions. Explanations usually were not based on universal laws but rather were pluralistic. In short the theories of biology violated every canon of ´true science´, as the philosophers had derived them from the methods and principles of classical physics.*[383]

Certainly, the social aspect of expansion of science shows that it is of a secondary importance to ask *where* exactly one form of science first appeared when compared to its assimilation by all cultures—through transformations from their original forms. Levi-Strauss even questioned what importance it has to know in which culture industrial and scientific revolution began? The simultaneous coming out of the same technological overthrow followed by social upheaval in societies having accepted it show that these modifications did not hold to the peculiarity of the genius of a culture, but ¨to conditions that are so general that they are located outside the consciousness of men¨.[384] Such ¨revolutions¨ are not limited to the modalities of their coming out, rather, they get to take new forms, to which all cultures on the inhabited Earth will take part, whatever the conditions.

5.7 HISTORICAL ASPECT OF SCIENCE EXPANSION

Modern science, as it developed in Europe through Renaissance in the sixteenth and seventeenth centuries, inherited from science of Greek Antiquity, from science in Arabic language and from science of European Middle Age—all these scientific traditions were in filiation with each other although in a nonlinear way. As the Needham thesis (see sections 2.7.1, 2.7.2 and 2.7.2.1) has shown, modern science is also indebted to other

[383] E. Mayr, *Towards a New Philosophy of Biology: Observations of an Evolutionist.* (Cambridge, MA: Belknap Press of Harvard University Press, 1988) p. 9

[384] Claude Lévi-Strauss, *Race and History*. (Paris: UNESCO, 1952) p.38

traditions, such as those from the East, through the complex and various exchanges that never ceased from Antiquity and Middle Ages to European Renaissance, between East and Mediterranean shores and from there to Western Europe. We know about caravans and trades, about military and political conquests, and for sure exchanges of ideas and of knowledge have gone along with them, though little is still known on this. In such exchanges, openness to difference and novelty from inside a tradition towards others is indeed a factor that benefits the first and makes it gain in universality.

Modern science itself began with an Italian period, which culminated, with respect to the science of nature, with Galileo; its second period witnessed the active participation of other parts of Europe, with the British and French sharing the first rank. Thereafter, the current spread and multiplied, passed to numerous European countries, and the development of the different branches of knowledge occurred in the most varied directions, giving science a new form.

5.8 THE ROLE OF SCIENTIFIC INSTRUMENTS

The universality of modern science became an issue of debate because philosophy of science had long ignored the role of instruments and laboratory experiments in science. In the traditional philosophical view, the aim of science is the production of reliable, adequate or true knowledge about the world. The role of experiments is testing hypotheses in controlled laboratory settings. Hence, the production of empirical knowledge by instruments is ignored. However, the resulting picture of nature the scientist observes is influenced by the technological spectacle he/she uses in the process, thereby showing that instruments are vital to the articulation and justification of scientific knowledge. Karin D. Knorr-Cetina´s citation in section 5.5 had shown that scientists operate upon (and within) a highly preconstructed artifactual reality. In the same vein, Kuhn had shown that the paradigm is basic to our knowledge of the world, and observations through scientific instruments, only exist in so far as they emerge within the paradigm (see sections 2.12.1, 2.12.2 and 2.12.4). Consequently, the view that non-empirical factors, such as ontology and theoretical background knowledge, are prior to observation and experiments thwarts the logical positivists and logical empiricists´ view that scientific theories are tested by means of an empirical and logical

methodology. It shows that experimental results are not just accepted on the basis of epistemological or methodological arguments, since there are other extra-scientific and social-cultural factors which play vital role, as some of the historicist historiographies had shown.

For social constructivists like Bruno Latour, the universality of modern science is a social construct, which has been created by the networks of science and specifically by metrological standardizations. He wrote thus,

> *People think that the universality of science is a given, because they forget to take into account the size of the ´métrologie.´ Ignoring this transformation that makes all displacements possible is like studying an engine without the railway or the freeway networks… The cost of making society conform to the inside of laboratories so that the latter´s activity can be made relevant to the society is constantly forgotten, because people do not want to see that the universality is a social construction as well.*[385]

The role of instruments in science shows that the ´seeming universality´ of modern science drives from the process of standardization which is both social and situated. It, thereby, makes void the idea of ´placeless´ and ´non-influence´ implied by the concept of ´universality´. Ironically, students of science and practitioners are first encouraged to use robust instruments, wherein right techniques are learnt, and thereafter are told that the absolute system depended on no particular instruments, techniques or institutions. Such positivist approach strives to foster complete certainty on the validity of scientific knowledge produced in the laboratory. Affirming Shapin and Kuhn´s perspective on the nature of objectivity in science, Harry Collins (1985) argued that certainty increases

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[385] Bruno Latour, ¨Give me a laboratory and I will raise the world¨, *Science Observed: Perspectives on the Social Study of Science*, eds. Karin D. Knorr-Cetina and Michael Joseph Mulkay. (London: Sage, 1983) p. 176

when the details of the social processes that went into the creation of certainty become invisible.[386]

The appearance of universality is the consequence of the adoption of the same kind of instruments, education, practices, methods and units all around the world. Joseph O´Connell (1993) clearly characterized the process of standardization as a situation where one tries to establish a stable collective that would use the same measurement procedures and share the same methods.[387] An example of such standardization process was the distribution of the boxes of resistance coils to telegraph companies, manufactures and physicists throughout the world by the British Association for the Advancement of Science. This kind of box had three important features. It had a certificate that connected it to its local laboratory of origin. More importantly, such certificate confirms that the box represented the ´legal volt´. Further, it had terminals that enabled a connection to what was to be calibrated. Finally, it had a handle that let the volt escape ¨the localism of one lab¨ and travel to others.[388]

[386] H. Collins, *Changing Order.* (Chicago: Chicago University Press, 1985) p. 162

[387] J. O´Connell, ¨Metrology: The creation of universality by the circulation of particulars¨, *Social Studies of Science,*1993, **23,** p. 134

[388] Ibid., p. 148

CONCLUSION

1.1 THE IMPORTS OF HISTORICISM

One of the major highlights of the historicist account of the scientific revolution has been the importance of understanding the processes and norms of modern science as model, not mode. Although its analysis of the scientific revolution might appear divergent on the nature of scientific advancement—with debates comprising internalism versus externalism, continuity versus discontinuity theses, physical versus hermeticist theses and so on—the appraisal of the traditional claims of science was the fundamental factor that underlie the dimension of its respective approaches.

It proffers that the logical way of resolving the complex question that arise from the validity of scientific knowledge on the basis of rationality, realism, objectivity and truth is by resort to historicism and contextual development of early modern science. In this way, we would see that the standards of science change over time. They are mutable. They change with the change of scientific beliefs. No standard or method in science is insulated from the periodic changes that occur in science. Hence, it is not logical to accept the existence of super scientific standards which survive the revolutions in sciences. It is the presumption of the existence of such super scientific standards that gave credence to the notion of the universality of modern science. Such presumption derived from the theory-dominated perspective on science of positivists. Logical positivism and logical empiricism have long given predominant consideration to the logic of science while neglecting its context as non-essential.

Invariably, the historicists adoption of hermeneutic contextualism implied that the traditional philosophical accounts of how observation provides an objective basis for evaluation of theories—by the use of confirmation theory or inductive logic—should be replaced by accounts of science that reflect, the influence of extra-scientific/social factors, and how experimental knowledge is actually arrived at and how this knowledge functions. Hence, the traditional distinction between the ¨context of discovery¨ and the ¨context of justification¨ has to be rejected. The historicists demonstrated this rejection by appealing to a historical notion of rational progress rather than to a logical notion of

rational inference as previously conceived by logical positivism and logical empiricism. Nonetheless, the discussion of the historicist historiography of the scientific revolution demonstrated that it does not approve the idea of universal rationality and objectivity of science.

The issue is not whether the major scientists of the early modern period had good arguments for the reality of the phenomena they dealt on, the real question is whether the propositions employed to describe those phenomena are universally valid. Rehearsing the events of the Copernican revolution, McMullin concluded that ¨Copernicus and those who followed him believed that they had good arguments for the reality of the earth´s motion around the sun¨[389] However, McMullin´s conclusion was based on the use of ¨super-empirical¨ values, which carry ¨special epistemic weight¨ in theory choice. The implication is that those super-empirical factors like ontology and theoretical background knowledge are precursory to observation and experiments thereby justifying the theory-ladeness of observation and active role of instrument in generation of empirical knowledge.

One of the principal connections among the various approaches of the historicist historiography of the scientific revolution has been their use of history to demonstrate the local nature of rationality. Science is historically or locally rational. We should not forget that the origin of modern science resides in one specific geographical and cultural locality called Europe. Cunningham and Williams highlighted how small the area where modern science was born. They wrote thus,

> *[A]lmost all the material with which the history of science discipline has been concerned comes from a tiny geographical area, about the same size as Zaire or the Sudan, and considerably smaller than Brazil. The only thing that is unusual about the countries in this area, apart from the fact that they are where we live, is that it was these countries which rose to world-domination during the nineteenth century, through the formation*

[389] E. McMullin, (1993), ¨Rationality and paradigm change in science,¨ in *World Change: Thomas Kuhn and the Nature of Science,* Horwich, P. (ed) (Cambridge, MA: MIT Press, 1993) p. 74

> *of overseas empires. It was only this historical accident that has meant that what began as their own native culture—by that time including that recent invention, science—has now become world culture.*[390]

The ´domination´ highlighted above suggests the notion of the ´empire of science´. It implied that the subordination of other alternatives—the so-called pre-scientific local practices and standards of ´ethnosciences´—is what makes the standards and practices of Western science seem natural and appear to be derived from ´nature´ itself. However, Needham´s illustration of the great progress of science in China at the time shows that the West´s dominant way of doing science was one among many possible ones. Therefore, the standards and practices of Western science cannot be a manifestation of a neutral and universal framework of knowing across human history and cultures, nor a universal feature of human nature or human civilization. In fact, the knowledge of any society is an integral product of that society, and embodies within it the values and social relations of that society. Marcum cited Kuhn´s perspective on the local nature of scientific rationality thus,

> *...the generation of scientific knowledge cannot be wrested from its historical (local) context; it is situated in a particular time and location. And if we are to understand the science of a particular time and location, according to Kuhn, we must climb inside the heads of its practitioners.*[391]

This perspective is in line with what the historicist historiography has demonstrated so far—to understand the science of the early modern period would be to look into the thinking of its practitioners and the socio-cultural context in which they worked. Rather than focus entirely on the practices and standards of science in early modern Europe Needham had made wonderful illustrations of those of other cultures. The historicist model of the scientific revolution cannot just be denigrated as a dogmatic ´localist´ theory of scientific rationality. It has to be noted that this model was also very

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[390] A. Cunningham & P. Williams, ¨De-centring the ´big picture´: The origins of modern science and the modern origins,¨ *British Journal for the History of Science,* 26, 1993 p. 431

[391] James A. Marcum, *Thomas Kuhn´s Revolution: An Historical Philosophy of Science*, p. *167*

instrumental in initiating the argument for the validity of the science of other cultures, and the logical way of understanding the similitude among them. It demonstrated that every science has its own ´outside´. However, the seeming divergence in the various approaches of the historicist has been to what constitute the ´inside´ of science. Even though the internalists like Koyré and Hall argued that concepts and ideas are what constitute the ´inside´ of science, they maintained, unlike the logical positivists, that this ´inside´ of science is influenced.

1.2 THE ´INSIDE OF SCIENCE´

The ´inside of science´ has been the central point of controversy regarding the nature and authority of the scientific claims. From the discussion so far it is evident that the demarcating factor between logical positivism and the historicist accounts of the scientific revolution is whether or not the ´inside of science is influenced. The historicists argue that the inside of science is influenced by religious, social and ideological forces, but the logical positivists deny it. However, there is huge similarity between the *logical positivists* and the *´internalists´* of the scientific revolution regarding the constituents of the inside of science. Both view the inside of science as comprising of only intellectual elements, concepts and ideas. They attribute simple conceptual, intellectual, cognitive essence to Science. Nevertheless, the factor that separates both groups is the importance of extra-scientific factors in shaping the content of science and in driving the process of knowledge generation. While the logical positivists maintain that such factors do not affect the content of science, the ´internalists´ argue that they are vital in shaping it.

The principal internalist treated in this work, Koyré, explored the change in intellectual ¨mentalité¨ from the high scholastic period through the Renaissance: namely, the development of a consciousness of man being different from, and in a sense above Nature. Koyré highlighted the importance of metaphysics in science. His theory of scientific advancement even suggests that the scientific changes are more or less ´spiritual changes´, which however, defined, are nonetheless social in character. In the *Galilean Studies* Koyré illustration of the Galilean and Newtonian revolution in

reflectivity shows that knowledge of the world is like divine knowledge in intension and as far as it is so, it is totally law-dependent in extension too.

But then, these developments are to be explained not in terms of individual minds but as socially determined changes in the images of knowledge. Inside any science is a smaller sub-culture of the larger society, and as such that science has a definite social structure. Galileo invested himself in telescopic skills which were part of the social set-up of astronomy. It is at this juncture that the externalists of the historicist model countered the arguments of the internalist to demonstrate that even the inside of science is conditioned by external factors. There is ¨no doubt *that even the* mathematical discoveries *of Galileo and Newton* are conditioned by outside events of every kind, political, economic, scientific, military, and by the incessant demands of the arts of peace and war.[392] Hence, It is an undeniable fact that, if we want to seek out the causes of the ´Scientific Revolution´, we must look for them among the wider changes taking place in that sea-change of European history.[393]

Of course, careful judgement of the tenets of the externalist and internalist shows that both accepts that no concept, idea or intellectual element emerge from the void. However, unlike what the internalists might have feared, the externalist did not propose to reduce science entirely to its social, political, religious and economic foundation. For instance, Hessen´s materialism informed his attack on the supposed absolute autonomy of ideas—the basis for the proposal of universality. But neither he nor the historical materialist tradition from which his thesis derived did propose to reduce science totally to its economic foundation. He wrote that, ¨According to the materialistic conception of history, the final determining factor... is the creation and recreation of actual life. But this does not mean that the *economic factor* is the sole determining factor.¨[394] For instance, the mechanical philosophy was probably shaped more by religious and ideological concerns than directly by the rising middle-class. Moreover, the Mertonian thesis makes us believe that in the 17th century the main external influence on science was from religion and the institutions of religion and education, not directly from the economy or the capitalist class. Nevertheless, empirical historical research shows that in

[392] George Sarton, *The study of the history of mathematics and The study of the history of science* (2vols, bound as 1; New York: Dover, 1957; orig. publ. 1936), p.15. Italics are mine.
[393] John Henry, *The Scientific Revolution and the Origins of Modern Science,* p.9
[394] Borris Hessen, ¨The social and economic roots of Newton´s ´Principia´¨, p. 177

the 19th century, the emerging industrial capitalist system did affect science and influenced its direction of progress.

1.3 ´INTERACTIONIST EPITEMOLOGY

What I have done with the historicist historiography of the scientific revolution has been to demonstrate the import of its hermeneutic contextualism to genuine understanding of science. The historicist accounts have shown that history also serves a valuable pedagogical role in science. It explains that though scientific rationality might be naturally local, such rationality is capable of transcending its locality. We can only expect a science cultivated in one place to take root firmly in another when it´s adaptability does not subjugated the other´s innate character to expand its scope in a way that its contents are truly ¨hardcore¨ of their statements. In order to achieve such goal, we need an appropriate epistemology—an interactionist epistemology—as opposed to the objectivist and subjectivist epistemologies of the past. Such epistemology should take its starting point in a higher level of integration, in the interaction between us and the world. It is an interaction which bears always the impress of ourselves and of all the socio-historical forces which have made us what we are, as well as the impress of a world we encounter as irreducible to ourselves.

The dichotomised epistemologies were responsible for the radical cleavage between object and subject, between nature and history, between us and the world. But then we can never extricate ourselves from our social milieu to be able to say what they world looks like apart from it. The discussion on the historicist´s appraisal the traditional claims of science show that both epistemologies have a socio-historical basis, representing stages in the development of our rationality, but stages to be transcended. Therefore, there is need to reconstruct our notion of the scientific claims and scientific progress at a higher level of integration. We need to see science as the highly complex, cognitive process that it is, intricately and inextricably interwoven with a larger network of processes which have shown to be progressive. Likewise, the frontiers of modern science need to be opened so that the functional aspect of the practices and standards of the so-called ethnosciences can be effectively studied and, if found genuine, incorporated into the mainstream science.

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