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Mikuláš Teich

**The Scientific Revolution Revisited**



# THE SCIENTIFIC REVOLUTION REVISITED

Mikuláš Teich



To the memory of

Alistair Crombie (1915-1996)

Rupert Hall (1920-2009)

Joseph Needham (1900-1995)

Roy Porter (1946-2002)

scholars most learned and friends most loyal



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## PREFACE

One can access the history of the sciences from various angles and with various interests. The approach taken by Mikuláš Teich in the present endeavour is macroscopic in that it aims to capture a highly complex and long-lasting process: the Scientific Revolution, i.e. the crystallization and establishment of scientific knowledge in the Early Modern Period. The particular focus of the present endeavour is not on the individual ideas or methods that surfaced in the context of this epochal process, but rather on the connections to the specific economic, social, and political contexts. This is not to be understood in the narrow sense of a history of science proceeding externalistically, emphasizing how ideas and methods are influenced by society. Rather, Teich is concerned with construing the history of science as a part of general history, as an active element in the formation of modern society. Science is seen both as the product and the ferment of social change. Put more pointedly, there is an internal coherence between the Scientific Revolution and the transformation from feudalism to capitalism in Early Modern Europe. As Teich stresses, the Thirty Years' War and the beginning globalization functioned as catalysts of this systemic change.

Today, such an approach to the history of science has become the exception, and it is clear that it has biographical and thus historical roots. Mikuláš Teich was born in July 1918 in Eastern Slovakia, i.e. as a subject of the Austro-Hungarian Empire. He began to study medicine in Prague but, as a Jew, emigrated to Great Britain in 1939. There he studied chemistry and earned a PhD in 1946. In the same year he returned to Prague to help building a socialist society; his wife Alice, who was born in Vienna and is an historian of economy, followed him. In 1952 he was expelled from the Communist Party. In the 1960s he became a member of a working group rallying around Radovan Richta which dealt with the topic of the "Scientific-Technological Revolution". The book that resulted from this work, *Political Economy of the Twentieth Century* counts among the theoretical foundations of the "Prague Spring". When the troops of the Warsaw Pact invaded Czechoslovakia, Mikuláš Teich and his wife were on their way to take up research fellowships in the USA, whereupon they decided to emigrate for the second time. In 1977 Mikuláš Teich became a founding fellow of *Robinson College* in Cambridge.

His area of research is the history of the sciences, in particular of biochemistry. Let us here only mention his opus magnum *Bier, Wissenschaft und Wirtschaft in Deutschland 1800-1914. Ein Beitrag zur deutschen Industrialisierungsgeschichte*, Böhlau Verlag, Wien 2000 (Beer, Science and Economy in Germany 1800-1914. A Contribution to the History of German Industrialization), in which the scientific and technological dimension of beer brewing in Germany is thoroughly described and its significance for the Industrial Revolution analyzed. An extensive bibliography of Teich's works is to be found in the Festschrift to his 80<sup>th</sup> birthday: *From Physico-Theology to Bio-Technology. Essays in the Social und Cultural History of Science*, eds. Kurt Bayertz and Roy Porter, Rodopi, Amsterdam-Atlanta 1998.

We are glad to be able to present this text to the reader as a preprint of the Max Planck Institute for the History of Science in Berlin, where Mikuláš Teich was a fellow in the year 2000.

Kurt Bayertz

Hans-Jörg Rheinberger

## PREFACE

In 1969, after taking up a Visiting Scholarship at King's College, Cambridge, I was approached by the Department of the History and Philosophy of Science, Cambridge University, to give a public lecture. The subject-matter I chose was 'Three Revolutions: the Scientific, Industrial and Scientific-Technical'. When it was announced in the *University Reporter* [100 (1969-70), 1577], for some reason, the Scientific-Technical Revolution metamorphosed into the Scientific-Industrial.

I gave the lecture on 4 May 1970 in which I attempted to convey that the Three Revolutions were products of and factors in historically far-reaching societal transformations, and that the place of science and technology cannot be left out of the picture. It was this perspective that led me to return to the subject-matter and address it in book form.

Apart from underestimating the difficulties to present a short account of the problematic, other commitments prevented me to focus solely on the project. When I reached my 90<sup>th</sup>, it occurred to me that if I was to contribute to the debates regarding the three great movements of thought and action, a viable course would be to produce the work in three separate parts of which *The Scientific Revolution Revisited* is the first. The other two parts are in preparation.

Autumn 2011

## NOTE ON TERMINOLOGY AND ACKNOWLEDGEMENTS

In a book about the much debated Scientific Revolution unavoidably problems arise with terminology. They pertain to terms such as science/normal science/modern science; social/societal and others. I regret possible ambiguities in their employment despite efforts to be consistent. There is also the question of references. They are given in full but I apologize for inadvertent omissions. This also applies to bibliography relevant to the debate.

I am indebted to Dr. Albert Müller who read the large part of the early version of the book and Professor Sir Geoffrey Lloyd who commented on chapters 1 and 2 in draft. The responsibility for the published text is mine. It is a pleasure to record discussions with Professors Kurt Bayertz, Herbert Matis and Michael Mitterauer, and Dr. Deborah Thom. Thanks are due to the late Professor William N. Parker. Lastly and firstly, my warmest words of gratitude go to my family, above all to Professor Alice Teichova and daughter Dr. Eva Kandler – without their assistance the book would not see the light of day quite literally.

## INTRODUCTION

### I

This book is about interpreting the Scientific Revolution as a distinctive movement directed towards the exploration of the world of nature that came into its own in Europe by the end of the seventeenth century. The famed English historian Lord Acton (1834-1902) is said to have advised that problems were more important than periods. If he held this opinion, he ignored that problems are embedded in time and place and do not surface autonomously. This has been amply demonstrated in six collections of essays, examining the 'national context' not only of the Scientific Revolution but other great movements of thought and action, which Roy Porter and I initiated and co-edited.<sup>1</sup>

In general terms, one way of encompassing the world we live in is to say that it is made up of society and nature with human beings belonging to both.<sup>2</sup> It is reasonable to connect the beginnings of human cognition of inanimate and animate nature (stones, animals, plants) with the ability of systematic making of tools/arms within a framework of a hunting-and-gathering way of life, presently traceable to about 2.5 million years ago. It is also reasonable to perceive in the intentional Neanderthal burial, about 100,000 years ago, the earliest known expression of overlapping social and individual awareness of a natural phenomenon: death.

While the theme of interpenetration of the social, human and natural has a long history, there is scant debate over reciprocal links between perceptions of nature and perceptions of society from Antiquity to the present. This is most important not only for the understanding of evolution of knowledge of nature as well as knowledge of society but also of type of truth produced in the process. It takes us to the heart of the issue highlighted by the late Ernest Gellner, noted social anthropologist and philosopher, when he stated 'The basic characteristics of our age can be defined simply: Effective knowledge of nature does exist, but there is *no* effective knowledge of man and society'<sup>3</sup>

This assertion, as indeed Gellner's essay as a whole, gives the impression of a *cri de coeur* of a despondent social scientist, before he sadly passed away while the text was in print. By then, Gellner undeniably came to believe that social knowledge compared badly with natural knowledge. He particularly reproved Marxism because it

claimed to possess knowledge of society, continuous with knowledge of nature, and of both kinds – both explanatory and moral, prescriptive. In fact, as in the old religious style, the path to salvation was a corollary of the revelation of the nature of things. Marxism satisfied the craving of Russia's Westernizers for science and that of the Russian populist mystics for

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<sup>1</sup> Published by Cambridge University Press, the volumes formed part of a sequence of twelve collections of essays which included *The Enlightenment in National Context* (1981), *Romanticism in National Context* (1988), *The Renaissance in National Context* (1991), *The Scientific Revolution in National Context* (1992), *The Reformation in National Context* (with Bob Scribner, 1994), and *The Industrial Revolution in National Context: Europe and the USA* (1996).

<sup>2</sup> What follows, draws on the Introduction in M. Teich, R. Porter and B. Gustafsson (eds.), *Nature and Society in Historical Context* (Cambridge, 1997).

<sup>3</sup> E. Gellner, *Knowledge of nature and society*, *ibid.*, p. 9.

righteousness, by promising the latter in terms of, and as fruit of, the former.<sup>4</sup>

It is noteworthy this critique contrasts with Gellner's position five years before the demise of communism in Central and Eastern Europe which he clearly did not envisage:

I am inclined to consider the reports of the death of Marxist faith to be somewhat exaggerated, at least as far as the Soviet Union is concerned. Whether or not people positively believe in the Marxist scheme, no coherent, well-articulated rival pattern has emerged, West or East, and as people must need think against some kind of grid, even (or perhaps especially) those who do not accept the Marxist theory of history tend to lean upon its ideas when they wish to say what they do positively believe.<sup>5</sup>

This was in line with what John Hicks noted a year after receiving the Nobel Memorial Prize for Economics (1972). Venturing to develop a theory of history 'nearer to the kind of thing that was attempted by Marx', he declared:

What remains an open question is whether it can only be done on a limited scale, for special purposes, or whether it can be done in a larger way, so that the general course of history, at least in some important aspects can be fitted into place. Most of those who take the latter view would use the Marxian categories or some modified version of them; since there is so little in the way of an alternative version that is available, it is not surprising that they should. It does, nevertheless, remain extraordinary that one hundred years after *Das Kapital*, after a century during which there has been enormous developments in social science, so little else should have emerged. Surely, it is possible that Marx was right in his vision of logical processes at work in history, but that we, with much knowledge of fact and social logic which he did not possess, and with another century of experience at our disposal, should conceive of the nature of those processes in a distinctly different way.<sup>6</sup>

As I sat down to write this introduction, I read what the economics editor of *The Guardian* wrote regarding the unrest Britain experienced in early August 2011: 'To understand the mess we are in, it's important how we got here... This is a system in deep trouble and is waiting to blow up'.<sup>7</sup> In this situation Hick's suggestion regarding Marx's approach to encompass and decipher human history has not lost force.

## II

There is no point here to recapitulate what is argued in the book. But, as I have found the strongly disputed Marxist conception of a period of transition from feudalism to capitalism a useful framework within which to place the forging of the Scientific Revolution, it may be worthwhile to dwell on it briefly.

According to the Marxist historian Eric Hobsbawm

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<sup>4</sup> Ibid., p. 13.

<sup>5</sup> E. Gellner, 'Along the historical highway', in *The Times Literary Supplement*, 16 March 1984.

<sup>6</sup> J. Hicks, *A Theory of Economic History* (rep. Oxford, 1973), pp. 2-3

<sup>7</sup> L. Elliot, 'We've been warned: the system is ready to blow', in *The Guardian*, 15 August 2011.

the point from which historians must start, however far from it they may end, is the fundamental and, for them, absolutely central distinction between establishable fact and fiction, between historical statements based on evidence and subject to evidence and those which are not.<sup>8</sup>

The problem is what is established fact? Take the categories 'feudalism' and 'capitalism'. There are historians who find them of little or no use. There are others who may, curiously, employ both variants in a text: feudalism/'feudalism'; capitalism/'capitalism'. In other words, the categories have the semblance of both, fact and fiction. Often than not, the assessment that feudalism/capitalism are not viable historical categories is politically and/or ideologically motivated. This of course is vehemently repudiated on the basis that true historical scholarship does not take sides.

In this connection Penelope J. Corfield's 'new look at the shape of history, as viewed in the context of long-term-time' comes to attention. Her interest in this question was triggered by the Marxist historians, E. P. Thompson and Christopher Hill (her uncle). Though she clearly disagrees with their world-view, she hardly engages with their work. Criticizing the old 'inevitable Marxist stages', she finds gradually

over time, historical concepts become overstretched and, as that happens, lose meaning. And 'capitalism'/'communism' as stages in history, along with 'modernity', and all their hybrid variants, have now lost their clarity as ways of shaping history. To reiterate, therefore, the processes that these words attempt to capture certainly need examination – but the analysis cannot be done well if the historical labels acquire afterlives of their own which bear decreasingly adequate reference to the phenomena under discussion.<sup>9</sup>

Penelope Corfield's model of making sense of the past is that 'the shape of history has three dimensions and one direction'. The three dimensions, she argues are: 'persistence/microchange/radical discontinuity'.<sup>10</sup> While her long view approach is to be welcomed, her formula gives the impression of being too general to be of concrete value in casting light on, say, the Scientific Revolution.

### III

*Scientific Revolution in National Context* illustrated that no nation produced it single-handed. So in what sense was it a distinctive movement? In that in Europe it had brought into being 'normal science' as *the* mode of pursuing natural knowledge – universally adopted in time and still adhered to at present. Thus 'when an Indian scientist changes places with an Italian or an Argentinian with an Austrian, no conceptual problems are posed. Nobel Prizes symbolize the unity of science to-day.'<sup>11</sup>

In Europe the social, economic, political and ideological conditions were diverse, under which the historically evolved ways of knowing nature, wrought into a whole, brought about the Scientific Revolution. They included procedures, such as classification, systematization, theorising, experimentation, quantification – apart from

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<sup>8</sup> E. Hobsbawm, *On History* (London, 1997), p. viii.

<sup>9</sup> Penelope J. Corfield, *Time and the Shape of History* (New Haven and London, 2007), pp. ix, 182-3.

<sup>10</sup> *Ibid.*, p. 248.

<sup>11</sup> Introduction in Porter and Teich (eds.), *Scientific Revolution in National Context*, p. 1.

observation and experience, practised from dawn of human history. Still, the social context of this transformation of the study of nature into normal science – institutionalized over time and in the places it did – may be understood in terms of the passage from feudalism to capitalism. It was a long-drawn-out process of which the Renaissance, the Reformation and the Enlightenment with the Scientific Revolution form 'historically demarcated sequences'.<sup>12</sup> By the eighteenth century, normal science arrived in latecomers, such as Sweden and Bohemia.

Outside Europe the assimilation of normal science had taken place under historical circumstances that differed from those in Europe. Indeed, we witness that it takes place in our days as part of fierce global interchange. Existing stone age human groups come into contact with latest scientific technology – ancestrally descended from the Scientific Revolution - and eventually they acquire skills to use electric saws, mobiles, etc., without having passed through the historical learning process, experienced by European and non-European peoples under the impact of early capitalist expansion.

The adaptation to tangible contemporary scientific-technical advance by 'primitives', testifies to lasting legacy of the fundamental transformation of the mode of pursuing natural knowledge, both theoretical and practical, between the middle of the sixteenth and the close of the seventeenth century. The much maligned Scientific Revolution remains a useful beast of historical burden.<sup>13</sup>

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<sup>12</sup> D. S. Landes, *The Unbound Prometheus Technological Change and Industrial Development in Western Europe from 1750 to the Present* (Cambridge, 1969), p. 1.

<sup>13</sup> Introduction in Porter and Teich (eds.), *Scientific Revolution in National Context*, p. 2.

## 1. FROM PRE-CLASSICAL TO CLASSICAL PURSUITS

### THE THEME

In the main, historians and philosophers of science have come to differentiate between the *Scientific Revolution* and *scientific revolutions*. The first term generally refers to the great movement of thought and action associated with the theoretical and practical pursuits of Nicolaus Copernicus (1473-1543), Galileo Galilei (1564-1642), Johannes Kepler (1571-1631) and Isaac Newton (1642-1727), which transformed astronomy and mechanics in the sixteenth and seventeenth centuries. In the process, first, the earth-centred system in astronomy based on Ptolemy's (c. 100-170) celestial geometry was replaced by the heliocentric system with the Earth and other then known planets (Mercury, Venus, Mars, Jupiter and Saturn) revolving around the Sun. Second, laws governing the motion of celestial as well terrestrial bodies based on the theory of universal gravitation were formulated.

The origins of the idea interpreting the changes in astronomy and mechanics, between Copernicus and Newton, as revolutionary, are to be found in the eighteenth century.<sup>14</sup> Offering an essentially intellectual treatment of it, Alexander Koyré is being credited to have coined the concept of Scientific Revolution in the 1930s.<sup>15</sup> Since then much has been written about the periodization, nature and cause(s) of the Scientific Revolution.<sup>16</sup> Broadly two seemingly incompatible approaches have been employed. The 'internalist' perspective, greatly indebted to Koyré, identified the Scientific Revolution as a societally disembodied supremely intellectual phenomenon. The alternate approach, greatly influenced by Marxist ideas, focused on social, political, economic, technical and other 'external' factors to clarify the emergence of the Scientific Revolution.

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<sup>14</sup> I. B. Cohen, 'The eighteenth century origins of the concept of scientific revolution', in *Journal of the History of Ideas* 27 (1976), pp. 257-8. See also I. B. Cohen, *The Revolution in Science* (Cambridge, Mass., 1985). For an instructive account how writers from Bacon to Voltaire discussed the origins of modern science, A. C. Crombie, 'Historians and the Scientific Revolution', in *Physis [Rivista Internazionale di Storia della Scienza]* 11 (1969), pp. 167-80.

<sup>15</sup> A. Koyré, *Études galiléennes* (Paris, 1939 - 40), pp. 6-7.

<sup>16</sup> For latter-day discussions of 'the state-of the-art', see I. Hacking (ed.), *Scientific Revolutions* (Oxford, 1981); A. Rupert Hall, *The Revolution in Science* (London and New York, 1983); R. Porter, 'The scientific revolution: a spoke in the wheel?' in R. Porter and M. Teich (eds.), *The Revolution in History* (Cambridge, 1986), pp. 290-316; D. C. Lindberg and R. S. Westman (eds.), *Reappraisals of the Scientific Revolution* (Cambridge, 1990); R. Porter and M. Teich (eds.), *The Scientific Revolution in National Context* (Cambridge, 1992); J. V. Field and Frank A. J. L. James, (eds. and introd.), *Renaissance & Revolution Humanists, Scholars, Craftsmen and Natural Philosophers in Early Modern Europe* (Cambridge, 1993); A. Cunningham and P. Williams, 'De-centring the 'big picture': The Origins of Modern Science and the modern origins of science' in *The British Journal for the History of Science* 26 (1993), pp. 387-9; H. F. Cohen, *The Scientific Revolution. A Historiographical Inquiry* (Chicago and London, 1994); J. Henry, *The Scientific Revolution and the Origins of Modern Science* (Basingstoke, 1997, 3rd ed. 2008); S. Shapin, *The Scientific Revolution* (Chicago and London, 1998); M. Teich, 'Revolution, wissenschaftliche' in H. J. Sandkühler (ed.), *Enzyklopädie Philosophie*, vol. 2.0-Z (Hamburg, 1999), pp. 1394-7; Margaret J. Osler (ed.), *Rethinking the Scientific Revolution* (Cambridge, 2000); J. P. Dear, *Revolutionizing the Sciences European Knowledge and its Ambitions, 1520- 1700* (Basingstoke, 2001); P. J. Bowler and I. Rhys Morus, *Making Modern Science. A Historical Survey* (Chicago and London, 2005), pp. 23-53.



Since Copernicus's seminal *De revolutionibus orbium coelestium* was published in 1543, and Newton's no less influential synthesis *Philosophiæ naturalis principia mathematica* appeared in 1687, some have been perplexed that a phase in scientific history can be denoted 'revolutionary' when it lasted around 150 years. Others have dwelt on the fact that the protagonists in the transformation of astronomy and mechanics - deemed to be revolutionary - did not fully divest themselves of traditional ancient and medieval approaches and ideas. This connects with the issue how to view later scientific breakthroughs associated, say, with Antoine-Laurent Lavoisier (1743-1794), Charles Darwin (1809-1882) or Albert Einstein (1879-1955). Are the novelties of Lavoisier's oxygen theory of combustion, Darwin's theory of evolution, or Einstein's linking of space and time comparable in revolutionary terms with the Scientific Revolution? If they qualify as 'scientific revolutions', is then the Scientific Revolution the first in time among equals?

#### KUHN'S PARADIGMS AND NORMAL SCIENCE

A determined attempt to address the general question of how scientific revolutions emerge, including their identification, has been made by Thomas S. Kuhn in the highly influential *The Structure of Scientific Revolutions*, which first appeared in 1962 and enlarged in 1970, containing a 'Postscript-1969'. Setting out to portray scientific development (as a succession of tradition-bound periods punctuated by non-cumulative breaks)<sup>17</sup>, Kuhn's approach centres on the utilization of three notions: paradigm, scientific community and normal science. He treated them as mutually connected categories.

For the reader the grand problem is the truly protean notion of 'paradigm'. After being told that it was used in at least twenty-two different ways, Kuhn admitted: 'My original text leaves no more obscure or important question.'<sup>18</sup> As a consequence, Kuhn preferred to equate a paradigm with 'a theory or set of theories' shared by a scientific community. The question of whether scientific community's common research activities, denoted by Kuhn as 'normal science', determine a paradigm or is sharing a paradigm that defines a scientific community was answered by him as follows: 'Scientific communities can and should be isolated without prior recourse to paradigms; the latter can then be discovered by scrutinizing the behaviour of a given community's members.'<sup>19</sup>

To put it succinctly, Kuhn conceives of scientific revolutions as transitions to new paradigms. The motor of this process is not testing, verification or falsification of a paradigm but the scientific community's gradual realization of a current paradigm's inadequacy. That is, while engaged in normal science, the scientific community finds the paradigm's cognitive utility wanting when confronted with riddles or anomalies, which it does not encompass. The response to the crisis is the emergence of a new paradigm bringing about small as well as large revolutions whereby 'some revolutions affect only the members of a professional subspecialty, and [...] for such groups even the discovery of a new and unexpected phenomenon may be revolutionary.'<sup>20</sup>

The intellectual impact of Kuhn's historical scheme of scientific revolutions was wide-ranging and stimulated much debate during the late 1960s and early 1970s but was beginning to wane afterwards. For one thing, on reflection, not only the notion of paradigm

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<sup>17</sup> T. S. Kuhn, *The Structure of Scientific Revolutions*, 2<sup>nd</sup> ed. enlarged (Chicago, 1970), p. 208.

<sup>18</sup> *Ibid.* p. 181.

<sup>19</sup> *Ibid.* p. 176.

<sup>20</sup> *Ibid.* p. 49.

but also that of scientific community and normal science appeared to be vague. Take Kuhn's notion of normal science associating it with three classes of problems: determination of fact, matching of facts with theory, and articulation of theory. Useful as the concept of normal science is, there is more to it than these three categories into one of which, Kuhn maintains, 'the overwhelming majority of the problems undertaken by even the very best scientists usually fall'.<sup>21</sup>

Everything has a history and so does normal science evolving and materializing first in Classical antiquity as *peri physeos historia* (inquiry concerning nature) with entwined elements of scientific methodology, such as observation, classification, systematization and theorizing. In Europe by the seventeenth century these practices, extended by systematic experimentation and quantification, were bringing forth generalizations in form of God-given laws of nature. Moreover institutionally shored up by newly founded scientific organizations and journals, these pursuits paved the way for science to operate as a collaborative body. That is, an integral part of these developments was the institutionalization of scientific activities through scientific societies (academies) and journals which came into being in Italy, Germany, England and France. Focusing attention on these historical aspects of normal science, we recognize that essentially they still mould its fabric today.

Neither the duration of the coming of normal science into its own nor the blurred line that separates the old and the new in Copernicus's or Newton's thought is the problem.<sup>22</sup> It was the coming into existence of a methodologically consolidated mode of 'inquiry concerning nature' sustained institutionally, during the sixteenth and seventeenth centuries, that distinguishes the investigations into natural phenomena from those in previous centuries, which lays at the heart of the Scientific Revolution.

What the Scientific Revolution arrived at was that science was eventually instituted as *the* human activity for the systematic theoretical and practical investigation of nature. In a complex interactive process intellectual curiosity and social needs were involved and intertwined; and it is not easy to disentangle the 'pure' and 'applied' impulses and motives which advanced the Scientific Revolution. Historically, perhaps, the most significant achievement of the Scientific Revolution was the establishment of science as an individual and socially organized activity for the purpose of creating an endless chain of approximate, albeit self-correcting, knowledge of nature - a veritable extension of the human physical and physiological means to understand, interpret and change it.<sup>23</sup>

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<sup>21</sup> Ibid. p. 34.

<sup>22</sup> K. Bayertz, 'Über Begriff und Problem der wissenschaftlichen Revolution', in K. Bayertz (ed.), *Wissenschaftsgeschichte und wissenschaftliche Revolution* (Hürth-Efferen, 1981), pp. 11-28. Take William Harvey's discovery of the circulation of the blood (1618-1628). It was a product of *both* Aristotelian thinking (in which the idea of the circle plays a major role) and non-Aristotelian quantitative reasoning. See W. Pagel, *William Harvey's Biological Ideas* (Basel and New York, 1967), pp. 73f.; J. J. Bylebyl, 'Nutrition, quantification and circulation', in *Bulletin of the History of Medicine* 61 (1977), pp. 365-85; A. Cunningham, 'William Harvey The Discovery of the circulation of the blood', in R. Porter (ed. and introd.), *Man Masters Nature 25 Centuries of Science* (London, 1987), pp. 65-76.

<sup>23</sup> J. D. Bernal, *The Extension of Man* (London, 1972), p. 16f.

Relevant to the historical understanding of the Scientific Revolution is to distinguish between empirical and scientific knowledge of nature, and to be aware of their historical relations. Broadly considered, empirical knowledge of nature derives from human activity based on observation and experience. Whereas scientific knowledge derives, as pointed out, from historically evolved and interlocked characteristic procedures of investigating nature, including observation.

Observation is an activity not specific to humans. The human perceptual experience of nature, attained through observation, differs qualitatively from that of non-human animals in that it entails mental, verbal, manipulatory and societal dimensions, which are hard to disentangle. According to the 'food-sharing hypothesis' propounded by the anthropologist Glyn Isaac, 'the collective acquisition of food, postponement of consumption, transport and the communal consumption at a home base or central place' constituted a major stage in human evolution, assisting 'the development of language, social reciprocity and the intellect'.<sup>24</sup>

It is believed that early humans embarked on producing tools and weapons about 2,5 million years ago. This in combination with meat-hunting and plant-gathering, the use of fire and ability to make and control it are activities which stand at the very beginnings of empirical knowledge of nature. Take the making of stone tools - it involved the finding out about the relative hardnesses and cleavabilities of stones by trial and error. The underlying dialectics between doing and learning has been pinpointed by the anthropologist Nicholas Toth, who spent many years experimenting with techniques for making stone tools, as follows: 'Toolmaking requires a coordination of significant motor and cognitive skills.'<sup>25</sup>

This applies even more markedly to the manipulative prowess of modern humans (*Homo sapiens*) who created Palaeolithic art, traceable, to the Blombos cave in South Africa to about 75.000 and the Chauvet cave in France to about 30.000 years ago. Explanations and interpretations abound, for example, whether mural pictures of animals with arrows on them should be looked upon as hunting magic. Be that as it may, the position of the arrows in the heart region indicate the hunters' familiarity with the (anatomical-physiological) locus where the animal could be mortally wounded. Representations of women with pronounced female sexual attributes (breasts, buttocks, pubic triangle) are evidence that prehistoric humans attached particular importance to fertility and sexual matters. Human interest in reproduction and sexual activity have a prehistoric past.

It is accepted that the extinct *Homo neanderthalensis* - the evolutionary relations between him and the surviving *Homo sapiens* are still being debated - was burying deads about 100.000 years ago. As mentioned, the Neanderthal burials are regarded as the earliest expressions of human awareness of a natural phenomenon: death. With them originates not only the history of human perception of the relation and distinction between life and non-life, but also of time.

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<sup>24</sup> G. Ll. Isaac, 'Aspects of human evolution', in D.S. Bendall (ed.), *Evolution from Molecules to Men* (Cambridge, 1983), pp. 532-5.

<sup>25</sup> Quoted by R. Leakey, *The Origin of Human Kind* (London, 1994), p. 38.

'Time is a word', we read in an authoritative encyclopaedia of astronomy and astrophysics, 'that eludes definition until it is given some practical application'.<sup>26</sup> The quandary of envisaging time has found reflection in the dichotomy between linear and circular visions of time, depicted vividly by the palaeontologist J. S. Gould as 'time's arrow' and 'time's cycle' respectively. Gould holds that 'time's arrow' - encapsulating unidirectionality of events - 'is the primary metaphor of biblical history'.<sup>27</sup> Doubtless the lineage of time's cycle is more ancient - it goes back to the hunter-gatherers' observing recurrent events, such as heavenly cycles, annual seasons or female menstruations.

As to perception of time's 'twin' - space - it assumes tangible form in terrestrial measurement, in the wake of the growth of permanent agricultural settlements. Heralding the Neolithic Age, agriculture based on the cultivation of soil and manipulation of plants and animals arrived in parts of Western Asia about 10,000 years ago.<sup>28</sup> It brought about a shift from hunting and gathering to production and storage of food hinged on irrigation and drainage - as in the river valleys of the Nile and Euphrates and Tigris. The establishment of sedentary life was accompanied by empirically attained technical developments embodied in a host of arts and crafts, such as pottery, spinning and weaving, dyeing, metal working, house and boat building and others. All these developments contributed to the growth of specialized material production, including that of food. The distribution of products, as well as political, military and religious activities came under institutional, palace or temple, control, administered by officials variously described 'scribes', 'clerks', 'bureaucrats' - the literate minority of society. Thus the basis was laid for the making of socially stratified and centrally governed polities, encountered in Ancient Egypt and Mesopotamia.<sup>29</sup>

Apart from Western Asia where the cultivation of wheat and barley began, other sites of origin of agriculture are recognized. For example, China for rice and millet, or Central America and the northern Andes for maize. Agriculture as a means of supplying human food wants turned out to be a worldwide activity. Even today the majority of the world population lives off the land. Because of its unprecedented impact on world history - comparable with the Industrial Revolution - the changeover to economies sustained by

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<sup>26</sup> W. J. H. Andrews, 'Time and clocks', in S. P. Maran (ed.), *The Astronomy and Astrophysics Encyclopaedia* (New York-Cambridge, 1991), p. 429. It is argued that 'on the cosmic (though not human) scale, size is visible in a way that age is not'. See B. Dainton, 'Past, what past?', in *The Times Literary Supplement*, 8 January 2010.

<sup>27</sup> S. J. Gould, *Time's Arrow Time's Cycle Myth and metaphor in the Discovery of Geological Time* (Harmondsworth, 1990), p. 11.

<sup>28</sup> S. Jones, R. Martin and D. Pilbeam (eds.), *The Cambridge Encyclopedia of Human Evolution* (Cambridge, 1992), p. 378.

<sup>29</sup> In a study of Ancient Mesopotamia, Susan Pollock shares the view of critics of the 'overarching notion of the temple economy'. See S. Pollock, *Ancient Mesopotamia The Eden that Never Was* (Cambridge, 1999), p. 119. But even she writes in the concluding chapter: 'Temples, which have been identified as far back as the Ubaid period, are one of the most obvious testimonials to the central place of religion within Mesopotamian societies. Yet they were also economic and political institutions; any attempt to apply to them our contemporary notions of the separation of religion, politics, and economy forces us to recognise that our concepts are products of a particular history and culture rather than eternal verities.' *Ibid.*, p. 221.

agriculture during Neolithic times - deserves to be called *the Agricultural Revolution*.<sup>30</sup>

#### RIVER VALLEY CIVILIZATIONS AND KNOWLEDGE OF THE NATURAL WORLD

The Neolithic agricultural and craft activities, in contact with living and non-living things, broadened the empirical knowledge of diverse natural materials, and natural and artificial processes enormously. Historically of incalculable import became concurrent inventions related to state, commercial and communication needs of the river valley civilizations, such as measures and weights, numerical symbols and arithmetic, writing and alphabet.<sup>31</sup>

The advent of agriculture activated astronomical observations, and with it brought forth measurement of time realized in the construction of the calendar. Thus in Ancient Egypt, since about 3000 BC, the length of the year amounting to 365 days was accepted. The number corresponded to the interval between two observed predictable events that recurred and coincided annually. That is, the agriculturally vital flooding of the Nile and the rising of the brightest star in the sky (known today as Sirius) after its period of invisibility, just before sunrise in July. The Egyptian year became the basis for calendar computation and reform. It was largely this achievement, together with the recognition of the influence of solar and stellar observations on the alignment of those truly towering works of engineering - the pyramids - that made out the fame of pre-Hellenistic Egyptian astronomy.

The emphasis on the agricultural context of ancient astronomy should not obscure that there were other factors at play. Certainly a mixture of religion, astrology and politics was a major stimulant for Babylonian solar, lunar and planetary observations. Take the observations of periodical appearance and disappearance of the planet Venus - identified with the goddess Ishtar - extending over two decades (c.1582-1562 BC). They were copied and referred to through centuries. The observed phenomena were taken to furnish positive or negative omens affecting the future of the ruler (wars), community (harvests) and the individual (fertility). Historically noteworthy is the intertwining of astronomy and astrology that went into the construction of the equal-sign zodiac. That is, the circle or belt of star clusters through which the sun was thought to move annually. On the one hand, its division into twelve 'signs' of 30 degrees, named after important star groups, amounted to construction of a system of celestial coordinates - a significant event in the history of mathematical astronomy (c. early fifth century BC). On the other hand, the old 'signs' have retained their astrological connotation for predicting a person's future to the present. Because of precession of the equinoxes, it is necessary to differentiate between slowly

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<sup>30</sup> See J. Vandermeer, 'The agroecosystem: The modern vision crisis, the alternative evolving', in R. Singh, C. B. Crimbas, Dianna B. Paul and J. Beatty (eds.), *Thinking about Evolution, Historical, Philosophical and Political Perspectives*, vol. 2 (Cambridge, 2001), p. 480. Regarding the juxtaposition of the (disputed) Neolithic Revolution and the Industrial Revolution, see C. M. Cipolla, 'Introduction', in C. M. Cipolla (ed.), *The Fontana Economic History of Europe: The Industrial Revolution* (London and Glasgow, 1973), pp. 7-8. See also, by the same author, *The Economic History of World Population* (Harmondsworth, 1962), Ch. 1.

<sup>31</sup> The case for making writing, in Mesopotamia (about 3000 BC), an integral part of the history of weights and measures has been restated by J. Ritter. 'One outcome of this interplay', he writes, 'was of striking importance at the conceptual level - the development of an abstract use of numbers, independent of any metrological system, and the creation of a positional system of base sixty'. See J. Ritter, 'Metrology, writing and mathematics in Mesopotamia' in *Acta historiae rerum naturalium nec non technicarum*, N. S. (1999), 215-41 (p. 239).

revolving constellations and 'fixed' zodiacal signs carrying the same names.<sup>32</sup>

Regarding the Babylonian observations what matters, in retrospect, is not their accuracy – seemingly overplayed - but that 'there was a social mechanism for making and recording astronomical observations *and for storing and preserving the records*'.<sup>33</sup> The 'astronomical diaries', as the resulting records are called, contain astronomical as well as meteorological, hydrological and other entries. The oldest are datable to the seventh century BC but, in view of the age of the observations of the planet Venus, the practice of recording must be older.<sup>34</sup> Comparable are Chinese records of celestial phenomena since the fifth century BC. Among several affinities between Babylonian and Chinese astronomy is that observation of celestial phenomena fell under state control. In China it found the expression in the setting up of the Astronomical Bureau, as part and parcel of the completion of the unification of the realm under the Han dynasty (202 BC – AD 220). The following comment elucidates the situation neatly:

Celestial portents were not merely natural phenomena, but expressions of the will of Heaven communicated to the ruler as admonition. According to the Chinese theory of monarchy, the supreme ruler was the Son of Heaven, and through him the celestial will was to be transmitted as the basis of social order. Though the Chinese Heaven is neither a creator nor a god in the theological sense - later, seen more philosophically, it *was* the cosmos or natural order itself - it provided criteria for moral and political conduct and thus occupied a crucial position in Chinese political ideology. To supervise the heavenly ritual was the ruler's privilege as well as his duty, for it was an essential service which only he could perform on behalf of its subjects.<sup>35</sup>

In the light of what has been said, the vital role of empirical knowledge of the natural world, bound up with observation and experience, for the early human existence and advance is manifest. What has to be cleared up is that there is more to human perception of nature than observations of natural phenomena *per se*. Historically, the names of stars and constellations furnish a striking example. It may be assumed that not a few go back to prehistoric times when hunters watching the sky with the naked eye 'recognized' figures described as a lion, bear, etc. These names reflected the hunters' preoccupation and familiarity with the world of animals. To them as indeed to the peoples of the river civilisations the natural world appeared to be 'alive'. Natural and artificial processes appeared to be 'living' and ideas about 'livingness' were derived from experiences with, and observations of, human as well as animal bodily functions. It is not difficult to see that the beginning or origin of anything was linked to human/cattle procreation through sexual union. Akkadian texts refer to male and female stones and metals. Producing metals by the

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<sup>32</sup> B. L. van der Waerden, 'Basic ideas and methods of Babylonian and Greek astronomy' in A.C. Crombie (ed.), *Scientific Change* (London, 1963), p. 42f; Precession of the equinoxes was recognized by Hipparchus (second century BC); see J. North, *Cosmos* (Chicago and London, 2001), pp. 14, 114.

<sup>33</sup> J. Evans, *The History and Practice of Ancient Astronomy* (New York and Oxford, 1998), p. 16. (Emphasis - JE).

<sup>34</sup> *Ibid.*

<sup>35</sup> K. Yabuuti, 'Chinese astronomy: Development and limiting factors' in S. Nakayama and N. Sivin (eds.), *Chinese Science Explorations of an Ancient Tradition* (Cambridge, Mass. and London, 1973), p. 93. For an original account of the history of Chinese astronomy, see J. Needham, *Science and Civilisation in China* (Cambridge, 1959), Vol. 3, pp. 169ff. For critical remarks, see N. Sivin, 'Introductory bibliography of traditional Chinese science' in Nakayama and Sivin (eds.) *Chinese Science*, pp. 298-9.

smith was imagined as something related to child birth. From this animate/biological angle to metal extraction, the alchemical idea of 'marriage of metals' ensued, crystallizing eventually into the basic chemical concept of 'combination'.<sup>36</sup>

In Mesopotamia there was a socio-political side to observation of the celestial world which, as we know in retrospect, was to contribute to the demarcation of pursuits of natural knowledge from other human activities. It concerned the prehistory of the idea of law of nature that comes to light, as it were, in the process of drawing an analogy between the earthly state and the cosmic state. That is, in a late Babylonian 'creation' poem the sun-god Marduk is pictured as the giver of law to stars. According to Joseph Needham, the prodigious student of comparative history of science, the genesis of the 'conception of a celestial lawgiver 'legislating' for non-human natural phenomena' may be viewed against the background of unification and centralization of southern Babylonia Hammurabi (*fl.* 1700 BC).<sup>37</sup>

#### CONCEPT OF NATURE: *PHUSIS*

Before the idea of law of nature could materialize, the notion of 'nature' had to take shape. Termed *phusis* in Greek, the word (as its Latin counterpart *natura*) is etymologically connected with the idea of genesis or birth.<sup>38</sup> It is traceable, it has long been acknowledged, to sixth- and fifth-centuries BC speculations regarding natural phenomena by so-called Presocratic natural philosophers, who hailed from Ionian cities in Asia Minor. To all intents and purposes, their approach to natural phenomena was free of myths and interventions by personal gods. This is not to say that these 'earth-bound' Greek inquirers into nature as well as others (including medical writers), who followed them to Galen (*fl.* AD 180), were without religious beliefs.

The relative geographical proximity of the Ionian cities to Egypt and Babylon has prompted recurring debates regarding the impact of the ancient Near Eastern civilizations upon the Greek world. Going back to the sixth and fifth centuries BC, the knowledgeable classicist Geoffrey Lloyd confirms that there were both transmissions and independent developments (writing, numerical notation). Lloyd validates noticeable differences between pre-Greek geometry and astronomy. The Near East possessed knowledge of geometrical truths (e.g. properties of the 'Pythagorean' right-angled triangle) but not the notion of the proof of geometrical truths which did develop in Greece. Whilst Babylonian

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<sup>36</sup> R. J. Forbes, 'Metals and early science', in *Centaurus* 3 (1953-4) p. 30.

<sup>37</sup> J. Needham, *Science and Civilisation in China* (Cambridge, 1956), Vol. 2, p. 533. The conjecture has been heavily criticized. But Descartes, Leibniz, Newton and others returned to the idea that a heavenly legislator (God) enacted the laws of nature underlying the motion of matter. See W. Krohn, 'Zur Geschichte des Gesetzesbegriffs in Naturphilosophie und Naturwissenschaft' in M. Hahn und H.-J. Sandkühler (eds.), *Gesellschaftliche Bewegung und Naturprozess* (Cologne, 1981), pp. 61-70 (p. 68). It has been noted that Descartes who more or less established the conception of nature being governed by laws to be discovered by those who investigated nature never talked about laws of nature with regard to refraction or optics in general. See F. J. Dijksterhuis, 'Constructive thinking: a case for dioptrics' in Lissa Roberts, S. Shaffer and P. Dear (eds.), *The Mindful Hand Inquiry and Invention from the Late Renaissance to Early Industrialization* (Amsterdam, 2007), pp. 63-4. The discovery that the ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant for any material Second Law of Refraction – is ascribed to Descartes (1638).

<sup>38</sup> See entry 'Nature' in W. F. Bynum, E. J. Brown and R. Porter (eds.), *Dictionary of the History of Science* (London and Basingstoke, 1981), p. 289.

astronomical practice employed arithmetical procedures with respect to planetary movement, the Greeks turned to geometrical models. As to medicine, Lloyd points out that it 'was one of the chief battlefields on which the attempt to distinguish between the 'rational' and the 'magical' was fought'. It found expression in the Hippocratic collection of Greek medical texts – the oldest of which belonged to the beginning of fifth century BC – where magical practices and beliefs came specifically under attack.<sup>39</sup>

What is significant is that no other ancient civilization evolved the notion of nature equivalent to *phusis*. Multifaceted and disputed as the concept of *phusis* was, it stood effectively for objective, intelligible reality and thus viable to rational inquiry.<sup>40</sup> This connected with the belief in the orderliness of the cosmos – a word of Greek origin. Etymologically bound up with the notion of military orderliness, cosmos was used to signify 'order'/'ordered whole' and eventually stood for the world or universe as an ordered entity. The rational inquiry into the origin and make-up of cosmos, inaugurated by the Ionian thinkers, paved the way for knowledge in fields, such as medicine, mathematics, astronomy and physics that had to wait 1500 years before it began to be superseded. The concrete attainments by Greek workers were highlighted by the influential classicist Moses Finley as follows:

The Hippocratic practice of auscultation of the heart, Euclid's *Elements*, Archimedes' discovery of specific gravity, the treatise on conic section by his younger contemporary Apollonius of Perge Eratosthenes' estimate of the diameter of the earth to within a few hundred miles of the correct figure Hipparchus' calculation of the precession of the equinoxes, Hero's steam-operated toys...<sup>41</sup>

No less noteworthy than the achievement is the *modus operandi* that produced it. Underlying it was the unprecedented approach that the natural as well as the social – perceived as ordered – were comprehensible without having to resort to the supernatural. While the originality of this position – an enduring legacy of Greek antiquity diagnosed by some as the 'Greek miracle' – has not been in question, its origin has been the subject of debate. During the last four decades or so research has gone some way to demystify, as it were, the phenomenon by looking into its societal context. Here it is pertinent to recall Finley's uncompromising statement regarding slavery:

This was a universal institution among the Greeks one that touched upon every aspect of their lives without exception. It rested on very fundamental premises, of human inequality, of the limits authority and debasement, of rights and rightlessness.<sup>42</sup>

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<sup>39</sup> 'The debt of Greek philosophy and science to the ancient Near East' in G. E. R. Lloyd, *Methods and Problems in Greek Science* (Cambridge, 1991), Ch. 12, pp. 278-98.

<sup>40</sup> G. E. R. Lloyd, 'Greek antiquity: the invention of nature' in G. Torrance (ed.), *The Conception of Nature The Herbert Spencer Lectures* (Oxford, 1992), Ch. 1, p. 22. Reprinted as 'The invention of nature' in Lloyd, *Method and Problems*, Ch. 18, p. 432. Aristotle (384-324) in *Physics* seems to be the first to have formulated clearly: 'Nature is a principle of motion and change... We must therefore see that we understand what motion is; for if it were unknown, nature too would be unknown'. See M. Oster (ed.), *Science in Europe 1500-1800. A Primary Sources Reader* (Basingstoke, 2002), p. 8.

<sup>41</sup> M. I. Finley, *The Ancient Greeks* (Harmondsworth, 1982), p. 123. The *floruit* dates of the named persons (BC): Euclid (300), Archimedes (250), Apollonius (210), Eratosthenes (250), Hipparchus (135). Hippocrates (425) has almost certainly not authored any of the sixty treatises or so ascribed to him. Hero was active in the first century AD (60).

<sup>42</sup> *Ibid.*, p. 148.



What concerns us here is the relevance of Greek slave-owning society to the understanding of ancient Greek 'inquiry concerning nature'.

#### SLAVERY AND 'INQUIRY CONCERNING NATURE' IN ANCIENT GREECE

Tradition has it that it was the Ionian city Chios where the first buying of slaves from the barbarians took place around 550 BC. This was also the period of the beginning of early Greek natural philosophy, personified by the Milesians Thales (585), Anaximander (555) and Anaximenes (535). The question regarding the connection between their naturalistic speculations, including those of later Ionian thinkers, about the ordered cosmos and the rise of slavery in ancient Greece has remained problematical. They include notions drawn from legal, social, military and political spheres, such as justice, equality (*isonomia*), war, strife, rule, contract and others. As pointed out by Lloyd, they are used 'by one Presocratic after another to convey different conceptions of how the world as we know it, made up of a variety of different things, is never the less an ordered whole.'<sup>43</sup>

But what we know about the ideas of Presocratics is fragmentary and largely second-hand. Hence their uncertain connotation with regards to the historically developing system of slavery in Greek city-states – within a democracy practised solely by male citizens.

Here as in other matters, Aristotle proves to be illuminating. That is, if we turn to *Politics*, one of his late writings, where he addresses the nature of slavery. In this connection, he generalizes that the ruler/master/slave relationship permeates 'every composite thing where a plurality of parts, whether continuous or discrete, is combined to make a single common whole'. Aristotle exemplifies it operating in the (inanimate) case of a musical scale ruled by its keynote or in the (animate) case of the body governed by the soul 'with the sway of a master'.<sup>44</sup>

Aristotle's position on the relation of soul and body as well as on the cognate, but more general issue of the relation of form and matter – as opposites – is germane to the exploration of the role of dichotomies in the evolution of scientific methodology. While rejecting the separateness of soul and body, form and matter, Aristotle envisaged their union to be founded on the subordination of body to soul and matter to form.

Aristotle's fundamental notions, such as form, causes of things or scale of being are hierarchically predicated. More should be appreciated how much Aristotle's commitment to hierarchy and order owes to his acceptance of the naturalness of social and human inequality, manifestly incarnated in the opposites free and slave. At the time of the Peloponnesian war (431-404), it is estimated that there were 60.000 to 80.000 slaves in Athens – the total population (men, women and children, free and slave) was about 250.000 to 275.000.<sup>45</sup> Such social reality palpably underlay Aristotle's conviction that authority and subordination of all sorts and kinds conditioned the ordered existence and functioning of both *polis* and *phusis*. *Polis*, the inegalitarian Greek city-state, was the subject matter investigated in *Politics*.

Rooted in observation and experience – the age-old means of gaining knowledge of the world – the idea of opposites (not unlike that of similarity and difference) supplied a vantage point for theoretical and practical classification and systematization. Aristotle

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<sup>43</sup> 'Greek cosmologies' in Lloyd (ed.), *Methods and Problems*, Ch. 7, p. 150.

<sup>44</sup> Aristotle, *Politics*, I, ii, 9-11 (Loeb Classical Library, Vol. 21, transl. H. Rackham) (Cambridge, Mass. London, 1977), pp.19-21.

<sup>45</sup> Finley, *Ancient Greeks*, pp. 72, 55.

recognized in these procedures attributes of scientific methodology – in effect its history begins with him.

The propensity for resorting to value-laden opposites of inferiority and superiority in scientific inquiry, against the background of the Greek system of slavery, is highlighted by Lloyd as follows:

The Greeks did not deploy opposites to legitimate a single particular type of political regime. But over and over again their uses of opposites mirror an essential feature of the social structures of Greek society, namely the fundamental division between rulers and ruled. A perceived hierarchical distinction within pairs of opposites that we might have expected to have been totally value-free is a feature that is made to do explanatory work in a variety of scientific contexts ... In Aristotle's view ... male is held to be 'naturally' superior to female, the latter said to be a 'natural' deformity. Again the members of the pairs right and left, above and below, front and back, are strongly differentiated as to value. Right, above and front are the principles (*archē*), first of the three dimensions (breadth, length and depth respectively), and then also of three modes of change in living beings mainly locomotion, growth and sensation. Moreover, this doctrine provides him with the basis of his explanation of a range of real or assumed anatomical facts (the relative positions of the windpipe and the oesophagus, those of the two kidneys, the function of the diaphragm and the positions of the vena cava and the aorta) and even further afield it is the principle he invokes in his admittedly tentative discussion of the difficult problem of why the heavens revolve in one direction rather than in the other.

The point can be extended to what we might have assumed to be the purely neutral mathematical pair, odd and even. They provide the basis for the Greek classification of integers and are thus fundamental to Greek arithmetic.<sup>46</sup>

Lloyd also raises the question of the sociopolitical background of a pervasive element in Greek natural philosophy, mathematics and medicine. That is, the preoccupation of searchers with foundations, certainties and proofs of truthful knowledge in various domains of inquiry. The most telling example of this tendency provides the axiomatic-deductive manner of demonstrating geometrical truth, displayed by Euclid in his *Elements*. Lloyd points out that the astronomer and cosmologist Ptolemy and the physician Galen, canonical figures of Hellenistic science, subscribed to the idea that proof *more geometrico* establishes certainty of knowledge. Lloyd suggests that this may have something to do with the way participants in hard-hitting debates and confrontations in political assemblies and law courts of the city-states argued their case. The winning depended crucially on marshalled evidence and proof.

This approach leads Lloyd to throw open to discussion the vexed issue of the place of experimentation in Greek science. It is particularly striking, he writes,

that on many of the occasions when deliberate and explicit testing procedures are invoked, the aim was not so much to devise an experimental set-up that could be seen to be neutral between antecedently equally balanced alternatives, but rather to provide further supporting argument in favour of a particular theory. It is remarkable that even in what are some of the best

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<sup>46</sup> 'Greek and Chinese dichotomies revisited' in G. E. R. Lloyd, *Adversaries and Authorities Investigations into ancient and Greek Chinese Science* (Cambridge, 1996), Ch. 6, pp. 134-5.

prepared and most systematic experiments carried out in Greek antiquity, the quantitative investigations of the amount refraction between various pairs of media (air to water, air to glass, and water to glass) reported in Ptolemy's *Optics*, the results have clearly been adjusted to suit his general theory, since they all fitted exactly.<sup>47</sup>

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<sup>47</sup> Cf. G. E. R. Lloyd, 'Democracy, philosophy and science in ancient Greece' in J. Dunn (ed.), *Democracy The Unfinished Journey 508 BC to AD 1993* (Oxford, 1993), pp. 41-56 (p.45).

## 2. EXPERIMENTATION AND QUANTIFICATION

### MEDIEVAL WORLD

Since the end of the 1970s sociologists of science and sociologically orientated historians of science began to pay attention to experimentation. Even if their claim that experimentation has been neglected is overstated, it is true that historical literature is neither rich in works dealing with experimentation nor systematization.

Uncertainties persist regarding experimentation in the medieval world before it began to occupy, jointly with quantification, the centre-stage of scientific activities since the seventeenth century.

This has something to do with the course of the discussion regarding the medieval origins of normal science, stimulated by Alistair Crombie in the early 1950s. It became overshadowed by the debate on the structure of scientific revolutions, engendered by Kuhn's seminal essay – after its publication in 1962 to about the mid-1980s.<sup>48</sup>

Medieval science as such was not a concern of Kuhn's except in the context of his interpretation of scientific revolutions as paradigm shifts. Not surprisingly, to the author of the renowned *The Copernican Revolution* (1957) the emergence of Copernican astronomy represents a classical case of a paradigm change. Kuhn acknowledges, it is worthy of notice, the role played by 'external' factors in the emergence or transition to new paradigms. Regarding the replacement Ptolemaic astronomy by Copernican astronomy, Kuhn lists among external factors: calendar reform, medieval criticism of Aristotle, rise of Renaissance Neoplatonism 'and other significant historical elements besides', but he chooses not to address them:

In a mature science – and astronomy had become that in antiquity – external factors like those cited above are principally significant in determining the timing of breakdown, the ease with which it can be recognized, and the area in which, because it is given particular attention, the breakdown first occurs. Though immensely important, issues of that sort are out of bounds for this essay.<sup>49</sup>

By contrast, Crombie was concerned with the medieval origins of modern science which he associated with the use of experiment and mathematics. First he traced them back to the thirteenth century if not to earlier times. But by 1961, he stated: 'I have been responsible for claims that now seem to me exaggerated.'<sup>50</sup>

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<sup>48</sup> For probably the earliest public presentation of the ideas developed in the essay, see T. S. Kuhn's paper 'The function of dogma in scientific research'. It was given at the symposium on *The Structure of Scientific Change*, held at Oxford, 9 – 15 July 1961. See Crombie (ed.), *Scientific Change*, pp. 347-69. The paper was commented by A. R. Hall and Michael Polanyi respectively (pp. 370-80). Curiously, neither Kuhn nor Hall mentioned that the latter employed the term 'paradigm' in the paper 'The scholar and the craftsman in the scientific revolution' (Hall uses the lower case). It was presented to a history of science conference, attended also by Kuhn. It was held at Madison between 1–11 September 1957. See M. Clagett (ed.), *Critical Problems in the History of Science* (Madison, 1959), pp. 3-29 (p. 19). Here Hall famously stated that although the roles of the scholar and the craftsman in the Scientific Revolution are complementary ones, the former holds the prime place in its story (p. 21).

<sup>49</sup> Kuhn, *Structure*, p. 69.

<sup>50</sup> See Crombie's contribution to discussion on Lynn Whyte's, Jr. paper 'What accelerated technological progress in the Western Middle Ages?' in Crombie (ed.), *Scientific Change*, p. 316.

Even so Crombie's approach, at that time, to medieval theoretical and practical engagement with the natural world is still valuable. For example, when he underlines the importance of study of medieval technical texts for the understanding of the evolution of experiment:

The technological writings of the Middle Ages are still relatively unexplored, and yet it seems to me that it is there that one must chiefly look for those habits developed by the demand made by the problems themselves for accurate, repeatable results. These are of the essence in practical life where it matters if you are given short measure or the wrong product, are subjected to incompetent surgery, or arrive at an unintended destination. They are also of the essence in experimental science. For the history of science in the whole medieval and early modern period, the relations between the intellectual habits and methods of theoretical science and of practical technology present a vast field that has scarcely been investigated. The history of 'practical mathematics' in the Middle Ages would especial repay systematic study.<sup>51</sup>

Let us look at the approach of another authority in this field of historical research – Edward Grant. On experiments in the Middle Ages in the book in which, as one reviewer put it, he distilled 'a lifetime of scholarly research', Grant has this to say:

Occasional experiments had been made, and mathematics had been routinely applied to hypothetical, though rarely real, problems in natural philosophy. In the seventeenth century, the new scientists applied mathematics to real physical problems and added experiments to the analytic and metaphysical techniques of medieval natural philosophy. The developments did not emerge from a vacuum.<sup>52</sup>

No doubt, Crombie would have had agreed. The problem is the difference in the thinking of the two historians on what constitutes the milieu or in Grant's words 'a societal environment in the Middle Ages that eventually enabled a scientific revolution to develop in the seventeenth century'. Basically Grant equates it with (1) the translation of Greco-Arabic works on science and natural philosophy into Latin; (2) the formation of the medieval university and (3) the emergence of the theologian-natural philosopher.<sup>53</sup>

What emerges from Grant's account is that medieval savants set themselves suppositional problems and sought intellectual solutions to them.

Crombie impressively returned to this problematic in his massive three-volume *Styles of Scientific Thinking in the European Tradition* (1994), where he discussed the apparent predisposition of Western society to experimental investigation of nature in conjunction with the medieval philosophical theology of the Creator as a divine mathematician. Accordingly, God created the world in which all things were ordered by measure, number and weight. God also created man in his image endowed with senses and reason to unriddle God's thinking. Such belief, Crombie argues, offered the way not only to systematic use of observation, experiment and logical argument to bring nature under control but also to improvement of the human condition. But Crombie contends:

The habit of systematic measurement and its instrumentation by appropriate procedures was characteristically a response not to the

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For Crombie's erstwhile statements see his *Augustine to Galileo The History of Science A.D. 400 – 1650* (London, 1952); *Robert Grotteste and the Origins of Experimental Science* (Oxford, 1953).

<sup>51</sup> Crombie (ed.), *Scientific Change*, p. 319.

<sup>52</sup> E. Grant, *The Foundations of Modern Science in the Middle Ages* (Cambridge, 1996), p. 202.

<sup>53</sup> *Ibid.*, p. 171.

theoretical demands of natural philosophy but to the practical demands of the technical arts. Academic natural philosophy put a premium on logical precision and internal coherence; practical life required exact and repeatable measures of the external world as experienced and used. Technical ability to specify the conditions for producing a desired result was an essential need of theoretical science and of practical art alike; a quantified experimental science depended on a dialogue between the two. That could take place at a suitable level of education. The technical innovations which came to quantify many aspects of practical medieval life in the 12<sup>th</sup> century were being matched from early in the 12<sup>th</sup> century by an increasing attention of scholars to the practical arts, both within general encyclopedias and in more specialized treatises. Intellectual contact was encouraged at once by the improved education of superior craftsmen and by the enlargement of the technical content of the university curricula especially in the mathematical *quadrivium*.<sup>54</sup>

Crombie found confirmation for this viewpoint when he considered the evolution of quantification of fundamental entities during 1200-1500: time, space and weight.

#### QUANTIFICATION OF TIME: MECHANICAL CLOCK

Regarding the measure of time, it is accepted that the spread of the mechanical clock effected a radical change in Europe since about 1300. Its operation depended on the ingenious combination of a driving mechanism (falling weight) and a regulating mechanism ('foliot-and-verge' escapement).

The perception of time as a continuum was transformed by slicing it into concrete identical small time portions (*minutae*). That was due to the mechanical clock's capability to indicate the time of the day – reckoned from one midnight to the next – split into equal 24 hours each of 60 minutes of 60 seconds. It should be added that the weight-driven mechanical clock was not accurate enough for measuring small intervals of time. Never the less, in comparison with the current methods of telling day time by the sundial and astrolabe respectively, the superiority of the mechanical clock as a timer was obvious. Of the two, the fixed sundial was simpler to handle – the shadow indicated the sun's progress through the sky. Though portable and usable by day, or night, the astrolabe was a more complicated implement as was the armillary sphere, to be employed as a timekeeper. They were devices for measuring the position of stars and from the obtained values it was possible, in the thirteenth century, to calculate time reliable to 2-5 minutes.

When and who actually invented the mechanical clock is unknown – the first firm date is 1286.<sup>55</sup> As the eminent historian of technology Donald Cardwell stated:

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<sup>54</sup> A. C. Crombie, *Styles of Scientific Thinking in the European Tradition* (London, 1994), Vol. 1., p. 416-17. The notion 'superior craftsman' originates with Edgar Zilsel's 'superior artisan' See his 'Sociological roots of science' (1942) reprinted in D. Raven et al. (eds.), *Edgar Zilsel. The Social Origins of Modern Science* (Dordrecht, 2000), pp. 7-21. [Boston Studies in the Philosophy of Science, vol. 200]. The historian T. Inkster differentiates between 'higher artisanal' and 'lower craftsman' knowledge. See his 'Thoughtful doing and early modern economy' in Lissa Roberts, S. Schaffer and Dear (eds.), *The Mindful Hand*, p. 445.

<sup>55</sup> By and large, scholars do not accept the claim by Joseph Needham (and his collaborators Wang Ling and D. J. de Solla Price) that the hydro-mechanical escapement of the astronomical clock described by the eminent Chinese scholar and state servant Su Sung (1088) represents an

Its design may have resulted from the speculations of some millwrights who knew about gearing and the problems of uniform motion, and who moreover, had astonishing insight into mechanical principles.

All we can suppose is that there must have been many attempts to devise a machine to indicate the position of the sun in its daily journey round the earth, and therefore to tell the time. Certainly many of the first clocks were astronomical ones, some of them of such elaborate design that the positions of the sun, the moon, the other five planets and even the motions of the tide could be displayed.<sup>56</sup>

Undoubtedly we are on a firmer ground when we inquire about social conditions that favoured the invention of this crucially novel device for measuring time. The mechanical clock was a product of the need to regulate the timing of religious and burgeoning multifarious urban (civic) activities as well as a factor in achieving this. It is no accident that it came to adorn conspicuously monasteries, churches and town halls.

Especially during its early phases, clockmaking and astronomy intertwined professionally. The ingenuity underlying the making of clocks was regarded so highly that Nicole Oresme (c. 1325-1382), the great French medieval savant, was prompted to visualize God the Creator as a clockmaker. Just as man contrived to produce a self-moving clock, so 'did God allow the heavens to move continually according to the proportions of the motive powers to the resistances and according to the established order (of regularity)'.<sup>57</sup> An early instance of invoking the image of God as the heavenly clockmaker!

#### QUANTIFICATION OF SPACE: COMPASS AND CARTOGRAPHY

In some ways the part played by the magnetic needle compass in the history of space measurement was analogous to that of the mechanical clock in the history of time measurement. The compass is for the first time described in a Chinese text about 1088 whereas in Europe the first reference to it occurs in Alexander Neck(h)am's (1157-1217) *De naturis rerum* (c. 1200). A letter known as *Epistola de magnete* by Petrus Peregrinus/Pierre de Maricourt (*fl.* 1269) contains a summary of the European knowledge of magnetic phenomena in the late Middle Ages. Peregrinus conceives the compass both as an astronomical and a navigational instrument.<sup>58</sup>

Peregrinus describes magnetic compasses without and with a pivot and scale. They were in use in the Mediterranean clearing the way for the drawing of first medieval maps, known as *portolani* (compass-charts). Made by practical men, Crombie states, and based on the direct determination of distances and azimuths by using

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important stage in the development of the mechanical clock with its verge-and-foliot escapement of late thirteenth century Europe. See 'The Chinese measured time by the continuous flow of water, the Europeans, by the oscillatory movement of a *verge-and-foliot*. Both techniques used escapements, but these have only the name in common. The Chinese worked intermittently, the European, in discrete but continuous beats.' D. S. Landes, *Revolution in Time* (Cambridge, Mass. and London, 1985), p. 21.

<sup>56</sup> D. Cardwell, *The Fontana History of Technology* (London, 1994), p. 41.

<sup>57</sup> Quoted in J. Kaye, *Economy and Nature in the Fourteenth Century Money, Market Exchange, and the Emergence of Scientific Thought* (Cambridge, 1998), p. 224.

<sup>58</sup> For an English translation, see *The Letter of Peregrinus* in E. Grant (ed.), *A Source Book in Medieval Science* (Cambridge, Mass., 1974), pp. 368-76.

log and compass, they were specifically guides to coastlines. From the earliest extant examples the *Carte Pisane* (1274), the portolans showed scales of distances. By the 16<sup>th</sup> century they gave two essential pieces of information for navigation: the route to follow and the angle it must make with the north-south axis as given by a magnetized needle; and the distance to run in the direction thus determined.<sup>59</sup>

Compass bearing in conjunction with observations of currents and winds rather than methods of astronomical observation guided the first Portuguese and Spanish voyages of discoveries, including Columbus's transatlantic crossing, in the late fifteenth century.<sup>60</sup>

Against this it is pointed out that the influential Ptolemy's *Geography* had become well-known in Portugal and Spain before Bartholomew Diaz, Vasco da Gama and Christopher Columbus embarked on their voyages and thus played a role therein. The Latin translation of the work appeared in print for the first time in Florence in the early fifteenth century. It contained maps drawn on a gridwork of parallels and meridians located with respect to the positions of celestial bodies. Ptolemy's coordinate system, Crombie notes, 'by its emphasis on an accurate linear measure of the arc of the meridian it came to transform quantitative mapping.'<sup>61</sup>

Crombie accepts also that Ptolemy's work played a part in the rediscovery of linear perspective. That is, Ptolemy showed how to draw a map as a projection from a single viewpoint. It is generally acknowledged that the technique of linear perspective was invented and demonstrated by Filippo Brunelleschi (1377-1446), the eminent Florentine architect, between about 1413 and 1425. Whether he was acquainted with Ptolemy's work is unclear. Be that as it may, the latter guided multitalents, such as P. Toscanelli da Pozzo (1397-1482), B. L. Alberti (1404-1472), L. Ghiberti (1378-1455), Nicolaus of Cusa (1401-1464) and others in 'their common search for a quantified space and techniques for its measurement in astronomy, cartography, optics and painting alike.'<sup>62</sup>

#### QUANTIFICATION OF WEIGHT: STATICS AND ASSAYING

Historically the quantification of weight by measurement has empirical origins going back to the invention of the balance with equal arms. It was in use in Egypt and Mesopotamia since 2700 BC. Apparently, it took about two and a half millennia before the balance with unequal arms was invented.<sup>63</sup> Its principle was known to the author of

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<sup>59</sup> Crombie, *Styles*, Vol. 1, p. 420.

<sup>60</sup> D. Goodman, 'The scientific revolution in Spain and Portugal' in Porter and Teich (eds.), *Scientific Revolution*, p. 166.

<sup>61</sup> Crombie, *Styles*, Vol. 1, p. 433.

<sup>62</sup> *Ibid.*, p. 455. For a valuable contribution on the relationship between mathematics and painting in the late Middle Ages, see J. V. Field 'Mathematics and the craft of painting: Piero della Francesca and perspective' in Field and James (eds.), *Renaissance & Revolution*, pp. 73-95. Field underlines the Euclidian rather than the Ptolemaic impulse. English seamen in the sixteenth century began to employ astronomical observations and mathematical calculations in navigation instead of relying largely on practical experience. See Suzan Rose, 'Mathematics and the art of navigation: The advance of scientific seamanship in Elizabethan England', in *Transactions of the Royal Historical Society* 14(2004), 175-84.

<sup>63</sup> Here, including what follows, I draw on P. Damerow, J. Renn, S. Rieger and P. Weinig, *Mechanical Knowledge and Pompeian Balances*, Preprint 145, Max-Planck-Institut für



*Problems of Mechanics* which, it is now accepted, was authored by a follower of Aristotle. He was familiar with the use as well with the properties of the lever. Thus, for instance, he asks:

Why is it when two men carry a weight between them on a plank or something of the kind, they do not feel the pressure equally, unless the weight is midway between them, but the nearer carrier feels it more? Surely it is because in these circumstances the plank becomes a lever, the weight the fulcrum, and the nearer of the two carrying the weight is the object moved, and the other carrier is the mover of the weight.<sup>64</sup>

What we have here is an empirical recognition of the law of the lever later presented by Archimedes (287-212) in a formal mathematical language. Archimedes's status as a great researcher in pure and applied mathematics was acknowledged already in Antiquity. What has remained unclear was his attitude to practice. On the one hand, the biographer Plutarch (*fl.* 83) refers to Archimedes's disdain for the work of an engineer and artisanal activities in general. On the other hand, his inventive abilities are praised by authors, such as Polybios (*fl.* 164 BC) and Livius (59 BC-AD 17). Apart from the device known as the Archimedean screw, he was said to have invented powerful contrivances for lifting and moving heavy loads and the steelyard.

What cannot be disputed that Archimedes thought deeply about methodological questions. That is, he was concerned about the truth of a theorem deduced geometrically. He believed that the truth of the proof demonstrated by geometry follows more easily from knowledge acquired previously by contemplating a mechanical problem.<sup>65</sup>

Archimedes conceived of a mechanical problem as belonging to statics. In effect, he brought into being scientific statics and hydrostatics as a branch of mechanics with weight as its foundational category – originated empirically and rooted in reality. This shows up clearly in the well-known, albeit apocryphal, story of Archimedes's discovery of the hydrostatic principle named after him. Accordingly, it enabled him to solve the problem posed by King Hiero of Syracuse, whether the royal crown was made of pure gold.

Archimedes's prestige was so great that authorship of medieval works on statics was wrongly ascribed to him. In comparison with the original text, a discernible shift occurred in the attitude towards practice. To the 'science of weights' (*sciencia de ponderibus*), as medieval statics was called, the theory underlying the mechanics of moving heavy objects was of interest. Thus the Toledan translator Domingo Gundissalvo (*fl.* 1140), drawing on Arabic authors, has this to say about what the science of weights was about:

The science of weights considers weights in two ways: either (1) according to the weights themselves that are being measured or according to what is measured with them and by them; and this is an inquiry about the principles of the doctrine on weights. Or (2) it considers them in so far as they are moved or according to the things with which they are moved; and this is an

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Wissenschaftsgeschichte (Berlin, 2000). See also G. E. R. Lloyd, *Greek Science after Aristotle* (London, 1973), p. 48.

<sup>64</sup> See Grant (ed.), *Source Book*, pp. 223-4, n. 22.

<sup>65</sup> Archimedes's thoughts on this are enshrined in *The Method*, an incomplete treatise. They are addressed to Eratosthenes, renowned for his remarkable method of calculating the circumference of the earth, See translation in T. L. Heath, *The Works of Archimedes* (Cambridge, 1912). Professor Lloyd comments: 'I don't think you have got mechanics in Archimedes quite right. It is not that he tried a mechanical problem first and then turned to a geometrical analysis. The problem is mathematical from the outset. The use of mechanics is limited to the application of the two ideas that a geometrical figure can be thought of as balanced around a fulcrum'.

inquiry about the principles of instruments by means of which heavy bodies are lifted and on which they are changed [or carried] from place to place.<sup>66</sup>

Evidence for the rise of awareness of worldly affairs in medieval intellectual circles provides the unknown author of the pseudo-Archimedean treatise *De insidentibus in humidum* (c. 1250). He displays distinct familiarity with price fixing in the market-place and transfers this insight into the solution of hydrostatic problems:

Since the size of certain bodies cannot be found geometrically because of their irregular shape, and since the price of certain goods is proportional to their sizes, it was necessary to find the ratio of the volumes of bodies by means of their weights in order to fix their definite prices, knowing the volume ratios from the weight ratios.<sup>67</sup>

Propelled by the silver-based economy, the quantification of weight by measurement came into its own in assaying during the Middle Ages. The purpose of assaying was the testing especially for the amount of gold and silver that could be extracted from ores and to find out whether coins and the precious metal used in jewellery were pure.<sup>68</sup>

The assayer essentially reproduced the large-scale smelting operation quantitatively on a small scale. The process involved the recovery of silver and gold from lead beads placed in a shallow dish made of bone ash (cupel) in a stream of air. The end of the process was indicated by the appearance of a bead of the precious metal in the dish which could be weighed. The limit of accuracy of the balance was about 0.1 milligram.

In a noteworthy characterization of the assayers' and the refiners' craft, Rupert Hall observed that it was

a *quantitative* craft; profit arose from successful use of the balance, for margins were small. Here, as in navigation, science and craft came close together; but while the navigator was the astronomers' pupil, the chemist descended from the assayer.<sup>69</sup>

A striking early illustration of science and craft connecting, in the context of assaying, provides an edict of Philip de Valois of 1343.<sup>70</sup> It contains two *caveats*, as it were, to be observed by the assayers. First, the balance is to be accurate – leaning neither to right nor left. Second, the assayers are advised to perform a blank test on a sample of the lead to be assayed. The idea was to find out whether it contained silver and if so how much. This is not quantitative chemical analysis but a step towards it.<sup>71</sup>

It was in the late Middle Ages that experimental weighing was beginning to become of interest to the learned as a means to acquire natural knowledge. Among those who realized its importance and wrote about it was that audacious thinker Nicolaus of Cusa in his *Idiota: De staticis experimentis* (1450). As pointed out by Crombie, Cusa envisaged a programme for measuring a wide range of properties and for determining by measurement the

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<sup>66</sup> See Grant (ed.), *Source Book*, pp. 75-6.

<sup>67</sup> Quoted by O. Pedersen and M. Pihl, *Early Physics & Astronomy A Historical Introduction* (London and New York, 1974), p. 210.

<sup>68</sup> It is of interest that the words 'test', 'testing' relate to the Latin 'testa', meaning an earthenware pot or vessel employed in metallurgical operations.

<sup>69</sup> A. Rupert Hall, 'Early modern technology to 1600' in M. Kranzberg and C. W. Pursell, Jr. (eds.), *Technology in Western Civilization*, Vol. 1 (New York, 1967), p. 94.

<sup>70</sup> Here I draw heavily on F. Greenaway's contribution to discussion of part three, 'Science and technology in the Middle Ages', in Crombie (ed.), *Scientific Change*, pp. 329-31.

<sup>71</sup> A. J. Ihde, *The Development of Modern Chemistry* (New York, Evanston and London, 1964), p. 23.

composition of different materials for which he proposed experimental procedures. Because, according to Cusa:

By the difference of weights, I think we may more truly come to the secret of things, and that many things may be known by a more probable conjecture ...<sup>72</sup>

Cusa himself did not perform experiments. But the idea of comparing weights of materials before their beginning and after their completion was to lead eventually to one of the great scientific generalizations by Lavoisier – the principle of conservation of matter (1789).

#### QUANTIFICATION OF QUALITIES: MOTION, CHANGE AND MONEY

The reference to the world of commerce in a pseudo-Archimedean medieval treatise may surprise. However, during the last quarter of the last century or so, studies have appeared substantiating that medieval scholars owed more to the monetized societal setting within which they were active than it was previously conceded or even thought of. This is brought to light credibly when the medieval approach to local motion as a problem of quantification of a quality is examined against its socioeconomic background.

But before we come to this, it is useful to recall the Aristotelian strict separation of quality and quantity as incommensurable categories. The Aristotelian denial that qualities could be quantified was called into question, during the fourteenth century, by some of the most eminent scholastics then active in the universities of Oxford and Paris – acknowledged centres of medieval scholarship. Underlying their discussion of 'intension and remission of forms and qualities' was the belief in that the variations in degree of qualities were measurable (*latitudo qualitatum*).

It included queries regarding quantifiability of divine grace but also probing into quantifiability of local motion, or velocity, comprehended as continuous magnitudes. Here, as in other areas of inquiry into natural and social phenomena, medieval scholarship was confronted with Aristotelian generalizations. Regarding the speed of a body in motion, Aristotle argued that it was directly proportional to its weight ('force') and inversely proportional to the resistance of the medium in which it moved ('density'). Accordingly any force, however small, could move any resistance however large.

Perceiving the paradox in Aristotle's position, scholars in Oxford associated with Merton College – known as Merton School or Oxford Calculators – challenged it.<sup>73</sup> Thus approaching variations in velocity as variations in the intensity of a quality mathematically, they arrived at what became known as the 'mean speed theorem'. It proposed that a uniformly accelerated velocity could be measured by its mean speed. The proposal has been hailed as 'probably the most outstanding single medieval contribution to the history of mathematical physics'.<sup>74</sup>

Other historical notable fourteenth-century challenges to Aristotle's approach to motion of bodies came from Paris. Certainly Jean Buridan (c.1300-c.1350) was critical for Aristotle's notion that the movement of a projectile depended on the propelling action of the air. He found Aristotle's explanation unsatisfactory because it was contradicted by

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<sup>72</sup> Crombie, *Styles*, Vol. 1, pp. 421-2.

<sup>73</sup> The Merton Group included Thomas Bradwardine (c. 1290-1349), John Dumbleton (died c. 1349), William Heytesbury (fl. 1235), Richard Swineshead (fl. 1340-1355).

<sup>74</sup> Grant, *Foundations*, p. 101.

experience:

The first experience concerns the top (*trocus*) and the smith's mill (i. e. wheel-*mola fabri*) which are moved for a long time and yet do not leave their places. Hence, it is not necessary for the air to follow along to fill up the place of departure over a top of this kind and a smith's mill. So it cannot be said [that the top and the smith's mill are moved by the air] in this manner.

The second experience is this: A lance having a conical posterior as sharp as its anterior would be moved after projection just as swiftly as it would be without a sharp conical posterior. But surely the air following could not push a sharp end in this way because the air would be easily divided by the sharpness.

The third experience is this: a ship drawn swiftly in the river even against the flow of the river, after the drawing has ceased, cannot be stopped quickly, but continues to move for a long time. And yet a sailor on deck does not feel any air from behind pushing him. He feels only the air from the front resisting [him]. Again, suppose the said ship were loaded with grain or wood and a man were situated to the rear of the cargo. Then if the air were of such an impetus could push the ship along so strongly, the man would be pressed very violently between that cargo and the air following it. Experience shows this to be false. Or, at least, if the ship were loaded with grain or straw, the air following and pushing would fold over (*plico*) the stalks which were in the rear. This is all false.<sup>75</sup>

The point of this is to bring to attention that practical activities had affected medieval scholastic thinking. Without doubt Buridan, who was Rector of the University of Paris according to documents in 1328 and again in 1340, took them on board. In the course of his studies of motions of material bodies, Buridan developed the notion of *impetus*. He associated it with the motive force imparted to the body by the agent that set it in motion. Without going into detail, viewed in retrospect, Buridan was coming to grips with the inertial tendency of bodies in motion which was to occupy the minds of René Descartes (1596—1650), Gottfried Wilhelm Leibniz (1696-1716) and Newton.<sup>76</sup>

It is noteworthy that Buridan employed *impetus* to discuss whether God is in need of assistance to move celestial bodies. Buridan found that God can do without it – his pervasive sway is sufficient to keep them going. Indeed prefiguring Newton, Buridan proposed that once launched by God they are on their own – possibly eternally. However, in order to avoid accusations of advancing opinions contrary to the teachings of the Church, Buridan was at pain to stress:

But this I do not say assertively, but [rather tentatively] so that I might seek from the theological masters what they might teach me in these matters as to how these things take place...<sup>77</sup>

It remains uncertain whether Buridan's *impetus* theory had influenced Oresme when he

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<sup>75</sup> J. Buridan, *The Impetus Theory of Projectile Motion*. Translation, introduction, and annotation by Marshall Clagett, in Grant (ed.), *Source Book*, pp. 275-6.

<sup>76</sup> According to Buridan 'by the amount the motor moves that moving body more swiftly, by the same amount it will impress in it a stronger impetus', *ibid.*, p. 277. This measure of *impetus*, as has been often observed, recalls Newton's *momentum* defined by the product of mass multiplied by velocity.

<sup>77</sup> *Ibid*, p. 277-8.

compared God to a celestial clockmaker allowing the heavens to move – like a clockwork on their own.<sup>78</sup>

Oresme is celebrated more often than not for employing geometrical lines and figures to represent and quantify qualities and motions.<sup>79</sup> The novel method is comprehensibly described in Kaye's account as follows:

[Oresme's] new approach, which he outlined clearly in the first part of his *De configurationibus*, was to construct a dual system of coordinates capable of representing at the same time the intensity of a quality and the extension of the subject in which the quality inhered. In Oresme's scheme, the extension of a given subject in space or time was measured by a base line [longitude], and the intensities of the quality or motion in that subject were represented by perpendicular lines erected on the base line [latitude]. Greater or lesser intensities at various points in the subject were represented by proportionally longer or shorter lines erected on the base line at these points. When drawn, these measuring lines along two coordinates formed two-dimensional surfaces of varying geometrical configurations and sizes.<sup>80</sup>

Thus the configuration of a quality or motion of uniform intensity – the heights of all vertical lines being the same – had to be a rectangle. A quality or motion of uniformly varying intensity was categorized by Oresme as 'uniformly difform', e.g. uniformly accelerated motion. It was represented by a right triangle.

Oresme was interested not only in the geometric representation of quality and motion but also in the measurement of the quantity of quality or motion which he imagined to be equal to the product of its intensity and its extension. Moreover, he arrived at what amounted to a geometric proof of the mean speed theorem when the areas of the rectangle (representing a uniform motion) and the right triangle (representing acceleration) were shown to be equal. The geometric demonstration of the theorem was to influence analysis of motion for the next 250 years or so.

To view Oresme's two-dimensional procedure as foreshadowing Cartesian analytical geometry is problematical. The simultaneous representation of the extension of a given subject in space or time and the intensity of a quality or motion was not equivalent to the axial system, named 'Cartesian coordinate system'. Rather it was a device to demonstrate geometrically that 'quantity (extension) and quality (intension) were bound together in a dynamic proportional relationship'.<sup>81</sup>

What marks off Oresme from medieval scholars concerned with proportionality was, as Grant puts it, his 'fascination with the subject of commensurability and incommensurability in mathematics, physics and cosmology ... evidenced by a number of treatises in which he saw fit to discuss or at least to mention it'.<sup>82</sup>

In fact, Oresme's intellectual interests extended beyond the natural world. Among others, he wrote a very influential treatise on money and minting known under its

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<sup>78</sup> See Crombie, *Augustine to Galileo*, p. 255.

<sup>79</sup> See N. Oresme, *The Configurations of Qualities and Motions, including a Geometric Proof of the Mean Speed Theorem*. Translation, introduction, and annotation by Marshall Clagett, in Grant (ed.), *Source Book*, pp. 243-52.

<sup>80</sup> Kaye, *Economy and Nature*, p. 204.

<sup>81</sup> *Ibid*, p. 206.

<sup>82</sup> Grant (ed.), *Source Book*, p. 529.

abbreviated title *De moneta*.<sup>83</sup> The question suggests itself whether Oresme's scientific and economic thinking connect and, if so, in which context. It has been perceptively addressed by Kaye's treatment of areas of historical investigation rarely considered together: economic history, the history of economic thought and the history of science' on which much what follows is based.<sup>84</sup>

#### MONETIZATION AND MARKET DEVELOPMENTS

Kaye's point of departure is the unfolding of the power and weight of the market place within European feudal society by the twelfth and thirteenth centuries. It had to do with the development of towns as centres of trade and handicraft production. Products of and factors in this process were widening monetization and heightening monetary consciousness. These connect with Oresme's *De moneta* in which the state's policy of debasement of coinage is critically examined. Devaluation and revaluation of coins were undermining money's role as a socially accepted general equivalent of value of commodities. Here was the situation, as Kaye notes, when society experienced relativity and proportionality on a grand scale. It furnishes the social background to analysis, for example, of Oresme's and Buridan's relativistic ideas about whether the earth is always at rest in the centre of the universe.

There is a good deal of evidence that the scholastic thinkers in Oxford, Paris and elsewhere were not cloistered intellectuals but did engage in academic and ecclesiastical administration, financial operations and politics. They could not avoid to become aware of the pervasive social and economic impact of expanding merchant capital on feudal economy and society.

Indeed, the term 'capital' in its Latin version *capitale* then enters the economic vocabulary apparently for the first time. That is, in a thirteenth-century work entitled *De contractibus usurariis*, composed by Peter John Olivi (Pierre de Jean Olieu), who hailed from the Provence and lived between 1248-1298. He was a member of the Franciscan order and a leader of its fraction pressing for the order to return to its original commitment to spiritual things and values. In fact, after Olivi's death the Franciscan superiors ordered the destruction of his works deemed to be heretic.

Though Olivi opposed Franciscan participation in the economic process, he understood that it constituted a core element of social reality cardinally affected, as it was, by the exchange of commodities for money. Versed in Roman and canon law-thinking on lending as well as familiar with lending practices in the commercial world, Olivi arrived at the notion of *capitale*. At its simplest, it represented the entrance value of borrowed money due to skilful activities of the investor. Olivi speculated that the relationship between the striker or thrower and the object set in motion recalls the relationship between the investor and the borrowed money turned into *capitale*. It has been argued that this amounted to the first formulation of the concept of impetus.<sup>85</sup>

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<sup>83</sup> The work's title is given as *Tractatus de origine et natura, iure, et mutationibus monetarum* and is said to have been written some time between 1355-1360. See Ch. Johnson (ed. and tr.), *The 'De moneta' of Nicholas Oresme and English Mint Documents* (London, 1956).

<sup>84</sup> Kaye, *Economy and Nature*, pp. 9-10. For a related study, see A. W. Crosby, *The Measure of Reality Quantification and Western Society 1250-1600* (Cambridge, 1998).

<sup>85</sup> Here I draw on M. Wolff's stimulating *Geschichte der Impetustheorie* (Frankfurt/Main, 1978), p. 163f.; see also idem., 'Mehrwert und Impetus bei Petrus Johannis Olivi' in J. Miethke and K.

Be that as it may, we have here medieval perceptions of economic and natural phenomena interacting. Conceptualizing, concludes Kaye, is tied to perception:

While the physical basis of reality does not change, the social basis of reality does. Over this period society was transformed through the many-faceted social processes of monetization and market development. Every level of society and every layer of institutional growth was affected. Philosophers, from their earliest days as students, were presented with social and economic experiences, rules of conduct, avenues of advancements and models of success unknown by previous generations. As social experiences change, so too do perceptions about how the world functions and is ordered.

The rigorous intellectual training of the university and its intense atmosphere of challenge and disputation transformed raw perceptions into insights capable of being elaborated through the technical instruments of mathematics and logic. The scholastic habit of synthesis encouraged the linking of insights and principles between different spheres of thought, between the comprehension of the economic order and the comprehension of the natural order. The result was the creation of a new image of nature based on the experience and observation of monetized society: a dynamic, relativistic, geometric, self-ordering, and self-equalizing world of lines. It was upon this model of nature, first imagined in the fourteenth century, that thinkers from Copernicus to Galileo constructed the 'new' science.<sup>86</sup>

Edward Grant's depiction of the medieval societal environment in which knowledge of nature developed appears to be distinctly narrow.

#### SOCIAL RELATIONS OF EXPERIMENTATION

The historic issue is the role of the form of capital, termed merchant capital, in the first phase of the transition from feudalism to capitalism. These are Marxist conceptions advanced for the understanding of the pre-industrial phase of capitalism in Europe. That is, the phase in which the control by capital over the monetary exchange was of greater importance than domination over the production process constrained, as it was, by urban guilds.

This certainly emerges from David Abulafia's incisive review of Italian banking in the late Middle Ages. But, along with other historians, Abulafia appears to be reluctant to employ the term 'capitalism' in the context of pre-industrial economy.<sup>87</sup> Be that as it may, it

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Schreiner (eds.), *Sozialer Wandel im Mittelalter* (Sigmaringen, 1994), pp. 413-23; for a biological Aristotelian approach to the impetus theory, see J. Fritsche, 'The biological precedents for medieval impetus theory and its Aristotelian character', in *The British Journal for the History of Science* 44 (2011), pp. 1-27 (appeared after completion of my text). Further R. W. Hadden, *On the Shoulders of Merchants Exchange and the Mathematical Conception of Nature in Early Modern Europe* (Albany, N. Y., 1994), p. 100.

<sup>86</sup> Kaye, *Economy and Nature*, pp. 245-6. See also J. Day, 'Shorter Notices', in *The English Historical Review* 109 (1994), 701.

<sup>87</sup> D. Abulafia, 'Italian banking in the Middle Ages' in A. Teichova, G. Kurgan-van Hentenryk and D. Ziegler (eds.), *Banking, Trade and Industry Europe, America and Asia from the Thirteenth to the Twentieth Century* (Cambridge, 1997), pp. 18, 31.

is worth noting that the prominent non-Marxist student of the Scientific Revolution, Steven Shapin, has recourse to the concept of the transition from feudalism to capitalism in Europe during the fifteenth and seventeenth century. He identifies it as a recognizable period of societal change within which mechanical modes of explanation of natural phenomena were gaining ascendancy. The transformation of the intellectual climate during this period was fuelled by the mounting awareness of mechanical devices in everyday life, symbolized by the clock:

The allure of the machine, and especially the mechanical clock, as a uniquely intelligible and proper metaphor for explaining natural processes not only broadly follows the contours of daily experience with such devices but also recognizes their potency and legitimacy in ordering human affairs. That is to say, if we want ultimately to understand the appeal of mechanical metaphors in the new scientific practices - and the consequent rejection of the distinction between nature and art - 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.<sup>88</sup>

Thus corresponding to the course of events, Leibniz acknowledges 1671 the preference of contemporary natural philosophers for a mechanistic interpretation replacing, as it did, the dominant organicist philosophy of Aristotle, as follows: 'All modern philosophers desire to explain natural phenomena mechanistically.'<sup>89</sup> About this time the term 'mechanical philosophy', coined by all accounts by Robert Boyle (1627-1697), entered scholarly vocabulary.

Among the numerous publications dealing with the work and life of the 'father of the steam-engine', Steven Shapin's and Simon Schaffer's *Leviathan and the Air-Pump* has attracted wide attention. As stated in the introductory chapter, they wanted 'to understand the nature and status of experimental practices and their historical products' and they wanted their 'answers to be historical in character'. To that end they write:

we will deal with the historical circumstances in which experiment as a systematic means of generating natural knowledge arose, in which experimental practices became institutionalized, and in which experimentally produced matters of fact were made into the foundations of what counted as proper scientific knowledge. We start, therefore, with that great paradigm of experimental procedure: Robert Boyle's researches in pneumatics and his employment of the air-pump in that enterprise.<sup>90</sup>

Here the reader is reminded that the two intertwined essential aspects of science: systematic and quantitative experimentation, and institutionalization (about which later), were coming into their own in the seventeenth century.

In fact, the vacuum pump was the first of the complex and large machines to be

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<sup>88</sup> Shapin, *Scientific Revolution*, p. 33.

<sup>89</sup> 'desiderant omnes philosophi recentiores physica mechanice explicari'. Quoted by H. Mayer, 'Gott und Mechanik Anmerkung zur Geschichte des Naturbegriffs im 17. Jahrhundert' in S. Mattl et al., *Barocke Natur* (Korneuburg, 1989), p. 12.

<sup>90</sup> S. Shapin and S. Schaffer, *Leviathan and the Air-Pump. Hobbes, Boyle, and the Experimental Life* (Princeton, 1985), p. 1. Note: 'The father of the steam engine would be a better title for Robert Boyle than the 'father of chemistry', Rupert Hall, *Revolution*, p. 338.



developed for laboratory use (the electrical machine was the other).<sup>91</sup> According to Shapin and Schaffer, it was the intellectual production ('matters of fact') by means of a purpose-built scientific machine that makes Boyle's experimentation historically a milestone. For one thing, the novel technology for experimental investigation of air-pressure ('spring of air') clarified on why suction pumps would not raise water more than about ten metres – an obstacle for development of mining in the deep. For another, it gave lie to the denial of the existence of a void in nature - an essential component of Aristotalian physics. Last but not least, from tabulated measurements of pressures and volumes of air emerged that their product is the same (1662). Historically, the reciprocal relationship, known as Boyle's Law, is believed to be the first experimental physical law.

To all intents and purposes, there is widespread agreement that the celebrated air-pump experiments were performed by Robert Hooke (1635-1703) and not by Boyle, his employer and backer of many years. All the same, Boyle wished to make a personal point when he stated:

And though my condition does (God be praised) enable me to make experiments by others' hands; yet I have not been so nice, as to decline dissecting dogs, wolves, fishes and even rats and mice, with my own hands. Nor, when I am in my laboratory, do I scruple with them naked to handle lute and charcoal.<sup>92</sup>

Obviously Boyle, the wealthy gentleman, signalled that it was socially not demeaning to engage in hands-on experimentation. Moreover, he exhorted scientists

to disdain, as little as I do, to converse with tradesmen in their work houses and shops' ... and 'he deserves not the knowledge of nature, that scorns to converse even with mean persons, that have the opportunity to be conversant with her.

In general, what the natural philosophers endeavoured to comprehend in their workshops (laboratories) was: matter in motion. It underlayed the processes the craftsmen, artisans were empirically mastering when plying their trades in their workshops. The natural philosophers's growing awareness of the contiguity of these activities weakened the reasoning that underwrote the traditional distinction between nature and art. It was not confined to England.

Take the sixteenth-century Czech polymath Tadeáš Hájek z Hájku (1525-1600), also known as Thaddeus Hagecius or Nemicus. On being appointed 1571 to the post of Chief Medical Officer of Bohemia, he was ennobled and because of his astrological and alchemistic interests he became an influential figure at the court of Emperor Rudolph II (1576-1612) in Prague. In 1585 he published in Frankfurt/Main a small book on brewing: *De cerevisia eiusque conficiendi ratione natura viribus et facultatibus opusculum*.<sup>93</sup>

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<sup>91</sup> S. A. Bedini and D. J. da Solla Price, 'Instrumentation' in Kranzberg and Pursell, Jr. (eds.) *Technology*, vol. 1, p. 178.

<sup>92</sup> This and the following quotation in J. G. Crowther, *The Social Relations of Science* (New York, 1942), pp. 364-5.

<sup>93</sup> Hagecius has a place in the history of astronomy. First, his findings related to the discovery of a new star in the Cassiopeia constellation (1572). He established that the star must be more distant from the earth than the moon and must be a fixed star. This disclosure contributed to the doing away with the Aristotelian doctrine of two disjointed, sublunary and supralunary, regions. He took a similar line in his writings on comets that appeared in 1556, 1577, 1580. Moreover, he was behind Rudolph II's invitation to Tycho Brahe (1546-1601) to move to Prague. The life and work of Hagecius examined by eighteen authors in the collection P. Drábek (ed.), *Tadeáš Hájek z*

What lay behind Hagecius's interest in beer? There was the medical and pharmaceutical dimension. It appears that the suggestion to Hagecius to write the booklet came from another personal physician of Rudolph II. But beyond that, there was the growth of large scale manorial economy in Bohemia. Centred on sheep-farming, brewing and raising fish (carp), apart from glass- and iron making, it was directed towards augmenting the declining cash income of the lord of the manor.<sup>94</sup> Whereby he was evolving into a large scale entrepreneur within feudalism and, unwittingly, into an accessory to its dissolution.

Hagecius's steps to get acquainted with brewing practice recalls Boyle's advising natural philosophers not to shy away from seeking enlightenment from socially inferior practitioners. Ignorant as Hagecius was of brewing, he consulted with humble brewers who provided him – he acknowledges – with full information even though it was simple and unsystematic. Poignantly, he regarded production of beer as a legitimate field for scientific inquiry and rejected the notion that it was an undignified scholarly pursuit. Clearly, Hagecius did not perceive the worlds of intellectual and manual labour to be separated by an impervious wall.

It is in this context that it is convenient to turn to Shapin's and Schaffer's account of Thomas Hobbes's (1588-1679) critique of Boyle's methodology. He took issue with the notion that trustworthy natural knowledge can come by way of (air-pump) experimentation.

For Hobbes the idea that the Boyleian pneumatic experiments, including crucially measurements of 'the spring of air', established the existence of the vacuum was defective in three related ways. To begin with, Hobbes held labouring in a laboratory akin to be to labours of 'workmen', 'apothecaries', 'gardeners' and, therefore, a class-bound manual activity beneath a philosopher's dignity. Experiment was one thing, philosophy another. By its very nature, knowledge produced by the former was inferior to that generated by the latter.

As to philosophy proper, Hobbes subscribed to plenism, a form of materialism, asserting that the world of nature is a plenum made of bodies in motion, there being no room for 'free space', i.e. vacuum.

Finally, Hobbes was politically a fervent advocate of absolute monarchy. Shapin and Schaffer stress that 'Hobbes's philosophical truth was to be generated and sustained by absolutism'.<sup>95</sup> This serves to remind us that they – unorthodoxly - seek 'to read *Leviathan* as natural philosophy'.<sup>96</sup> Unorthodoxly in the sense that the book has been perceived as a political tract, indeed, as 'the greatest work of political philosophy ever written in

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*Hájku* (Prague, 2000). The stock of factual knowledge about Hagecius's life is critically scrutinized by J. Smolka

'Thaddaeus Hagecius ab Hayck, Aulae Caesarae Majestatis Medicus' in Gertrude Enderle-Burcel, E. Kubů, J. Šouša and D. Stiefel (eds.), *Discourses – Diskurse. Essays for - Beiträge zu Mikuláš Teich & Alice Teichova* (Prague and Vienna, 2008), pp. 395-412. For a brief introduction in English to the period, including Hagecius's significance, see J. Smolka, 'The Scientific Revolution in Bohemia' in R. Porter and M. Teich (eds.), *Scientific Revolution in National Context* (Cambridge, 1992), pp. 210-39. For an English response to the discovery in the constellation of Cassiopeia, see S. Pumfrey, 'Your astronomers and ours differ exceedingly': the controversy over the 'new star' of 1572 in the light of a newly discovered text by Thomas Digges', in *The British Journal for the History of Science* 44 (2011), pp. 29-60.

<sup>94</sup> Echoed in a well-known contemporary German saying: 'Schäfereien, Brauereien und Teich, machen die böhmischen Herren reich.'

<sup>95</sup> Shapin and Schaffer, *Leviathan*, p. 339.

<sup>96</sup> *Ibid.*, p. 92.

English'.<sup>97</sup>

Shapin's and Schaffer's exegesis of Hobbes's rejection of vacuism on political grounds is bold:

... the argument against vacuum was presented within a political context of use ... He recommended his materialist monism because it would assist in ensuring social order. He condemned dualism and spiritualism because they had in fact been used to subvert order ... For Hobbes the rejection of vacuum was the elimination of a space within which discussion could take place.<sup>98</sup>

The employment of the term 'social order' is not clear. Does it refer to 'political order' (probably) or a type of society (feudal, capitalist – less likely)? At all events, the cited passage and other statements hinge on Shapin's and Schaffer's introduction and usage of the term 'space' in a wider sense. Thus 'experimental space' refers to congregations in laboratories for performing/witnessing experiments. Whereas 'philosophical space' or 'intellectual space' bear upon participation in scientific debates and meetings of groupings, such as the newly founded Royal Society.

Hobbes denies to natural philosophers the right to such activities because, in his understanding of the sovereignty of absolute monarchy, these could undermine it. As noted by Shapin and Schaffer:

Speech of a vacuum was associated with cultural resources that had been illegitimately used to subvert proper authority in the state.<sup>99</sup>

The state in question is absolute monarchy. Absolutism is said to be 'the first international State system in the modern world'.<sup>100</sup> Concurrently the institutional pursuit of natural knowledge (scientific societies and journals), transcending national boundaries, was evolving. The contemporaneousness is not accidental because both realms, the political and the scientific, were products of and agents in the transition from feudalism to capitalism. The complexities of the transition over time involving multiple factors (politics, economy, ideology, wars, etc.), do not allow here an analysis directed towards a primary cause. But it is worth noticing that during its early phase, systematic and quantitative experimentation became an integral part of the pursuits of natural knowledge, acquiring in the long run a degree of relative autonomy in relation to the state, opposed by Hobbes.

Regarding the status of experiment in scientific advancement, Boyle prevailed over Hobbes. What about the status of hypothesis? Can it be said that Boyle's empiricism triumphed over Hobbes's rationalism? That would be a simplistic option with regards to the philosophies of both protagonists. Certainly, it does not reflect the position of the Royal Society which from its inception (1600) until the early eighteenth century 'was the chief European centre of experimental physics'.<sup>101</sup> As Marie Boas Hall puts it in her close analysis of science in the Royal Society in the seventeenth century:

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<sup>97</sup> Cf. promotional description of *Hobbes and Republican Liberty* (Cambridge, 2008), authored by Quentin Skinner.

<sup>98</sup> Shapin and Schaffer, *Leviathan*, pp. 99, 109.

<sup>99</sup> *Ibid.*, p. 91. Here, perhaps, it is appropriate to refer to Quentin Skinner's focussing on Hobbes's description of liberty in *Leviathan* 'according to the proper signification of the word': 'As soon as we leave the world of nature, however, and enter the artificial world of the commonwealth, we are no longer simply bodies in motion; we are also subjects of sovereign power'. Skinner, *Hobbes*, pp. 162-3. Shapin's and Schaffer's book is not listed in Skinner's 'Printed secondary sources'.

<sup>100</sup> P. Anderson, *Lineages of the Absolute State* (London, 1974), p.11.

<sup>101</sup> Rupert Hall, *Revolution*, p. 260.

However much the Society as a body might hesitate to favour hypothesis, its aim was to establish something more than a collection of random experiment. Mere matter of fact was not valued for itself, but for light it could shed on the Society's object, the establishment of a true philosophy of nature.<sup>102</sup>

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<sup>102</sup> M. Boas Hall, 'Science in the early Royal Society' in M. Crosland (ed.), *The Emergence of Science in Western Europe* (London and Basingstoke, 1975), pp. 61-2.

### 3. INSTITUTIONALIZATION OF SCIENCE

#### ENGLAND

The founding of the Royal Society has been linked to Bacon's thinking on organized science (about which later). The Royal Society is the premier scientific body in Britain, and some would claim in the world, but it is not the oldest.

The Italian short-lived Accademia dei Lincei [Academy of the Lynxes] at Rome (1609-1630, or 1603-1651) and Accademia del Cimento [Academy of the Experiment] at Florence (1657-1667) are usually listed as earliest instances of modern institutionalization of science. The distinction of a continuous scientific society belongs to the Deutsche Akademie der Naturforscher Leopoldina. Its founding preceded the incorporation of the Royal Society of London by ten years (1652).<sup>103</sup>

The Royal Society's proximate beginnings go back to 1660 when a group of mathematicians, astronomers and physicians, interested in promoting systematic and experimental knowledge of nature, met weekly at Gresham College in the City of London. The meetings of the group had an informal character but very soon it operated formally as a private society. It was granted two royal charters by Charles II (1630-1685) in 1662 and 1663 respectively and denominated Regalis Societas Londini pro Scientia naturali promovenda. From the start the Royal Society became, and then on has remained, a self-governing organization whose members – Fellows of the Royal Society – have been charged a fee as persons belonging to a social club, as it were.<sup>104</sup>

The founding of Gresham College (still in existence) goes back to a bequest by Sir Thomas Gresham (?1515-1579). One of the great merchants of the day, he also founded the Royal Exchange of London (1568). Gresham College was primarily an educational institution providing instruction in divinity, astronomy, music, geometry, law, medicine and rhetoric. By 1645, it became also one of the venues for the coming together of persons interested in discussing scientific problems and in experimenting. In the wake of the Puritan Revolution, some members of the group moved to Oxford (1648-9) where the Oxford Experimental

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<sup>103</sup> It originated in the Academia Naturae Curiosorum founded, 1 January 1652, by four physicians in the then Imperial Freetown Schweinfurt (now Bavaria). In 1670 Emperor Leopold I (1640-1705) ratified it as Sacri Romani Imperii Academia Naturae Curiosorum. In 1687 he sanctioned the prerogative as an independent imperial institution (a rare if not unique case in fragmented Germany) when it became Sacri Romani Imperii Academia Caesareo Leopoldina Naturae Curiosorum. See L. Stern, *Zur Geschichte und wissenschaftlichen Leistung der Deutschen Akademie der Naturforscher 'Leopoldina'* (Berlin, 1952). On the neglected Florence Academy, see M. Beretta, A. Clericuzio and L. M. Principe (eds.), *The Academia del Cimento and its European Context* (Sagamore Beach, 2009).

<sup>104</sup> The origins of the Royal Society have been the subject of a seemingly unending series of studies. Thomas Sprat (later Bishop of Rochester) compiled its first history when it was five years old (1667): *The History of the Royal Society in London*. It has been reprinted and edited with critical apparatus by J. I. Cope and H. W. Jones (Missouri, 1958). It is still of value as are T. Birch, *History of the Royal Society*, 4 vols. (London, 1756-70) and C. R. Weld, *A History of the Royal Society*, 2 vols. (London, 1848). Charles Webster provides a perceptive picture of the complex origins in his encyclopaedic *The Great Instauration Science, Medicine and Reform 1626-1660* (London, 1975). It includes the role of controversial figures such as Robert Boyle, Samuel Hartlib (c. 1600-1652) and Comenius [Jan Amos Komenský (1592-1670)]. The 350<sup>th</sup> anniversary is marked by 22 contributions to B. Bryson (introd. and ed), *Seeing Further The Story of the Royal Society* (London, 2010).

Philosophical Group at Wadham College was established. According to the mathematician John Wallis (1616-1703), the London group (meeting weekly) agreed that

to avoid diversion to other discourses, and for some other reasons) we barred all discourses of divinity, of state-affairs, and of news, other than what concerned our business of Philosophy.<sup>105</sup>

This emphasis on the separation of questions belonging to the province of natural sciences from those with which theology and politics are concerned is significant. The same idea reappears in the widely quoted draft preamble to the Statutes of the Royal Society ascribed to Hooke in 1663:

The business and design of the Royal Society is – To improve knowledge of naturall things, and all useful Arts, Manufactures, Mechanic practises, Engynes and Inventions by Experiments – (not meddling with Divinity, Metaphysics, Moralls, Politicks, Grammar, Rhetorick or Logick, etc.<sup>106</sup>

After the restoration of the monarchy, Gresham College became the venue for weekly meetings of the Royal Society. Composed at the time, the following four sextains (from a poem containing twenty-four) are of more than passing interest. They document the contemporary awareness of the intertwined worlds of overseas commerce and science. Thus the problem of determining longitude loomed large – to be solved by the Yorkshire carpenter John Harrison not until 1764. Indicatively, what was taught at Oxford and Cambridge, was met with derision. While the Aristotelian rejection of atomism is laughed at, the Epicurian view that nothing exists besides the atoms and the void is approved of:

The Merchants on the Exchange doe plott  
To encrease the Kingdom's wealthy trade;  
At Gresham College a learned knott,  
Unparallel'd designs have lay'd,  
To make themselves a corporation,  
And know all things by demonstration.

This noble learned corporation,  
Not for themselves are thus combin'd,  
But for the publick good o' th' nation,  
And general benefit of mankind.  
These are not men of common mould;  
They covet fame, but condemn gold.

This College will the whole world measure,  
Which most impossible conclude,  
And navigation make a pleasure,  
By finding out the longitude:  
Every Tarpaulian shall then with ease  
Saile any ship to the Antipodes

The College Gresham shall hereafter

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<sup>105</sup> See Appendix A, Sprat's *History of the Royal Society*.

<sup>106</sup> Weld, *Royal Society*, vol. 1, p. 146.

Be the whole world's University;  
Oxford and Cambridge are our laughter;  
Their learning is but pedantry;  
These new Collegiates do assure us,  
Aristotle's an ass to Epicurus.<sup>107</sup>

John Wallis was one of the original Greshamites, active in discussing advances in scientific matters. Another member of the group was Theodore Haak (1605-1690), a native of the Rhenish Palatinate, who is reputed to have initiated 1645 its meetings – after returning from a diplomatic mission in Denmark in the service of the parliament. Also he erroneously was reported to have invested the group with the name 'Invisible College'. As pointed out by Charles Webster, this was a separate body, small and short-lived (?1646-7) in which Boyle was involved. Webster's scepticism regarding the bearing of the Invisible College on the genesis of the Royal Society stems from Boyle's limiting 'the principles of our new philosophical college' to 'natural philosophy, the mathematics, and husbandry ... that values no knowledge but as it hath a tendency to use'.<sup>108</sup>

#### COMENIUS AND THE ROYAL SOCIETY<sup>109</sup>

In confirmation with this utilitarian thinking, Boyle was drawn to the circle around Hartlib concerned with what may be briefly described as 'practical millenarianism'. He hailed from Prussian Elbing (now Elbląg in Poland) which had strong commercial ties with England. Hartlib's mother was English and, like Haak (who belonged to the circle), he also settled in England. Here he became known as patron and instigator of projects sustaining human progress through improvements in agriculture, reforms of education and promotion of religious peace. Though sympathetic to Bacon's vision of organized empirical interrogation of nature, he perceived it to be too secular.

It is in this context that Hartlib found the writings of the exiled Czech educational reformer Comenius more congenial. In the wake of the Counter-Reformation after the defeat of the rebellious estates of Bohemia and their allies in the Battle of the White Mountain near Prague (1620), Comenius - a member and priest of the proscribed *Unitas Fratrum* - was forced 1628 to emigrate, first to the Polish Leszno. It is here where he composed *Conatum Comenianorum praeludia etc.*, published at Hartlib's behest in Oxford (1637). The work contained an outline of Comenius's 'pansophic' Christian epistemology, rooted in the amalgamation of the senses, reason and revelation.<sup>110</sup>

Hartlib, who corresponded with Comenius since 1632 and procured some financial aid for him, was the leading spirit behind the moves to get him to England. Arriving on 23

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<sup>107</sup> Ibid., pp. 79-80, n. 10. Peter Dear points out that Gresham College intended to provide instructions to sailors and merchants in useful arts especially practical mathematical techniques. See his *Revolutionizing*, p. 53.

<sup>108</sup> Webster, *Great Instauration*, p. 61, n. 100.

<sup>109</sup> What follows draws in part on my article 'The two cultures, Comenius and the Royal Society', *Paedagogica Evropea* 4(1968), pp. 147-53.

<sup>110</sup> For Descartes's critique, see his letter to Hogelande, August 1638(?), in A. Kenny (transl. and ed.), *Descartes Philosophical Letters* (Oxford, 1970) pp. 59-61. An up-to-date account of Comenius's life and work in English is badly needed. For a brief and convenient treatment in Czech, see J. Polišíenský, *Komenský Muž labyrintů a nádeje* [Komenský. Man of labyrinths and hope] (Prague, 1996).

September 1641, it appears that he was to head a body that

would assimilate the most advanced information in each sphere of knowledge, their collaborative enterprise leading to an encyclopaedic understanding of the material world and the solution of religious controversies among the Protestants, to assist the subsequent reform of the church and education.<sup>111</sup>

The social and political upheavals consecutive to the Civil War which broke out prevented the realization of the plan and, in the end, Comenius left England via Holland for Sweden on 21 June 1642. A glimpse of Comenius's vision what this body of learning should have been doing can be obtained from the work which he wrote during his stay in England. Entitled shortly *Via Lucis*, it was printed at Amsterdam in 1668, and dedicated to the Royal Society. The rational kernel of *Via Lucis* is usually summarized as a plan for a universal language, universal schools and a universal college.<sup>112</sup>

It is no accident that Comenius decided to make *Via Lucis* generally known, within a year of the publication of the *History of the Royal Society* by Sprat, after such a long interval since it was composed. While paying respect to Bacon's ideas on collective scientific endeavour, Comenius considered the Royal Society to be *the* body which could and should have carried out his ideas into practice. Yet he clearly perceived that this happened only on part and that there were important differences between the project as set out in *Via Lucis* and the route taken by the Royal Society.

Comenius points out that the glorious efforts by the Fellows of the Royal Society, as shown by the published records, form a beautiful part of those aims which had been put down in *Via Lucis's* chapter XVI, beginning with the paragraph 12. On looking up the place in the book it is found that it deals with Panhistoria. What Comenius had in mind was to compose a critical inductive historical survey of man's knowledge of natural and artificial, moral and spiritual processes in order to sift truth from error.<sup>113</sup> In view of this it is not without interest to know that some of the Fellows of the Royal Society, according to Sprat, were required

to examine all Treatises, and Descriptions, of the Natural, and Artificial productions of those Countries in which they would be inform'd ... They have compos'd Queries, and Directions, what things are needful to be observ'd in order to the making of a Natural History in general: what are to be taken notice of towards a perfect History of the Air, and Atmosphere, and Weather: what is to be observ'd in the production, growth, advancing, or transforming of Vegetables: what particulars are requisite for collecting a compleat History of the Agriculture, which is us'd in several parts of this Nation.<sup>114</sup>

Sprat offered then particular cases of these inquiries which were concerned with the history

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<sup>111</sup> C. Webster (ed.), *Samuel Hartlib and the Advancement of Learning* (Cambridge, 1970), p. 29.

<sup>112</sup> The full title: *Via lucis, vestigata et vestiganda, hoc est rationabilis disquisitio, quibus modis intellectualis animorum Lux, Sapientia, per omnes omnium hominum mentes, et gentes, jam tandem sub mundi vesperam feliciter spargi posit. Libellus ante annos viginti sex in Anglia scriptus, nunc demum typis exscriptus et in Angliam remissus* (Amsterdam, 1668). At the time of writing, I was informed by Cambridge University Library that the copy of the English translation by E. T. Campagnac (Liverpool, 1938) was missing since 2007. I used the Czech-Latin version J. A. Comenii *Via Lucis*/J. A. Komenského *Cesta světla* (Prague, 1961).

<sup>113</sup> *Ibid.*, pp. 242-3.

<sup>114</sup> Sprat's *History of the Royal Society*, pp. 155-6.



of weather, saltpetre, gun-powder and dyeing.<sup>115</sup>

The dedication to the Royal Society in *Via Lucis* is as much laudatory of its pursuits to acquire knowledge in the school of nature (*physics*) as it is exhortatory not to leave out consideration the study of man with its inborn qualities and faculties (*metaphysics*), and finally the realm where God is the supreme teacher (*hyperphysics*). Whereas nature is apprehended by senses, they are useless for the understanding of man which can be based only on reason (Comenius calls it the internal light or the eye of souls). But both senses and reason are equally of no avail when it comes to the comprehension of God's own province which Comenius apparently limits to the 'ultimate' type of question such as: what was it like before the world had existed and what will it be like when the world will not exist any more, or what exists outside this world. According to Comenius the only counsellor and guide within this sphere can be faith in revelation.<sup>116</sup>

The Royal Society's declared policy to exclude all subjects not pertaining to the exploration of nature from the consideration of its members was strictly pursued. But it would be wrong to insist that the problems raised by Comenius had appeared to its contemporaries or those who came after them as pseudoproblems. However, the individual Fellow of the Royal Society had to solve them for himself. The relation of science and religion played an important role in Boyle's and Newton's life, just to mention to of the outstanding figures of the Royal Society. Boyle as a young man came under the direct influence of the Hartlibian/Comenian group, and retained its belief that revelation and scientific truth are perfectly compatible. The position of Newton, who did not believe in Trinity, is more complex. Newton thought about theological matters very deeply and had difficulties to reconcile his religious belief with the conception of the mechanical universe.<sup>117</sup>

Comenius was a devout Christian but it would be misleading to think that his criticisms of the Royal Society derived from the fear that natural sciences would intrude on theology's territory. He merely believed that the answers provided by scientific inquiries amounted only to 'the alphabet of divine wisdom and this was by no means sufficient'.<sup>118</sup> Comenius advanced the view that the natural sciences should set a good example to the politicians and theologians because the principles on which the politicians directed the world were unstable. These principles should be examined and everything untrue should be cast aside. The efforts of the Fellows of the Royal Society to penetrate to the truth on the basis of observations and exact experiments should set a wonderful example to those who stood at the helms of human society either as civil administrators or spiritual guardians of the conscience, in not fearing any examination of all their actions.<sup>119</sup> Comenius believed then that statecraft and Christian practice could have learned from the methods employed by natural scientists in their quest for truth. But to leave it at that would not do justice to Comenius because he was concerned with the universality of knowledge and education, and sensed the danger in the Royal

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<sup>115</sup> Ibid., 'A method For making a History of the Weather.' By Mr. Hook, p. 173; 'The History Of the Making of Salt-Peter.' By Mr. Henshaw, p. 260. 'The History Of Making Gunpowder', p. 277. 'An Apparatus To The History Of the Common Practices of Dying'. By Sir William Petty, p. 284. For an account of the early Royal Society's interest in secure natural history, including human society overseas, see J. Gascoigne, 'The Royal Society, natural history and the peoples of the 'New Worlds', 1600-1800', in *The British Journal for the History of Science* 42(2009), 539-62.

<sup>116</sup> Comenii *Via Lucis*, pp. 155-6.

<sup>117</sup> On this subject, chapter IV in J. S. Brooke, *Science and Religion Some Historical Perspectives* (Cambridge, 1991), is rewarding. See also M. Hunter's intellectual biography *Boyle: Between God and Science* (New Haven and London, 2009).

<sup>118</sup> Comenii *Via Lucis*, pp. 158-9.

<sup>119</sup> Ibid., p. 160.

Society's one-sided preoccupation with nature.

On the continent many of the scientific societies and academies, which were founded later, took up a different attitude and established sections (classes) not only for the study of nature, but also of humanities (philology, history, philosophy etc.). In this respect they approximated much closer Comenius's project on the organization of universal knowledge than the Royal Society but, at the same time, important differences should be noted. Knowledge became specialized and the specialists who met in their respective sections became gradually estranged from their colleagues in other fields – they had nothing or very little to say to each other. These societies provided a common roof to a house whose inhabitants largely tended to shut themselves in rooms with no common doors.

The universality which these societies aspired to was on paper and this became to a great extent also the basis of education. This universality was certainly of a different nature which Comenius desired. Of course, it could be argued that it was historically inevitable since scientific knowledge of nature and society could be accumulated only by investigations of relatively isolated facets of natural and social reality. Nevertheless, these were the historical roots of the polarization which eventually formed the basis for the development of the 'two cultures', and which today's educational theory and practice still struggles to come to terms with. In the light of this, Comenius's exhortation to the Royal Society in the preface to *Via Lucis*, and the work itself, merit more than a passing glance.

As to Comenius's visit and its disputed relevance to the foundation of the Royal Society, perhaps Rupert Hall's observation is apposite:

No one has yet succeeded in disentangling completely the personal relations of all those who figure more or less largely in the scientific world of mid-seventeenth-century England. It is likely that most of the forty or fifty men concerned knew something of each other, though mainly associated with one of three chief groups – the Hartlib circle, devoted to social and ethical reform and more occupied with technology than abstract science; or the club of mathematicians, astronomers and physicians meeting at Gresham College; or the Oxford Philosophical Society. There were no barriers between them.<sup>120</sup>

FRANCE<sup>121</sup>

The Royal Society was 'Royal' de jure but not de facto. Independent of the state, it was a self-governing organization of members who originally were asked to pay one shilling for expenses. This was not a hardship as the majority of Fellows were persons of independent means ('gentlemen'). While social rank retained its significance, the Fellows were – as Sprat put it – a '*mix'd Assembly*' [Sprat's italics] which has 'escap'd the prejudices that use to arise from Authority, from inequality of Persons ...'<sup>122</sup> The state virtually kept distance from the pursuits of the London Royal Society, be they practical or theoretical.

This did not apply to the Paris Académie Royale des Sciences, established four years

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<sup>120</sup> Rupert Hall, *Revolution*, p. 142.

<sup>121</sup> What follows under this and the ensuing heading owes much to mine 'Tschirnhaus und der Akademiagedanke' in E. Winter (ed.), *E. W. von Tschirnhaus und die Frühaufklärung in Mittel- und Osteuropa* (Berlin, 1960), pp. 93-107. R. Hahn's *The Anatomy of a Scientific Institution. The Paris Academy of Sciences, 1666-1803* (Los Angeles and London, 1971) is still relevant.

<sup>122</sup> Sprat's *History of the Royal Society*, pp. 91-2.

later (1666). Its origins also go back to private gatherings of persons with common interests in expanding knowledge of nature. It was J. B. Colbert's (1619-1683) grasp of the import of scientific investigations which was behind the assent of King Louis XIV (1643-1715) to embed them institutionally. Judging by the correspondence with a number of scientists, the mercantilist Colbert (surprisingly?) had not adopted a narrow utilitarian attitude towards research. He understood that investigators had to have room for the pursuit of knowledge for its own sake. Therefore the thirty to forty members of the Academy were freed from financial worries. They received an annual pension and a notable allowance for instruments and other research needs. This enabled the Paris Academy to become a centre of collective and conscious efforts to place scientific pursuits into the service of the state. Considerable attention was paid to the analysis of the modes of handicraft production, including assessment and efficiency of novel mechanical contrivances. The foundation of the Paris Academy and its state-link corresponded to the mercantilist policies, vigorously pursued by the French government in the seventeenth century.

#### PRUSSIA AND SAXONY

The foundation of the Royal Society in London and the Académie des Sciences in Paris made a strong impression on scientists in other countries, including Germany. Reproaching the members of the Leopoldina for not working creatively, Leibniz noted that it lacked sufficient means and social prestige. Altogether the social conditions for the development of scientific activities were not propitious in fragmented Germany in the aftermath of the Thirty Years War.

Indeed it was Leibniz who drew a sombre picture of the plight of the scientific-technical personnel in Germany at the time. While there was no shortage of mechanics, artisans and experimenters, the governments of the various kingdoms and principalities showed little interest in them. Thus they were really faced with two options: either to give up and bury their talents, or leave behind the beggarly living conditions at home, and seek opportunities abroad to the detriment of Germany. Leibniz made this point when he submitted a proposal for founding a scientific society in Prussia (approved in 1700 but established in 1711).<sup>123</sup>

Ever intent on promoting institutionalization of science in Germany, Leibniz corresponded on this subject (1693-1708) with the mathematician Ehrenfried Walther Tschirnhaus (1651-1708). He also was a constructor of circular and parabolic mirrors with which he succeeded, by focusing sunlight, to obtain high temperatures.<sup>124</sup> Sharing Leibniz's concerns, Tschirnhaus was thinking about collective forms of scientific activities in Saxony, especially after his dream to become a pensioner of the Paris Academy came to nothing (1682). Of historical interest is Tschirnhaus's letter to Leibniz (13 January 1693) in which the idea of holding a scientific congress is raised perhaps for the first time:

Merchants gather at the Leipzig Fair because of their perishable earthly

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<sup>123</sup> See Leibniz, 'Errichtung einer Societät in Deutschland (2. Entwurf)' in A. Harnack, *Geschichte der königlich preussischen Akademie der Wissenschaften zu Berlin*, vol. 2 (Urkunden u. Actenstücke) (Berlin, 1900), p. 23.

<sup>124</sup> To what extent Tschirnhaus's expertise with high temperatures contributed to the discovery of the Meissen porcelain by J. F. Böttger (1682-1719), and thus made him a co-discoverer, has been a subject of much discussion.

things [*vergängliche Dinge*]; could not also learned people meet here one day [*einmahl alda*] because of important reasons.

In response to a letter from Leibniz, who was thinking of a self-financing scientific society, Tschirnhaus suggested that the revenues could derive from the exploitation of scientific discoveries, such as his own in optics (27 January 1694). He also specified strict criteria that were to apply to the selection of members of the society: 1. The aspiring member was truly to employ scientific methods in his work; 2. Science and the desire to get to the truth was to be his main passion; 3. Self-interest was not to be his main motive; 4. Nor was hankering after personal glory to be reason for doing research.

At the same time, Tschirnhaus informed Leibniz that he freed himself from these weaknesses. As a proof, he offered to publish his own work anonymously – only under the name of the society. He would not ask for a greater share from the common purse than he was entitled to. He also was prepared to hand over to the common purse all the monetary gain he derived from his own optical inventions. But in the end, Tschirnhaus doubted that there were scientists who would come up to such expectations. Leibniz agreed that such persons did not exist. Moreover regarding scientific societies he observed that not much was to be expected from 'persons of high rank' [*grosse Herren*], however well-intentioned they were.

Further history confirmed this view. Tschirnhaus became involved, with the help of Prince Fürstenberg, in setting up a manufactory for producing large mirrors in Dresden (1707). They did not distort, owing to an invention of Tschirnhaus with respect to handling molten glass. Tschirnhaus's hope was that the revenues would secure the existence of a scientific society. This did not materialize, nor did other projects, considered by the two scientists. For example, there was a proposal (not theirs) to establish a central German institution for the improvement of the calendar, out of which an academy was to grow – financed from proceeds of the monopolized sale of calendars. Also Tschirnhaus's and Leibniz's own exertions to establish an academy in Dresden came to nothing. While Tschirnhaus remained optimistic, Leibniz tended to succumb to depressions, especially in view of obstructions to his plan in Berlin, which came to fruition five years before his death.

## BOHEMIA<sup>125</sup>

Traditionally the rise of organized science in Bohemia is linked to the activities of an informal body known as the Private Learned Society. Constituted around 1774, it included humanities from the outset as an integral part of its concerns, as well as natural sciences. This was clearly reflected in the title of its journal *Abhandlungen einer Privatgesellschaft in Boehmen, zur Aufnahme der vaterlaendischen Geschichte und der Naturgeschichte*, under the editorship of Ignaz [Inigo] von Born (1742-1791). It appeared six times as an annual between 1775 and 1786. The ideology that informed both the formation of the Society and its journal was patriotism to which practitioners of disciplines in both camps confessed. Not only were they socially a mixed assembly (like the Royal Society), but also ethnically. The Czech- and German speaking members considered themselves heirs of a long and honourable tradition of learning effectively inaugurated with the foundation of a *studium generale* at Prague, the first university in Central Europe (1348). Patriotism lay behind

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<sup>125</sup> What follows draws greatly on my previous treatments of the subject. See 'Bohemia: From darkness into light' in R. Porter and M. Teich (eds.), *The Enlightenment in National Context* (Cambridge, 1981), pp. 141-63; 247-53; 'Afterword', pp. 215-7.

their call not only for the exploration of the economic resources but also of the historical past of Bohemia. They agreed that critical analysis and rationalism, so relevant to the scientific study of nature, could be equally successful in the scholarly study of history.

The scientific-technical-economic interests of the founders of the Private Learned Society paralleled those of the founders of the Royal Society and other scientific societies in Europe. These societies were concerned with gaining systematic knowledge of nature for practical use in manufactories alongside agriculture.

The Oxford English Dictionary locates the first use of 'manufactory' in the year 1618. To all intents and purposes, it meant a place of work in which operations were carried out manually. By the 1690s, economic thinkers (W. Petty, J. Locke) were writing about improving productivity of labour through division of labour – machinery was largely limited to watermills and windmills. The classical analysis of the role of division of labour in raising the productivity of labour was offered by Adam Smith (1723-1790) in the *Wealth of Nations* (1776). It influenced Marx to perceive in manufacture the characteristic mode of production in the pre-industrial phase of capitalism. He called it the 'period of manufacture' [*Manufakturperiode*], and thought that it extended roughly from the middle of the sixteenth to the end of the eighteenth century. While this approach informed historians in the former socialist countries, it was largely ignored by Western historiography. Inasmuch as historians variously adopted the concept of 'proto-industrialization', since the 1970s, they found the Marxist framework of the manufactory stage of industrialization, in certain economically active European states or regions, wanting.<sup>126</sup>

Be that as it may, manufactories needed raw materials which could be ascertained through surveys of natural resources. Hence the surveying of natural resources, famously personified in the Swedish context by Carolus Linnaeus [Carl von Linné] (1707-1778), became one of the important tasks the scientific societies set themselves.

The need for an organized scientific survey of the Habsburg dominions had already been proclaimed by Philipp Wilhelm von Hornigk (1638-1712), the leading thinker of Austrian mercantilism, in 1684. Hornigk [Hornick, Hoernigk] recognized the importance of mathematics and mechanics for the development of manufactories. He emphasized that they should use indigenous raw-materials. He called for survey and experiments on the acclimatization of foreign plants and animals. He also thought it highly desirable to publish a technological encyclopaedia which would explain the significance of physics and mechanics for productive purposes. This task – according to Hornigk – could not be performed by a single person but by a group of disinterested specialists in various subjects who would not keep their knowledge to themselves but place it at the public's disposal.<sup>127</sup>

Hornigk's agitation against secretiveness and his request for specialists to combine their scientific and technical knowledge for production and commerce was not accidental. The principle of cooperation based on the division of labour, so characteristic of operations in manufactories, was also penetrating into the world of science. In some ways artisans and scientists had developed a similar attitude in refraining from divulging what was believed to constitute a 'trade' secret. With the growth of specialized scientific knowledge the need arose for exchange of observational and experimental results that could be tested

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<sup>126</sup> For an introduction and survey, see Sheilagh C. Ogilvie and M. German (eds.), *European Proto-industrialization* (Cambridge, 1996); see also Maxine Berg, *The Age of Manufactures*, 2<sup>nd</sup> ed. (London, 1994). For a non-Marxist critique of the theory, see D. C. Coleman, 'Proto-industrialization: a concept too many' in his *Myth, History and the Industrial Revolution* (London and Rio Grande, 1992), pp. 107-22.

<sup>127</sup> Ph. W. Hornigk, *Oesterreich ueber alles wann es nur will*, 2<sup>nd</sup> ed. (n. p. 1685), pp. 99, 94f., 261-3.

and expanded, leading up to the foundation of scientific societies and journals. Through them scientific activity became 'socialized' both in terms of organization and also in that its results became public property, available at no cost to those interested in its practical utilization in industry, agriculture and medicine.<sup>128</sup>

The conditions for Hornigk's suggestion for establishing an association of scientists for Austria's economic benefit matured only slowly, and it took almost hundred years before one was founded in Bohemia. The background of the setting up of the Private Learned Society will become clearer by referring to the exploration of natural resources of Bohemia and the Austrian Salzkammergut instigated by Empress Maria Theresa (1740-1780) and her husband Francis of Lotharingia (1745-1765), a leading entrepreneur himself in the 1750s and 1760s. They charged with this task Jan Křtitel Boháč [Johan(n) Tauffer Bohadsch], a professor and leading official of the Prague medical faculty.

One of the distinguished microscopists of his time, Boháč (1724-1768) was also a commercial counsellor to the Bohemian *Gubernium*. A university professor not isolated from life, Boháč had not the slightest doubt that the development of the natural sciences, arts and manufactures formed an inseparable unity. With great clarity he defended the social function of scientific investigations against those who tended to underrate it.

In the eighteenth century, under the influence of the much travelled Linnaeus, systematics came to occupy a central place in natural history. Sometimes these endeavours degenerated into aimless classifications of plants, animals and minerals for their own sake. Boháč condemned such tendencies, holding that classification of natural objects should be a means of utilizing them in material production. His comprehensive approach led him to appreciate the dependence of manufacture on agriculture. For instance, his concern with the cultivation of woad for animal feeding and dyeing indicated the connection between scientific, technical, economic and political aspects of his work.<sup>129</sup> It was to be crowned by a comprehensive survey of the plant, animal and mineral wealth of Bohemia. However, because of Boháč's untimely death, it remained in a manuscript that has been lost. There can be little doubt about the social and economic impetus that turned Boháč and others to apply their expert knowledge of properties and processes of nature, inanimate and animate, to practical fields, including the systemic survey of the natural wealth of Bohemia. But, unaided financially and working alone, this could be hardly completed by an individual.

It could have been expected that Prague University would house such a body because it counted among its members prominent scientists interested in the practical use of natural knowledge like Boháč or the able mathematician and physicist Joseph Stepling (1716-1778). At the order of the Empress Maria Theresa, a kind of university scientific society presided over by Stepling had been established in 1753. University teachers used to meet and hold lectures, but within less than a decade the society ceased to function, possibly due to the antagonism of the Jesuit order still in control of university life and imbued by thinking derived from the Aristotelian-Thomist synthesis.<sup>130</sup>

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<sup>128</sup> See K. Marx, *Capital* (London, 1938), vol. 1, p. 383.

<sup>129</sup> J. T. Bohadsch, *Beschreibung einiger in der Haushaltung und Faerbekunst nutzbaren Kraeutern ...* (Prague, 1755); *Abhandlung vom Gebrauch des Waides in der Haushaltung* (Prague, n. d.); *Der Dienst- und Nutzbarer Vorschlag ...* (Prague, 1758). See Z. Frankenberger, Jan Křtitel Boháč, *Věstník Královské české společnosti nauk* 12 (1950), pp. 1-122.

<sup>130</sup> Except for scattered remarks in eighteenth-century records, there is little solid information on these meetings, called variously *consessus philosophicus*, *consessus philosophici* and *consessus literarii*. As to Jesuits in Bohemia, it is necessary to differentiate between the unprogressive attitude of the order delaying the advance of science, and the progressive role of its individual

To complement the account mention should be made of the earliest scientific society in the Czech Lands and, indeed, in the Habsburg Empire. It was the short-lived *Societas eruditorum incognitorum in terris austriacis* at Olomouc (the former capital of Moravia). It was founded in December 1746, with the backing of Maria Theresa, by Joseph von Petrasch (1714-1772), a former *aide-de-camp* of Eugene of Savoy. The Society of Unknown Scholars arose from informal gatherings of laymen, clergy and military officers interested in discussing literary and scientific developments at home and abroad in an atmosphere free from limitations imposed by the Jesuits on the spiritual life of the fortress and university town. Containing only reviews and no original contributions, two volumes of its journal *Monathliche Auszuege Alt- und neuer Gelehrten Sachen* were issued at Olomouc in 1747 and 1748. Apparently to avoid censorship the third volume of the journal was printed outside Austria (1750) and afterwards its publication ceased.<sup>131</sup>

About two decades elapsed before the idea of a scientific society was taken up again by the well-known mineralogist Born. Writing to his friend Count F. J. Kinsky[ý] (1739-1805) Born emphasized that nobody had thought of setting up a learned society for the exploration of Austria's widespread territory, in order to assemble the observations made by naturalists and scientists. This is a pointer that a scientific society, centred on Austria as a whole, or restricted to Bohemia, did not exist before 1774.

Born criticized the aristocracy for its lack of comprehension of the utility of natural history. He stressed that those who took interest in it and had the ability to work creatively did not possess the means to explore nature. He explicitly mentioned the case of Boháč, who on his travels had collected natural objects at his own expense and on his death left his wife penniless. On the other hand, according to Born, the nobility had the means but did not encourage people of talent to investigate the natural wealth of the monarchy. Further in his letter he elucidates the usefulness of science to the economy, the state, the church, the doctor and the poet.<sup>132</sup>

He was particularly concerned with the perniciousness of not making scientific observation and technical discoveries available to all, under the cloak of state secrecy. Born here was condemning an official practice which had almost already landed him with the charge of treason. In 1771 he had published N. Poda's (1723-1798) descriptions of machines used in the mining district of Banská Štiavnica, one of the classical texts on eighteenth-century mining in Central Europe.<sup>133</sup> At that time, he occupied the post of assessor of the Mint and Mining Head Office in Prague, from which he chose to resign. The defence of open scientific communication was crucial to Born's drive to organize scientific

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members in furthering and participating in astronomical, mathematical and physical inquiries (e. g. J. Stepling). See also E. Winter, 'Die katholischen Orden und die Wissenschaftspolitik im 18. Jahrhundert', in E. Amburger, M. C. Cieřla and L. Sziklay (eds.), *Wissenschaftspolitik in Mittel- und Osteuropa* (Berlin, 1976), pp. 85-96.

<sup>131</sup> There is as yet no reliable treatment of the subject. Under these circumstances what can be said, in general, is that the *Societas incognitorum* embodied an effort to organize scientific and cultural life at an early stage of the Enlightenment in the Habsburg dominions but the social, intellectual, local and personal circumstances that engendered its birth was not adequate to keep it alive. See E. Wondrák, 'Die Olmützer 'Societas incognitorum'. Zum 225. Jubiläum ihrer Gründung und zum 200. Todestag ihres Gründers', in E. Lesky, D.S.K. Kostić, J. Matl and G. v. Rauch (eds.), *Die Aufklärung in Ost- und Südosteuropa* (Cologne and Vienna, 1972), pp. 215-28.

<sup>132</sup> Schreiben des Herrn Ignatz von Born...an Herrn Franz Grafen von Kinsky, *Ueber einen ausgebrannten Vulkan bey der Stadt Eger in Boehmen* (Prague, 1773), pp. 1-3, 11-16.

<sup>133</sup> N. von Poda, *Kurzgefasste Beschreibung der, bey dem Bergbau zu Schemnitz in Nieder-Hungarn, errichteten Maschinen etc.* (Prague, 1771).

life in Bohemia between 1770 and 1776, and afterwards in Vienna and, indeed, on an international scale.<sup>134</sup>

Major-General Franz Joseph [František Josef] Kinsky was descended from one of the great Czech aristocratic houses. A keen geologist and educationalist, he eventually became the head of the Military Academy at Wiener Neustadt. He supported Born's vision of putting scientific life in Bohemia on an organized basis, for economic, technical and educational reasons. Together with Born and aided by the head of the *Gubernium*, Prince Karl Egon Fürstenberg, he was instrumental in founding the Natural History Museum (1775) and brought into being the Prague University Library (1777) of which he became the first director.<sup>135</sup>

Kinsky shared Born's concern that the aristocracy as a social class was apt to regard science and technology with disdain. In a letter to Born published in the first volume of *Abhandlungen* (1775), Kinsky complained that the nobility were not properly informed that the administration of their domains required knowledge of natural and agricultural sciences. In his answer Born wrote that a mineralogical and geographical description of Bohemia was needed, adding that there were only a few mineralogists available. According to Born, the example of Saxony ought to be followed where specialists financed by public funds were preparing a mineralogical map.<sup>136</sup>

The Private Learned Society's transformation into a public institution occurred when it became the Bohemian Society of Sciences in 1784 and the Royal Bohemian Society in 1790. The problems which the scientists in Bohemia tried to solve, especially those associated with the Royal Bohemian Society of Sciences, or came within its orbit during the first period of its existence, were closely related to the idea of a scientific survey of Bohemian natural resources.

The Society approached the problem of a scientific survey of Bohemia basically from two angles. It launched prize essay competitions and organized expeditions for the purpose of surveying various regions of Bohemia. The aim of these endeavours was to collect a large amount of scientifically verified information for a map of Bohemia.

It embarked upon this plan because its members were convinced that the development of manufactures depended above all on knowledge of domestic economic resources. However, the social, financial and personal situation did not favour the transformation of this awareness into reality. For one thing, the continuing feudal relations and undeveloped capitalist relations affected negatively progress in agriculture and industry. For another, the Bohemian Society of Sciences was in continuous financial difficulties which were not made good by the support from a few interested aristocrats. In addition, the number of individuals able to perform a large-scale survey of the country was then small. The Society included amongst its members (nearly all non-nobles) the most distinguished scholars in Bohemia, but that amounted to no more than a few persons. As a consequence it succeeded only partially in achieving its aim.

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<sup>134</sup> The definitive study of this leading figure of the Enlightenment in the Habsburg monarchy still remains to be written. See H. Reinalter (ed.), *Die Aufklärung in Österreich. Ignaz von Born und seine Zeit* (Frankfurt/Main, 1996).

<sup>135</sup> Kinsky has received little serious attention. For an appreciation, see J. Haubelt, 'František Josef Kinský', in *Věstník Československé akademie věd* 58 (1969), pp. 560-77.

<sup>136</sup> 'Schreiben des Herrn Grafen von K... an Herrn von Born ueber einige mineralogische und lithologische Merkwuerdigkeiten', *Abhandlungen* 1 (1775), pp. 243-52; 'Antwort des Herrn von Born, auf das Schreiben des Herrn Grafen von K...', *ibid.* 1 (1775), pp. 253-63.



## 4. TRUTH(S)

### COLLECTIVE TRUTH: BACON

That the collaborative interrogation of natural world, promoted by the early Royal Society, could be more productive than the individual endeavour was brought home to the learned world by Francis Bacon. His depiction of imaginary Solomon's House in the *New Atlantis* (1627) was to serve as a prototype of organized scientific activities for the satisfaction of human needs. It was made up of thirty-six investigators engaged in collecting information and producing knowledge of nature, including surveys of natural resources and natural histories. Fundamentally, they were collectively concerned with the understanding how matter in motion works, and in using it for human advance:

The End of our Foundation is the knowledge of Causes, and secret motions of things; and the enlarging of the bounds of Human Empire, to the effecting of all things possible.<sup>137</sup>

The division of labour between the members of Solomon's House were functional: they were assigned to nine research groups, charged to perform specific jobs. The large one comprised twelve travellers who visited foreign countries. Their name 'Merchants of Light' is double-edged since they were engaged in clandestine scientific intelligence. As to the eight 'home-based' groups, they were made up of three persons each, and named no less arrestingly.

The 'Depredators' gleaned information about experiments from books. The 'Mystery-men' were concerned with tracking down trade secrets (techniques). The 'Pioneers of Miners' explored new avenues by designing novel experiments. The 'Compilers' summarized the results of the former four groups 'for the drawing of observations and axioms out of them'. The 'Dowry-men or Benefactors' were occupied with material benefits stemming from the 'experiments of their fellows'. The 'Lamps' – after meetings and consultations with the 'whole number' and adjudging what the collective managed to achieve – proposed 'new experiments, of a higher light, more penetrating into nature than the former'. The 'Inoculators' performed them and reported on them. Finally, the 'Interpreters of Nature' connected the findings and expounded them in general terms, including axioms and aphorisms.

There were twenty or so laboratories in Solomon's House serviced by a great number of male and female servants, and attendants. Additionally, there were novices and apprentices in order to secure continuity of researches. As Krohn points out, the description of the laboratories, including the equipment and work in Solomon's House must have filled a seventeenth-century reader with awe. While, there is the danger of ascribing anachronistically foreknowledge, a twenty-first-century reader should have no difficulty to discern what amounts to experimentation in hybrid sterility when he reads:

We find means to make commixtures and copulations of different kinds; which have produced many new kinds, and them not barren, as the general opinion is.

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<sup>137</sup> This and further citations are from Bacon's description of Solomon's House, reprinted as *Appendix* in B. Farrington, *Francis Bacon Philosopher of Industrial Science* (London and New York, 1973), pp. 179-91. A classical study which, along with P. Rossi's, *Francis Bacon From Magic to Science* (Chicago, 1968), influences W. Krohn's insightful (in German) *Francis Bacon* (Munich, 1987).

Historically, the celebrated instance is the mule – the sterile offspring of male donkey and female horse.

Briefly, Bacon's notion of scientific procedure embraced collaborative gathering of empirical/experimental facts combined with inductive generalizations – in the service of man. This was a radical departure from the attitude going back to Plato and Aristotle who held 'that the pursuit of knowledge was an end in itself.'<sup>138</sup> In this context William Harvey's reputed, and frequently quoted, gibe that Bacon wrote philosophy like a Lord Chancellor is beside the mark.

Nevertheless there is a historiographical issue regarding the interaction of law, politics and epistemology in Bacon's approach to understanding of nature. Demonstrably Bacon's legal and statemanly background had something to do with his analogy between 'axioms' and 'laws'. But it would be a step too far to trace Bacon's position solely to this source. In fact, there are good reasons to connect Bacon's 'laws of nature' with empirical 'rules', guiding the practice in dominant sectors of the economy in seventeenth-century Britain: agriculture and urban and countryside handicrafts. There are grounds, *pace* Farrington, to regard Bacon as a philosopher of pre-industrial science.<sup>139</sup>

On the face of it, Solomon's House was a self-governing and a self-financing institution for co-operative research. The funds to carry out the extended research programme essentially derived from home-bred manufacturing and commercial activities and inventions. Presumably the financial self-sufficiency enabled the scientists to maintain distance in respect to the state. This is revealed in a remarkable passage almost at the end of the description of Solomon's House. Decision to publish results or keep them under wraps even vis-à-vis the state, were collegiate:

And this we do also: we have consultations, which of the inventions and experiences which we have discovered shall be published, and which not: and take all an oath of secrecy, for the concealing of those which we think fit to keep secret: though some of those we do reveal sometimes to the state, and some not.

It is said that Hobbes served Bacon as a secretary for a while. True or false, he certainly had a different understanding of freedom of action for scientists than his (alleged) master and mentor.<sup>140</sup>

#### PERSONAL TRUTH: DESCARTES

Alongside of Bacon, traditionally, Descartes is presented as his antipode with respect to epistemology. One way to demarcate between the two thinkers (following Koyré) is to say: whereas Bacon was interested in the 'order of things', Descartes searched for the 'truth of ideas'. This is supported by autobiographical narratives (in as much they are credible) from which both emerge as persons confident of their own qualification for procuring truthful knowledge.

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<sup>138</sup> G. E. R. Lloyd, *Early Greek Science Thales to Aristotle* (London, 1970), p. 132.

<sup>139</sup> W. Krohn, 'Social change and epistemic thought (Reflections on the origin of the experimental method)' in I. Hronszky, Márta Fehér and B. Dojka (eds.), *Scientific Knowledge Socialized* (Boston Studies in the Philosophy of Science, vol. 108) (Dordrecht, Boston and London, 1988), pp. 165-78.

<sup>140</sup> H.-D. Metzger, *Thomas Hobbes und die Englische Revolution 1640-1660* (Stuttgart-Bad Constanz, 1991), p. 298.

There is one autobiographical piece by Bacon, as noted by Farrington, composed as a Preface (1603) to the work *On the Interpretation of Nature*, which was never written in the projected form. This is how Bacon detailed his inborn attributes to be a seeker of truth regarding the 'order of things':

For myself, I found that I was fitted for nothing so well as for the study of Truth; as having a mind nimble and versatile enough to catch the resemblances of things (which is the chief point), and at the same time steady enough to fix and distinguish their subtler differences; as being gifted by nature with desire to seek, patience to doubt, fondness to meditate, slowness to assert, readiness to reconsider, carefulness to dispose and set in order; and as being a man that neither affects what is new or admires what is old, and that hates every kind of imposture. So I thought my nature had a kind of familiarity and relationship with capital Truth.<sup>141</sup>

At the heart of Bacon's approach, as noted, was to seek knowledge for human welfare. Autobiographically, it is recorded as follows:

But above all, if a man could succeed, not in striking out some particular invention, however useful, but in kindling a light in nature – a light which should in its very rising, touch and illuminate all the border-regions that confine upon the circle of our present knowledge; and so spreading further and further should presently disclose and bring into sight all that is most hidden and secret in the world, - that man (I thought) would be the benefactor indeed of the human race, - the propagator of man's empire over the universe, the champion of liberty, the conqueror and subduer of necessities.<sup>142</sup>

As to Descartes, his best known work *Discourse on the Method* (1637) offers an autobiographical account of the evolution of his thinking. It supports Koyré's broad demarcation between the two thinkers. Not least because it contains the celebrated deduction whereby Descartes established (to his satisfaction) his own existence: 'I am thinking (*je pense*), therefore I exist'.<sup>143</sup>

Trust in personal truth and distrust in collective truth motivated Descartes to reconstruct human knowledge:

But from college days I had learned that one can imagine nothing so strange and incredible but has been said by some philosopher; ... at the same time, a majority of votes is worthless as a proof, in regard to truths that are even a little difficult of discovery; for it is much more likely that one man should have hit upon them for himself than that a whole nation should. Accordingly I could chose nobody whose opinion I thought preferable to other men's; and I was as it were forced to become my own guide.<sup>144</sup>

As noted, Bacon's path to generalizations was through inductive reasoning sustained by ensuing empirical/experimental evidence. Descartes argued for the opposite procedure

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<sup>141</sup> Farrington, *Bacon*, pp. 54-5.

<sup>142</sup> *Ibid.*, p. 54.

<sup>143</sup> 'Discourse on the Method, etc.' in Elizabeth Anscombe and P. T. Geach (ed. and transl.), *Descartes Philosophical Writings*, with an Introduction by A. Koyré (Sunbury-on-Thames, 1976), p. 31. It has been noted in *Meditations on Philosophy* (1641), Descartes dispenses with 'therefore'. See *ibid.*, p. 67f.

<sup>144</sup> Descartes, *Discourse*, pp. 18-9.

based on deductive reasoning downwards from a first principle which he traced to God, the supreme legislator. It was not that he was not aware of the part played by 'practical philosophy' in the replacement of philosophical speculations taught by Schoolmen:

For I thus saw one may reach conclusions or great usefulness in life, and discover a practical philosophy taught by the Schoolmen; one which would show us the energy and action of fire, air and stars, the heavens, and all other bodies in our environment, as distinctly as we know the various crafts of our artisans, and could apply them in the same way to all appropriate uses and thus make ourselves masters and owners of nature.

It was not that he regarded experiments and observations (he dissected animals) unnecessary, but they

often deceive us, so long as the causes of the more common are still unknown; and the conditions on which they depend are almost always so special and so minute that it is very hard to discern them. My general order of procedure on the other hand has been this. First, I have tried to discover in general the principles of first causes of all that exists or could exist in the world. To this end I consider only God, who created them, and I derive them merely from certain root-truths that occur naturally to our minds. Then I considered the first and most ordinary effects deducible from these causes,... and then I tried to descend to more special cases.<sup>145</sup>

This included anatomical investigations from the early 1630s to the late 1640s. While reinforcing Descartes's deciphering living processes along micro-mechanical lines, they raised the question of the relation of the material machine-like body and the incorporeal immortal soul.

The received wisdom is that Descartes, demarcating sharply between them, parented mind-body dualism. True, addressing the issue of how mind and body interacted Descartes famously visualized the pineal gland as the seat of the rational soul. There it was supposed to receive external physical stimuli and direct movements. Descartes's choice of pineal gland was guided by the notion (erroneous as it turned out) that it is an unduplicated anatomical structure present only in human brains. But this did not imply or signify that Descartes was doubting or even giving up the belief in the existence of God and immortality of the soul.

## MIND AND BODY

Shortly before his death, Descartes reiterated in the Preface to the unfinished *Description of the Human Body* (1647-1648) the importance of personal cognition: 'There is no more fruitful occupation than to try to know itself.' While granting the practical (medical) value of knowing 'the nature of our body', he was after 'not attributing to the soul functions which depend only on the body and on the disposition of organs':

When we make the attempt to understand our nature more distinctly, however, we can see that our soul, in so far as it is a substance distinct from body, is known to us solely from the fact that it thinks, that is to say, understands, wills, imagines, remembers, and senses, because all these

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<sup>145</sup> Ibid., p. 46-47. Noteworthy is that Marx in *Capital* refers to Descartes's counterpoising practical and speculative philosophy, but also characterizes Bacon and Descartes as philosophers of the pre-industrial phase of capitalism ('Period of manufacture'). See Marx, *Capital* (London, 1938), vol. 1, p. 387 n. 2.

functions are kinds of thoughts. Also, since the other functions that are attributed to it, such as the movement of the heart and the arteries, the digestion of food in the stomach and such like, which contain in themselves no thought, are only corporeal movements, and since it is more common for one body to be moved by another body than by the soul, we have less reason to attribute them to the soul than to the body.<sup>146</sup>

To Descartes the cognitive functions of the immaterial soul remained of central concern. Behind it lurked the problem of mind-body dualism, penetratingly raised by Elizabeth, Princess of Bohemia, in her correspondence with Descartes (1643-1646). That is, how an unextended, immaterial soul can move material things. This and other issues relating to emotions (passions) taken up in the correspondence, undoubtedly prompted Descartes to apply himself deeply to the dichotomy of mind-body dualism.<sup>147</sup>

It was not resolved by a convoluted 'doctrine of substantial union of mind and body'.<sup>148</sup> It was premised on the existence of two forms of mind. The 'embodied mind', tied to corporeal organs, perceived, remembered, imagined, etc. As to the 'disembodied mind', Descartes needed it on account of his belief in the personal immortality of the soul after death. Descartes wanted to have one's cake and eat it, that is, to have both a mind dependent on matter, and a mind independent of matter. Put by Engels, the basic philosophical issue is not passé:

The great basic question of all philosophy, especially of more recent philosophy, is that concerning the relation of thinking and being... The answers which the philosophers gave to this question split them into two great camps. Those who asserted the primacy of spirit to nature and, therefore, in the last instance, assumed world creation in some form or other comprised the camp of idealism. The others, who regarded nature as primary, belonged to the various schools of materialism.

These two expressions, idealism and materialism, originally signify nothing else but this...<sup>149</sup>

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<sup>146</sup> Descartes, 'The description of the human body, etc.' in S. Gaukroger (ed.), *Descartes. The World and Other Writings* (Cambridge, 1998), pp. 170-1.

<sup>147</sup> Elizabeth, Princess of Bohemia (1618-1680) was the daughter of Frederick V, the Elector of Rhenish Palatinate and Elizabeth Stuart, daughter of James I and VI, King of England and Scotland. Frederick V accepted the Crown of Bohemia but was driven out of the country in the wake of the failed uprising, rebellion of the Bohemian Estates (1618-1620), effectively setting in motion the Thirty Years War. In the history textbooks he is referred to as the 'Winter King' (4 November 1619-8 November 1620). For a selection of letters between Princess Elizabeth and Descartes, see Anscombe and Geach (eds.), *Descartes Philosophical Writings*, pp. 274-86. The Elizabeth-Descartes correspondence and relationship are discussed in S. Gaukroger's invaluable *Descartes. An Intellectual Biography* (Oxford, 1995), pp. 384f.

<sup>148</sup> Gaukroger, *ibid.*, pp. 388f.

<sup>149</sup> F. Engels, 'Ludwig Feuerbach and the end of classical German philosophy' in K. Marx and F. Engels, *Selected Works in Three Volumes*, vol. 3 (Moscow, 1973), pp. 345-6. For a contemporary stimulating treatment of the topic, see K. Bayertz, 'Was ist moderner Materialismus' in K. Bayertz, Myriam Gerhard and W. Jaeschke (eds.) *Weltanschauung, Philosophie und Naturwissenschaft im 19. Jahrhundert*, vol. 1: *Der Materialismus-Streit* (Hamburg, 2007), pp. 50-70.

## 5. THE SCIENTIFIC REVOLUTION: THE BIG PICTURE

### WAS SCIENCE BORN/INVENTED AND WHEN?

'There is no such thing as the Scientific Revolution and this is a book about it'.<sup>150</sup> With this somewhat baffling sentence Steven Shapin begins his scrutiny of the movement which, as I argue, came into its own in some European countries in the sixteenth and seventeenth century. That is, a universal mode of producing natural knowledge materialized, which did not exist anywhere before, and is still practised. It merits to be designated as *the* Scientific Revolution.

This approach to the thing 'Scientific Revolution' is not in the historiographical mainstream. Indeed since the 1980s, views have been gaining ground that the concept itself should be blotted out of the historiographical landscape mainstream altogether. This certainly is the message conveyed by Andrew Cunningham and Perry Williams in a thoroughly revisionist paper based on the unchallengeable principle, advanced in the first sentence: 'Like it or not, a big picture of history of science is something which we cannot avoid.'<sup>151</sup> It deserves to be taken up.

The concept of the so-called 'scientific revolution' [sic], the authors contend, proved to be double-edged. It was useful, before and after the Second World War, in-so-far it became a unifying concept in the history of science, and helped to establish it as an independent scholarly and teaching discipline. But it became obsolete in-so-far it promoted the big picture anchoring the origins of modern science in the seventeenth century – as distinct from medieval and ancient science. While conceding that 'there is no reason why science should have not originated at that time', they believe, 'this happens not to be the case'. Instead, they suggest 'the period 1760-1848 is a much more convincing place to locate the invention of science'.

In preferring the period 1760-1848, they acknowledge that they were influenced by E. J. Hobsbawm's *The Age of Revolutions 1789-1848* (1962). The book is about the transformation of the world impelled by the French Revolution of 1789 and the contemporaneous (British) Industrial Revolution. Cunningham and Williams enlarged the narrative by adding a German dimension which they call the 'post-Kantian intellectual revolution'. As a result of the three simultaneous and linked revolutions, they argue 'a new middle-class was constituted wielding the political power, the industrial power and the intellectual power'. It was to these social transformations, as one aspect of the Age of Revolutions, Cunningham and Williams trace the origins of science '(with England as partial exception, in that changes there took place later and more gradually than in Continental Europe)'. To sum up, they state:

historical relationships over the last twenty years enables us to identify the Age of Revolutions as the period which saw the origin of pretty well every feature which is regarded as essential and definitional of the enterprise of science: its name, its aim (secular as distinct from godly knowledge of the natural world), its values (the 'liberal' values of free enquiry, meritocratic expert government and material progress), and its history.

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<sup>150</sup> Shapin, *Scientific Revolution*, p. 1.

<sup>151</sup> Cunningham and Williams, *De-centring*, pp. 407. For citations that follow, see 409-10, 412, 425, 427-8.

The summary of Cunningham's and Williams's thesis raises questions that need to be pursued further. All the more since they justify 'the invention of science' in the period 1760-1848n as follows:

This term 'invention', which is our preferred term, helps to fix the revised view of science as a contingent, time-specific and culture-specific activity as only one amongst the many ways-of-knowing which have existed, currently exist, or might exist; and for this reason the phrase which we propose for the fundamental changes which took place in this period is 'the invention of science'. And we can of course now drop the qualifier 'modern', since the term 'science' can only be properly applied in our own time, the modern era. What we are speaking of is therefore not the origins of modern science, but the modern origins of science.

#### 'NATURAL PHILOSOPHY' AND 'SCIENCE': WHAT'S IN A NAME?

History of science is nothing if it is not about how knowledge of nature (variously termed) came to be the way it is today.<sup>152</sup> In the English context the replacement of 'natural philosophy' with 'science', around 1800, should not obscure that the terms cover common pursuits.<sup>153</sup>

Take the anti-Trinitarian Newton, deeply concerned with God, and his great successor P.-S. Laplace (1749-1827), who (reputedly) dismissed him unperemptorily. Whatever the grounds and impulses for their quests, godly or ungodly, both inquirers were engaged in the same enterprise: comprehension and explanation of natural phenomena. The implication of Cunningham's and Williams's proposition is that Newton's work was neither 'modern' nor 'scientific'. Patently, there is a problem as Newton's theory, in John North's telling phrase, 'even on a cosmological scale ... is not yet worn out',<sup>154</sup>

To distinguish between 'natural philosophy' and 'science' along 'godly' and 'secular' lines is to adopt a narrow standpoint. In 1931, the Soviet physicist Boris M. Hessen (1893-1936), inspired by the Marxist approach to history, first suggested that to understand Newton's work and world-view required to see them as a product of a specific period. He characterized it as the period of disintegration of the feudal economy, the development of merchant capital, of international maritime relationships and of heavy (mining) industry. Hessen presented his ideas in a paper, given at the 2<sup>nd</sup> International Congress of the History

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<sup>152</sup> I draw on Eric Hobsbawm's thesis 'that history is engaged on a coherent intellectual project, and has made progress in understanding how the world came to be the way it is.' See E. J. Hobsbawm, *On History* (London, 1997), p. x.

<sup>153</sup> According to the *Oxford English Dictionary*, the use of 'science' in the English language goes back to the fifteenth century. By 1830 when Charles Babbage (1792-1871) publishes his highly critical *Reflections on the Decline of Science and on Some of its Causes*, the word came to mean what it means today. According to the same source, the 'cultivator of science' became 'scientist', thanks to W. Whewell, in 1840. Babbage played a major role in the foundation of The British Association of Science (1830). It took its cue from the annual *Versammlung deutscher Naturforscher und Ärzte* (Annual Assembly of German scientists and physicians). Note that the literal translation of 'Naturforscher' is more like 'investigator' or 'explorer' of nature. 'Naturwissenschaftler' as an equivalent to the English scientist is of later date. For a nuanced note about 'Science', see the informative Deborah E. Harkness, *The Jewel House Elizabethan London and the Scientific Revolution* (New Haven and London, 2007), pp. xv-xviii.

<sup>154</sup> J. North, *Cosmos An Illustrated History of Astronomy* (Chicago and London, 2008), p. 417.

of Science and Technology in London (1931). Contended from the beginning, it proved to be highly influential.<sup>155</sup> It gave the study of Newton's life and work a turn which eventually brought to light a Janus-like Newton, engaged in 'scientific' and 'unscientific' pursuits. This apparent contradiction still provides food to be digested by the 'Newton industry'.

The paper effectively launched the persistent debate regarding 'externalism' and 'internalism' in the history of science. As it turned out, a young historically- and philosophically-minded biochemist, who attended the Congress, became a controversial participant in the debate. He was Joseph Needham, who forty years later re-affirmed his allegiance to Hessen's seminal ideas as follows:

The trumpet-blast of Hessen may ... still have great value in orienting the minds of younger scholars towards a direction fruitful for historical analyses still to come, and may lead in the end to a deeper understanding of the mainsprings and hindrances of science in East and West, far more subtle and sophisticated than he himself could ever hope to be.<sup>156</sup>

#### NEEDHAM'S TWO 'GRAND QUESTIONS'

To paraphrase Cunningham and Williams: Like it or not, a big picture of the history of science cannot avoid Needham's two 'Grand Questions'. This is not to say that they ignore Needham's 'Grand project', *Science and Civilisation in China* (1954-), but they err when they ascribe to him, for example the reductionist view 'that science *was* [sic] human civilization.<sup>157</sup> His opposition to gross reductionism emerges from the autobiographical piece (1972) where he clearly declares that, after many intellectual struggles, he reached the conviction that life consists in several

irreducible forms or modes of experience. One could distinguish the philosophical or metaphysical form, the scientific form, the historical form, the aesthetic form and the religious form, each being irreducible to any of the others but all being interpretable by each other though he sometimes in flatly contradictory ways.

And two years later, he states no less clearly: For myself I want to say I have not lost faith in science as a *part* [MT] of the highest civilization, and in its development as one single epic story for the whole of mankind.<sup>158</sup>

While the 'Grand project' has been widely acclaimed, Needham's approach has been

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<sup>155</sup> B. Hessen, 'The social and economic roots of Newton's 'Principia'' in *Science at the Cross Roads*, 2<sup>nd</sup> ed. (London, 1971), pp. 151-212. With a new Foreword by J. Needham and a new Introduction by P. G. Werskey. For recent re-appraisals of the Congress and Hessen, see C. A. J. Chilvers, 'The dilemmas of seditious men: the Crowther-Hessen correspondence in the 1930's', in *The British Journal for the History of Science* 36 (2003), pp. 417-35; *ibid.*, 'La signification historique de Boris Hessen' in S. Gerout (ed.), *Les Racines sociales et économiques de Principia de Newton* (Paris, 2006), pp. 179-206; G. Freudenthal, 'The Hessen - Grossman thesis: An attempt at rehabilitation', in *Perspectives on Science* 13 (2005), 166-93.

<sup>156</sup> Needham, *Science at the Cross Roads*, p. ix.

<sup>157</sup> Cunningham and Williams, *De-centring*, p. 412.

<sup>158</sup> H. Holorenschaw [J. Needham], 'The making of an Honorary Daoist' in M. Teich and R. Young (eds.), *Changing Perspectives in the History of Science* (London, 1972), p. 9; 'An Eastern perspective on Western anti-science' (1974) in J. Needham, *Moulds of Understanding a Pattern of Natural Philosophy Edited and Introduced by G. Werskey* (London, 1976), p. 297.



criticized if not turned down. Both the relevancy of the historical issue that first motivated Needham, and the way he proposed to deal with it, have come under fire. In the course of his work, Needham discovered that actually there were two questions to be answered. This is what he wrote, a quarter of a century or so, after he formed the idea of what became *Science and Civilisation in China*:

I regarded the essential problem as that of why *modern* science (as we know it since the +17<sup>th</sup> century, the time of Galileo) had not developed in Chinese civilization (or in Indian) but only in Europe. As the years went by, and as I began to find out something at last about science and society, I came to realize that there is a second question at least equally important, namely, why, between the -1<sup>st</sup> century and the +15<sup>th</sup> century, Chinese civilization was much *more* efficient than occidental in applying human natural knowledge to practical human needs?

The answer to all such questions lies, I now believe *primarily* [MT] in the social, intellectual, and economic structures of the different civilizations.<sup>159</sup>

NATHAN SIVIN

Among critiques of Needham's approach, Nathan Sivin's essay 'Why the Scientific Revolution did not take place in China – or didn't it?' has attracted particular attention for understandable reasons.<sup>160</sup> Sivin had worked with Needham, who thought of him very highly – 'a brilliant investigator of medieval Chinese astronomy and alchemy'.<sup>161</sup>

As far as I can make out, Needham's name appears in the text twice. First: In the introductory paragraph in which it is stated that 'Joseph Needham has given the 'Scientific Revolution problem' its classic formulation'.<sup>162</sup> Second: In the fourth section (Fallacies), in the context of Needham's discussion of the *Book of Changes*. By and large, Needham is

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<sup>159</sup> J. Needham, 'Science and society in East and West' in M. Goldsmith and A. Mackay (eds.), *The Science of Science Society in Technological Age* (London, 1964), pp. 127-8. I am referring to this publication not because it originated as a letter to me but because it contains what is regarded as Needham's 'classical' formulation of his 'Grand Question'. Indeed the German version 'Wissenschaft und Gesellschaft in Ost und West' heads the collection of Needham's essays sanctioned by him: J. Needham, *Wissenschaftlicher Universalismus Über Bedeutung und Besonderheit der chinesischen Wissenschaft* (Frankfurt/Main, 1979), pp. 61-86. (Edited, introduced and translated by T. Spengler).

Later Needham re-iterates that there was not one question but two: 'Not only why modern science originated in Europe alone, but why, during the previous fifteenth centuries, China had been much more advanced in science and technology than the cultures of the West.' See 'Man and his situation (1970)' in Needham, *Moulds*, p. 282.

<sup>160</sup> N. Sivin, 'Why the Scientific Revolution did not take place in China – or didn't it?' in E. Mendelsohn (ed.), *Transformation and Tradition in the Sciences Essays in Honor of I. Bernard Cohen* (Cambridge, Mass., 1984), pp. 531-54.

<sup>161</sup> Needham, *Moulds*, p. 283. Here, perhaps, is appropriate to dwell on, for the purpose of the book, why Needham's case for the Scientific Revolution to have happened in Europe and not in China should not be excluded from a serious debate about its make-up. The provision of chapter and verse may stand as excuse for the number and length of quotations. Also loose censures and generalized antagonistic assertions, born of politics and ideology, should not pass unnoticed.

<sup>162</sup> Sivin, 'Why', p. 531

referred to preferably in notes. 'Because of his knowledge of the Chinese sciences and the breadth of his hypotheses', we read, 'Needham's is the earliest discussion of the Scientific Revolution problem that still commands attention, and is still the best.'<sup>163</sup>

This comment is in stark contrast to what we encounter in the text. True, Needham is not named but can there be doubt that his approach is the target of unmistakable disapproval if not rejection:<sup>164</sup>

Why didn't Chinese beat Europeans to the Scientific Revolution? – happens to be one of the few questions that people often ask in public places about why something didn't happen in history. It is analogous to the question of why your name did not appear on page 3 of today's newspaper. It belongs to an infinite set of questions that historians do not make part of their research programs because they have no direct answers.

While practically not mentioned in the text, the essay constitutes a massive assault on Needham's approach to the history of science and technology in China. Indeed, authored by a leading scholar in the field, it is frequently cited as a valid critique of Needham's answer to his two questions.

The point here is not to dispute Sivin's unquestionable sinological expertise. What is open to discussion is his belief that the distinction between external and internal factors has no objective reality but exists only as something perceived by historians subjectively.

I call it in question in the light of my long-standing interest in the history of fermentation, possibly the earliest biochemical process made use by man in daily life. What has emerged from the historical study of the phenomena of fermentation that they belong as much to the history of biochemistry (and other sciences) as to the technological and economic history of several industries. Another feature of the history of fermentation that it was intimately connected with endeavours to answer the perennial question of the origin of living matter and the nature of the processes underlying it. A full historical treatment of the connection between extra-scientific and intra-scientific influences on fermentation theory and practice would require for example consideration of patriotism. This certainly prompted L. Pasteur's (1822-1895) work on beer after France's defeat by Prussia in the Franco-Prussian War (1870-1871).

This does not mean that the pursuit of 'external' and 'internal' aspects of the history of sciences respectively is meaningless. Both are justified provided we understand that the questions asked and the answers given are, by their very nature, partial and limited. The point at issue for an historian is how to amalgamate them because history is in reality an integral process, not divided into 'external' and 'internal' compartments, but governed by a multitude of circumstances deriving from and belonging inseparably to spheres 'outside' and 'inside' science.<sup>165</sup>

The line taken by Sivin conforms to Steven Shapin's cogent observation regarding the externalism-internalism issue: 'Instead of clarifying and engaging with the problematic I think over the last ten or fifteen years we rather turned our backs on it and wished it away'.<sup>166</sup>

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<sup>163</sup> Ibid., p. 552, n. 7.

<sup>164</sup> For following paragraphs, see *ibid.*, pp. 536-7, 539, 540, 543.

<sup>165</sup> M. Teich with Dorothy M. Needham, *A Documentary History of Biochemistry 1770-1940* (Leicester and London, 1992), pp. xxii-xxv.

<sup>166</sup> S. Shapin, 'Discipline and bounding: The history and sociology of science seen through the externalism-internalism debate', in *History of Science* 30 (1992), pp. 333-69 (p. 334).

Also the sinologist A. C. Graham queries the relevancy of asking why an event, such as the Scientific Revolution, did not happen in China. While expressing highest admiration for Needham, Graham cannot resist in revealing that his proficiency in the Chinese language is not up to par.<sup>167</sup>

Graham's target is Needham's original historiographical sin. That is, the assumption that the absence or presence of one set of conditions – rise of capitalism – underlies the non-genesis or genesis of modern science in seventeenth-century China and Europe respectively. Out of many features of capitalism, Graham chooses capitalist profit as 'the only conscious goal that anyone has been able to find in the social processes that led to modern science'.<sup>168</sup> Whatever historiographical sins Needham may have committed, the absence of capitalist profit was not central to his analysis of factors that inhibited the rise of modern science in China. Graham's version of Needham's general emphasis on the social and economic factors greatly simplifies the latter's approach to history.

Sivin's and Graham's reasonable starting point is that historians have enough on their plate than to think up imaginary events that did not happen. Nevertheless, as the great historian Eric Hobsbawm observes:

*Conjectural* history has a place in our discipline, even though its chief value is to help us assess the possibilities of present and future, rather than the past, where its place is taken by *comparative* history; but actual history is what we must explain. The possible development or non-development of capitalism in imperial China is relevant to us only insofar as it helps to explain the actual fact that this type of economy developed fully, at least to begin with, in one and only one region of the world. This in turn may be usefully contrasted (again in the light of general models) with the tendency for other systems of social relations – for example the broadly feudal – to develop much more frequently and in a greater number of areas. The history of society is thus a collaboration between general models of social structure and change and the specific set of phenomena which actually occurred. This is true whatever the geographical or chronological scale of our enquiries.<sup>169</sup>

By conventional intellectual criteria, Sivin suggests China had its own scientific revolution [lower case!] in the seventeenth century. This is intriguing on three accounts. First: Sivin bases his suggestion on the same kind of yard-stick as Needham, who is criticized for expecting China to follow the same route as Europe. Second: Commonly, the term scientific revolution/Scientific Revolution is associated with the radical transformation of the perception of the motions of the celestial *and* terrestrial bodies in the context of a unified theory. But Sivin limits the meaning of the term to changes amounting to a conceptual revolution in *astronomy*. Last but not least, even so, Sivin admits:

That revolution did not generate the same pitch of tension as the one going on in Europe at the same time. It did not burst forth in as fundamental a reorientation of thought about Nature. It did not cast

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<sup>167</sup> A. C. Graham, 'China, Europe, and the origins of modern science: Needham's The Great Titration' in Nakayama and Sivin (eds.), *Chinese Science*, p. 46 n. 2.

<sup>168</sup> *Ibid.*, p. 67.

<sup>169</sup> E. Hobsbawm, *On History* (London, 1997), p. 80.

doubt on *all* the traditional ideas of what constitutes an astronomical problem, and what significance astronomical prediction can have for the ultimate understanding of Nature and of man's relation to it.

Most important, it did not extend the domain of number and measure in astronomy until it embraced every terrestrial phenomenon (the Jesuits were obliged to conceal from the Chinese the development in Europe). What happened in China bears comparison with the conservative revolution of Copernicus rather than with the radical mathematization of hypotheses Galileo precipitated.<sup>170</sup>

Consequently, I would say the two movements are different beasts.

H. FLORIS COHEN

It is remarkable how authors, who go out of their way to sing Needham's praises, are at pains to demonstrate flaws in his approach to the history of science. A telling exemplar is H. Floris Cohen's ambivalent treatment of Needham's answering his Grand Question. Cohen devotes to this theme seventy pages (out of 662) in a stimulating historiography of the Scientific Revolution not least because of its combative style. Combative in the sense that, while wishing to be fair and giving his due to scholars from A(iton) to Z(ilsel), Cohen is not sparing with strictures right and left. This gives the impression that Cohen has a viewpoint. Regrettably, that is not the case: what he offers is 'a highly provisional sketch' in the last chapter of the book.<sup>171</sup>

*Has the time come for answering the Grand Question?* I would not so easily bring up the question just put, which I am in the end not qualified to answer, if it had not in effect been asked by some of Needham's most knowledgeable critics. Although they have not said so in quite so many words, it has been suggested by Nakayama and Sivin in particular (and much in our preceding account tends to support such a suggestion) that just about everything Needham has ever written to answer his Grand Question should be regarded as *one giant projection of Joseph Needham's collected preconceptions upon China's society and world of thought*.

When all is said and done what separates Needham from Sivin, Graham and other critics (on whom Cohen draws) is the weight he bestows on the part played by social and economic factors in the generation of the Scientific Revolution in Europe:

Whatever the ideological inhibiting factors in the Chinese thought-world may turn out to have been, the certainty always remains that the specific social and economic features of traditional China are connected with them. They were clearly part of that particular pattern, and in these matters one always has to think in terms of a package-deal. In just the same way, of course, it is impossible to separate the scientific achievements of the Ancient Greeks from the fact that they developed in mercantile, maritime, city-state democracy ... It may be that while ideological, philosophical and theological differences are never to be undervalued, what mattered most of all were the facilitating pressures of the transition from feudalism to

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<sup>170</sup> Sivin, 'Why', p. 540.

<sup>171</sup> See H. F. Cohen, *Scientific Revolution*, p. 471.

mercantile and industrial capitalism, pressures which did not effectively operate in any culture other than that of Western, Frankish, Europe.<sup>172</sup>

ROBERT FINLAY

Last but not least, let us turn to Robert Finlay's portrayal of Needham's perception of the Scientific Revolution. That is, in the context of Finlay's presentation of Needham's perspective on the celebrated sea-voyages during the early years of the Ming dynasty (1368-1644).<sup>173</sup>

Between 1405-1433 seven vast fleets sailed into the Indian Ocean reaching the Eastern shores of Africa. Each fleet comprised over 200 sailing ships with about 27000 men on board. Some of these vessels were the longest wooden ships ever built (117-134m long).<sup>174</sup>

Both the purpose of the state-directed voyages, under the command of the eunuch Zheng He [Chêng Ho] (1371-1433), and the reason why they were terminated have been much debated in the West. Indeed, Finlay states, they are

now renowned in the West precisely because Needham made them known to a wide audience for the first time. His dramatic contrast of these Ming expeditions with those of the Portuguese in the early sixteenth century captured the imagination of his readers. Rarely has a historical study been so widely applauded and universally accepted. It has been integrated into influential interpretations of world history... But the context which Needham establishes for the voyages and the part they play in his conception of world history remain unrecognized.<sup>175</sup>

Finlay's intent is to put the record straight. Needham's primary offence is that '[he] regards the 'proto-scientific' motive as most significant, stemming from his 'determination to present the Ming expeditions as embodying the virtues of China in contrast to the vices of the West'.<sup>176</sup>

Finlay's claim is not supported by the list of motives that Needham names one by one. In it the pursuit of natural and medical knowledge occupies the fifth place among seven.<sup>177</sup>

In fact, Needham's view of the purpose of the voyages, stated in 1970, accords with

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<sup>172</sup> Needham, *Moulds*, pp. 285-7.

<sup>173</sup> R. Finlay, 'China, the West, and world history' in Joseph Needham's *Science and Civilisation in China*, in *Journal of World History* 11(2000), pp. 265-303. See J. Needham with Wang Ling and Lu Gwei-Djen, *Science and Civilisation in China*, vol. IV, pt. 3: *Civil Engineering and Nautics* (Cambridge, 1971), pp. 487-535. For a convenient roundup (also referred to by Finlay), see J. Needham, 'Abstract of material presented to the International Maritime History Commission at Beirut' in M. Mollat (ed.), *Sociétés et Compagnies de Commerce en Orient et dans L'Océan Indien* (Paris, 1970), pp. 139-69 (pp. 146-54).

<sup>174</sup> For an acclaimed account, see E. L. Dreyer, *Zheng He China and the Oceans in the Early Ming Dynasty* (New York and London, 2007). 'It will be', so the knowledgeable Jonathan Mirsky, 'the last word for some time to come'. See his review 'Tribute, trade and some eunuchs' in *The Times Literary Supplement*, 26 January 2007, p. 11.

<sup>175</sup> Finlay, 'China', p. 269.

<sup>176</sup> *Ibid.*, pp. 293, 299.

<sup>177</sup> Needham, 'Abstract', p. 147.

Mirsky's summary of the 'state-of-the-art' thirty-seven years later:

While it is true that Zheng He brought back, for the exclusive use of the Ming household, lions, leopards, ostriches and giraffes, spices and minerals – his largest vessels were called Treasure Ships – the purpose of the voyages, as the main authorities now agree, was to enfold distant rulers, some of whom sent their envoys to China on Zheng He's ships, in the ancient Chinese 'tribute system'. According to this tradition the Emperor, ruling from the centre of the world, by his virtue and splendour attracted foreigners to his Court. There they presented him with their goods, deemed to be 'tribute' and performed the kowtow.<sup>178</sup>

Finlay's flawed presentation of Needham's position on the purposes of the voyages is not one of a kind. His account abounds with inaccuracies. Some are trivial, such as blaming Needham for casting Zheng He as the 'Vasco da Gama' of China. In fact, Needham attributes this designation to Frank Debenham, the author of *Discovery and Exploration An Atlas of Man's Journey into the Unknown* (1960). More serious is Finlay's assertion that '*Science and Civilisation* is a product of Cold War', conceived, 'when the People's Republic was proclaimed'. Oddly, Finlay contradicts himself because a few pages previously he writes:

Liberated by his exposure to Chinese culture in 1937, Needham first conceived of writing a book on Chinese science and technology in 1942, after completing *Biochemistry and Morphogenesis* and before leaving for China.<sup>179</sup>

As it happens, we can date more precisely when Needham announced, in the essay 'On science and social change', his intention to investigate after the war the failure of science

to arise in China one of the greatest problems in the history of civilization, since no other culture, except the Indian, equals that of the West in scope and intricacy more closely than that of China.<sup>180</sup>

Composed in September 1944 when Needham found himself

in a vacuum within a vacuum, cut off from all communication with the outside world by landslides and rockfalls, without telegraph or telephone, awaiting the clearing of the road.<sup>181</sup>

Ostensibly written for a collection on social organization, the essay is about many things: science, philosophy, religion, social orders, their history in the West and China. More specifically, about the intrinsic incompatibility of science with Nazism and Shinto-fascism because of the inherent democratic nature of science. Then Needham perceived democracy as 'that practice of which science is the theory.'<sup>182</sup>

Finlay refers to this essay several times without due care to chronology. That is, without taking on board that Needham was *then* clearing his mind for putting together *Science and Civilisation* while waiting for the clearing of the road to Burma. The theme of the correlation between science and democracy had surfaced in Needham's previous

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<sup>178</sup> Mirsky, 'Tribute'

<sup>179</sup> Finlay, 'China', pp. 301, 273-4.

<sup>180</sup> 'Science and social change' in J. Needham, *The Grand Titration Science and Society in East and West* (London, 1969), pp. 123-54 (p.148). The essay first appeared in *Science and Society* 10 (1946), p. 225.

<sup>181</sup> *Ibid.*, p. 123.

<sup>182</sup> *Ibid.*, p. 145.

historical work, including *The Levellers and the English Revolution* (1939), published under the pseudonym Henry Holorenschaw (with a foreword by himself).<sup>183</sup> Along the lines discussed above, Needham observes in 1944 that the rise of the merchant class to power, with their slogan of democracy, was the indispensable accompaniment and *sine qua non* of the rise of modern science in the West. But in China the scholar-gentry and their bureaucratic feudal system always affectively prevented the rise to power or seizure of the State by the merchant class, as happened elsewhere.<sup>184</sup>

This approach is an anathema to Finlay. He is worried that

Needham's conception of world history has gone unnoticed, however, and most readers certainly are not aware of a large-scale scheme informing the massive detail of *Science and Civilisation*.<sup>185</sup>

In the unremitting quest to alert and enlighten the ignorant reader Finlay, as other critics, damns with faint praise.<sup>186</sup>

Finlay and Needham have a different take on China, the West and world history. But that does not justify him to misrepresent Needham's world-view of history. Needham believed that the rise of modern science was connected with the rise of mercantile capitalism in Europe, constituting an aspect of the transition from feudalism to capitalism. This does not warrant Finlay to attribute to Needham the reductive world-view that

the rise of modern science in Europe was not merely the outcome of developments within Western civilization but was a direct result of the diffusion of Chinese technology; hence, if China did not give birth to the Scientific Revolution, it at least was responsible for its conception. In other words, the transition to modernity sprang from the long-distance influence of China on the West.<sup>187</sup>

It is noteworthy that Finlay refrains from citing any of Needham's writings in support of the statement – although he refers to them copiously.

#### CHINESE SOCIETY, AGRICULTURE AND TECHNICAL PROGRESS

Needham's accent on the divergence, regarding the development of the Scientific Revolution in Europe and China, connects with broader questions.

It was due to Marxian ideas that Needham regarded the Scientific Revolution as an aspect of the transition from feudalism to capitalism in Europe. He held that 'the

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<sup>183</sup> I concur with Finlay that there was no intention to deceive by presenting 'Henry Holorenschaw' as the author of 'The making of an Honorary Taoist' in Teich and Young (eds.), *Changing Perspectives in the History of Science*. Originally, the publishers expected me to write on Needham. After considering the idea, it occurred to me that a contribution by Needham's *alter ego* would be of greater interest. Finding the suggestion intriguing, Needham accepted the invitation to contribute.

<sup>184</sup> Needham, *Titration*, p. 150.

<sup>185</sup> Finlay, 'China', p. 267.

<sup>186</sup> For example: 'Even though he employs many outdated concepts and makes countless unsupported assertions, his rendering of world history is remarkable for its synoptic vision'; 'Although not without internal coherence and a grain of truth, his depiction of European history amounts to little more than a mechanical application of Marxist clichés that were outdated before the first volume of *Science and Civilisation* appeared'. *Ibid.*, pp. 268, 301.

<sup>187</sup> *Ibid.*, pp. 281-2.

development of modern science occurred in Europe and nowhere else'<sup>188</sup> – to be part and parcel of European historical singularity. It has been recently addressed by the distinguished Austrian social historian Michael Mitterauer. He points to contemporaries of Max Weber (his great inspiration), acknowledging as 'valid' science only the one developed in the West.<sup>189</sup>

Mitterauer does not concern himself with either the Scientific Revolution or the transition from feudalism to capitalism. Nonetheless what emerges from his account is that a string of factors, operating within Frankish feudalism (agriculture and technical innovations, manorial/estate system, commerce, crusades, printing) had generated, by the fourteenth and fifteenth centuries, circumstances conducive to the rise of capitalism in some Italian and Flemish cities. Pushed forward by incipient world market economy, they may be (following Marx) written down: growth of trade, employment of free labour in mining and manufacturing, separation of the peasantry from the land, and coercive accumulation of surpluses ('primitive accumulation of capital').

Medieval China did not participate in the burgeoning world market economy, associated with the global expansion of trade by European powers.<sup>190</sup> This had something to do with its underdeveloped money economy and non-maturation of capitalist relations, constituting two sides of the same coin. Moreover, the size of the country and its population put a premium on self-sufficiency in food production, demanding both extension of the cultivated area and intensive agriculture and this, in turn, required more labour. This is where, in Needham's terms, the 'bureaucratic feudal state system' is distinctive by not driving the agricultural producers from land. The intensification of agriculture doubtless stimulated inventions, such as the water-powered blowing engine for the casting of iron agricultural implements. Tendency to rely on self-sufficiency encouraged technical developments but also derived momentum from them.

Before the impact microelectronics on machinery, it can be said, it essentially consisted of three elements: the driving, the transmission and the actual operational mechanism. In the light of this assortment, the characteristic Chinese achievements, such as the gear-wheel, the crank, the piston-rod and the method of interconversion of rotary and longitudinal motion, belong to the category of transmission mechanism. Revolutionary changes in production, at any rate, in the European context of the transition from feudalism to capitalism, appear to have been connected with the working element of the machinery, which had replaced manual operations in the production processes. The flying shuttle and the spinning jenny preceded Watt's steam engine, but they were hand-powered.

Chinese inventions, such as the humble wheel barrow, were labour saving in an agrarian society which needed labour to produce food in order to satisfy the basic requirements of the very sizeable population; but they could hardly become the starting point of radical changes in production since paradoxically no surplus labour existed. Given that in China the monetary system was underdeveloped, the Chinese bureaucratic feudal state organization collected taxes and paid its apparatus in kind, but proved to be

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<sup>188</sup> Needham, *Titration*, p. 193.

<sup>189</sup> M. Mitterauer, *Why Europe? The Medieval Origin of its Special Path* (Chicago and London, 2010), p. xx.

<sup>190</sup> What follows draws on my comments on the manuscript of the public lecture by J. Needham at the University Hong Kong on 30 April 1974. See J. Needham and R. Huang (Huang Jen-Yü), 'The nature of Chinese society – a technical interpretation' in *Journal of Oriental Studies*, reprinted from vol. 12, Nos. 1 and 2 (1974), 1-16. See also J. Needham with Wang Ling, *Science and Civilisation in China*, vol. 4, pt. 2 (Cambridge, 1965), p. 262.



incompatible with the creation of surplus capital. This then reinforced the immobility of the agrarian society, hindered its social stratification, and retarded the stimuli to the commercialization of agriculture and development of productive forces despite the existence of a tremendous reservoir of technical skill.

## 6. WEST AND EAST EUROPEAN CONTEXTS

### DEMISE OF THE FEUDAL SYSTEM IN EUROPE: TECHNICAL DEVELOPMENT AND INTERNATIONAL TRADE

Printing, gunpowder and the magnetic compass have been cited as hallmarks of the cultural and technical superiority of medieval China – ever since Francis Bacon pinpointed them as the three discoveries, unknown to the ancients, that

have changed the whole face and state of things throughout the world; the first in literature, the second in warfare, the third in navigation; whence have followed innumerable changes, insomuch that no empire, no sect, no star seems to have exerted greater power and influence in human affairs than these mechanical discoveries.<sup>191</sup>

Rupert Hall writing some 350 years later confirms Bacon's opinion on the marked effects of the discoveries gunpowder and printing on European society:

We might well choose to date the beginning of modern European history from the introduction of gunpowder. By 1325 primitive cannon were in action, and from 1370 mechanical artillery (on the lever principle) was falling into abeyance. By 1450 the hand gun had appeared, beginning the obsolescence of crossbow and longbow. Powder-making became an important industry, along with cannon-founding and gun-making. By 1500 heavy guns, mortars, and explosive mines had made the medieval castle almost untenable ...

Only the wealthiest and most powerful rulers could afford the new gunpowder weapons and the more expensive and larger armies. The rebellious feudal nobility in their isolated castle fortresses could no longer withstand the power of the monarchs more powerful gunpowder weapons. Thus the changes in the technology of warfare brought about through the introduction of gunpowder aided in that process of administrative and territorial consolidation which was to give rise to monarchical states and to the nation-state system of Europe as one knows it today ... Just as the invention of gunpowder to batter down the political positions of feudalism, so did the invention of printing help to remove the barriers of communication between men. And, like gunpowder, the invention has had incalculable significance to human history, far beyond its immediate technological effect.<sup>192</sup>

For the historian the problem is that the use of gunpowder and printing in the wake of technological improvements (incendiary properties of mixtures of nitre, sulphur and charcoal, papermaking, printing with movable type) became widespread in Europe but not in China before 1600. How and why this came about has been the subject of

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<sup>191</sup> F. Bacon, *Aphorisms – Book One* in *The New Organon and Related Writings* (edited with an Introduction by F. H. Anderson) (New York and London, 1986), p. 118.

<sup>192</sup> Rupert Hall, 'Early modern technology', pp. 98-100. There is, of course, also the question of stagnation that affected Islamic civilization. Here Michael Mitterauer's discussion of the Muslim hostility to the printing of the Qur'an is illuminating. Thus the first printing-house in Istanbul to work with Arabic letters was opened in 1726 only to be shut down from 1730 to 1780 and again in 1800. See Mitterauer, *Why Europe?*, p. 266.

continuous examination, assigning rightfully a place of pride to Arabic-Islamic mediation.

In this context Hall's periodization of the beginning of modern European history is noteworthy. He associates it with the demise of the feudal system in Europe – in which the spread of gunpowder and movable type printing played a significant part. Without spelling it out, Hall clearly implies that a societal transformation was at play, conceptualized by Marxist historians as a period of transition from feudalism to capitalism. Doubtless Hall, a stern critic of the Marxist approach to history, would have been horrified to be aligned with it, as it were.

Be that as it may, research bears out the historical role of merchant capital (brought out earlier) in the undermining of feudalism in Europe through international trade. Moreover, research finds it relevant for the understanding of the genesis of the Scientific Revolution. Thus in the concluding chapter of a penetrating study of commerce, medicine and science in the Dutch Golden Age (c. 1550-1700), Harold J. Cook has this to say:

It was no accident, then, that the so-called Scientific Revolution occurred at the same time as the development of the first global economy. That world linked the silver mines of Peru to China as well as Europe, the sugar plantations of the Caribbean and the nutmeg-growing regions of Southeast Asia to slave labor as well as to luxury consumer goods, and a wealth of new information circulating in coffeehouses and lecture halls to books and the natural objects available in European gardens, cabinets of curiosity, and anatomy theaters.<sup>193</sup>

#### PURSUIITS OF NATURAL KNOWLEDGE: COURT OF RUDOLF II IN PRAGUE

Among the European cabinets the one, created by Emperor Rudolf II in Prague, acquired widespread fame. As the knowledgeable Paula Findlen puts it:

Rudolf assembled a rich array of flora and fauna and an extensive collection of specialized instruments that might help him pursue knowledge of nature. At the height of his reign, a deer park surrounded Hradčany Castle, complemented by an aviary (in which one might glimpse the Emperor's birds of paradise and, after 1598, a dodo) and a botanical garden where distinguished naturalists such as Rembert Dodoens and Carolus Clusius tended exotic plants. From the 1580s onwards, a steady stream of visitors such as the English alchemists John Dee and Edward Kelley, the Italian mystic and Neoplatonist Giordano Bruno, and the physicians and occultists Oswald Croll and Michael Maier enjoyed audiences with Rudolf, bearing gifts of magic talismans, their own writings and promises to unlock

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<sup>193</sup> H. J. Cook, *Matters of Exchange Commerce, Medicine, and Science in the Dutch Golden Age* (New Haven and London, 2007), p. 411. Intentionally or not this passage echoes Marx's analysis of what he characterized as 'primitive accumulation of capital': The discovery of gold and silver in America, the extirpation, enslavement and entombment in mines of the aboriginal population, the beginning of the conquest and looting of the East Indies, the turning of Africa into a warren for the commercial hunting of black-skins signaled the rosy dawn of the era of capitalist production. These idyllic proceedings are the chief momenta of primitive accumulation. On their heels treads the commercial war of the European nations, with the globe for a theatre. It begins with the revolt of the Netherlands from Spain, assumes giant dimensions in England's anti-jacobin war, and is still going on in the opium wars against China. See, Marx, *Capital* 1, p. 775.

the secrets of nature.<sup>194</sup>

These persons do not exhaust the circle of prominent pursuers of magic, mysticism, alchemy and knowledge of nature, connected with Rudolf's court. Under Rudolf's auspices and the behest of Hagecius (mentioned earlier), the collaboration of Brahe and Kepler came about. Eventually, it was to transform Copernican astronomy to genuine heliocentrism. Equipped with mathematical and astronomical skills, the excellent instrument makers Jo(o)st Bürgi and Erasmus Habermehl were at hand.<sup>195</sup> The Imperial mathematician Nicholas Reymarus/Raymers Baer (Ursus) developed a kind of heliocentric system famously prompting Brahe to charge him with plagiarism. As North pointed out: 'Baer's system differed from Tycho's in one important respect: he gave the earth a daily rotation on its own axis, half-loosening it from its old bonds, so to speak'.<sup>196</sup>

Rudolf's patronage of Brahe and Kepler has been well-known. What historians of astronomy seemed not to have noticed is a remarkable passage in Kepler's letter to Galileo on 8 April 1610 (Julian calendar) before the Czech scholar Josef Smolka spotted it. It documents that Rudolf carried out his own astronomical observations:

It is three months that the Emperor put to me various questions regarding the constitution of moonspots and thought the images of lands and continents shine brightly on the Moon or in the telescope. He asserted to have probably seen the image of Italy with two nearby islands. In the next days he also placed the telescope at disposal for the same kind of observations but no use was made of it. At the same time, Galileo ... through your beloved observations the Monarch of the Christian world is

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<sup>194</sup> Paula Findlen, 'Cabinets, collecting and natural philosophy' in Eliška Fučíková et al., *R. Rudolf II and Prague* (Prague, London and Milan, 1997), pp. 213-4. The volume provides a notable introduction in English to Rudolf II and his era. See also R. J. W. Evans, 'Rudolf II: Prag und Europa um 1600' in [no editor], *Prag um 1600 Kunst und Kultur am Hofe Kaiser Rudolf II*, vol. 1 (Freren, 1988), pp. 27-37. For Evans's previous full-length treatment, see *Rudolf II and His World. A Study in Intellectual History 1576-1612* (Oxford, 1973). For a Czech historiographical perspective, see J. Válka, 'Rudolfine culture' in M. Teich (ed.), *Bohemia in History* (Cambridge, 1998), pp. 117-42. Here I cannot but register the recent publication of the massive multiauthored survey of alchemical activities, associated with Rudolf's II court, see I. Purš and V. Karpenko (eds.), *Alchymie a Rudolf II Hledání tajemství přírody ve střední Evropě v 16. a 17. století* [Alchemy and Rudolf II Searching secrets of nature in Central Europe in the 16<sup>th</sup> and 17<sup>th</sup> century] (Prague, 2011) [English summary].

<sup>195</sup> A. Švejda, 'Prager Konstrukteure wissenschaftlicher Instrumente und ihre Werke' in J. Folta (ed.), *Science and Technology in Rudolfinian Time in Acta historiae rerum naturalium nec non technicarum. Prague Studies in the History of Science and Technology*, N.S. 1 (1997), pp. 90-4.

<sup>196</sup> North, *Cosmos*, p. 336. For an analysis of the Baer-Brahe controversy, see N. Jardine, *The Birth of History and Philosophy of Science Kepler's. A Defence of Tycho against Ursus with essays on its provenance and significance* (Cambridge, 1988). For a scholarly bilingual French-Latin collection of related documents, see N. Jardine and A.-Ph. Segonds, *La Guerre des Astronomes: La Querelle au sujet de l'origine du système géo-héliocentrique à la fin du XVIe siècle*. Vol. 1: Introduction (Paris, 2008); N. Jardine and A.-Ph. Segonds, *La Guerre des Astronomes: La Querelle au sujet de l'origine du système géo-héliocentrique à la fin du XVIe siècle*. Vol. 2/1: Le *Contra Ursum* de Jean Kepler, Introduction et textes préparatoires and Vol 2/2: Le *Contra Ursum* de Jean Kepler, Édition critique, traduction et notes (Paris, 2008). Brahe's furious reaction had something to do, it has been suggested, with the different social provenience of the protagonists. Whereas Brahe was of noble parentage, Baer was of peasant stock and hence less trustworthy.

surpassed.<sup>197</sup>

Rudolf II was also a patron of artists, such as the Milanese painter Giuseppe Arcimboldo (1527-1593), whose portraits of human heads and paintings of elements and seasons affectively bridge art and natural history. They encompass detailed observations of flowers, fruit, vegetables and trees in the style identified as 'scientific naturalism'. One of its forerunners, if not founders was Leonardo da Vinci, the other Milanese interdisciplinary artist whom Arcimboldo repeatedly wished to equal. Anyhow, as a recent commentator puts it, Arcimboldo's paintings grow out of 'the mysterious interweaving of art, science and the occult in Renaissance Europe'.<sup>198</sup>

#### AN EARLY FORM OF INSTITUTIONALIZED SCIENCE?

The pursuits of natural knowledge, associated with the Prague court, were by no means unique. There were greater and lesser aristocratic courts in Europe at the time of Rudolf II, when he supported inquiries into natural phenomena, suffused with astrological, alchemical and cabalistic thinking. Since the late 1950s, these activities began to be discussed as an early form of institutionalized pursuit of natural knowledge.

Then this idea was taken up and debated by a group of six historians of science, collaborating on the production of a history of exact sciences in Bohemia (up to the end of the nineteenth century). In the published volume the late well-informed Zdeněk Horský refers to the 'Rudolfian centre of scientific work' which 'was not a mere accidental result of the activity of foreign scientists temporarily staying at Prague but evolved with the direct participation of Thaddeus Hagecius in an environment in which astronomical research had been continually growing and deepening since the middle of the sixteenth century'.<sup>199</sup> Horský reiterates this position, after more than a quarter of a century, albeit now referring to a 'scholarly centre' [*Gelehrtenzentrum*].<sup>200</sup>

Another well-informed member of the group, Josef Smolka, more than thirty years later, voices justifiable scepticism about applying the expression 'centre' to the circle of inquirers into natural phenomena, supported by Rudolf II. It implies an organized and programmed activity which 'we do not encounter anything of the sort with the exception of the short time Tycho's group was at large'.<sup>201</sup>

This has something to do with Rudolf's II apparent dislike of extreme confessionism in spite of the Council of Trent's clarion-call to Counter-Reformation (1545-1563). Not only were the Protestants Brahe and Kepler offered the opportunity to co-operate, but the Jew David Gans was able to strike up a relationship with both. A German Jew, educated in Poland and settled in Prague, he authored a variety of books on astronomy, mathematics,

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<sup>197</sup> J. Smolka, 'Böhmen und die Annahme der Galileischen astronomischen Entdeckungen', *Acta historiae ... Prague Studies in the History of Science and Technology*, N. S. 1(1997), pp. 41-69 (p. 49).

<sup>198</sup> J. Jones, 'Natural wonders', *Saturday Guardian*, 26 April 2008. See also T. da Costa Kaufmann, *Arcimboldo: Visual Jokes, Natural History, and Still-Life Painting* (Chicago, 2009).

<sup>199</sup> J. Folta et al., *Dějiny exaktních věd v českých zemích do konce 19. století* [History of the exact sciences in the Czech Lands (up to the end of the nineteenth century)] (Prague, 1961), p. 47 [Russian and English summaries].

<sup>200</sup> Z. Horský, 'Die Wissenschaft am Hofe Rudolfs II' in *Prag um 1600*, pp. 69-74.

<sup>201</sup> J. Smolka, 'Scientific Revolution in Bohemia' in Porter and Teich (eds.), *Scientific Revolution*, p. 220.

geometry, history and other topics. 'He did it in part', writes Noah J. Efron, 'because he was persuaded that these subjects might provide common language for Jews and Christians.'<sup>202</sup>

Conspicuously, the list of persons, associated with Rudolf's court does not contain prominent indigenous figures. Indeed, apart from Hagecius, there were hardly any. One was the astronomer Martin Bachacius [Bacháček] (1539/1541-1612), who collaborated with Kepler without apparently understanding the latter's heliocentrism. Rather than as astronomer, Bachacius is remembered as organizer of higher education – he repeatedly occupied the post of Rector of Protestant Prague University (*Collegium Caroli*, Karolinum) between 1598-1600 and 1603-1612.

Another Rector of Prague University, linked with the court, was a native of Breslau/Wrocław where he was born into a burgher family. At Brahe's bidding Jan [Johannes] Jessenius (1566-1620), a medical man with astronomical interests and diplomatic skills, came to Prague after performing a celebrated autopsy in 1600. He was among the 27 notables, executed in the Prague Old Town Square (21 June 1621) for their leading role in the anti-Habsburg uprising of the Bohemian estates in 1618. Largely aristocratic, their concern was to defend their power interests against the mounting centralizing aspirations of the Habsburg rulers. The 'Bohemian War' set in motion by the defenestration of two highest state officials (and their secretary) from a window of the Prague Castle, is looked upon as the first phase of the Thirty Years War (1618-1648).

Robert Evans observes that there was a close connection between Rudolf II and the outbreak of the Thirty Years War. In 1609 he was forced to sign a famed 'Letter of Majesty', endorsing Czech Protestantism ('Czech Confession'). Accordingly religious freedom was granted not only to nobles and knights, including their feudal subjects, but also to royal towns. Only, the then most liberal religious document European-wide did little to reduce tension between the Catholic and Protestant creeds. However, there is more to the 'Bohemian War' and to the Thirty Years War than to view the two events in terms of unresolved religious and political polarity.<sup>203</sup>

## THE THIRTY YEARS WAR AND THE SCIENTIFIC REVOLUTION

Epitomized by the social and cultural life of Emperor Rudolf's II and Queen Elizabeth I courts, Prague and London were in the same rank about 1600. During the next hundred years the situation changed radically in the wake of interstate rivalry for a stake in the opening world market. It is in this context that the Thirty Years War and the Scientific Revolution became both a product of and a factor in the uneven transformation of late medieval (feudal) Europe to early modern (capitalist) Europe. Remarkably, in traditional accounts of this period, we would be hard pressed to find discussions or explanations of a link between two of its defining events. Hal Cook's exploration of the rise of medicine and science in the context of Dutch sea-bound commerce is rare.

True, here and there, we read that Descartes, an iconic figure in the story of the Scientific Revolution, joined 1618 the Protestant army of Maurice Nassau, the captain-general of the Dutch Republic, and later that of Count Tilly, the commander of the Catholic League. Stationed in the later part of 1619 at Ulm at the River Danube in Southern

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<sup>202</sup> N. J. Efron, 'Liberal arts, eirenism and Jews in Rudolfine Prague' in *Acta Historiae... Prague Studies*, pp. 24-35 (p.24).

<sup>203</sup> Evans, 'Rudolf II Prag', p. 35.

Germany, Descartes famously experienced a moment of revelation. According to the reminiscent narrative Descartes spent 'the whole day shut up in a stove-heated room and 'at full liberty to discourse with myself about my own thoughts', when he began to develop his solution enshrined in the *Discourse on the Method* (1637), how to distinguish truth from falsehood. One wonders whether Descartes's longing to establish criterion for truth had something to do with his service in two armies, each upholding the sole – Protestant/Catholic – religious truth. It should be noted that Descartes's serving in armies of both faiths became less exceptional as the war continued. Recruitment evolved into a problem frequently solved by forcing prisoners of war to change sides.

The inclination to regard the Thirty Years War primarily in terms of German religious and political history has not died out. It connects with the fact that geographically the Holy Roman Empire of the German Nation became the arena of military operations. The limitation of this viewpoint becomes apparent when account is taken of incursions of Danish and Swedish armies, the participation of France and Spain with money and soldiers, and the resistance of the Dutch Republic (at war with Spain) to the deployment of Spanish troops.

While the religious and political agenda cannot be passed over, it does not circumscribe the Thirty Years War's place in history. It was a European war encompassing more than half of the Continent, though not at the same time. It was also a global war in that behind it lurked the rivalry between European states seeking a share in, if not domination of, the expanding world trade and world market. It outstripped previous military conflicts in material and financial costs, size of deployed armies, military and civil casualties and, last but not least, savagery.<sup>204</sup>

The exigencies of money and credit provided the setting for intensified private and public money-lending activities, including money-changing. They underpinned monetary circulation, a crucial feature of financial business in the pre-industrial phase of capitalism. But monetary transactions suffered from chaotic currency exchanges until some order was established in 1609, when the municipal Amsterdam Exchange Bank was founded. Apart from fostering the trade of northern Netherlands with the Baltic, the Levant and the Far East, the aim of the bank

was the establishment of a clearing system based on transfers from one client's account to another's in bank guilders of account representing a constant silver content. These Amsterdam clearing transactions required a special dimension because of the city's dominant position in world trade at that time. The obligation imposed by the municipality to clear all bills of exchange of an amount above 600 guilders through the bank induced all-important Amsterdam merchants and in fact all important firms involved on world trade to open an account at the Amsterdam Exchange Bank, which thus grew in the course of the seventeenth century into a bank of world stature – indeed, into *the* great clearing house for international trade, with the stable bank guilder serving as the world's convertible key currency.<sup>205</sup>

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<sup>204</sup> Texts dealing with the Thirty Years War and the period are legion. I draw attention to undervalued J. V. Polišíenský with F. Snider, *War and Society in Europe 1618-1648* (Cambridge, 1978) and V. G. Kiernan, *State & Society in Europe 1550-1650* (Oxford, 1980). For a recent examination in English, see P.H. Wilson, *Europe's Tragedy. A History of the Thirty Years War* (London, 2010).

<sup>205</sup> H. Van der Wee, 'The influence of banking on the rise of capitalism in north-west Europe, fourteenth to nineteenth centuries' in Teichova et al (eds.), *Banking*, p. 180.

Amsterdam's financial dominance was part and parcel of the long-drawn-out shift of commercial gravity from the Mediterranean to the Atlantic (c.1200-1600). We now can see it as a phase in the history of world economic integration in which merchants from the northern and southern Low Countries were foremost involved. In the course a societal transformation was set in motion whereby merchant *burgers* not only metamorphosed into capitalist bourgeois, but the Dutch also experienced the Scientific Revolution examined by Cook in *Matters of Exchange*.

#### THE SCIENTIFIC REVOLUTION: BOHEMIA AND THE NETHERLANDS

The Thirty Years War enhanced the historically momentous partition of Europe into unevenly developing, geographically ill-designated West and East, with dissimilar consequences. They profoundly affected not only the political, social and economic spheres but also the pursuits of natural knowledge.

Before 1618 Bohemia, located in middle Europe, was the richest Habsburg dominion. It housed some of the great European mining centres: Jáchymov [Joachimsthal] and Kutná Hora [Kuttenberg]. It was not fortuitous that the authors of the two classical texts on mining and metallurgy (reprinted for nearly 150 years) were active in these towns. Whereas Georgius Agricola/Georg Bauer (1494-1550), who authored *De re metallica* (1556), was physician in Jáchymov, Lazarus Ercker (?-1593), the author of *Beschreibung Allerfürnemisten Mineralischen Ertzt/vnnd Berckwercksarten etc.* (1574), was Warden and eventually Master of the Kutná Hora mint. He ultimately occupied the post of the Chief Mining Officer of the Kingdom of Bohemia (*Oberster Bergmeister*).

As mentioned, the growth of large-scale manorial economy, encompassing brewing, the raising of sheep and carp in ponds, built for the purpose, made the 'Bohemian nobles rich'. It was this milieu that aroused Hagecius to get acquainted with brewing practice, described in the pioneering booklet *De cerevisia etc.* (1585).

Deep mining and construction of fish ponds depended on adequate surveying. Horský interestingly points to the basically identical methodologies and instruments employed in mines and fishpond surveying and astronomy.<sup>206</sup>

On the eve of the defenestration, economic and intellectual omens in Bohemia appeared to augur well for moving not only the body politic, but also the pursuits of natural knowledge, in the Dutch direction.

The clue to why it was not to happen lies in the difference of what the uprising/rebellion in Bohemia and the revolt in the Netherlands were about. Ostensibly Bohemia and the Netherlands faced a common foe. That is, the Catholic Habsburgs aspiring to dynastic dominance in Europe, albeit in the shape of two branches, the Austrian and the Spanish. Other intertwined factors, politics, economics and social structure played their part to generate unlike outcomes, affecting also the scientific sphere. The timelag in the development of the Scientific Revolution in Bohemia, compared with the Netherlands, is unambiguous.

For one thing, there was a difference in the role and interests of the nobility and burghers in the two countries. Whereas as a class the nobility in Bohemia was strong and the burghers weak, in the Netherlands the situation was reversed. In Bohemia nothing like a defeudalization/bourgeoisification, like in the Netherlands, had taken shape nor did

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<sup>206</sup> Horský in *Prag um 1600*, p. 70.



a noble-burgher inter-class alliance, which had earmarked the Dutch fight against Spain, materialize.

When the Bohemian nobles, the elite social strata, raised the banner of rebellion, they primarily were concerned with their socio-political interests. The dispute was over the character of the monarchy and Bohemia 'became one of the focal points of the conflict where a program of freedom of religion and the maintenance of liberties of the estates represented a defence against centralization.'<sup>207</sup> This is not to say, as Victor Kiernan seems to suggest, that Bohemia was virtually turning itself into a republic, but its leaders shrank from the final step. As he himself points out:

To set up a republic was an enterprise which only the most advanced and most revolutionary nations had courage for; the Dutch only half succeeded, the English only momentarily. Its time would come in the end far away from Europe, beyond the Atlantic.<sup>208</sup>

Indeed, but not simultaneously, and under unlike socio-political economic and cultural circumstances. Contrast Cook's appraisal<sup>209</sup> with Smolka's analysis of scientific evolution in Bohemia from the middle of the sixteenth to the middle of the eighteenth centuries, when Newton and Linnaeus had arrived there. It specifically draws attention to the long-term negative impact of the putting down of the 1618-uprising on the evolvment of the Scientific Revolution in the Czech Lands. It was moulded

in a quite decisive manner by the social situation which developed in the Czech area: re-catholization and the near-absolute ideological hegemony of the Jesuit Order, intellectual oppression and lack of freedom which went hand in hand with complete isolation from modern European scientific trends. And it is in a way paradoxical that whereas the historical conditions for scientific development at the beginning of the period involved were relatively favourable, at its end, when the Enlightenment and rationalism were beginning in Europe, Bohemia and Moravia were as it were starting from scratch, from the very beginning, but only slowly, hesitatingly and uneasily ...<sup>210</sup>

As it happened, there was a Dutch dimension to this reform in the person of Gerard van Swieten, Empress Maria Theresa's physician. On his advice, medical teaching was restructured along the lines developed in Leiden by his influential teacher Herman Boerhaave. Moreover and no less crucially it was due to van Swieten that the Jesuit hold on education and censorship was broken.

#### CONTEXT AND CONTENT OF SCIENCE

In a notable collection investigating the historical relationship between instruments, travel and development of science, the editors go out of the way to point out that their historiographical approach is 'contextual'. Over the last two decades, they state

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<sup>207</sup> J. Petráň and Lydia Petráňová, 'The White Mountain as a symbol in modern Czech history' in Teich (ed.), *Bohemia*, p. 144.

<sup>208</sup> Kiernan, *State & Society in Europe*, p. 195.

<sup>209</sup> H. J. Cook, 'The new philosophy in the Low Countries' in Porter and Teich (eds.), *Scientific Revolution*, pp. 137-8.

<sup>210</sup> Smolka, 'Bohemia', in Porter and Teich (eds.), *ibid.*, pp. 234-5.

historians of science engaged in writing contextually have argued against a view of the development of knowledge, and particularly of scientific knowledge, as a *unilinear* process, and against the notion that the universality of science progressively imposes itself by the sheer force of the uniformity of the laws of nature. Conversely, these historians have described through multiple case studies how the universal dimension of science in fact predicated upon the context of its making and deeply grounded in locality.<sup>211</sup>

This should not obscure that the contextual approach to the history of science has a past before 1980. To all intents and purposes it goes back to Hessen's seminal analysis (1931) of *Principia* against the background of the period Newton worked and lived. To ignore Needham's *Science and Civilisation in China* (1954-) as a work in contextual history is to fly in the face of evidence. Written under Marxist influence, these and such-like studies were suspect *ab ovo*. Even scholars, acknowledging the relevance of the social context for the historiography of science, feel that novel forays, such as Shapin's and Schaffer's *Leviathan and the Air Pump*, have not delivered. That is, 'they place the history of science within a social context, but they did not discuss the possible influence of the content of science'.<sup>212</sup> As it happens Schaffer's contribution to the itineraries volume illustrates that the relationship between the social context and the content of science is not reducible to a point-to-point relationship, but is mediated. To come to grips with it needs a more nuanced discussion based, for example, on an interdisciplinary approach exemplified below.

The subject matter of Schaffer's piece is the English gold trade in the seventeenth and early eighteenth centuries and the metrological concerns of Robert Boyle and Isaac Newton, protagonists of the gold system. It crucially depended on gold, as commodity, to be 'true gold, perfect metal' (John Locke).<sup>213</sup> Gold must have attracted the attention of humans in prehistoric times. The use of sheep skins in the washing of gold-bearing sands to return gold particles may have given rise to the myth of the Golden Fleece. The notion of gold being superior, in comparison with other metals, be in economy or medicine, is alchemical.

It is well established that Boyle's, Locke's and Newton's alchemical interests did not prevent them to look for and obtain 'hard' knowledge of nature. What Schaffer shows is that state-sponsored and commercial natural history mattered to them too. That is, precision methods to distinguish between true gold and its counterfeits, shipped from the Gold Coast of Guinea to the Royal Mint in London where Warden Newton ruled supremely:

Newton constructed a ferocious regime of governance within the institutions of natural philosophy and the walls of the Tower. In Mint he insisted on accurate weighings and corrected what he judged an unacceptably large tolerance of error in the average weight of coins, called 'the remedy'. The Newtonian mint became an emblematic site of

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<sup>211</sup> Marie-Noëlle Bourget, Ch. Licoppe and H. O. Sibum (eds.), *Instruments, Travel and Science. Itineraries of Precision from the Seventeenth to the Twentieth Century* (London and New York, 2002), p. 3.

<sup>212</sup> Margaret J. Osler, 'The canonical imperative: Rethinking the Scientific Revolution' in Osler (ed.), *Rethinking*, p. 19.

<sup>213</sup> S. Schaffer, 'Golden means: assay instruments and the geography of precision in the Guinea trade' in Bourget et al. (eds.), *Instruments*, p. 22.

administrative metrology.<sup>214</sup>

Ever since the publication of Hessen's paper it has been criticized, by non-Marxist and a number of Marxist historians, for its socio-economic 'determinism', 'reductionism' and such-like. This points to an appreciable misreading of what Hessen was about. That is, 'to determine the *basic tendency* [MT] of the interests of physics during the period immediately preceding Newton and contemporary with him'<sup>215</sup>

Turning to Schaffer's article, one has the impression that he owes a good deal to Hessen, if not to Marx. Newtonian projects he states

were not, of course, limited to fiscal standardisation. Between 1709 and 1713, ably assisted by the young Cambridge mathematician Roger Cotes, Newton prepared a revised edition of his *Principia mathematica*. Some 'hypotheses' which has prefaced its third book in 1687 now became reworked as '*regulae philosophandi*'. The second rule stated that 'the causes assigned to natural effects of the same kind must be, so far as possible, the same. Examples are ... the falling of stones in Europe or America. The *Principia*, in this sense was a handbook for travellers. Newton described the celebrated marvels of tidal ebb and flow in the East Indies, the Straits of Magellan and the Pacific. Keen to show the universal grip of his gravitational model of lunar pull, Newton here faced characteristic troubles of trust in travellers' tales. Against Leibnizian rivals, Newton and Cotes now sought massively to reinforce the apparent precision of their measures. They discussed whether to omit or include tide data from variably reliable mariners using assumptions about such parameters as the earth's destiny. The link between trust in persons and in creation's constancy was even clearer in their work on the length of isochronic pendulums in Europe, American and in Africa too. In the 1680s Newton had hoped that 'the excess of gravity in these Northern places over the gravity at the Equator' would be 'determined exactly by experiments conducted with greater diligence. Cotes now 'considered to make the Scholium appear to the best advantage as to the numbers'. They would make a table of the variations in the length of a seconds pendulum at different points on earth, visibly accurate over very small length differences of fractions of an inch. Cotes held 'that the generality of Your Readers must be gratified with such trifles, upon which the commonly lay ye greatest stress.'<sup>216</sup>

#### INTERDISCIPLINARITY IN BECHER'S THOUGHT

Boyle, Locke and Newton shared engrossment with the historically linked fields of mining, metallurgy, alchemy, chemistry, including coinage, with continental contemporaries, such as Johann Joachim Becher (1635-?).<sup>217</sup> In general histories dealing

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<sup>214</sup> Ibid., p. 39.

<sup>215</sup> Hessen, *Science at the Cross Roads*, p. 165.

<sup>216</sup> Schaffer, 'Golden means', pp. 37-8.

<sup>217</sup> See G. Frühsorge and G. F. Strasser (eds.), *Johann Joachim Becher (1635-1682)* (Wiesbaden, 1993). It includes my 'Interdisciplinarity in J. J. Becher's thought' on which I draw (pp. 23-40). It was previously published in *History of European Ideas* 9(1988), pp. 145-60.

with the rise of modern chemistry, he usually has a place in the discussion of the origins of the doctrine of 'phlogiston'. In works surveying the evolution of economic thought Becher is mentioned as the leading representative of German (Austrian) mercantilism.

Among the most striking features of Becher's life is his continuous fascination with alchemy. Becher emerges as somebody who unquestionably believed that transmutation was possible but had little regard for pursuits concerned with preparations of an elixir of life. However, scepticism regarding this or that aspect of alchemy does not hinder Becher from re-iterating that without alchemy metallurgy cannot be fully understood. Indeed, he goes on, anyone who is opposed to alchemy should realize that he either does not comprehend or appreciate fully that metallurgy and coinage form the foremost part of his prince's income.

Becher's reference to the sphere of coinage touches on an element of German political and economic history which should not be lost sight of. That is, the German system of coinage was non-uniform, being in part a product of political and economic division of Germany but also contributing to it, a long time before and after the Thirty Years War.

Arising out of these coinage conditions in Germany was, among other things, the problem of the exchange of currencies between the independent territories within the framework of the Holy Empire of the German Nation, as well as between these territories and the non-German states. Discussing money-exchange in the section of coinage in *Politische Discurs*, Becher proposes to control it institutionally by establishing a discount-house (*Wexel-Banck*).<sup>218</sup>

Underlying the proposal was Becher's preoccupation with the character of movement of money and commodities and their relation. The interest of this lies in that Becher ascribes to money the function of commodity. Becher may be among the first writers to espouse such an idea. Here is what he says: '... thus in respect of a country there is no commodity as expensive and necessary as money; and no commodity going out of the country should be charged with more duty than money because money is equally the nerve and the soul of the country'.<sup>219</sup>

This proposition ties in with the impact of merchant capital which the centre of Europe was experiencing, as part of the transformation from feudal to capitalist economy at the time when Becher was composing his substantive work. An inherent feature of this process was the growing production of the commodities to be sold, that is exchanged for money, on the market at home and abroad. Becher was concerned precisely with such questions in the context of Germany's political and economic ruin after the Thirty Years War. That is, with the ascendancy of merchant capital in the economic life of this geographical area, characterized by the interlocking of the circulation of commodities and money. There is first-hand evidence for Becher having actually spelt out the idea of the

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<sup>218</sup> J. J. Becher, *Politische Discurs von den eigentlichen Ursachen des Auf- und Abnehmens der Staedt, Laender und Republicken* (Frankfurt/Main, 1688), p. 269. This is the third edition of Becher's arguably most renowned publication, apart from *Physica Subterranea*. The first edition *Politischer (!) Discours* – appeared in 1668 and the second edition in 1673. The original title of *Physica Subterranea* was *Actorum Laboratorii Chymici Monacensis, Seu Physicae Subterraneae Libri Duo* (Frankfurt/Main, 1669). Despite the title it was a one-volume book. A second edition with three supplements, published separately earlier (1671, 1675, 1680) appeared in 1681. It was Becher himself who translated his own opus into German and published it as *Chymisches Laboratorium Oder Unter-erdische Naturkuendigung* (Frankfurt, 1680), with first and second supplements and another publication *Ein Chymischer Raetseldeuter*. A second issue appeared in 1690.

<sup>219</sup> Becher, *Politische Discurs*, p. 269.

circuit of merchant capital. It is contained in his appraisal of merchant-manufacturers as the mainstay of the community:

Now finally regarding the point about *consumption*, I wish to add in praise and honour of the *Verlaeger* [merchant-manufacturers] the following. Namely that they are solely to be regarded as the pillars of the three estates because the artisan lives from them, from him the nobleman, from him the Prince, and from all these again the merchant. These are the hands which have to join.<sup>220</sup>

Becher's thought reveals 'cycle-mindedness' as permeating just as much his natural philosophy as his economic thinking. For Becher, who was not affected by growing specialization, it became the concept through which the natural and economic worlds interrelated. Cycle-mindedness and circulation-mindedness respectively were terms employed by Joseph Needham when he called attention to the Taoist appreciation of cyclical change. At the same time he highlighted the eminent role of the notions 'circle' and 'circulation' in the intellectual life of the Renaissance when the foundation of what is called modern science were laid. The scholar to whose stimulating work we owe most insight was Walter Pagel but in these matters he appears not to have become an influence as he did in others.<sup>221</sup> Cycle-mindedness is bound up with the idea of 'recurrence' and 'continuity'. In fact, it constitutes one of the most enduring visions of being from prehistoric times to the present. Thus it comes into play in beliefs in the possibility of life after death or pursuits of perpetual motion machines. Such themes, we know, were of concern to Becher. They should be viewed in the context of his belief in circulation – grounded on his reading and literal interpretation of the Bible – as the underlying principle of the natural and economic order of things.

But beyond that, probably, Becher owes the circulation idea to his alchemical and chemical interests. Can one doubt that he was familiar with the alchemical symbol of the serpent with his tail in his mouth? The circular form of the *Uroboros* was taken by the alchemists to stand for 'death' and 'resurrection' of matter undergoing eternal chemical change. Moreover since the sixteenth century, at least, the terms 'distillation' and 'circulation' came to be used analogically. There is direct evidence, in fact, for Becher making use of this analogy when he stresses that nature is in a state of perpetual motion and that this motion is circular and can be compared to distillation.<sup>222</sup>

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<sup>220</sup> Ibid., p. 106.

<sup>221</sup> J. Needham, *Grand Titration*, pp. 227-8; W. Pagel, *William Harvey's Biological Ideas Selected Aspects and Historical Background* (Basel and New York, 1967).

<sup>222</sup> 'Revera autem, perpetua haec circulatio destillationi Chymicae comparari potest', *Physica Subterranea*, p. 50; 'Nun kam aber? in der That dieser staete Cirkelgang mit einer Chymischen distillation verglichen werden', *Chymisches Laboratorium*, p. 131.

## 7. EPILOGUE

Becher was a polymath whose interests included: human and veterinary medicine, mathematics, physics and chemistry, education, philology, technology, husbandry, political economy and social organisation, colonialism, natural philosophy. It is the sheer breadth of inquiries that predicated the interdisciplinary approach to the assessment of Becher's place in the world of seventeenth-century learning.

As illustrated above, Becher had a pretty good understanding of the dominating role of mercantile activity in the society he lived and was involved in. As an economist and chemist, Becher was superior to Leibniz with whom he is occasionally juxtaposed.<sup>223</sup> Becher certainly was inferior to his great polymath contemporary in mathematics and physics in which Leibniz was primarily and originally active. Where a useful comparison may be attempted is to look into how Becher and Leibniz read the Bible and thought about God in the context of investigating natural phenomena.<sup>224</sup>

Stripped down to essentials, Becher's philosophy of nature may be summarized as follows. God is the first Being, a Being which is not created but creates everything. As such He has created nature as the vehicle of orderly motion. The primary stuff or raw material of nature is earth of which everything is ultimately composed and into which everything is eventually decomposed. In Becher's opinion God is a chemist who made nature exist, from the time of the creation of the world up to its coming to an end, as a cycle of transformation of one kind of earth into another.

In Leibniz's speculation, the all-provident God ordained that the world He brought into being was to exist in harmony. It was to be the best of possible worlds, once created, not needing His continuous intervention to keep it running like a clockwork. This ultimately was due to the combining of multiple primary entities ('monads') endowed with 'soul', that form all matter.

*Au fond*, Becher and Leibniz were confronted with squaring the circle, as were Boyle, Descartes, Newton, Linnaeus and score of other seventeenth- and eighteenth century explorers of nature. That is, to harmonize findings and explanations of natural phenomena with the words of Scripture. To ignore this maxim was perilous in the light of Giordano Bruno's burning at the stake (1600) and Galileo's trial (1633). When Descartes learns of Galileo's condemnation by the Inquisition, he suppresses his treatise on *The World* (1634).

Protestant Christianity could be no less intolerant than the Roman Holy Office. The Reformation, in effect, had reinforced the Bible as the undisputable authority. The Spanish physician Michael Servetus, whose inklings of the lesser circulation of blood were contained in his unorthodox *Restitutio Christianismi* (denial of Christ's divinity) was burnt in Geneva at Calvin's behest (1553). Newton was very careful when it came to conceal his heretical Arianism. And the deeply religious Linnaeus, who believed in God, in the Bible as the Word of God and saw himself as God's interpreter of nature – was not an orthodox Christian. So much so that, after Linnaeus's death, his son had to defend him in the face of

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<sup>223</sup> H. Breger, 'Becher, Leibniz und die Rationalität' in Frühsorge and Strasser (eds.), *Becher*, pp. 69-84. See also Pamela Smith's valuable juxtaposing Becher and Leibniz in her *The Business of Alchemy Science and Culture in the Holy Roman Empire* (Princeton, 1994).

<sup>224</sup> H. Rudolph, 'Kirchengeschichtliche Beobachtungen zu J. J. Becher', *ibid.*, pp. 173-99; M. Stewart, *The Courtier and the Heretic: Leibniz and Spinoza and Fate of God in the Modern World* (New Haven and London, 2005).

accusations of atheism.<sup>225</sup>

The burning of suspected or real heretics was the uncompromising reaction of Christianity that had become the dominating intellectual and cultural force in Europe since it was instituted as the state religion of the *imperium Romanum* in the fourth century. Paradoxically, as the eminent historian of science Richard Westfall put it, the result of the many treatises, demonstrating the existence of God from natural phenomena, had been the separation of science from revealed theology. Westfall compared two incidents supporting his point about science asserting its autonomy by the end of the seventeenth century:

Early in the seventeenth century, the Catholic Church, under the leadership in this respect of Cardinal Bellarmino, condemned Copernican astronomy because it conflicted with the overt meaning of certain passages of Scripture. Sixty-five years later Newton engaged in a correspondence with Thomas Burnet about Burnet's *Sacred Theory of the Earth*. Burnet had convinced himself that the Scriptural account of the creation was a fiction, composed by Moses for political purposes, which could not possibly be true in a philosophical sense. In the correspondence, Newton defended the truth of Genesis, arguing that it stated what science (chemistry in this case) would lead us to expect. Where Bellarmino had employed Scripture to judge a scientific opinion, both Burnet and Newton used science to judge the validity of Scripture. To speak merely of the autonomy of science does not seem enough; we need to speak rather of its authority, to which theology had now become subordinate. The positions of the two had been reversed. That change also has never been reversed anew.<sup>226</sup>

The Christian Westfall saw in the new relation between science and Christianity 'one dimension of the new order that the Scientific Revolution ushered into being. They are one more reason why I will not part with the concept'. He was convinced 'that it is the key not only to the history of science but to modern history as well'. Indeed Westfall argued that the separation of the Western world from the rest of the globe stemmed from the growing scientific foundation that European technology acquired since the seventeenth century.

Westfall appears to have believed that no one has seriously addressed the question 'of what it was about the new science that made it adaptable to technological use'. He connected it with its three distinguishing features: quantitative character, employment of experimentation and a more satisfactory account of nature.

In more general terms, the question was addressed by Marx, 'that most astute historian of nineteenth-century technology (and Manchester)'.<sup>227</sup> He did it in a preparatory work (1857-8), published under the title *Grundrisse der Kritik der politischen*

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<sup>225</sup> For religious views of Linnaeus, see contributions by Sten Lindroth and Tore Frängsmyr in T. Frängsmyr (ed.), *Linnaeus The Man and his Work* (Berkeley, Los Angeles and London, 1983). K. H. Hagberg, *Carl Linnaeus* (London, 1952) still provides useful information on the religious as well as economic and political dimension of the Swedish naturalist's activities. For a more recent treatment, see Lisbet Koerner, *Linnaeus Nature and Nation* (Cambridge, Mass., 1999).

<sup>226</sup> R.S. Westfall, 'The Scientific Revolution reasserted' in Osler (ed.), *Rethinking*, p. 50. For the following, see pp. 50-1.

<sup>227</sup> Noted by a much respected non-Marxist historian of science. See J. V. Pickstone's thoughtful synthesis of the state-of-the-art of scholarship in the history of science, technology and medicine, *Ways of Knowing* (Manchester, 2000), p. 24.

*Ökonomie (Rohentwurf)* in 1939-41 for the first time. As is known or should be known, the chief aim of Marx's theoretical endeavour was to discover the laws underlying the formation and development of capital and thus to provide the key to comprehending capitalism as a historically evolved system of social production. It is in this connection that Marx encountered the problem of the role of science and technology in the development of the productive forces under capitalism.<sup>228</sup>

In the *Grundrisse* Marx touches on the problem, among other things, when he analyses categories such as 'labour process', 'fixed capital', 'machine', etc. Marx notes

Nature builds no machines, no locomotives, railways, electric telegraphs, self-acting mules, etc. These are products of man-made industry ... they are *organs of the human brain, created by the human hand*, a power of knowledge objectified. The development of fixed capital [appearing as a machine] reveals to what degree general social knowledge has become a *direct force of production*.

On following up Marx's thinking on this subject in *Capital* (1867), his major published work, we find that by then he regarded science as an intellectual potency (*geistige Potenz*) of the process of production rather than as a direct force. Marx frequently refers in *Capital* to *Produktivkraft der Arbeit* in the sense of 'productivity' and writes that it is 'determined by various circumstances, among others, by the average skill of the workmen, the state of science and the degree of its practical application, the social organization of production, the extent and capabilities of the means of production and by physical conditions.'

No doubt what happened was that Marx on maturer reflection concluded that the more subtle relationship between science and production had to be contemplated than the point-to-point one he had previously predicated. It has been my view for a long time that practitioners as well as theoreticians concerned with this issue could benefit from this approach. That is, to recognize that the relationship between science and production is a mediated one, depending on factors such as military needs, economic expectations, technological feasibility, political interests and others. Looked at it in this way, scientific knowledge represents a *potential* rather than a direct force of production.

This assigns to mediation a centrally important epistemological function for the understanding of the part played by interaction of plurality of factors in transitional phases of history. It is in this context that it repays to return to Westfall's reaffirmation of the concept of the Scientific Revolution with which I agree in principle, but do not find adequate.

Take Westfall's observation that the Scientific Revolution brought into being a new order and, moreover, that it provides a guide not only to the history of science but also to modern history. For one thing, it is not clear what he means by 'new order' – political, social, economic, intellectual, conceptual, methodological, epistemic, etc.? True, Westfall points to the subordination of theology to science as one of its hallmarks, including the closer relation of science and technology. But his lack of interest in placing the Scientific Revolution within the wider, plural, history of the period he discusses (1543-1687) is evident. It actually makes it difficult if not impossible to realize his historical vista.

This contrasts with the view of the editor of a volume on Galileo, emphasizing that the development of science is affected by external conditions in which it is done:

What cannot be in doubt is that between, say somewhat arbitrarily, the dates of 1543 and 1687, many things had radically changed and the world

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<sup>228</sup> What follows draws on mine 'The scientific-technical revolution: an historical event in the twentieth century?' in Porter and Teich (eds.), *Revolution in History*, pp. 317-30.



was, and was further becoming, a widely different kind of place. Science, as any other human endeavour, does not exist in a vacuum. It is not an isolated, independent system of thought and practice. What happens in other realms affects how science is practiced, perceived, and received.<sup>229</sup>

Alas, this perspective is not reflected in the actual contributions to the valuable, if traditional, collection – apart from the attention paid to Church and Scripture.

As stated at the beginning of this book, it is about the Scientific Revolution as a distinctive movement of thought and action that came into its own in some areas of Europe by the seventeenth century. By then the Greek 'inquiry concerning nature' had acquired the form that had been adopted universally though not at the same time.

Some ways of knowing, as observation and experience, go back to the times when ape-like creatures began to employ them purposefully and, in the process, became recognizably human. Others – classification, systematization and theorizing - had been developed in classical antiquity. Systematic experimentation and quantification represent procedures of investigating and comprehending nature that began to materialize in Europe during the late Middle Ages and Renaissance.

By and large, historians have come to identify this phase as the transition from the late medieval to the early modern period in Europe. Some influenced by Marxism view it as the opening stage of transition from feudalism to capitalism in Europe – with merchant capital in control of commerce and manufacture.

It is in this context Bernal wrote in his seminal *The Social Function of Science* (1939) that the rise of capitalism and the birth of modern science in about the middle of the fifteenth century are related processes, arguing: 'Though capitalism was essential to the early development of science giving it, for the first time, a practical value, the human importance of science transcends in every way that of capitalism, and, indeed, the full development of science is incompatible with the continuance of capitalism'.<sup>230</sup>

The reading of this work in 1940 was pivotal in arousing my interest in the history and philosophy of science in general, and in the Marxist materialist conception of history in particular. It led to my earliest publication – on the eve of my taking the first degree – in *Nature* (1944).<sup>231</sup> Sixty-seven years later, as I write these lines, I find this approach to history still most enlightening though not dogmatically prescriptive.

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<sup>229</sup> P. Machamer (ed.), *Cambridge Companion to Galileo* (Cambridge, 1998), p. 3.

<sup>230</sup> J. D. Bernal, *The Social Function of Science*, 3<sup>rd</sup> ed. (London, 1942), pp. 408-9. See mine 'J.D. Bernal the historian and the Scientific Technical Revolution' in *Interdisciplinary Science Reviews* 33 (2008), pp. 135-9.

<sup>231</sup> M. Teich, 'Influence of Newton's work on scientific thought' in *Nature* 153 (1944), pp. 42-5.



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