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Science and Change 1500-1700

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1 Three traditions in science

In this book, I shall argue that the key to interpreting the origins and course of the Scientific Revolution is to be found in three distinctive traditions or paradigms – the organic, magical and mechanistic. Before I discuss this in detail, however, I would first like to offer some criticisms of a historical outlook which tends to dominate and distort general accounts of the Scientific Revolution and which I will call 'the Whig interpretation of history'.

The Whig interpretation of history

This interpretation implies a view of the past which divides men essentially into two simple categories, progressive or reactionaries, forward-looking or backward-looking, Protestants or Catholics. As Sir Herbert Butterfield pointed out in a brilliant essay, this way of looking at history leads to gross distortions because it imposes the standards of the present upon the past. One danger lies in the assumption that the purpose of the past has been to prepare the way for the present. Another is to trace a simple line of continuity from past to present. Perhaps the basic error is to substitute explanation based on logical progression for a less rational and more complex interpretation of the past.

The Whig interpretation takes its name from the account of English constitutional history given by nineteenth-century Whig historians, who saw English liberty 'slowly broadening down from precedent to precedent'. The foundations of freedom were laid with Magna Carta in 1215, rescued in the Civil War of the seventeenth century, and confirmed by the Glorious Revolution of 1688, the implications of which were worked out in the Reform Acts of the nineteenth century. The basic assumptions which lay behind this interpretation of English

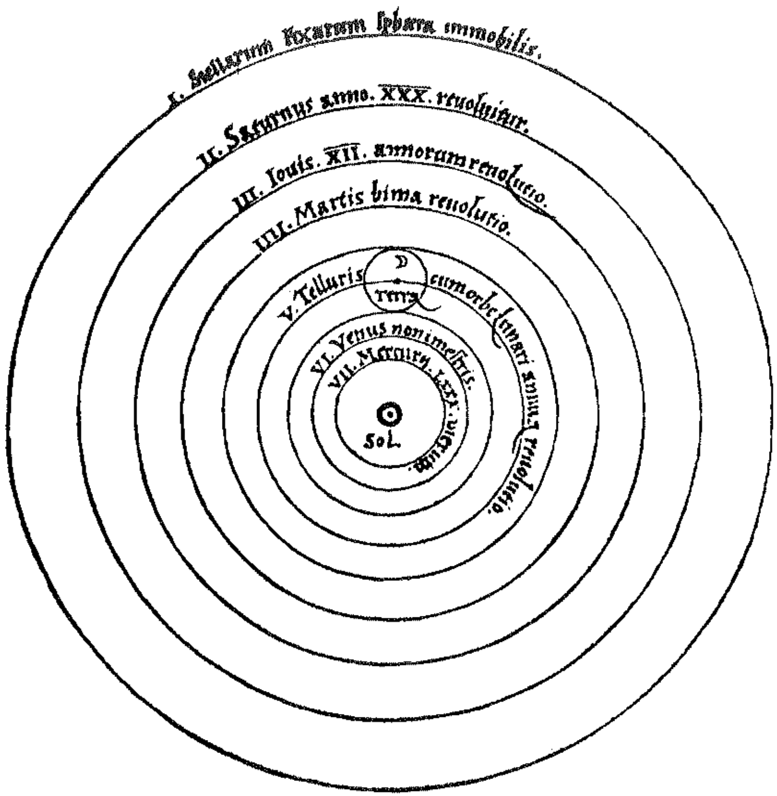
The Copernican universe with the sun at the centre from *De Revolutionibus Orbium Coelestium*, Nuremberg (1543). Copernicus retained an immobile sphere of stars beyond the planets, of which the earth was now one. A comparison between this and the illustration on page 31 epitomises the Copernican revolution.

history was a simple one. Englishmen were divided into two simple categories, those who loved liberty, the Whigs, and those who did not, the Tories. By this test, English history assumed an intelligible pattern, which ultimately was enshrined as a myth.

But it would be misleading to restrict our attention to England and the Whig historians. Most nationalist interpretations of history make similar judgments about the past. History appears as a story of those who supported the rise of the nation and those who did not. Crucial differences between the patriots of one generation and another are lost sight of and essential distinctions between men of the same generation are slurred over. Nationalist history of this kind seems to be the response of an overpowering emotional need within newly established political societies, which feel the need to create a 'past' for themselves.

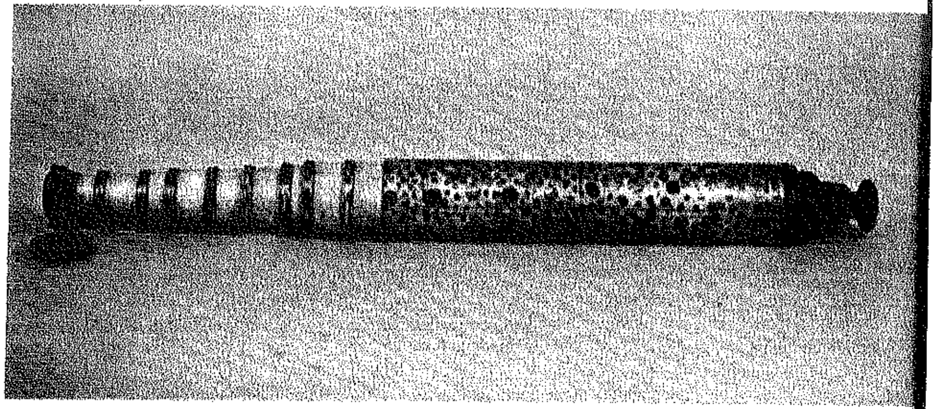
Perhaps the most influential example of the Whig interpretation of history today is provided by Marxists. This fact is glossed over by the Marxist claim to be writing 'scientific' history and by the undoubted erudition and imagination of many Marxist historians. But behind much Marxist history lies the assumption that history is a record of progress, with progressives on one side and reactionaries on the other. Great play is made with such terms as 'forward-looking' and 'backward-looking' as if it were possible to apply such concepts to the complexities of the past, as if indeed these concepts had meaning of an ascertainable kind. We must group such Marxists with the Whigs, as historians who are committed to seeing the past in terms of the present, and to applying what are in effect two simple moral categories to history.

What has all this to do with the history of science? I believe, everything. For the most part, general histories of science have



been written on the assumption that beneath all the technical detail there was a simple tale to be told. From this point of view, the history of science appears as the story of the emergence from clouds, irrationalism or superstition of a rational method of interpreting nature. The early scientists are seen as groping for the discovery of a scientific method which was to be finally revealed in all its clarity by later generations. If these early scientists were opposed in their own day, the reason was simple: they were the progressives and their opponents were the reactionaries.

Reduced to skeleton form, the Whig interpretation of the history of science runs as follows. The first substantial break-



through was made by Copernicus, the Polish astronomer (1473-1543), who put forward the theory that the earth went round the sun instead of the sun going round the earth, as the conservatives thought. His view was taken up at the end of the century by the German scientist Johannes Kepler (1571-1630) and by the Italian Galileo Galilei (1564-1642). Kepler discovered that the paths of the planets were elliptical not circular, and Galileo was the first to use the telescope in astronomy and to formulate the mathematical law of falling bodies. Finally came Sir Isaac Newton (1642-1727) who in his *Principia* brilliantly applied the same law to planetary motion and to falling bodies alike.

This essentially is the Whig version of the Scientific Revolution, the basic structure underlying for example such books as E.J.Dijksterhuis's monumental study *The Mechanisation of the World Picture* (1950). Copernicus, Galileo, Kepler and Newton are the key names, but other scientists may be fitted into the scheme of things – Tycho Brahe, Descartes, Robert Boyle and Leibniz – once the initial judgment has been made that they are 'forward-looking'. Those who do not fit into these categories are consigned to oblivion. (Even Butterfield on occasion cannot avoid using harsh judgments like 'lunacy' about the views of men who do not fit into his interpretation.)

The attractions of this simple model are obvious. It reduces

An English terrestrial telescope, *c.* 1680, made by William Longland who became Master of the Spectacle Makers' Company in 1686-7 and 1694-5. The body of the telescope is made of pasteboard covered with vellum decorated with patches of colour and with gold tooling; the overall length (closed) is 60 cm. There are nine draw-tubes; the lenses are in mounts of *lignum vitae* and the eye lens is, contrary to later practice, in the larger mount.

a very technical piece of intellectual history to manageable proportions. As a logical structure, stressing the logical progression of ideas, it makes an appeal to the philosophical and scientific mind. But it is in fact open to exactly the same objections as the Whig interpretation proper, or to nationalist history, or to Marxist history. The proof of the pudding is in the eating. A Whiggish history of science breaks down like other Whig interpretations as soon as detailed research into specific problems or particular periods is undertaken.

Indeed the Whig interpretation of the history of science no longer seems convincing precisely because of the amount of detailed historical research in recent years which has appeared in such periodicals as *Isis*, *Ambix*, *Archives Internationales pour l'histoire des Sciences* and *Journal of the History of Ideas*. It is perhaps true to say that a greater amount of distinguished work has appeared in print since the Second World War than ever before. But even apart from this, there is a general dissatisfaction with the artificial confines of Whig interpretations. Hence, many historians following the example of the French school of Marc Bloch and Lucien Febvre have moved towards 'histoire intégrale'. History written on these lines aims at total history, in order to make intelligible all aspects of life in particular societies, not merely a single line of apparent progress.

To some extent, the Marxists had already pointed the way in this direction. Indeed, it may be said that one of the beneficial effects of Marxist interpretations of history has been to force historians to take the broad view, and to see interconnexions between apparently disparate topics. Unfortunately, however, Marxism in practice is often too rigid and too predictable, providing only one form of explanation and one kind of analogy. A more fruitful example has been set by sociologists and social anthropologists. We are now less tempted to make simple distinctions between rational and irrational behaviour. We look instead for the social function of certain modes of activity. We see that what is called 'magic' in a primitive society may correspond to what is called 'science' in a more sophisticated one. We are also introduced to a wider range of concepts than is supplied in a Marxist 'class' analysis, such as 'roles', 'function', 'status' and other concepts. And what applies to the political and intellectual historian applies with equal force to the historian of science. Thus the history of science no longer appears as a self-contained activity, an enclosed scientific tradition, with truth 'slowly broadening down from precedent to precedent'. Historians of science are now engaged in seeking the influence of allegedly non-scientific and non-rational factors upon scientists.

To some extent, this approach has been practised for a long time. Darwinism is an obvious case in point. It seems certain that Darwin's scientific imagination was kindled by the Malthusian law of population. Malthus, in stressing the continual pressure of population upon food supply, provided the key for Darwin's theory of natural selection. In other words, to explain the origins of *The Origin of Species*, the historian of science must come to terms with the general history of the early nineteenth century.

The three scientific traditions

In attempting to escape from the bonds of a Whig interpretation of the Scientific Revolution I will argue that there were, during this period, at least three approaches to nature which may be broadly termed 'scientific' in the sense that they all produced discoveries which have been incorporated within

the modern scientific tradition. But 'modernity' is a dangerous criterion. All three of them were bound up with religious assumptions about the universe, whereas modern science by definition is a secular activity. No exponent of a particular tradition had a concept of science in its modern sense, indeed, the term 'scientist' was first invented in the nineteenth century. Hence, the exploration of natural phenomena during our period must be seen according to its own terms of reference, even though much of it may seem 'magical' or 'superstitious' to us. There is no direct line of progression from them to us, and whenever we are tempted to identify our own concerns with one or other of these traditions, we are victims of an optical illusion which further analysis will expose.

In general terms the three traditions may be described as organic, magical and mechanistic. Within the organic tradition the scientist explained the natural world in terms of analogies drawn from what we now call biology. The language which he used originated in observation of growth and decay, with the analogy of the acorn growing into the oak always ready to hand. Thus the veins of metallic ore were accounted for by the explanation that the metal had 'grown' in a favourable place. What struck this type of mind about nature was not its regularity and uniformity, but its constant change. Yet within the process of change there was a consistency which had to be accounted for. Acorns did not grow into chickens. This led to the view that there was a potentiality or purpose built into all natural phenomena, a so-called 'final cause', which dominated development.

Within the organic tradition, the scientist turned almost inevitably to the study of living organisms. And even when he dealt with what we would now regard as inanimate nature, he tended to attribute life to it or to use language and terms

The salamander from the *History of Animals* by the Swiss naturalist Conrad von Gesner (1516-65). The title shows that it was intended to emulate Aristotle's work of the same name. The salamander was believed by many to live in fire because of the presumed coldness of its temperament. But J. P. Wurffbain in his *Salamandrologia* (1683) disposed of this myth.

derived from his primary interest in life and growth. The terms 'natural' and 'unnatural' were applied within the organic tradition to problems of motion. A falling stone was behaving 'naturally', a projectile hurled upwards was moving 'unnaturally'.

A second tradition, the magical, provided a scientific framework in which the world of nature was seen as a work of art. (I use the word 'magical' in preference to 'aesthetic' because it suggests the overtones of mystery which I think were involved.) The appropriate analogies and the language of the scientist derived from a view of nature in which beauty, contrivance, surprise and mystery were seen as its dominant characteristics. Within this general framework, however, there was room for an immense variety of emphasis. Some interpreters turned to mathematics, and to a world which was presumed to lie beyond the constant change of the observable world. Others saw the role of the interpreter of nature as akin to that of the magician, whose possession of the secrets of nature brought him power.

Within the magical tradition, the Christian deity took on some of the attributes thought appropriate to a magician or artist, and the scientists who worked on these lines saw themselves as following the creator's example and, by the pursuit of clues in the world of nature, gaining an insight into the 'divine artist's' mind.

The third tradition rested upon a view of nature in which the dominant analogy was the machine. What struck scientists who worked within this framework was the regularity, permanence and predictability of the universe. The planets were seen in mechanical terms, as were also the human body, the animal kingdom and even the processes of artistic creation. From this point of view, the Christian God took on some of

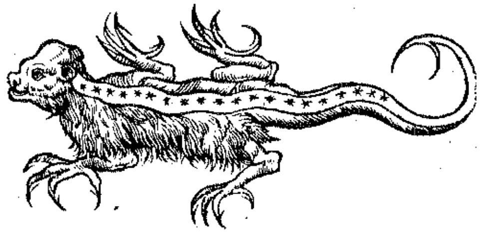


Figura prior ad viuum expreſſa eſt. altera verò quæ ſtellas in dorſo gerit, in libris quibuſdam publicatis reperitur, conficta ab aliquo, qui ſalamandram & ſtellionem à ſtellis dictum, animal vnum putabat, vt coniicio. & cùm à ſtellis ſtellionem dictum legiſſet, dorſum eius ſtellis inſignire voluit.

the characteristics of an engineer. Mechanists concentrated upon those aspects of the world which were most easily explained in mechanical terms. Questions which were thought marginal within the organic and aesthetic traditions, such as problems of acceleration, took on a new significance within the mechanistic framework. The concept of unchanging scientific laws, expressible in mathematical terms, was of particular importance in this tradition and a mathematical approach came to be its dominant characteristic.

In historical terms we may think of the magical tradition as being a reaction against the organic tradition, and the mechanical as a reaction against magic. But it must be said that within each tradition there were sub-groups and distinctive schools of thought. What we have done in effect is to construct three models or paradigms which explain many aspects of the course of the Scientific Revolution, but, as we will see, each tradition was related to some aspect of Greek thought, the organic tradition to Aristotle, the magical tradition to neo-Platonism and the mechanist tradition to the atomists and Archimedes.

The organic tradition

The organic tradition in science rested upon a threefold base of Aristotle, Galen and Ptolemy – and of these the greatest was Aristotle. Aristotle's biological treatises, Galen's medical observations and Ptolemy's great astronomical corpus, the *Almagest*, provided a mass of empirical data which was unrivalled over a thousand years after it had been produced. The sheer bulk of this work gave confidence to scientists within the organic tradition and made it possible for them to dismiss objections as marginal. If we look at the Aristotelians through Galileo's eyes we see a group of simple-minded theorisers. In their own estimation, which was not without justification, they were the empiricists.

Aristotle's own empirical treatises, notably the *Natural History of Animals*, showed powers of patient observation combined with a healthy distrust of excessive theorising. To the influence of this aspect of Aristotelianism was added the empiricism which Galen displayed in his anatomical treatises. Ptolemaic astronomy may also be regarded as the record of observations made in a celestial laboratory, where the 'experiments' were repeated endlessly under the same conditions.

But the organic tradition was something more than a collection of scientific observations. It was also a philosophical system, extending into metaphysics, ethics and logic, which within most European universities during most of our period (1500-1650) was thought to provide the only acceptable synthesis of human knowledge, even though it might be open to modification in detail. Thus the organic tradition served two inter-connected purposes; it was a source of scientific information and it provided a pattern of intellectual coherence.

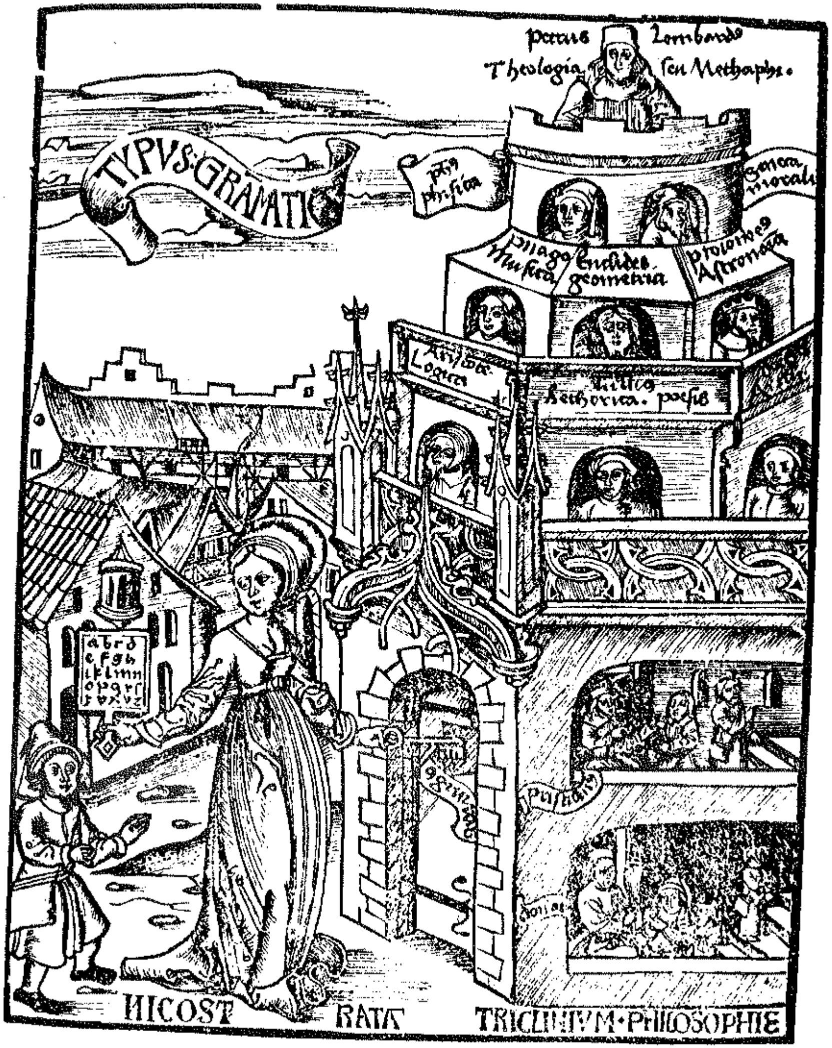
Aristotelian science, as expounded in countless text books

of the sixteenth and seventeenth centuries, stressed the role of purposive development in the world. Change was a constant feature in nature but it was change controlled by the end in view (or final cause). In this emphasis we may see the impact of Aristotle's own biological researches, which he used as the key to other sciences. In Aristotelian science the dominant analogy was provided by natural growth, which, in Aristotelian terms, was movement directed towards an end. Aristotelians saw this process repeated throughout nature, not merely in living things but in the movement of inanimate objects and in 'chemical' change.

This was not entirely an academic point. Aristotle looked upon his scientific approach as a conclusive answer to the mechanistic assertions of Democritus. Galen, five centuries later than Aristotle, had also attacked the mechanism of his contemporaries. Thus from the first the organic tradition was a series of entrenched theoretical positions, which were anti-mechanist in spirit. We can understand the renewed appeal which this made in the sixteenth century when Greek mechanistic doctrines enjoyed a new lease of life and threatened the basis of Christian belief in providence.

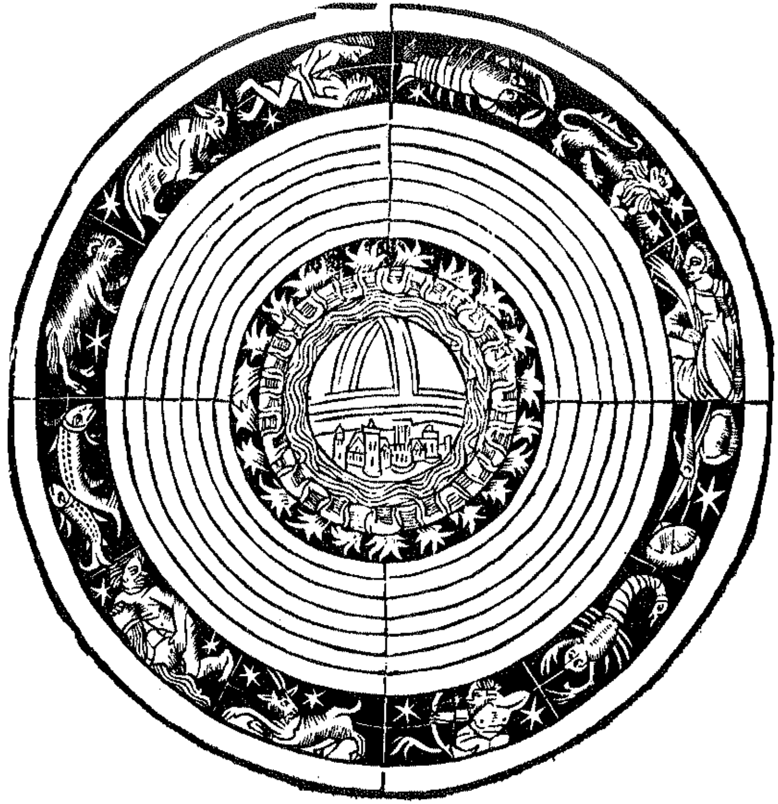
Aristotelian theories of physics and of chemical change were bound up with Aristotelian cosmology. The earth was at the centre of the universe and around it revolved the planets and the sun, each in their sphere. There was an absolute up and down and there was also a complete division between the lunar world and the sub-lunar world, each of which had its own physics and its own 'chemistry'. In the lunar world, the planets moved in circular orbits and their composition was of an incorruptible element. In the sub-lunar world, change was a constant feature, motion was rectilinear and matter was composed of four elements.

Two of the three liberal arts, Grammar and Logic, which, with Rhetoric, formed the trivium. In the medieval world this was regarded as the educational foundation leading eventually to theology. The tower in the illustration below shows the gradation from the liberal arts to divine truth. The role of logic is suggested in the illustration on the right, 'Typus Logice'. Armed with an axe and a sword, symbolising the techniques of question and



syllogism, the student makes for a wood of opinion. He steps gingerly through a morass of fallacies, following the two hounds truth and falsehood. In the wood, various schools of thought are also indicated (e.g. Occamists and Thomists). These illustrations from an early sixteenth-century book *Margarita Philosophica* show how influential scholasticism was *c.* 1500–1600.

The Pre-Copernican universe, showing the earth at the centre, with Aristotle's four elements, Earth, Air, Fire and Water, surrounded by the spheres of the planets and the sphere of the fixed stars. From *Practica compendiosa artis Raymond Lull* (1523).

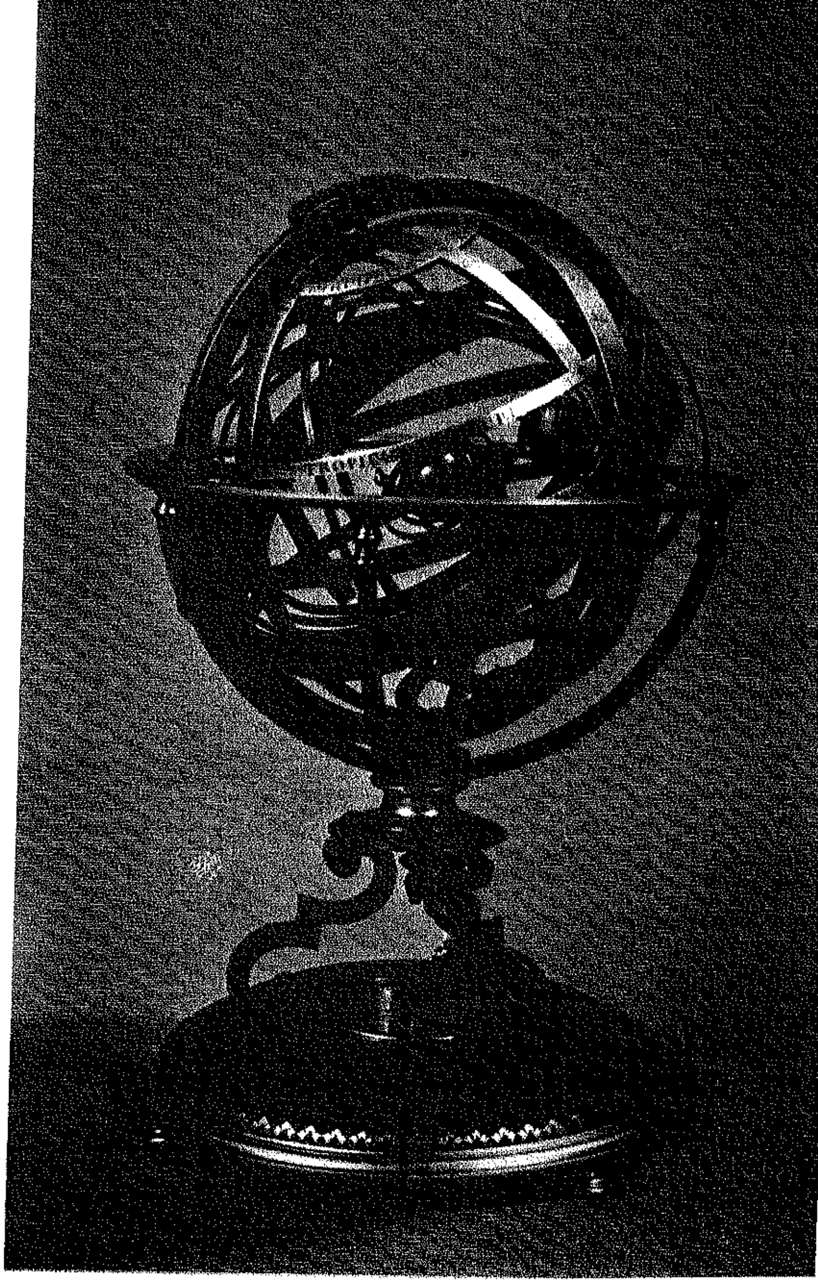


It is easy to dismiss this picture as fanciful, but we must try to understand the reasoning which lay behind it. The astronomical observations of Ptolemy's *Almagest* supported the view that the planets moved at varying speeds in circular orbits, with the earth at the centre of the cosmos. Ptolemy in 1500 could be quoted in support of Aristotelianism, not in poetic terms but as the source of the most advanced astronomical observations available. Aristotelians used this technical information as support for their philosophical principles by which the circular motion of the planets, eternal and unchanging, was perfect motion, to be contrasted with the limited rectilinear and hence imperfect motion of bodies on earth.

Within the imperfect sub-lunar world, different scientific principles operated. From Empedocles onwards (*c.* 450 BC) the world of matter was assumed to be composed of four elements, earth, air, fire and water, two of which were 'heavy' (earth and water) and two 'light' (fire and air). On this basis, the Aristotelians explained both 'physics' and 'chemistry'. Motion was the movement of heavy or light elements to their natural place in the universe. Objects in which earth or water were predominant moved downwards, whereas the contrary occurred with fire and air (e.g. smoke, clouds etc.). This conclusion rested upon rudimentary observation. It also fitted in with the Aristotelian view that movement towards an end was the dominant feature of the universe. A falling body fell at increasing speed because it was 'seeking' its natural position. It fell in a straight line because this was the form of limited motion appropriate to an imperfect world.

Aristotelians did not exclude mathematical considerations from their general explanation of falling bodies. Following Aristotle himself, most of them took the view that the speed of a falling body was proportional to its weight, hence lead fell many times faster than a feather. Experiments in water 'proved' the point with some justification, experiments in air were more ambiguous. From the fourteenth century, some Aristotelians, such as the Frenchman Oresme (+ 1382) tried to discuss the behaviour of falling bodies in geometrical terms.

The 'difficult case' for Aristotelian theory was the behaviour of a projectile which followed a course of 'unnatural' motion against its 'natural' proclivity to return to earth. This was explained by most Aristotelians as the effect of the movement of the air. From the fourteenth century more sophisticated analysts explained it in terms of a quality ('impetus') which the projectile acquired and gradually lost.



An armillary sphere was a skeleton celestial globe. The one shown here illustrates the Copernican planetary system. It was made for Robert Boyle's nephew, Charles Boyle (1676-1731) fourth Earl of Orrery. Hence the name 'Orrery' often given to such spheres. By 1700 in England Copernicanism was universally accepted.

The four elements, earth, air, fire and water, provided the key within the organic tradition to the composition of matter. Here, as in physics, Aristotle's emphasis was anti-mechanist. In defending the existence of four elements, Aristotle refuted those who believed in a single element composed of mechanically interacting atoms. Aristotelians explained chemical change in terms of a changing composition of the four elements in a substance. (Thus charcoal on this view had lost much of its 'air' and hence had a higher 'earth' content than wood). But material change was not the only factor. It was accompanied by a change of 'substantial form', i.e. the qualities ('form') of wood were different from those of charcoal. Thus even in chemical change where only inanimate objects were concerned there was 'purposive' development in the transition from one form to another. Aristotelian emphasis on substantial form and qualitative difference ruled out the possibility of a mechanical explanation of chemical change. Even in physics 'impetus' was regarded as a quality possessed by a projectile.

Although we must admit that there was a hard core of empirical data at the centre of Aristotelianism, the fact remains that Aristotle and his followers could not resist systematising and generalising on a slender basis. The accepted instrument for such reasoning was the syllogism, which in its simplest form appeared as: 'All men are mortal, Socrates is a man, Socrates is mortal.' Using this, and elaborations of it, Aristotle constructed a philosophical system which is either imaginative or fanciful according to one's point of view. It led him to elaborate on the destruction between circular and rectilinear motion in the following way:

It can now be shown plainly that rotation is the primary locomotion. Every locomotion, as we said before, is either rotatory or rectilinear or a compound of the two: and the two former must be prior to the last, since they are the elements of which the latter consists. Moreover, rotatory locomotion is prior to rectilinear locomotion because it is more simple and complete, which may be shown as follows. The straight line traversed in rectilinear motion cannot be infinite: for there is no such thing as an infinite straight line; and even if there were, it would not be traversed by anything in motion: for the impossible does not happen and it is impossible to traverse an infinite distance. On the other hand, rectilinear motion on a finite straight line is, if it turns back a composite motion, in fact two motions, while if it does not turn back it is incomplete and perishable: and in the order of nature, of definition, and of time alike the complete is prior to the incomplete and the imperishable to the perishable. Again, a motion that admits of being eternal is prior to one that does not. Now rotatory motion can be eternal: but no other motion, whether locomotion or motion of any other kind, can be so, since in all of them rest must occur, and with the occurrence of rest the motion has perished. Moreover, the result at which we have arrived, that rotatory motion is single and continuous, and rectilinear motion is not, is a reasonable one. In rectilinear motion we have a definite starting-point, finishing-point, and middle-point . . . On the other hand, in circular motion there are no such definite points: for why should any one point on the line be a limit rather than any other? Any one point as much as any other is alike starting-point, middle-point, and finishing-point.[1]

The universal application of this type of reasoning, together with Aristotelian emphasis upon substantial forms and final causes, was the chief target for attack in the seventeenth century. Its critics complained that Aristotelianism in explaining everything, explained nothing. In defence it must be said that in 1600 there was no comparable system of scientific explanation. Aristotelianism provided a framework of discussion and a target to aim at. This paradigm with all its faults

was better than no paradigm at all. Not until Descartes wrote his *Principia Philosophiae* (1644) was there an alternative.

Though Aristotle was not a Christian, and much of his teaching (e.g. the eternity of the world) was unacceptable to the Christian church, he had become by 1500 the dominant intellectual influence upon theology. Aristotelian terms such as substance and accident, or matter and form were used to explain Christian teaching on the Eucharist (e.g. transubstantiation), and the Aristotelian emphasis upon final causes helped to elucidate the operation of God in the world of nature. The god of the theologians, if not the Bible, was a deity whose mind was revealed in the purposive working of the universe. God was a logician whose premises could be scrutinised and his nature examined. The very working of divine grace was open to logical analysis. In this emphasis on purpose and logic, Aristotelian science and scholastic theology marched together.

Thus over and above all considerations of the intellectual and scientific calibre of Aristotle, Galen and Ptolemy, and the emotional satisfaction of explaining all natural phenomena, the strength of the tradition during our period lay in its close association with religious orthodoxy. In all Catholic and most Protestant universities during much of the sixteenth and seventeenth centuries, scholasticism gained ground. The organic tradition was in power, so to say, backed by the resources of church and state and strongly entrenched in the universities. The two rival traditions operated at the margin, under pressure if not persecution.

Despite the entrenched position which they enjoyed within the establishment, the Aristotelians could not suppress all criticism and they found themselves attacked on several crucial issues – the geocentric theory of the universe, the im-

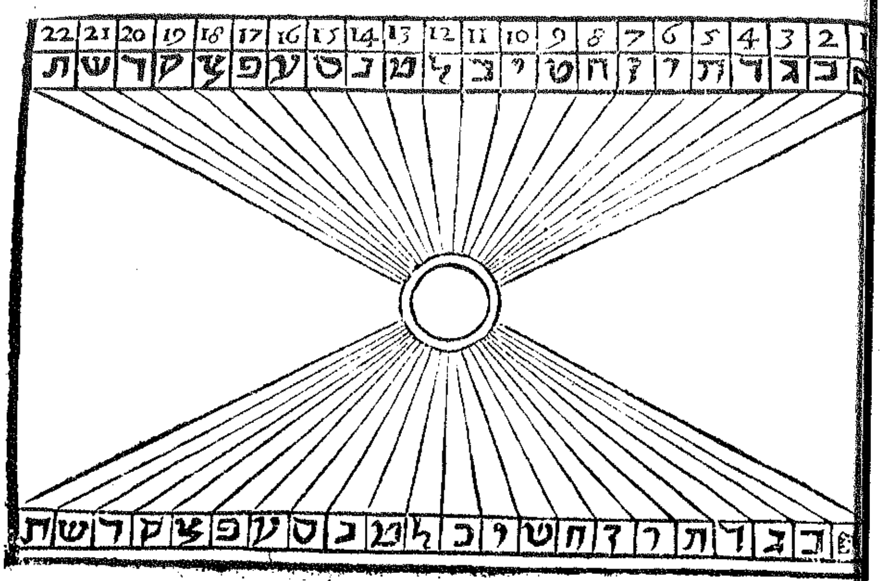
This mosaic of Hermes Trismegistus, dating from the 1480s, is to be found in the cathedral at Siena. It bears witness to the strange vogue which Hermetic ideas enjoyed during the Italian Renaissance. Trismegistus, seen here with Moses (?) and an Egyptian personage, is described as the contemporary of Moses. For someone who never existed, he had an extraordinary hold on contemporary minds.

possibility of a vacuum and the course taken by a projectile. In all three instances, empirical observation showed Aristotelian theory to be wanting. If we ask why these issues came up rather than others, the answer is that Aristotle's deductive reasoning was particularly extended at these points and the divergence between theory and practice was most startling. If we ask why they came up at this time and not earlier, the key factor seems to be the availability of alternative scientific paradigms, themselves derived from Greek sources and thus as worthy of respect as Aristotle – the magical and mechanistic traditions. From within these new paradigms certain aspects of Aristotelianism seemed more open to criticism than others.

The magical tradition

The role of the scientist within this intellectual framework was to become attuned to the message of the universe and to be something of a magician, whereas the organic scientist was close to being a logician. God was a magician, a wonder-worker, not the rational first mover of Aristotle, and the best model for the scientists to follow was to become a mystic who could hear the magical music of the universe.

Much of the inspiration for this attitude came from the writings attributed to an ancient and mysterious Egyptian figure Hermes Trismegistus. Trismegistus (thrice blessed Hermes), who never in fact existed, was thought to be the author of over a dozen treatises (The Hermetic Writings) which claimed to expound the wisdom of the Egyptians during the period of Moses. The treatises first became available to the West after the fall of Constantinople (1453) and they were translated from the Greek by Marsilio Ficino (1433-95)



This illustration from Bruno's *Art of Memory* (1583) provides an example of the workings of the Magical Tradition. Bruno believed that the human mind 'reflected' a divinely ordered universe in such a way that the magus could tap the hidden powers of the universe. The illustration suggests that the light emanating from 'the centre of the universe' is linked in some mysterious way with the Hebrew alphabet (i.e. the Cabbala) and numbers (the mysticism of numbers).

as a matter of urgency by order of Cosimo de Medici, who wished this task to be given precedence over the translation of Plato himself. From then onwards, until well into the seventeenth century, they exercised a powerful fascination over the western mind.

It is easy to see the reason for the influence of the Hermetic tradition. In Trismegistus, the Christian Church now had a source of wisdom which went back (or at least was believed to) beyond Plato to the original Mosaic revelation. Trismegistus was thought to have been the recipient of divine revelation about the physical world, as Moses had been about the moral world. From this point of view, the Egyptians were seen as the custodians of secular wisdom, as the Jews were of sacred wisdom. Hitherto, (it had been thought), the Greeks, in the persons of Pythagoras and Plato, had been the only source of access to Egyptian lore, and the West had only known it at second hand. Now, towards the end of the fifteenth century, the Egyptian treatises were available (or seemed to be) in their original form.

What was the message of the Hermetic writings? Among other things, they taught that the sun was the centre of the universe, round which the earth revolved. Light was the source of life. The sun was a symbol of the Godhead. The Hermetic treatises also incorporated certain Pythagorean assumptions, which stressed a mathematical harmony in the cosmos. The secrets of the cosmos had been written by God in a mathematical language, which could be discerned, for example, in musical harmonies.

The Hermetic writings provided the basis for a view of the cosmos which had implications for science and scientific method. It was a world full of magical powers, the secrets of which were open only to the chosen few who were willing to look beyond surface phenomena. The explorer of nature was an ascetic, studying the occult, within the confines of an esoteric community. The watchwords of this approach were mysticism, mystery and secrecy. There was thus a sharp contrast between the Hermetic and the Aristotelian 'scientist'.

Thanks to the work of the great classical scholar Isaac Casaubon (1559-1614), who first dated the Hermetic writings accurately, we now know that they originated in the second century AD. They belong in fact to the movement of mysticism and philosophy, known as neo-Platonism, founded by Plotinus (AD 205-270) and carried on by Porphyry (AD 232-303). Plato himself regarded the material world as 'unreal' (true reality lay in the unchanging world of forms) and Plotinus used this approach as the starting point for a philosophy in which the material world was the last and lowest form of being. Under the influence of Eastern mysticism, Plotinus believed that the source of being was 'the One' from which derived a trend of emanations, life, mind and soul, and finally, matter. For the neo-Platonist the human soul was spirit encased in matter, *Overleaf* Two illustrations from Thomas More's *Utopia* (1515-16). It was in no sense a scientific treatise, but his life of Pico della Mirandola (1510) links him interestingly with the neo-Platonism of the Renaissance. The *Utopia* may be seen against this intellectual background, though this is not the only profitable perspective. The interest of the illustration on the left lies more in what it anticipates than in itself. In the seventeenth century, John Wilkins, among others, played with the notion of an artificial language which would be free from the traps of ordinary discourse as described by Bacon in the *New Organon*.

whereas for the Aristotelian it provided 'form' to 'matter'. The neo-Platonic soul was imprisoned in the material world; the Aristotelian soul was an informing principle.

The late fifteenth century was marked as we have suggested earlier by a reaction against Aristotelian rationalism and its technicalities. The Hermetic Writings were only one among several treatises which were permeated with neo-Platonic influences. They included the Jewish Cabbala (literally – 'tradition'), which claimed to reveal the hidden secrets of the Old Testament by the use of ciphers. Among these 'secrets' was the neo-Platonic doctrine of the creation of the world by means of emanations from the Divine Being. In this atmosphere, the figure of Pythagoras took on a new significance, as the model of a mathematician who sought and found mystical combinations of numbers. Mathematics in this new view offered the key to a world of unchanging realities, close to, if not identical with, the Divine Mind. The pursuit of mathematics was not a secular activity. It was akin to religious contemplation. For Aristotelians, on the other hand, mathematics ranked low as an intellectual pursuit and had no religious connotation.

If neo-Platonism had remained the obsession of a few eccentric thinkers, there would be little point in discussing its significance in a book on the Scientific Revolution. In fact however the neo-Platonic approach made an enormous impact upon the intellectual world of the sixteenth century. It may be seen in More's *Utopia*, in the work of Pico della Mirandola and not least in the writings of Copernicus and Kepler. In the seventeenth century its influence extended to the Cambridge Platonists (more properly, the Cambridge neo-Platonists) and their greatest pupil, Sir Isaac Newton.

The neo-Platonic theory of matter offered an exciting alternative to the prevailing Aristotelian orthodoxy of the four elements. Matter, for the neo-Platonist, was a link with the world of the spirit. Neo-Platonists held that the mineral and vegetable kingdoms offered reflections of spiritual realities. The 'microcosm' of this earth was believed to reflect the 'macrocosm' of greater reality. Here chemistry took on a quasi-religious aura which acted as an emotional stimulus towards novelty. Paracelsus for example, applied the neo-Platonic trend to chemical theory and the same approach may be seen in his seventeenth-century successor, Van Helmont (see page 126).

To men with imagination, the message of neo-Platonism offered a heaven-sent escape route from the rationalism of academic Aristotelianism. This was the sixteenth-century equivalent of Romanticism. Indeed we could do worse than look upon Shakespeare's *The Tempest* as an illustration of the appeal possessed by the Hermetic tradition. Prospero was the ideal type of the Hermetic scientist bringing justice and peace to a disturbed world, an approach which had great appeal in a century torn by religious bitterness.

The mechanist tradition

The magical tradition reached the peak of its influence at the end of the sixteenth century. From then on a reaction set in against it based upon a mechanistic view of the universe and propagated during the next century in the work of Mersenne, Hobbes and Descartes.

If we seek an origin for mechanism we may first consider the economic background of the period. There is a tempting connection to be made here between the increased use of machinery in the world of the sixteenth century and the mech-

VTOPIENSIVM ALPHABETVM.

a b c d e f g h i k l m n o p q r s t v x y

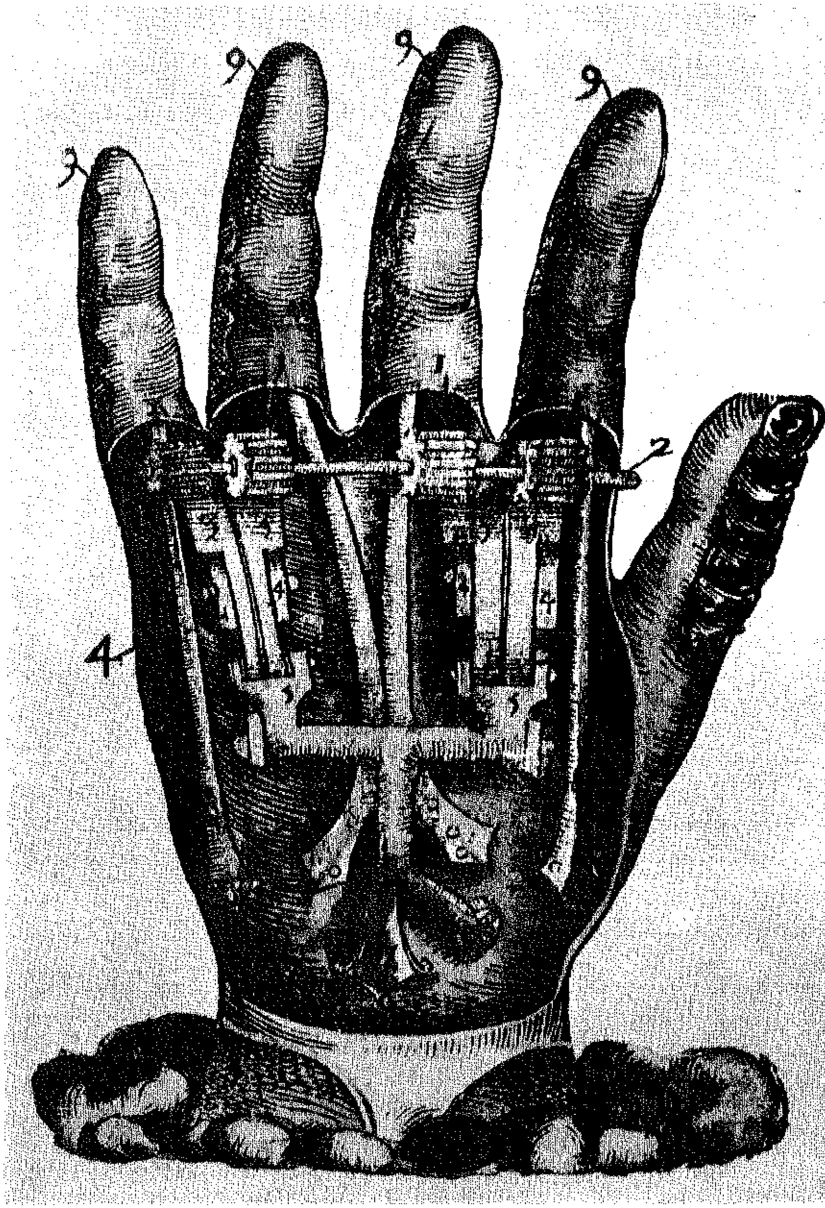
Tetrastichon vernacula Vtopiensium lingua.

Vtopos ha Boccas peu la
chama polta chamaan
Bargol he maglomi baccan
soma gymno sophaon
Agrama gymnosophon labarembacha
bodamilomin
Voluala barchin heman la
lauoluola dramme pagloni.

Horum versuum ad verbum hæc est sententia.

Vtopus me dux ex non insula fecit insulam
Vna ego terrarũ omnium absq; philosophia
Ciuitatem philosophicam expressi mortalibus
Libẽter impartio mea, nõ grauatim accipio meliora.

VTOPIAE INSVLAE FIGVRA

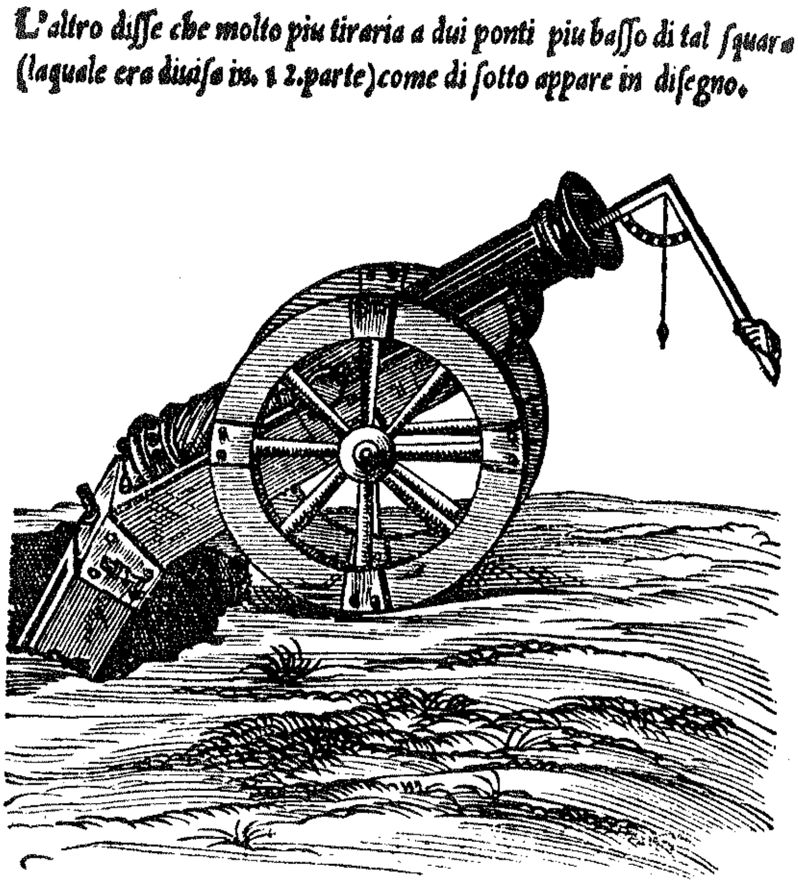


The beginnings of the mechanistic tradition in medicine. An artificial hand worked by machinery, from Ambroise Paré (1510-90) *Instrumenta Chyrurigiae et icones anatomicae* (1569). Paré was a prolific writer on surgical questions.

anical analogies to which Galileo and Mersenne turned. The American historian John U. Nef (1940), argued that there was an 'industrial revolution' in France and England during the sixteenth century and other historians have drawn attention to the economic importance of Venice and the influence of this upon the neighbouring university of Padua. For a Marxist, indeed, this attractive analogy assumes the status of self-evident truth, according to which the mechanistic view of the universe reflects the mechanically dominated economy of the early modern period.

It is worth considering, however, that the machine was no new phenomenon in western Europe and the kind of machines with which the sixteenth century was familiar were not revolutionary in design or concept. The most characteristic machines such as the windmill, the sailing ship and the wind pump used a source of power which had long been familiar to the West. The most radical machine was the cannon, a weapon of war, but hardly mechanical in its inspiration. In a sense the cross bow was more typically a machine, and this would bring us back to the thirteenth century. Nicolas Oresme (d. 1382) used scientific analogies based on the clock. In short, mechanical analogies were available to natural philosophers well before the end of the sixteenth century. What is needed is an explanation why at this time Galileo and his successors should seize upon a mechanical analogy as particularly appropriate.

The answer seems to lie in the revival of Archimedean science during the course of the sixteenth century. Archimedes (287-212 BC) was the greatest Greek mathematician. He was fascinated by mechanical analogies, as for example in his analysis of the lever, though the machines he conceived were designed for ornament and interest, not practical use. For



some sixteenth-century scientists, the works of Archimedes provided information about an aspect of Greek science which was neither Aristotelian nor Platonic.

There was an immense gap between the approach of the magical tradition and the detached intellectual curiosity of Archimedes. The Archimedean tradition was that of the mechanical engineer. It was not esoteric, it was not obsessed with the occult and it was not searching for mathematical

The sixteenth-century Italian engineer Niccolo Tartaglia (d. 1557) was one of the precursors of the mechanistic tradition in science. This drawing shows the application of geometric analysis to artillery projectiles.

harmonies of a religious significance. All this came as a novelty in the sixteenth century, though the works of Archimedes were known in manuscripts to a few medieval intellectuals in Latin translation. But the appearance of a printed edition in the mid sixteenth century was the real turning point.

The most important Archimedean of the early sixteenth century was Niccolo Tartaglia (1499-1557) who published the first Latin edition of Archimedes in 1543. This was followed by another version, Commandino's, published in 1575. Tartaglia himself was interested in problems with a practical bent, such as the trajectory of projectiles, a problem which had devastating implications for Aristotelian physics though Tartaglia himself did not raise them. Tartaglia was interested essentially in the principles of machines, an interest which was carried forward into Galileo's day by the *Liber Mechanicorum* (1577) of Guidobaldo, mathematician and patron of Galileo. The Archimedean revival, stretching from Tartaglia up to Galileo and beyond, laid the basis for a mathematical approach in which the world was open to measurement and analysis. In this tradition, numbers did not possess the mystical appeal that they did for the Platonists and neo-Platonists.

If mechanism was a reaction against magic, it was equally a reaction against the organic tradition. It was impossible to look upon the universe as a machine and to leave intact the existing Aristotelian assumptions about the nature of God, Christian revelation, miracles and the place of purpose in the world. The mechanist assumption was that the universe operated on the basis of mechanical forces, and, as Mersenne explicitly put it, God was the Great Engineer. Thus the task of the scientist was to explore the inter-relationship of the various parts of the universe, on the assumption that they would fit together like those of a machine.

These were then the three main intellectual traditions which are relevant to the study of Scientific Revolution, each with their own assumptions about God, Nature and scientific method. Inevitably the picture has been over-simplified. There were differences of emphasis within each tradition and there were variations in the course of time. Nevertheless, if we see the history of science in terms of three traditions, we will in some measure escape from the dangers of the Whig interpretation of the history of science. We are now more likely to think in terms of several scientific methods than of a single one. And we will certainly place less emphasis upon rational assumptions. Indeed, judged by rational criteria the magical tradition appears to be the least rational of the three; yet judged by its contribution to the Scientific Revolution, we may see it as the most important.

4 The mysterious universe

Copernicus

During the sixteenth century, the tradition of magic and art introduced a distinctive dimension to science which may be seen in the growing importance attached to mathematics, astrology, astronomy and chemical analysis. It was from within this tradition that the first radical criticisms were made of the geocentric theory of the universe, which centuries of Aristotelian dominance had turned into orthodoxy. During the fifteenth century, the voice of Nicholas of Cusa (1400-64), cardinal and theologian, had been raised in the Platonist cause, but the first decisive steps were taken by the astronomer Nicholas Copernicus (1473-1543).

The history of modern science is normally taken to begin with Copernicus and the grounds for the judgment are substantial. Copernicus rationalised the Ptolemaic cosmology by placing the sun at the centre of the universe, with the earth moving round it in an annual revolution. In addition to this, Copernicus argued that the earth rotated on its axis every twenty-four hours. Thus the difference between day and night was no longer explained on the basis of a cosmology, according to which the sun and the planets revolved around the earth each day.

This was certainly a revolutionary step, but Copernicus did more than assume it as a general proposition. He carried its implications into a re-assessment of the mass of astronomical observations which were available in Ptolemy's *Almagest*. His achievement was an extraordinarily imaginative detailed working out of original assumptions, performed by a mathematician of very high competence. In short it was not simply a poetic vision, though it was that; it was also a piece of technical mathematics.

In many respects, Copernicus seems a most unlikely person to have taken such a radical step. He was born in the frontier regions between Germany and Poland at Torun (in German, Thorn), where urbanisation had made little progress and where, we might assume, the pursuit of scholarship was unlikely to flourish. His nationality was Polish, or German, or both, a problem which gave rise to difficulty during the Second World War when the fourth centenary of his book was celebrated (1943). Copernicus himself was the nephew of a bishop and, though he himself never became a priest, he enjoyed ecclesiastical preferment which enabled him to follow a life of leisure. He was, in fact, a gentleman, albeit one of recent origin.

In astronomy, Copernicus found the leisured occupation par excellence. He himself made few astronomical observations. He was content to deal with mathematical calculations on the basis of observations made by others, and in this we may see him as thoroughly within the Greek intellectual tradition, uninterested in the practical world. From 1512 until his death in 1543 Copernicus was canon of the cathedral at Frauenburg. He had no ecclesiastical duties and he was able to follow a life of secluded study, in contrast to the semi-military activities of his fellow canons. Copernicus was a classic case of the isolated intellectual, cut off from society, enclosed within the walls of the cathedral grounds, remote from the pursuits of his fellows and part of a social unit which was in its turn isolated from the society around it.

Copernicus's devotion to astronomy appears against this background as a form of retreat from the demands of the 'real' world. He was not a professor and he never became one. Astronomy of this kind was a form of scientific asceticism, a sixteenth-century equivalent of the life of the hermit. (Indeed

The Copernican system of the universe from *Harmonia Macrocosmica* (see the caption on page 9).

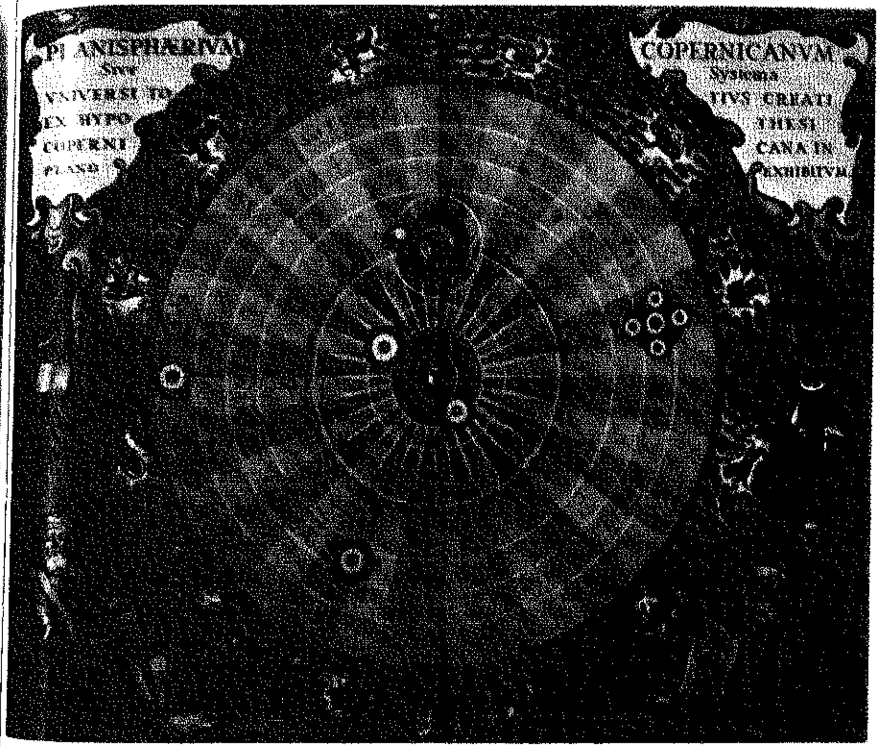
Pythagoreans like the Florentine Toscanelli were literally ascetics.)

But his isolation in Poland is not in itself sufficient to account for his revolutionary outlook. The explanation for this must be sought in the ten years which he spent in Renaissance Italy. After four years' student life at the university of Cracow, Copernicus left for further study at the universities of Bologna and Padua. It was in Italy that he came under the influence of neo-Platonism, an influence revealed in a letter attributed to Pythagoras which he translated and which stated: 'it is not permitted to let ordinary men into the sacred mysteries of the Elysian goddesses'.[13]

This and other pieces of evidence show that the Renaissance by which Copernicus was influenced was the Renaissance of Ficino and the Florentine academy. Perhaps we should see his introduction to neo-Platonism as the equivalent of a religious conversion.

The link with neo-Platonism was provided by Copernicus's associate and teacher at Bologna, Domenico Maria de Novara who knew the Florentine neo-Platonists and who translated Proclus and Hermes Trismegistus. Proclus (AD 412-85) attributed a mystical value to mathematics:

> The soul [of the world] therefore, is by no means to be compared to a smooth tablet, void of all reasons, but she is an ever-written tablet, herself inscribing the characters in herself, of which she derives an eternal plenitude from intellect . . . All mathematical species, therefore, have a primary subsistence in the soul, so that before sensible members there are to be found in her inmost recesses, self moving members; vital figures, prior to the apparent; ideal proportions of harmony . . . here we must follow the doctrine of Timaeus, who derives the origin and consummates the fabric of the soul, from mathematical forms . . .[14]



Neo-Platonic emphasis upon the sun may also be seen in a quotation from Marsilio Ficino:

> Nothing more reveals the nature of the Good (which is God) more fully than the light (of the sun). First light is the most brilliant and clearest of sensible objects. Second, there is nothing which spreads out so easily, broadly, or rapidly as light . . .
> Just look at the skies, I pray you, citizens of the heavenly fatherland . . . The sun can signify God himself to you, and who shall dare to say that the sun is false.[15]

Finally, a quotation from Copernicus which explicitly mentions Trismegistus:

> In the middle of all sits the Sun enthroned. In this most beautiful temple could we place this luminary in any better position from

which he can illuminate the whole at once? He is rightly called the Lamp, the Mind, the Ruler of the Universe; Hermes Trismegistus names him the visible God, Sophocles Electra calls him the All-seeing. So the sun sits as upon a royal throne ruling his children the planets which circle around him.[16]

The link between modern science and the Renaissance has often been discerned. Butterfield, among others, stressed the importance of the close natural observation which Leonardo undertook. Others have drawn attention to the mathematical expertise which was involved in an artistic use of perspective. But the kind of Renaissance influence implied in Proclus, Trismegistus and Ficino is of a very different order. Neo-Platonism flourished during the later years of Cosimo de Medici and Lorenzo de Medici. It involved a turning away from involvement in the 'real world' either of politics or of art. The kind of masterpiece which it fostered was Botticelli's *Primavera* with its aura of symbolic magic. This neo-Platonist tradition led towards a mystical reverence for numbers, not a wholesome respect for practical mathematical techniques. It encouraged secrecy and an interest in the occult for its own sake by which a work of art was seen as a magical emblem or a coded message for the initiate. This Renaissance was a world away from the rationalism of Machiavelli, and its full secrets, thanks to the work of Wind and others, are only now being revealed.[17]

This was the background of Copernicus. Indeed Rheticus thought that Copernicus delayed publication of his work to preserve its secret for the favoured few, so that: 'the Pythagorean principle would be observed, that philosophy must be pursued in such a way that its inner secrets are reserved for learned men trained in mathematics'.[18]

The neo-Platonic background of Copernicus also explains why his theories were almost universally rejected through the sixteenth century. Only the neo-Platonists accepted Copernicus without reserve. Edward Rosen has listed those of the religious establishment who spoke out against the apparently absurd notion that the earth went round the sun. The reaction to Copernicus from the world of orthodoxy, both Catholic and Protestant, was hostile. Even before Copernicus's treatise had been published, Luther reacted violently to rumours about it. Luther, who was nothing if not biblically minded, said:

That is how things go nowadays. Anyone who wants to be clever must not let himself like what others do. He must produce his own product as this man does, who wishes to turn the whole of astronomy upside down. But I believe in the Holy Scripture, since Joshua ordered the sun, not the earth, to stand still.[19]

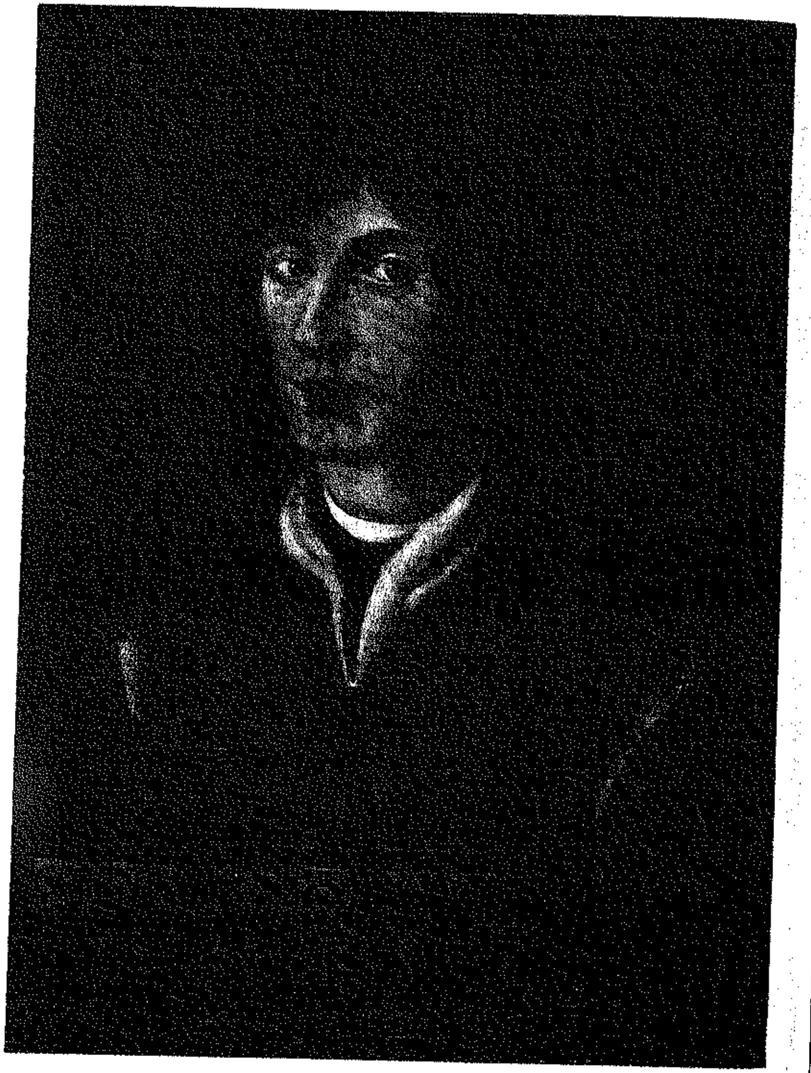
Melanchthon, who was much more of an Aristotelian than Luther, made similar criticisms ten years later, in 1549:

Out of love for novelty or in order to make a show of cleverness, some people have argued that the earth moves. They maintain that neither the eighth sphere nor the sun moves. Whereas they attribute motion to the other celestial spheres, and also place the sun among the heavenly bodies. Nor were these jokes invented recently. There is still extant Archimedes' book on *The Sandreckoner* in which he reports that Aristarchus of Samos propounded the paradox that the sun stands still and the earth revolves around the sun.

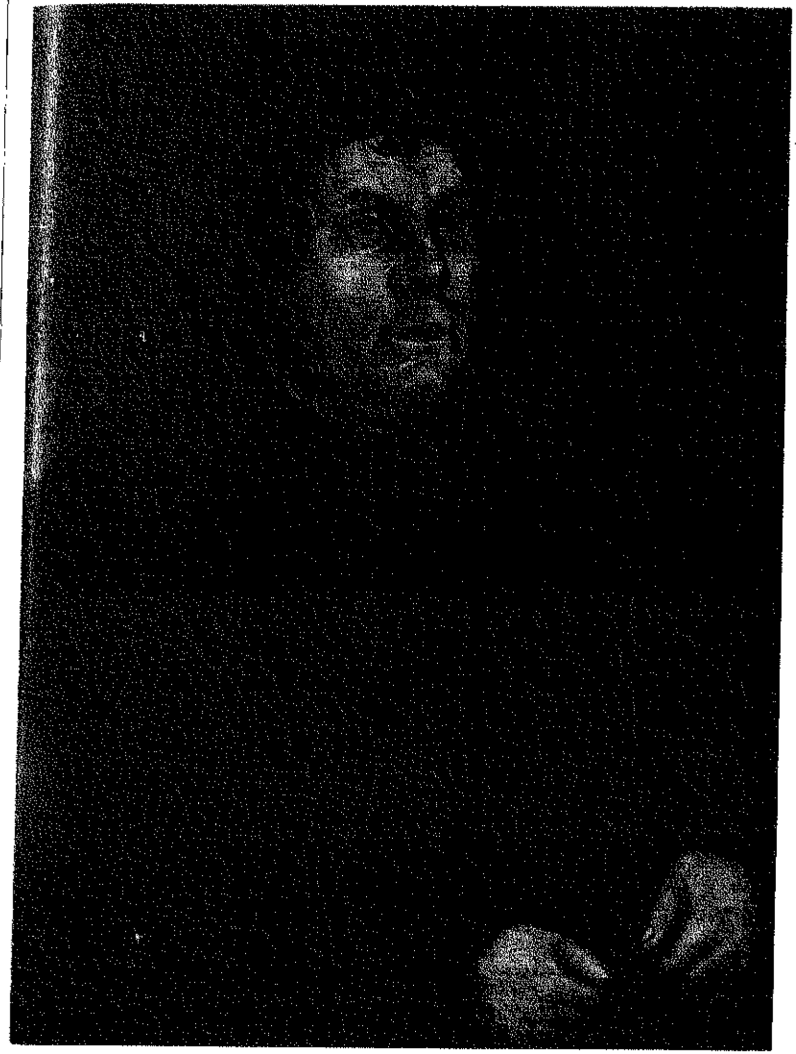
Even though subtle experts institute many investigations for the sake of exercising their ingenuity, nevertheless public proclamation of absurd opinions in indecent and sets a harmful example.[20]

Professor Rosen lists several other examples in the late sixteenth century, including Robert Recorde, author of *The Castle of Knowledge*, the standard textbook on astronomy in

'The most famous and most learned doctor, Nicolaus Copernicus, incomparable astronomer'.



R. H. Tawney described Luther's reactions to the economic changes of the early sixteenth century as those of a savage examining a watch which he could not comprehend. Luther's attitude to the theories of Copernicus was much the same.



England. Scaliger and Buchanan both held anti-Copernican views and Jean Bodin, so often cited in textbooks of political thought as a modern, argued that it was impossible for a simple body like the earth to move in the three different ways which Copernicus assigned to it. The same point was made by the most eminent astronomer of the late sixteenth century, Tycho Brahe (1546-1601), when he wrote:

> What need is there without any justification to imagine the earth, a dark, dense and inert mass, to be a heavenly body undergoing even more numerous revolutions than the others, that is to say, subject to a triple motion, in negation not only of all physical truth, but also of the authority of the Holy Scripture which ought to be paramount.[21]

The truth is that within the general range of religious opinion, Catholic, Lutheran and Calvinist alike, the Copernican view was dismissed as an absurdity. All the accepted authorities were against it. The Bible contradicted it expressly. The weight of common sense acted as an additional obstacle. Equally powerful was the fact that there seemed to be no way of proving it. During the sixteenth century the heliocentric view was accepted only within the Pythagorean-Hermetic tradition. On Hermetic assumptions the central place of the sun in the universe seemed axiomatic because it was 'fitting'. On Aristotelian assumptions, the earth was the central point of the universe for exactly the same reasons. And since Aristotelianism was so strongly entrenched in the universities, it was inevitable that Copernicus's views should be rejected in the academic textbooks. Not until Galileo published his *Sidereus Nuntius* (1609), followed up by the *Letter to the Archduchess Christina* (1612) and the *Dialogues* (1632), did Copernicus obtain a champion outside the Hermetic tradition.

Bruno

The intellectual tradition which we have associated with Copernicus survived among a coterie, in the margins of the established educational and religious institutions of the age. It lost ground before the revival of Aristotelianism which followed the Council of Trent. It was attacked on the Protestant side by Thomas Erastus (1524-83). It suffered from the policies of intolerance in the late sixteenth century. In the world of art, the neo-Platonic tradition died the death. There was no Botticelli in the Italy dominated by Philip II. The Florentine Academy ceased to exist. Nevertheless, though it was under pressure, neo-Platonism survived.

The three men who were associated with Italian neo-Platonism during the period 1550-1600 were Francesco Patrizzi (1529-97), Giordano Bruno (1548-1600), and Tomaso Campanella (1568-1639). In 1591 Patrizzi published a large collection of the Hermetic writings with a dedication to Gregory XIV in which he appealed to the Pope to encourage the teaching of Plato and of Platonists like Plotinus, Proclus and the early church Fathers. He himself had lectured on neo-Platonism at the University of Ferrara, but Ferrara was a centre of minor academic importance and Patrizzi's appeal met with only a temporary and limited response and his book was condemned as heretical. He died in his bed in 1597, but the fate of his book was symptomatic of the general intellectual climate of Italy. The tide was running hard in favour of Aristotelianism and a philosopher who pressed the claims of heliocentricism was bound to run into trouble.

The outstanding Italian exponent of the magical tradition was Giordano Bruno, born at Nola, near Naples in 1548, who became a Dominican in 1563. His intellectual precocity led to charges of heresy and he went into exile. He adopted the life of a wandering scholar, and his life recalls that of Paracelsus whom indeed he admired (see page 114). The difference between the two men may be explained by the publication of Copernicus's treatise *De Revolutionibus* in 1543, the year before Paracelsus died. Paracelsus was unaffected by Copernicanism, Bruno was dominated by it.

Bruno was the most enthusiastic exponent of the heliocentric doctrine in the second half of the century. He lectured throughout Europe on it and in his hands Copernicanism became part of the Hermetic tradition. Copernicus had hinted at this, but Bruno drew out the implications, and more, of Copernicus's reference to Trismegistus. Sixteenth-century reaction to the heliocentric doctrine cannot be fully understood without realising that heliocentrism remained within the Hermetic tradition until Galileo. Bruno transformed a mathematical synthesis into a religious doctrine.

Bruno saw the universe in the same terms as Lull, Ficino, and Pico had done, as a magical universe in which the earth and the stars were alive. Above all, the sun was alive, providing its light as a source of life at the centre of the universe. The task of the philosopher was to make use of the invisible forces which pervaded the universe, a task in which Trismegistus provided the essential key.

Inevitably these views brought him into conflict with the orthodox academics. The most famous of these controversies was his visit to Oxford in 1583 when he lectured to the dons upon the theory of Copernicus and 'many other matters'. Bruno has had historians of science on his side for the most part, for in spite of his eccentricities he seemed to represent 'rationalism'. But a recent discovery places beyond all doubt the fact that for him Copernicanism was part of a new

intellectual system which derived in large measure from Trismegistus and the neo-Platonists. George Abbot in a work published in 1604 described how Bruno

> . . . The Italian Didapper . . . got up into the highest place of our best and most renowned schools, stripping up his sleeves like some jugler, and telling us much of theritrum and chirculus and circumferenthia (after the pronunciation of his Country language) he undertooke among very many other matters to set on foote the opinion of Copernicus that the earth did goe round, and the heavens did stand still; whereas in truth it was his own head which rather did run round and his brains did not stand still. When he had read his first lecture, a grave man, and both then and nowe of good place in that University, seemed to himself, somewhere to have read those things which the Doctor propounded: but silencing his conceit till he heard him the second time, remembered himself then, and repairing to his study, found both the former and later lecture taken almost verbatim out of the workes of Marsilius Ficinus.[22]

This passage tells us as much about Oxford as it does about Bruno. There is more than a hint of irrationalism about the description of the Italian Didapper and his odd, non-Oxonian pronunciation of Latin. The passage also reveals why Bruno's stand on Copernicanism should carry such little weight. It was based upon the pre-Copernican judgments of the Italian humanist Ficino, not upon any new arguments or observations. Not least interesting is the fact that Bruno's critic George Abbot had Puritan sympathies, which makes any close correlation of Puritanism and Science seem too simple. Perhaps Aristotelian logic stood here for rational thinking as against mystical enthusiasm.

Gilbert and magnetism

Bruno's precise contribution to science remains a matter for conjecture, but with his contemporary, the physician William Gilbert (1540-1603), there is no doubt. Gilbert's *De Magnete*, published in 1600, but written *c.* 1580, is the first substantial scientific treatise in English history, as well as being a landmark in the Scientific Revolution. Gilbert's originality lay in undertaking a study of magnetism, a phenomenon which had been known at least since the age of the Greeks, and producing a new theory about its nature, based upon a series of precise and carefully recorded experiments.

Gilbert conducted about fifty experiments to illustrate the nature of magnetism. Much of what he had to say was well known to seamen from common observation of the magnetic compass, for example the fact that the compass needle varied considerably in its declination from the north. Gilbert sought an explanation for this phenomenon after first ridiculing the ideas of recent commentators. Gilbert's main point was that the erratic changes in the behaviour of the needle indicated that local variations in the earth's crust were responsible and not a constant cause such as the stars suggested by Ficino and others. He proved his point by describing an experiment with a spherical lodestone (magnetic iron oxide) which was 'crumbled away at a part of its surface and so had a depression comparable to the Atlantic sea or great ocean'. Several needles were then laid on the lodestone and it was observed that variation occurred at the borderline between the sound areas of the stone and the decayed parts. Gilbert saw in this an appropriate analogy to that which happened on earth.

Gilbert's originality in devising experiments should not be exaggerated. For example, he took over from his contemporary

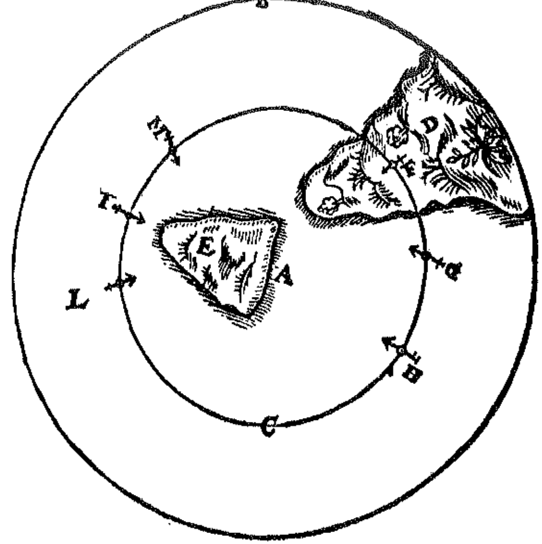
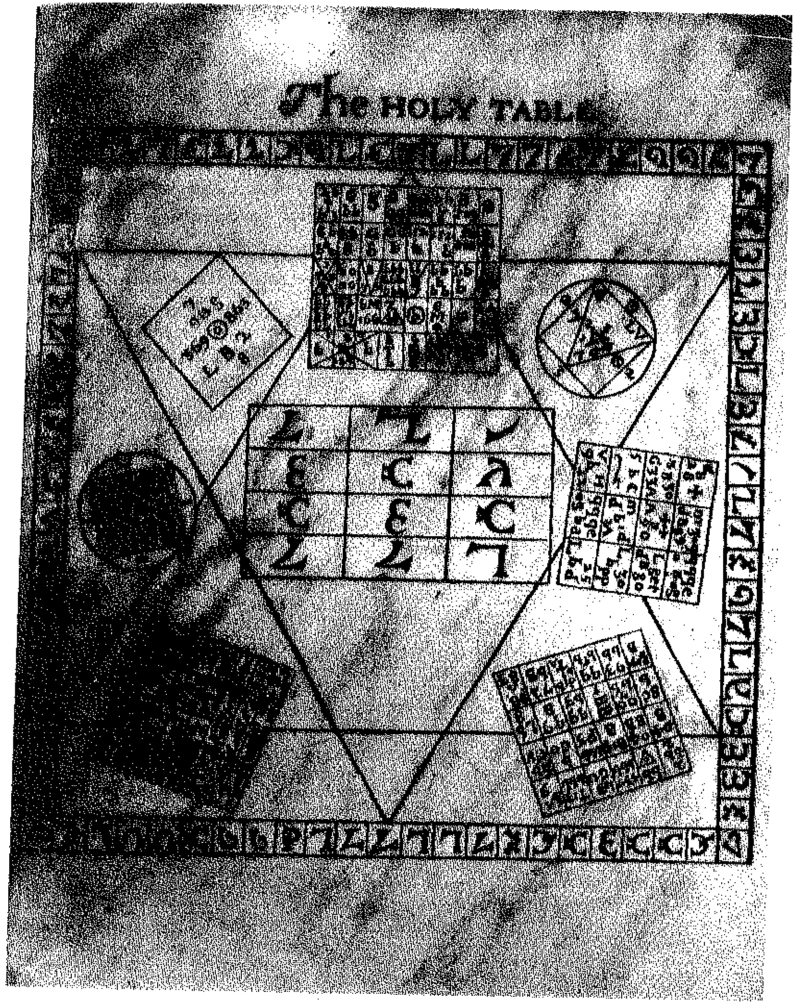


Diagram by William Gilbert to illustrate the behaviour of a magnet at different positions around the north pole of the earth, from *De Magnete* (1600).

Robert Norman an experiment in which a needle was pushed through a cork and made to float just below the surface in a glass of water. The object of this experiment was to disprove the theory that the basis of magnetism was attraction, since in fact the needle remained stationary in the water. Moreover, the sixteenth-century writers whom Gilbert attacked most, the Italians Porta and Cardano, believed in experiments as much as he did.

The interest of Gilbert lies as much in the formulation of his general theory of magnetism as in his experimental technique, though perhaps the distinction is an artificial one in view of the fact that the experiments were devised to lead to a general conclusion. Gilbert's theory of magnetism rested upon his judgment that the earth itself was a gigantic lodestone, and that 'every separate fragment of the earth exhibits in indubitable experiments the whole impetus of magnetic matter'. He held that the five main magnetic phenomena: attraction (which he called 'coition'), direction towards the earth's pole, variation, declination or dip and finally circular movement,



A marble copy, 60 × 50·5 cm., of the 'Holy Table' constructed by the mathematician and geographer, Dr John Dee (1527-1608), following the directions of the angelic spirits delivered through Edmund Kelley (1555-95). The characters in the centre and round the edge belong to Dee's so-called 'Enochian' alphabet. This marble table was probably copied from the engraving in Meric Casaubon's *True and Faithful Relation of what passed … between Dr John Dee … and Some Spirits* (1659).

could only be explained in terms of the earth's own magnetism.

The fifth aspect of magnetism, circular movement, provides a clue to Gilbert's views on the motion of the earth. He was not an avowed Copernican but he accepted the diurnal motion of the earth and proved it to his own satisfaction from the behaviour of lodestones. He thought that the lodestone, of all familiar objects, resembled the essential qualities of the earth in its capacity for 'whirling' motion.

Gilbert's attack on authority, his belief in experiment, his critical approach to evidence in constructing a general theory and his acceptance of the diurnal motion of the earth, all point to his modernity, and in a Whig interpretation of the history of science this is the conclusion which would be reached. A closer look at the *De Magnete*, however, will lead to second thoughts. For all his criticism of his predecessors, Gilbert found it impossible to avoid using much of their terminology and despite his condemnation of 'occult causes', his own explanation of magnetism remains fundamentally mysterious.

In fact, Gilbert's views fall into place as part of the 'magical tradition'. His experimental methods seem modern to us but his world outlook and his scientific assumptions are remote from the mechanism of the modern scientist. A quotation from *De Magnete* in which Gilbert specifically mentions Hermes Trismegistus serves to illustrate this point:

> Aristotle's world would seem to be a monstrous creation, in which all things are perfect, vigorous and animate, while the earth alone, luckless small fraction, is imperfect, dead, inanimate and subject to decay. On the other hand, Hermes, Zoroaster, Orpheus recognise a universal soul. As for us, we deem the whole world animate, and all globes, all stars and this glorious earth too, we hold to be from the beginning by their own destinate souls governed and from them to have the impulse of self-preservation . . .
>
> . . . Pitiable is the state of the stars, abject the lot of earth, if this high dignity of soul is denied to them, while it is granted to the worm, the ant, the roach, to plants . . . [23]

He goes on to say that there are in the stars

> reason, knowledge, science, judgment, whence proceed acts positive and definite from the very foundations and beginnings of the world.[24]

And again:

> Wherefore not without reason Thales, as Aristotle reports in his book *De Anima*, declares the lodestone to be animate, a part of the animate mother earth and her beloved offspring.[25]

This Hermetic background led him to appreciate the virtues of Copernicus whom he described as 'the restorer of astronomy'. Gilbert referred to the 'primum mobile' of Aristotelian astronomy as 'inadmissible', 'this fiction', 'this product of imagination and mathematical hypothesis'.

This puts in brief many of the assumptions which we have ascribed to the magical tradition, notably that the world was animate, a belief which separated Gilbert from the Aristotelians, as well as from the mechanists. But it did not make him less of a scientist. Indeed we may argue that it was precisely his belief in the earth soul which led him to seek an explanation for magnetic phenomena which within the Aristotelian paradigm remained merely a curiosity.

From this point of view Gilbert was very much the contemporary of that fascinating and mysterious figure John Dee (1527-1608) who spanned the world of 'magic' and of 'science'. It is in fact impossible to separate Dee's magical interests from what we would now regard as 'legitimate' scientific ones. Like Gilbert he turned to Trismegistus and wrote in his diary of taking

> Ghostly Council of Doctor Hannibal the great divine that had now set out some of his commentaries upon Pymander Hermetis Trismegisti.[26]

A similar kind of interest was to be seen in the scientific activity of the so-called 'Wizard Earl', Henry Percy, ninth Earl of Northumberland, who was imprisoned in the Tower of London from 1605 to 1621. Percy's place in the magical

tradition is referred to in a poem by George Peele in which he was described as:

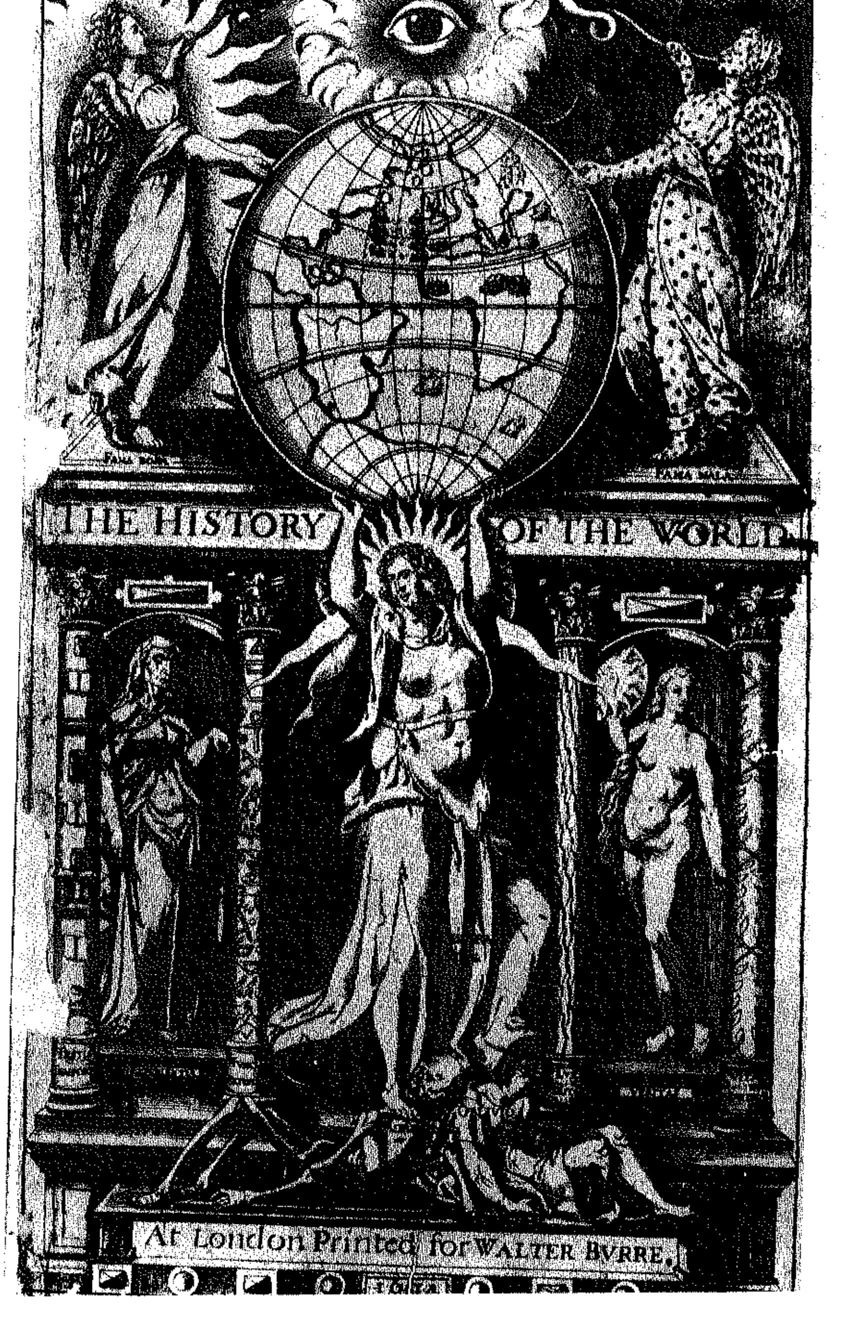
> Leaving our Schoolmen's vulgar trodden paths
> And following the ancient revered steps
> Of Trismegistry and Pythagoras
> Through uncouth ways and unaccessible
> Dost pass into the spacious pleasant fields
> Of divine science and philosophy.[27]

It is also illustrated by the fact that his library included Bruno's treatise on Lull (1588) and several treatises on alchemy, as well as Baptista Porta's *Natural Magic* (1585). Percy was not an isolated figure but the patron of gifted mathematicians such as Thomas Hariot (1560-1621).

Another member of the same group was Sir Walter Raleigh (1552-1618), who, like the Wizard Earl, was imprisoned in the Tower for many years. Raleigh's interest in chemical experiments has long been known. More recently, attention has been drawn to the emphasis he gave to alchemy and natural magic in his *History of the World* (1614). Raleigh praised four kinds of magic: divine magic, prophecy, astrology and chemical magic. Of this last, he wrote:

> The third kind of Magick containeth the whole philosophy of Nature; not the babblings of the Aristotelians but that which bringeth to light the inmost virtues, and draweth them out of Nature's hidden bosome to humane use.[28]

Among the names he mentioned were Hermes, Ramon Lull, and Francesco Patrizzi, the Italian Platonist. Raleigh and Bacon wrote at the same time but they represent two distinct traditions in science, the one neo-Platonist and magical, the other neo-Aristotelian and anti-magical.



The title page of Raleigh's *History of the World* (1614) in which he accepted the teaching of Hermes Trismegistus as genuine. The title page has a suitably moral tone, though some historians have tried to read 'experientia' as 'experiment'.

Paracelsus

The figures of Copernicus and Paracelsus are not normally linked and superficially have little in common, but if we do bring them together we are led to appreciate the strength of the 'magical tradition' in the sixteenth century. Indeed it is only by bringing Copernicus and Paracelsus together that we may see the real shape of science during the period. If we do not do so, we will inevitably exaggerate the rationalism and the unity of the Scientific Revolution.

Paracelsus was a German doctor, born in Switzerland (1493-1547). Like Copernicus, he had some connection with the land-owning class, but his life took its shape from his sympathy with the lower social groups of Germany during this period, with the miners and the peasantry particularly. We may see him as a man with Anabaptist sympathies, taking his stand with the oppressed. This inevitably brought him into conflict with the social conservatism of Lutheran and Catholic orthodoxy and of the German universities. The failure of Paracelsus to make a substantial impact on the academic medicine of the day was because he was felt to be subversive. He was anti-intellectual in the sense of being anti-academic.

Paracelsus took as his main target the medical teaching of the universities, which drew its inspiration from Hippocrates and Galen and which in addition catered largely for the medical needs of the upper social groups. Physicians who qualified in the universities took the landowners and the bourgeoisie for their clientèle. The peasantry and the labourers sought help from the self-taught apothecaries who relied upon traditional rule of thumb and their own intuitions. It is difficult to decide who was worse off.

Academic physic rested upon the assumptions derived from

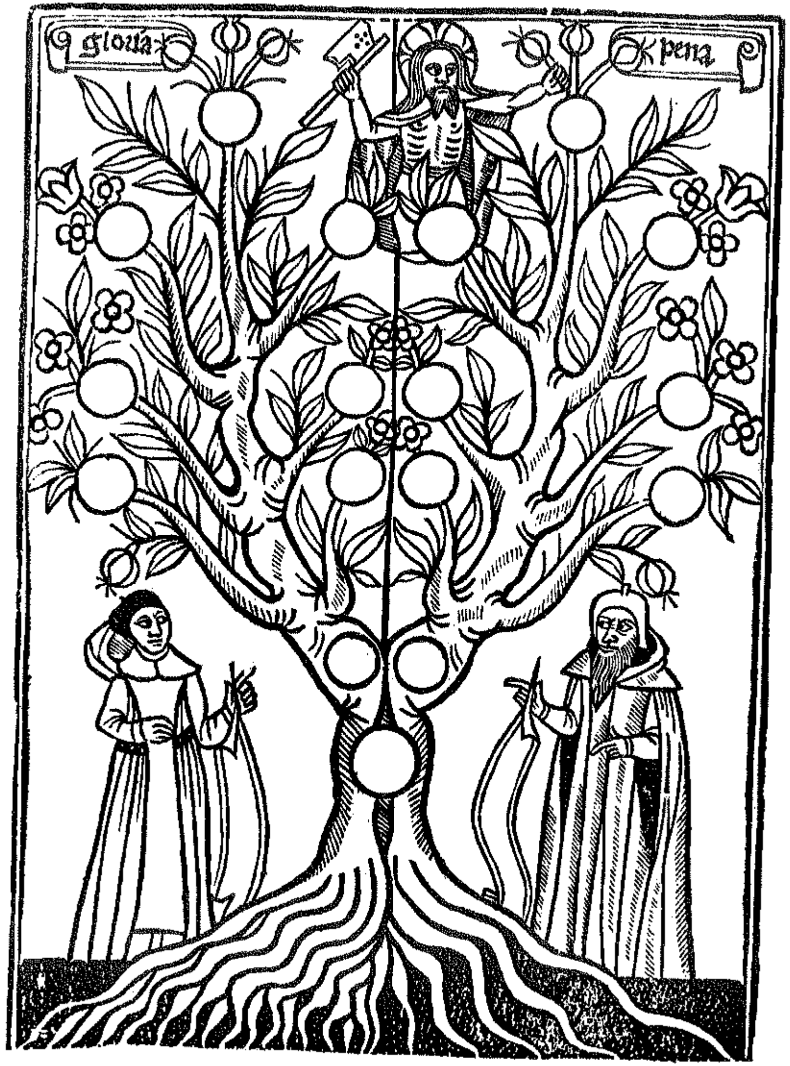
Raymond Lull (d. 1315), 'the enlightened doctor', developed 'the Lullian method' which enjoyed a revival in the sixteenth century. This diagram of the 'apostolic tree' formed part of a unified system of knowledge. His ideas form part of a tradition which, in its belief in mechanical aids to the acquisition of knowledge, stretched as far as Bacon and Comenius, and beyond.

two thousand years of Greek tradition that disease in the body derived from disorder in the balance of the four humours – phlegm, choler, melancholy and blood. This imbalance was known as 'distemper', hence all diseases were in a sense 'distemper'. The imbalance of the humours was thought to affect the body as a whole, not a particular part of it. Hence treatment was carried out with reference to the whole body, by attempting to redress the balance of the humours by means of blood-letting or induced vomiting or sweating. This was Greek medicine, still dominant in sixteenth-century Europe among those who were able to study it and to afford its benefits.

(This picture is no doubt over-simplified. Perhaps a distinction should be made between the influence of Hippocrates and that of Galen, with the Hippocratic tradition stressing the need for natural rest in achieving a cure, but it was Galen's influence which increased in the Renaissance period.)

Paracelsus attacked Galenic orthodoxy because of his social antagonism to a privileged elite. But there was also an intellectual foundation behind his radicalism. He drew inspiration from most of the anti-Aristotelian movements of the day, and not least from the neo-Platonism of Ficino. Paracelsus took the neo-Platonic doctrine of macrocosm and microcosm and applied it to the world of medicine. He saw the organs of the human body as the equivalent of the stars. The human body itself was a microcosm of all that existed in the world – animal, vegetable and mineral and spirit. The task of the doctor was to bring remedies from the macrocosm to cure the diseases of the microcosm.

In a sense, this looked forward to modern developments much more than did Galenic doctrine. But to make this judgment is to lose sight of the intellectual background in which Paracelsus had his origins. The world of Paracelsus



was the world of the Spanish eccentric Ramon Lull (1232-1315), Nicholas of Cusa, Pico della Mirandola (1463-94) and Ficino. It was a harking back to the pantheistic universe of Plotinus in which natural substances contained 'virtues' which were eternal in character and part of the divine nature. The universe was a magical universe in which God was the Magus. It was a world full of hidden secrets (the occult) which it was the task of the physician to overhear or to 'tune into'. It was a world dominated by spirit, not by matter, and hence completely different from the mechanistic world of Descartes and Hobbes. But it was not so very far from the worlds of Copernicus, and Kepler or of Bruno and Fludd. The place of Paracelsus in this tradition is quite clear.

All this sounds as strange to modern ears as the Galenic doctrine of the humours. But it did lead Paracelsus to concentrate his attention upon local areas of the body – the liver for example – rather than the body as a whole. He saw disease as coming from outside the body, not the result of humoral upsets, and he looked for specific remedies for specific diseases rather than resorting to generalised treatment like blood-letting. The Paracelsan cure for dropsy was mercury:

For example, Mercury is the specific remedy in dropsy. This is due to a morbid extraction of salt from the flesh, a chemical process of solution and coagulation. As such this process does not depend at all upon quality and complexion, but is a 'celestial virtue' endowed with its own 'monarchy' to which quality and complexion are subservient. Mercury will drive out the dissolved salt, which has a harmful corrosive action on the organs, and preserve the solid – coagulated – state of the salt in the flesh, where it is needed to prevent putrefaction. Mercury will effect the cure specifically in everybody, although it causes vomiting in one and sweating in another. Neither vomiting nor sweating – the universal cures of the ancients – are therefore the curative factors. Hence he errs who says the patient must be cured with sweating or vomiting, for he fails to consider the manifold variety of man and that any effect of such remedies is merely the expression of the different reaction of individuals to the same remedy, not the cure itself.[29]

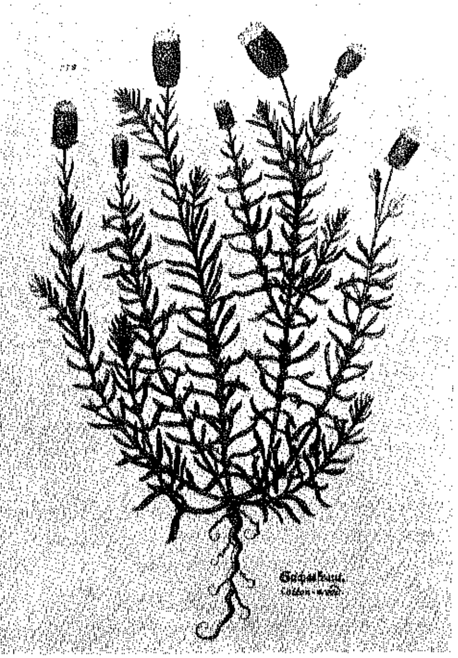
Above all perhaps, Paracelsus gave a fillip to the study of chemistry within a disciplined framework. He went beyond the four traditional elements of Greek science (earth, air, fire and water) to three principles: sulphur, salt and mercury. These were not substances in the modern sense, but principles of activity, by which Paracelsus provided a new paradigm for the study of medicine and of 'chemistry'. He pointed the way for a search for new chemical remedies and a new emphasis upon experiment. The science of iatro-chemistry, in which chemistry was studied for use in medicine, was born.

Where he differed from Copernicus and Kepler was in his attitude to mathematics. He did not regard the universe as being written in mathematical characters. But in a sense this is a marginal difference. All these neo-Platonists believed in the same kind of universe and were all searching for a code which would reveal its secrets. Paracelsus differed from Copernicus in turning to the laboratories of the earth, the mines particularly, rather than the celestial laboratory.

Thus Paracelsus provides a link with the magical and mystical side of the Renaissance, which was once, and perhaps still is, grossly underrated. He looks back to the medieval world of Ramon Lull and forward to the seventeenth-century chemist, John Baptist van Helmont (1577-1644). If his achievements have not been appreciated it is because historians of science have always stressed the rationality of their pursuit of knowledge. But if Paracelsus was a lunatic so also were Nicholas of Cusa, Copernicus, Kepler and even Newton.

We have stressed the importance of Paracelsus's magical, religious and social assumptions in providing him with a basis from which he could attack Galenic orthodoxy. But we must not conclude too rashly that his emphasis upon localised centres of disease or the use of chemical medicines was an

The hazards of physic and surgery in the seventeenth century. From the title page of *De efficaci medicina* (1646).

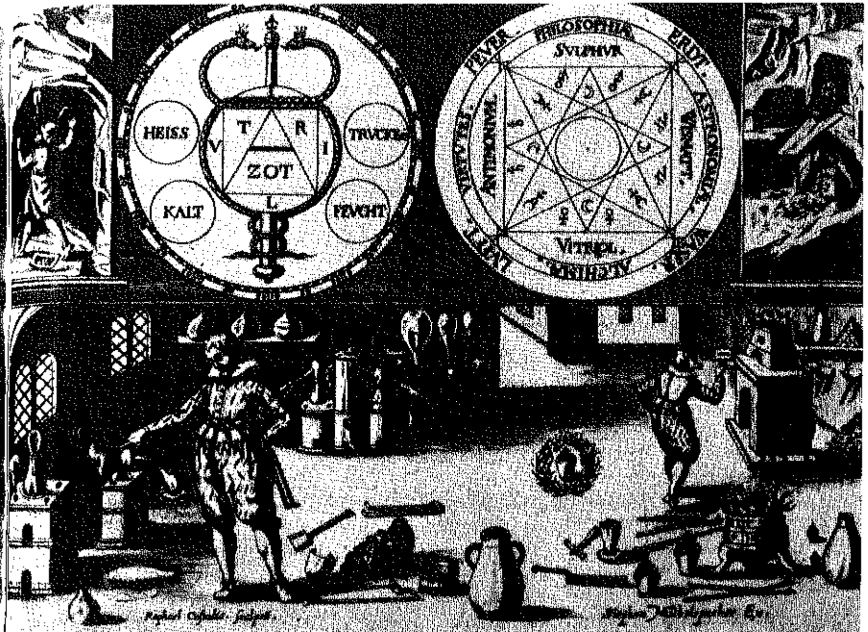


Left Cottonwell from *De historia stirpium commentarii* (1542) by Leonard Fuchs (1501–66). In this, as in other sixteenth-century engravings, art and science are inextricably intertwined.

Right 'The grete herball which geveth parfyt knowledge and un[der]standing of all maner of herbes and there gracyous vertues … London 1526.' Herbals were descriptions of plants thought useful for medical purposes. The best known herbal was that of Dioscorides (first century AD) which appeared in print in 1478.

unmixed blessing. Paracelsus's emphasis in local causes may have blinded his followers to the essential unity of the human organism which modern medicine is at pains to emphasise and his use of chemical medicaments may have set back the clock as much as it moved it forward. In short, there were no ancients and no moderns in our sense of the word.

Paracelsus derived many of his ideas from another source impregnated with neo-Platonic ideas – the Cabbala. The Jewish Cabbala (literally 'tradition') was a body of teaching, dating from the later Middle Ages, which interpreted the Old Testament by esoteric methods, including cyphers. The revival of Hebrew among Christian scholars like Reuchlin (1455-1522) made the Cabbala accessible to those who sought wisdom behind the literal text of the Scriptures. The Cabbala and the Hermetic writings appealed to the same cast of mind. The Cambridge neo-Platonists for example studied the Cabbala.



The atmosphere of alchemy is successfully conveyed here. Note the reference to Vitriol, the cabalistic signs and the apparatus to be found in an alchemist's laboratory.

The Paracelsan universe, in so far as it was neo-Platonic, was alive. The three elements of Paracelsus were live sources of spiritual energy analogous to the Trinity, which indeed they 'reflected'. All things had a spiritual directing force (an *Archeus*) which guided their development.

What would be body without spirit? Absolutely nothing. The spirit then and not the body contains concealed in itself the virtue and power . . . [it] conserves the living body and when this perishes the spirit escapes and leaves the dead body and returns to the place whence it came, into the chaos, the air below and above the firmament . . . know that spirit is the true life and balsam of all corporal things.

Behind his insistence upon chemical remedies lay the assumption that he was living in a magical universe in which material substances rightly chosen could achieve remarkable, indeed miraculous, effects. Thus it was a magical not a 'rational' assumption which led Paracelsus to bring about an alliance between chemistry and medicine.

Before Paracelsus the world of alchemy was largely bound up with the search for the philosopher's stone, which would turn base metals into gold. The chances of success in this venture were remote, to say the least, but the degree of skill required in the search was considerable. The alchemist employed many of the techniques which were used in practical trades, such as distilling and glass blowing. (The analogy here is with Galileo, who took over a practical instrument, the telescope, and used it to explore the heavens.)

There seems little doubt that alchemy revived during the Renaissance. Classical fables were re-interpreted as sources of alchemical knowledge. The Tale of the Golden Fleece, to take one example, provided obvious inspiration for an alchemist seeking the philosopher's stone. But the nature of alchemy tended to preclude any large-scale development. The alchemist concealed the technical secrets of his success and wrapped up his ideas in language of intentional obscurity in order to put his competitors off the scent.

Against this background, the achievement of Paracelsus seems to lie in bringing alchemy into the clearer world of iatro-chemistry and of medicine. Relatively speaking, Paracelsus stood for an open, less secretive approach in alchemy. He wished to spread the gospel of the three elements, not to hide his light under a bushel. His language was obscure but it was not deliberately so; it lay in the nature of his ideas. But the tradition of secrecy in the alchemical tradition was a long time a-dying. Rudolph Glauber, the seventeenth-century chemist, described in a deliberately perverse way this method of producing *sal mirabile* (sodium sulphate), though his motives in doing so, the preservation of a patent and hence of profit, were 'rational' by modern standards.

Van Helmont

The influence of Paracelsus certainly increased during the first hundred years after his death, particularly among the apothecaries, who were concerned with the preparation of remedies. Since apothecaries were regarded as socially inferior to physicians, the advocacy of Paracelsan iatrochemistry possessed overtones of social radicalism.

In these circumstances it is odd to find that the most significant Paracelsan of the seventeenth century was a man of noble birth, Jean Baptista van Helmont (1577-1644). Helmont lived in the Spanish Netherlands, where aristocratic values were dominant but his views were not characteristic of his social environment, which he reacted against at an early age. For much of his life he was closely watched by the ecclesiastical authorities. His Paracelsan beliefs, it seems, were regarded as socially subversive as well as politically dangerous.

As a student, Helmont turned away from the scholasticism of his teachers to study the Cabbala, mysticism and magic. He took the degree of MD at Louvain at the age of thirty in 1609 after a period of travel which led at one stage to an offer of employment from Kepler's imperial patron, Rudolph II. He was never free from the attentions of the Inquisition from 1621 onwards. Helmont claimed to be orthodox and willing to submit to the Church over such matters as Copernicanism, but there seems little doubt that his Paracelsan interests led him into assumptions which were dangerous by the standards of the authorities.

Helmont never tired of criticising the orthodoxy of the universities and throughout his life he kept up a bitter attack on academic Galenic medicine. He rejected the Galenic doctrine of the humours as nonsense:

> I have shown the vanity and falsehood of the device of Humours, whereby Physicians from a destructive foundation have circumvented the whole world, . . . have destroyed families, have made widows and orphans by many ten thousands. (*Opera Omnia* p. 1013)

Not the least reason why Helmont rejected the teaching of the schools was its paganism, He did not think God had revealed the gift of healing to pagan authors. Hence whoever assented to the doctrine of 'Paganish schools' was excluded from 'the true principles of Healing'.

The medical interests of Helmont emerge most clearly in his treatises on the stone and on blood-letting. In both cases he rejected the beliefs on which Galenic remedies were based. But his own cures rested upon assumptions about God, Nature and Man. He stressed the overwhelming significance of the spiritual source of life:

> Life is a Light and a formal beginning whereby a thing acts what it is commanded to act: but this light is given by the creator . . . even as Fire is struck out of a Flint. (*Opera Omnia*, p. 744)

The soul leaves its stamp upon the flux of material existence.

The Fall of Adam, however, had changed the character of man's relationship to the natural world. Before the Fall, man's spiritual principle, his immortal mind, acted directly upon nature. After the Fall, the immortal mind was weakened and it was forced to act indirectly through the soul. The soul, in Helmont's view, ranked below the mind in significance. The task of the philosopher was to recognise the fundamental structure of reality and to create a situation in which the mind might operate as powerfully as possible upon the soul and ultimately upon the living principles or seeds (Archeus) of things. In Helmont's own words:

The mortal sensitive soul coexists in man (in his present state) with the immortal mind (*mens*), the soul being as it were the husk or shell of the mind, and the latter works through it, so that at the bidding of the mind, the soul makes use of the Archeus, whether it itself will or not. Before the Fall of Adam, man had only the immortal mind which acted directly on the Archeus, discharging all the functions of life, and man was immortal, the shadows of the brute beast not blurring his intellect. At the Fall, God introduced into man the sensitive soul and with it death, the immortal mind returning into the sensitive soul and becoming as it were its kernel.[30]

His assumptions about particular ferments and seeds in different organs of the body led him to assume different chemical processes and to foreshadow the modern concept of the enzyme. Helmont also seems to have been the first to describe the role of acid digestion in the stomach.

His anti-Galenic assumptions led him on to examine gases. He spoke of 'a spiritual gas containing in it a ferment . . . one thing is not changed into another without a ferment and a seed'. He described how the addition of nitric acid to sal ammoniac created a wild spirit which would burst a closed vessel. This he compared to the Greek 'chaos' from which he took the name gas. This particular gas, he called wild gas (*gas sylvestre*). He also distinguished other gases, all unknown to the Galenists, although some differed merely in name. They included *gas carbonum, gas pingue* and *gas sulfuris*. In all this scientific activity, Helmont asked questions which did not arise within the Aristotelian or mechanist traditions.

Helmont was conscious of belonging to the same tradition as Paracelsus though he rejected the Paracelsan concepts of 'macrocosm' and 'microcosm'. He referred to Paracelsus on many occasions as the first man to attack the Galenic doctrine of the humours. Helmont was also influenced by William Gilbert. He quoted Tauler, the fifteenth-century religious writer, and his attacks on atheism won him the approval of the Cambridge Platonists. Helmontian doctrines enjoyed a certain vogue in mid seventeenth-century England and Helmont's son Francis Mercury paid a protracted visit there.

One of the attractions of Helmont's teaching at that moment of time was that it offered an answer to mechanism. Helmont's emphasis upon the sovereignty in nature of the immortal mind made an understandable appeal to those who felt that Christian teaching was in peril. God for the Helmontian was not an engineer but an artist who

As a painter, doth first conceive in his mind a spiritual Idea of the picture he intendeth to draw and afterwards by peculiar motions of his hand, which are guided by the said Idea, he produceth a Perfect picture corresponding with that in his mind.[31]

This quotation from an English Helmontian, Thomas Shirley, shows a typical emphasis upon the directing role of the mind.

We may conclude with a poem addressed by a contemporary to Helmont:

Shut up thy schools, O Galen, for enough of men are slain
So now it is sufficient: full graves do ring again
For Blood and Clyster are thy medicines: nothing oftentimes
Thou giv'st: but to a Critick day, thy hope alone confines.
In touching of a vein, the while, and eke of parched tongue,
And in the Urine wholly th'art dismayed, and so in dung.
A medicine's to be got for him, this helps not the sick man:
No need of tests of the Disease; but of a Physician,
Yet thou expect'st a great reward, after the man's enshrined
So doth the Dog look for and love, the cattle sickly kind.
Helmont is one, who able is by his Apollo's art
To snatch from th' jaws of Death whom t'other left to dye in smart.
(Helmont, *Opera Omnia*, p. 811)

Tycho Brahe's famous observatory, Uraniborg, on the island of Hveen off the coast of Denmark. Tycho (1546–1601) drew up elaborate horoscopes for members of the Danish royal family. At bottom left is the Emperor Ferdinand's villa at Prague, from which Tycho made observations during 1600-1.

Kepler

In the work of the German astronomer, Johannes Kepler (1571-1630), the magical tradition reached one of its climaxes. Kepler was a convinced Copernican in his youth, which marked him out as exceptional among contemporary astronomers and made him conscious of being a member of a small minority under pressure. It was for this reason that he urged Galileo to speak out openly in defence of the Copernican cosmology. The fact that Copernicanism was still very much an eccentric view in 1600 is worth stressing once more, for it establishes the important point that Kepler himself was an eccentric.

Kepler's role within the magical tradition was made distinctive by two factors. The first of these was the mass of astronomical observations which the Danish astronomer, Tycho Brahe (1546-1601), assembled and which Kepler was able to put to good use. Secondly, Gilbert's work on magnetism had a profound influence upon Kepler's formulation of his cosmological hypotheses.

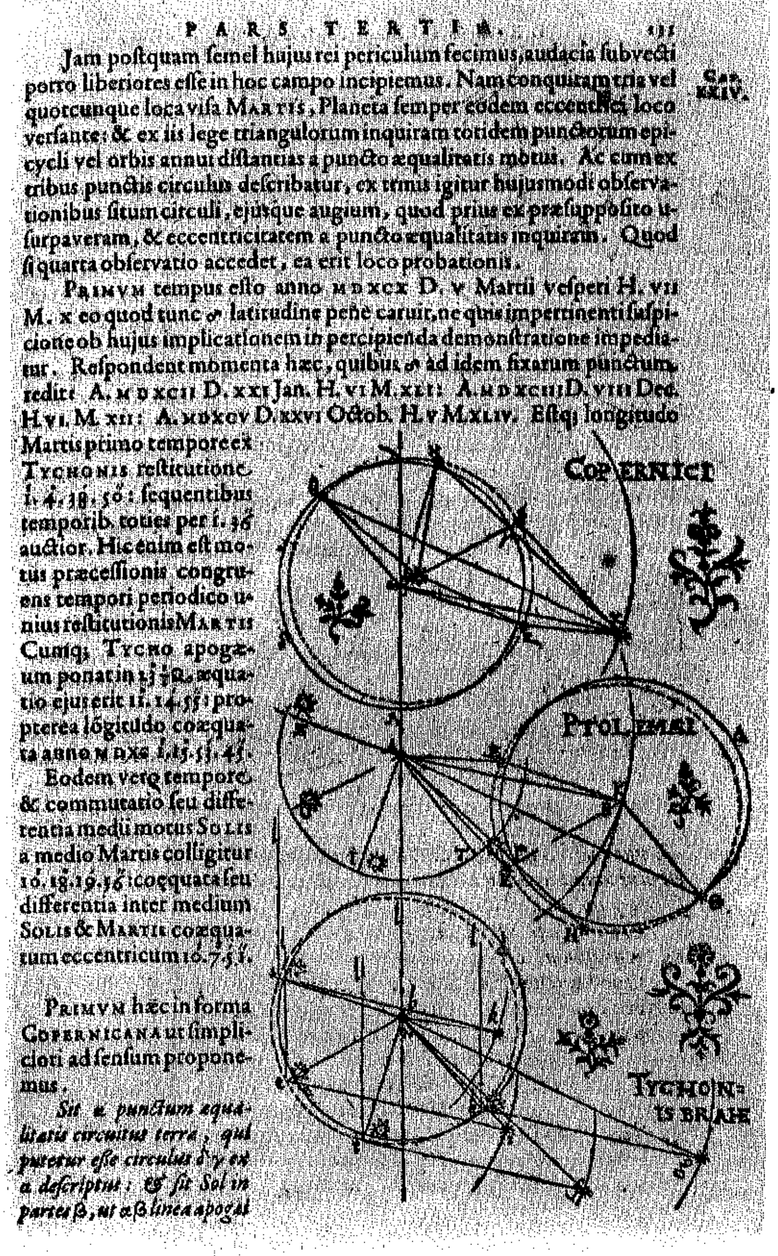
Tycho's interest in astronomy sprang from a consuming obsession with astrology, which spilled over into natural magic. He devoted himself to constructing instruments which enabled him to re-map the night sky with an accuracy hitherto unknown, but this was not a detached scientific curiosity. It was an enthusiasm which rested on the assumption that more accurate knowledge of the stars and planets would lead to more accurate horoscopes. The information thus gathered he did not propose to share with his fellow 'scientists'. Tycho's observations were a private collection of data which he proposed to use to build up an unchallenged position of privilege in the world of astrology. On the basis of his observations, he succeeded in becoming the astrologer *par excellence*.

A diagram from Kepler's *Astronomia Nova* (1609) in which he used the observations taken of Mars by Tycho Brahe to argue in favour of Copernican cosmology. The three sketches illustrate the path of Mars according to Copernicus, Ptolemy and Tycho. Copernicus' heliocentric theory made the explanation simpler but his belief in circular orbits posed many false problems. Kepler himself proved the existence of elliptical orbits.

The career of Tycho is enormously interesting because it demonstrates how much of sixteenth-century interest in astronomy sprang from a quasi-religious belief in the importance of the stars. Tycho resembled the great scientists of the nineteenth century in his devotion to observation, but there the resemblance ceases. He was a mystic seeking his salvation in the night sky, and jealously guarding the results which he achieved. Kepler managed to make use of Tycho's data for his own purposes only by accepting the post of 'research assistant' in Tycho's entourage. The information was not freely volunteered for the sake of the advancement of learning and the Scientific Revolution. Tycho's science was essentially esoteric, in the great magical tradition.

If Tycho's observations provided Kepler with a means of testing his hypotheses, Gilbert's theory of magnetism provided him with a stimulus to his imagination. Following Gilbert, Kepler saw the earth as a great magnet, but he went further than this and applied the concept of magnetic attraction to the planetary system as a whole. Magnetism, as Kepler saw it, did away with the need for stellar intelligences among the planets in their orbits. It provided a hint that the mysterious links between sun and planets might be less powerful as the distance grew. In turning to Gilbert, Kepler was turning to a kindred spirit who provided evidence for Copernican hypothesis within the magical framework.

Kepler was born a Lutheran and was educated at the Lutheran university of Tübingen. As a poor scholar, his obvious choice of career was the ministry, but his religious beliefs were unorthodox, or thought to be by the authorities. He became a mathematics teacher in the Protestant seminary at Graz, which had ties with the university of Tübingen. While he occupied this humble teaching post (1594-1600),


PARS TERTIA.

Jam postquam semel hujus rei periculum fecimus, audacia subvecti porro liberiores esse in hoc campo incipiemus. Nam conquiram tria vel quotcunque loca visa Martis, Planeta semper eodem eccentrici loco versante: & ex iis lege triangulorum inquiram totidem punctorum epicycli vel orbis annui distantias a puncto æqualitatis motus. Ac cum ex tribus punctis circulus describatur, ex ternis igitur hujusmodi observationibus situm circuli, ejusque augium, quod prius ex præsupposito usurpaveram, & eccentricitatem a puncto æqualitatis inquiram. Quod si quarta observatio accedet, ea erit loco probationis. Cap. XXIV.

Primum tempus esto anno MDXC D. V Martii vesperi H. VII M. X eo quod tunc ♂ latitudine pene caruit, ne quis impertinenti suspicione ob hujus implicationem in percipienda demonstratione impediatur. Respondent momenta hæc, quibus ♂ ad idem fixarum punctum redit: A. MDXCII D. XXI Jan. H. VI M. XLI: A. MDXCIII D. VIII Dec. H. VI M. XII: A. MDXCV D. XXVI Octob. H. V M. XLIV. Estq; longitudo Martis primo tempore ex Tychonis restitutione I. 4. 38. 50: sequentibus temporib. toties per I. 36 auctior. Hic enim est motus præcessionis congruens tempori periodico unius restitutionis Martis. Cumq; Tycho apogæum ponat in 23. 30. æquatio ejus erit 11. 14. 55. propterea lõgitudo coæquata anno MDXC 1. 25. 55. 45. Eodem vero tempore & commutatio seu differentia medii motus Solis a medio Martis colligitur 10. 18. 19. 56. coæquata seu differentia inter medium Solis & Martis coæquatum eccentricum 10. 7. 55.

Primum hæc in forma Copernicana ut simplicioni ad sensum proponemus.

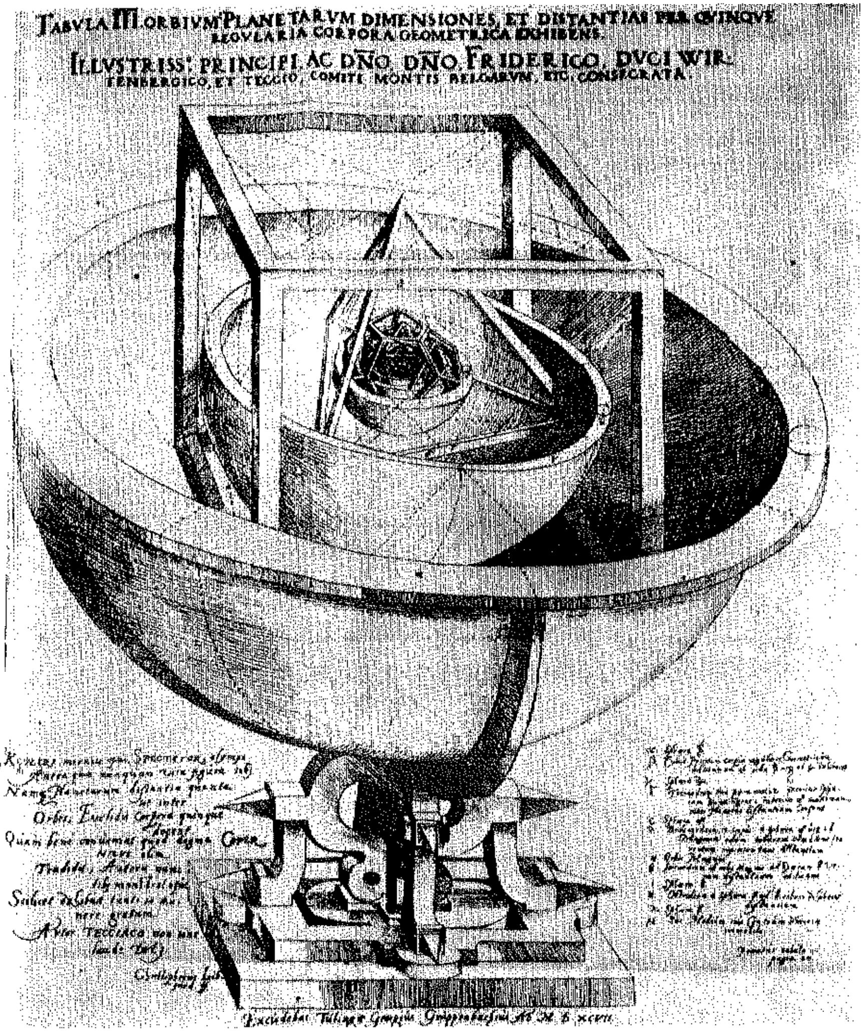
Sit α punctum æqualitatis circuitus terræ, qui putetur esse circulus δγ ex α descriptus: & sit Sol in partes β, ut αβ linea apogæi

Kepler wrote his first major book, *Mysterium Cosmographicum*. He wrote it before being influenced by Gilbert and before meeting Tycho. Though it was much less of a piece of cosmological speculation than the title suggests, Kepler claimed to show in it that the spheres of the six planets (including the earth) in the Copernican system corresponded to the five perfect solids of Euclid: four-sided, six-sided, eight-sided, twelve-sided and twenty-sided figures:

> The earth is the measure for all other orbits. Circumscribe a twelve-sided regular solid about it; the sphere stretched about this will be that of Mars. Let the orbit of Mars be circumscribed by a four-sided solid. The sphere which is described about this will be that of Jupiter. Let Jupiter's orbit be circumscribed by a cube. The sphere described about this will be that of Saturn. Now place a twenty-sided figure in the orbit of the earth. The sphere inscribed in this will be that of Venus. In Venus' orbit place an octahedron. The sphere inscribed in this will be that of Mercury. There you have the basis for the number of planets.[32]

The interest of this passage is twofold. It reveals Kepler the Pythagorean attempting to apply to the cosmos the kind of mathematical insights which Pythagoras had discovered in music. It also shows us Kepler the Copernican accepting the earth as a planet. The two roles cannot be distinguished. Kepler was not trying merely to describe the paths of the planets. He was attempting to explain *why* there are only six planets. In other words, he was providing an insight into God's mind. God created the cosmos upon the basis of the divinely inspired laws of geometry. Hence Kepler's conclusions were mystical and geometrical at one and the same time. It is true that the *Mysterium* is early Kepler, written by a young man, but the same tone is to be found in his later writings.

Kepler became convinced in 1595 that the structure of the planetary system was based upon the five regular polyhedra. He tried to persuade Frederick Duke of Württemberg to have a drinking cup made after the model of the universe. Each planetary sphere would provide its own beverage, ranging from the sun's *aqua vitae* to Saturn's 'bad old wine'. This plan was dropped in favour first of a globe, then of a mobile planetarium. Nothing came of Kepler's enthusiasm.



Portrait of Johannes Kepler (1571-1630), whose astronomical discoveries provided a vital transition between the world of Tycho Brahe and the world of Newton.

Kepler's next book *Astronomia Nova* was written around 1605-6, though not published until 1609. By then he had moved to Prague first in the service of Tycho and then as Imperial Astronomer to Rudolph II. It was during this period that he read Gilbert's *De Magnete* and was strongly influenced by it. It seems also that after writing the *Mysterium* Kepler devoted more time to mathematics.

The *Astronomia Nova* was the first revolutionary piece of astronomy since Copernicus's *De Revolutionibus*. In it, Kepler put forward two radical innovations. First he argued that the planets moved in elliptical orbits round the sun, and secondly, that the velocity of the planets was not uniform in the course of their individual orbits. These were the bases of Kepler's first two laws, and they owed a great deal to the influence of Tycho and Gilbert. Tycho's data enabled him to test his hypotheses and to reject them when they failed to fit

the facts. It was indeed only after many formulations that Kepler was driven to accept the ellipse as the planetary orbit. Gilbert's magnetic theories provided him with an idea which enabled him to accept the possibility of the planets moving at varying speeds, which could be explained in terms of the weakening magnetic interraction at greater distances between them and the sun.

In addition to his debt to Tycho and Gilbert, Kepler owed an immense amount to the sustaining power of his Pythagorean belief in the mathematical harmony of the universe. Kepler refused to give up when failure followed upon failure and the facts did not fit his successive hypotheses. This persistence had its origins in his quasi-religious belief that God had created the universe in accordance with the laws of mathematics.

Kepler's first two laws radically modified not only the Ptolemaic system but also Copernicanism, as originally set out in 1543. Copernicus had retained the notion of circular motion which inevitably involved holding on to epicycles as part of his explanation. He also assumed that the planets moved at uniform speed. Kepler destroyed both of these assumptions, or he destroyed them in theory. In fact his *Astronomia Nova* had remarkably little influence. Kepler was too neo-Platonic for most of his fellow astronomers and he was too mathematical for his fellow neo-Platonists. This book which appears so revolutionary to us was perhaps not appreciated until Sir Isaac Newton saw its true value over fifty years after its publication. Galileo and Descartes, the most influential of all seventeenth-century scientists before Newton, accepted as axiomatic that the planets moved in circular orbits at uniform speed and hence dismissed Kepler's theories as unfounded speculation.

Kepler's third major book, *Harmonice Mundi*, published in

1619, was the fruit of his years spent as mathematician in the Protestant school at Linz, where he moved in 1612 after the death of Rudolph II. In this book, Kepler, building upon earlier work but perhaps also in reaction to the restricted circumstances of his daily existence, attempted a neo-Platonic synthesis, and sought to reveal the mathematical language of the creator in almost every aspect of the universe. The interest of the book to later astronomers lay in the exposition of Kepler's third law, that there is a constant ratio between the square of the planetary period of revolution and the cube of the planets' mean distance from the sun. But this equation, proving that God was a mathematician after all, was almost hidden in a mass of neo-Platonic speculation.

What the historian cannot do is to separate Kepler the 'scientist' from Kepler the neo-Platonic mystic. Kepler would not have been moved to question the basis of existing cosmological theories unless he had been a neo-Platonist in the beginning. The *Mysterium* shows us this. But the tone of the *Mysterium* of 1597 is to be found in Kepler's language twenty years later when he described how

I feel carried away and possessed by an unutterable rapture over the divine spectacle of the heavenly harmony.[33]

He spoke in *Harmonice Mundi* (1619) of how 'the configurations strike up: sublunary nature dances after the fashion of music'.[34]

In *Harmonice Mundi*, Kepler applied the analogy of modern polyphonic music to the planets. Each planet had its own scale which was determined by its speed and the musical climax was a chord sounded by all six planets. Thus Kepler's God was an artist who took satisfaction in the musical instrument he had created. 'The motions of the heavens', he wrote, 'therefore, are nothing else but a perennial concert, made up of rational [unheard] music'. If polyphonic music gave such pleasure the reason was because it was a reflection of celestial music.

Kepler, like Gilbert and Bruno, believed that the sun was a soul. His early Copernicanism revealed in the *Mysterium* rests upon the idea that the sun as a spiritual 'force' acting at a distance was responsible for moving the planets in their orbits:

If we want to get closer to the truth and establish some correspondence in the proportions (between the distances and velocities of the planets) then we must choose between these two assumptions: either the souls which move the planets are less active the further the planet is removed from the sun, or there exists only one moving soul in the centre of all the orbits, that is the sun, which drives the planets the more vigorously the closer the planet is, but whose force is quasi-exhausted when acting on the outer planets because of the long distance and the weakening of the force which it entails.[35]

He believed that there was an earth-soul which perceived geometrical relationships and which expelled its 'subterranean humours' (our volcanoes and earthquakes of today), when planetary rays met at an appropriate angle:

It is the custom of some physicians to cure their patients by pleasing music. How can music work in the body of a person? Namely in such a way that the soul of the person, just as some animals do also, understands the harmony, is happy about it, is refreshed and becomes accordingly stronger in its body. Similarly the earth is affected by a harmony and quiet music. Therefore there is in the earth not only dumb, unintelligent humidity, but also an intelligent soul which begins to dance when the aspects pipe for it. If strong aspects last, it carries in its function more violently by pushing the vapours upwards, and thus causes all sorts of thunderstorms; while otherwise when no aspects are present, it is still and develops no more exhaltation than is necessary for the rivers.[36]

Kepler saw the role of the scientist as akin to that of the priest or the seer; the poet, the lover and the scientist were of imagination all compact. He related in *Harmonice Mundi* how

I gave myself up to sacred frenzy. I have plundered the golden vessels of the Egyptians, in order to furnish a sacred tabernacle for my God out of them far from the borders of Egypt.[37]

Kepler saw God not as the logician or the engineer but as the playful magician leaving his marks in the universe for us to discover. The world of nature carried signs, or signatures, left by God as clues to indicate their true significance, or utility. Thus a plant designed to cure a particular disease, would carry a 'signature' indicating this:

God himself was too kind to remain idle and began to play the game of signatures signing his likeness on to the world; therefore I chance to think that all nature and the graceful sky are symbolised in the art of Geometria.[38]

In Kepler's scientific approach we recognise a distinctive style which has as much in common with Pico, Lull, and Paracelsus as with Galileo. He resembled Michelangelo more than Leonardo in his search for the unseen harmony of nature. It is true that he clashed with the Englishman Robert Fludd over Fludd's Hermetic and mystical use of numbers. But Kepler and Fludd from our vantage point seem to be far closer than they appeared to themselves or their contemporaries. Kepler was a mathematician of genius but he thought 'more Hermetico', after the manner of the neo-Platonists.