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✓ **Mathematics and Nature in the Chemical Texts of the Renaissance**

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No. 1

MATHEMATICS AND NATURE IN THE CHEMICAL TEXTS
OF THE RENAISSANCE

BY ALLEN G. DEBUS*

By the late seventeenth century the triumph of our modern mathematicized science would seem to have been fully confirmed. One need only look at the first sentence of the preface of the *Principia Mathematica* to flavour the main theme of the new science—

Since the ancients (as we are told by *Pappus*) esteemed the science of mechanics of greatest importance, in the investigation of natural things, and the moderns, rejecting substantial forms and occult qualities, have endeavoured to subject the phenomén of nature to the laws of mathematics, I have in this treatise cultivated mathematics as far as it relates to philosophy.¹

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¹ Isaac Newton, *Mathematical Principles of Natural Philosophy*, trans. Andrew Motte (1729), revised with historical and explanatory appendix by Florian Cajori (Berkeley: Univ. of California Press, 1934), p. xvii.

Even fifty years earlier Galileo had insisted that the power of mathematical demonstrations "prepares the mind to understand and ascertain other facts without need of recourse to experiment".² The history of the past three centuries shows an ever increasing emphasis on mathematics and quantification in the study of nature.

The significance of the emergence of a quantified science has never been ignored by historians of science, but for the most part non-modern views of the role mathematics should play have been neglected.³ In an important monograph Pauli called our attention to the Kepler-Fludd debate as a crucial chapter in the rise of the new science in which the "new, quantitative, scientifically mathematical way of thinking collided with the alchemical tradition expressed in qualitative, symbolical pictures".⁴ Yet, Fludd himself had argued no less passionately than Kepler that we cannot understand nature without mathematics as a guide. In the sixteenth and early seventeenth centuries there was surely no argument over the necessity of mathematics in science—there was, however, considerable disagreement as to how it might best be applied.

Since the Paracelsians offered a universal view of nature which clashed with that of the rising mechanical philosophers,⁵ and since the place of mathematics in science was a point of contention between the two schools, it seems not inappropriate to devote this paper to the place allotted to mathematics in the study of nature as seen by Renaissance iatrochemists. We shall find that the mathematics of Paracelsus and Robert Fludd bears a close affinity with the work of the mystical neo-Platonists, Pythagoreans and natural magicians of this period. At the same time we sense a reaction against mathematical abstraction in science—a feeling which finds its culmination in the work of van Helmont who would have happily limited the intrusion of this subject into nature to calculations based on weight determinations. Both of these views

² Galileo Galilei, *Dialogues Concerning Two New Sciences*, trans. Henry Crew and Alfonso De Salvio with an introduction by Antonio Favaro (New York: Macmillan, 1914), p. 276.

³ The reader is particularly directed to the June, 1961, issue of *Isis* (vol. 52), which includes the papers given at the "Conference on the History of Quantification in the Sciences" held in Nov., 1959.

⁴ Wolfgang Pauli, "The Influence of Archetypal Ideas on the Scientific Theories of Kepler", trans. Priscilla Silz in C. G. Jung and W. Pauli, *The Interpretation of Nature and the Psyche* (London: Routledge and Kegan Paul, 1955), p. 205.

⁵ On the chemical philosophy of the Paracelsians see Allen G. Debus, *The English Paracelsians* (London: Oldbourne Press, 1965; New York: Franklin Watts, 1966); Allen G. Debus, "Renaissance Chemistry and the Work of Robert Fludd", included in *Alchemy and Chemistry in the Seventeenth Century* (William Andrews Clark Memorial Library: Univ. of California, Los Angeles, 1966), pp. 1-29; *ibid.*, (reprinted in a slightly revised version), *Ambix*, 14 (1967), pp. 42-59.

may be found in the writings of Nicholas Cusanus, and they both carry religious overtones. It is to be hoped that the present study will contribute to our understanding of the background of the Scientific Revolution in pointing out that a significant proportion of the scientific community was moving away from the modern concept of mathematical abstraction in natural philosophy at precisely the time when that concept was beginning to show its power in the hands of the mechanical philosophers.

A. THE BACKGROUND OF THE PROBLEM

The fourteenth century scholastic analysis of Aristotelian mechanics is today rightly considered to be one of the well-springs of modern science. The scholars of Merton College and Paris had founded a critical tradition which was still alive in the sixteenth century and which influenced the young Galileo.

Yet, while this may be readily admitted, it is true also that scholasticism was under heavy attack in the Scientific Renaissance. The Theology and Philosophy of the schools seemed to many to have become enmeshed in arid verbal controversies, and an ever increasing number of scholars were demanding something new to replace a system which they could no longer tolerate. One answer to this call may be found in a revived interest in the neo-Platonic and Hermetic writings—sources which were currently thought to have strong and valid connections with Christian thought and teaching.⁶

With some this path of inquiry led to a search for truth in an alchemical cosmology, but, for nearly all, it resulted as well in a new emphasis on mathematics as a key to the universe. No better example of this may be found than in the work of Nicholas Cusanus (1401–64). For him both philosophical truth and Holy Writ lead us to the same conclusion, that a knowledge of mundane and divine truth may only be had through a knowledge of numbers. In *Wisdom* 11:17 we read that God created “all things in number, weight and measure”.⁷ The Creation itself then may be interpreted as a mathematical process since arithmetic, geometry, music and astronomy are the “same sciences God employed when He made the world”.⁸ One could hardly argue that such

⁶ See Frances A. Yates, *Giordano Bruno and the Hermetic Tradition* (Chicago: University of Chicago Press, 1964).

⁷ Nicolas Cusanus, *The Idiot in Four Books. The first and second of Wisdom. The third of the Minde. The fourth of statick Experiments, Or Experiments of the Ballance* (London: William Leake, 1650), p. 172. Nicolas Cusanus, *Of Learned Ignorance*, trans. Fr. Germain Heron, O.F.M., Ph.D. (London: Routledge and Kegan Paul, 1954), p. 119.

⁸ Cusanus, *Of Learned Ignorance*, p. 118. “With arithmetic the Creator adjusted the World to unity, with geometry he balanced the design to give it stability and controlled movement while with music its parts were so allotted that there should be no more earth in the earth than water in the water, than air in the air or than fire in the fire, so that no element could be wholly transmuted into another: whence it comes that the physical system cannot sink into chaos”.

a process could not be studied profitably in a mathematical way, and that from it we might learn of our Creator, since we would be using his own method of Creation as our guide.

Yet, for Cusanus more than Biblical truth leads us to this conclusion. Philosophers agree that the visible universe is a faithful reflection of the invisible one and we may surely expect to rise to a firm knowledge of our Creator if we properly study the creatures and objects of our world.⁹ But a study of the multiple beings in nature can only lead to our belief in an underlying unity pervading all things. We don't know why, but

we know for a fact that all things stand in some sort of relation to one another, that, in virtue of this inter-relation, all the individuals constitute one universe and that in the one Absolute the multiplicity of beings is unity itself.¹⁰

One may, then, use experimental science as an approach to truth, and surely Cusanus did just this in his book of static experiments. But no amount of experimental knowledge can give us complete truth since the things of this world are not perfect. If possible we must begin our search in the perfect world of ideas and here we—like so many philosophers in the past—may rely on mathematics which starts with the finite, but allows us to progress confidently to the simple infinite. It is quite proper to use an image in our search for reality—provided that we can be certain of its validity. In this guise we may confidently rely on mathematics as the perfect example of abstract truth.

That explains why philosophers so readily turned to mathematics for examples of the things which the intellect had to investigate; and none of the masters of old, when solving a difficulty used other than mathematical illustrations, so that Boethius, the most learned of the Romans, went so far as to say that knowledge of things divine was impossible without some knowledge of mathematics.¹¹

Cusanus could call with confidence on time-honoured authority for support. Not only might the reader turn to Boethius, he would also learn of the indispensable nature of mathematics in the writings of the Pythagoreans, St. Augustine and Plato. Even Aristotle although he had disagreed with his master had proceeded to use mathematical examples.¹²

⁹ *Ibid.*, p. 25. For a comparison of man with nature, Cusanus turned to Plato—"The earth, as Plato says, is like some vast animal whose veins are rivers and whose hairs are the trees; and the animals that feed among the hairs of the earth are as the vermin to be found in the hair of beasts". *Ibid.*, p. 119.

¹⁰ *Ibid.*, p. 25.

¹¹ *Ibid.*, p. 26.

¹² *Ibid.*

There is no question that the Pythagoreans were thought to be the ultimate source for those who believed in mathematics and number as the true key to nature. Aristotle had complained that their system really was not mathematics or the legitimate study of number. Rather, he had explained,

all their discussions and interests concern nature: for they explain the generation of the heavens and carefully note the events, changes, and revolutions in the celestial regions. Thus, they employ all the principles and explanations, as if they agreed with the physicists that all being is perceptible and is contained under the vault of heaven. But their explanations and principles, as we have said, are suitable for even most exalted beings, more suited to them, in fact, than to nature.¹³

Indeed, Aristotle understood the Pythagorean Creation in terms of material numbers which formed the elements and all other substances.¹⁴ Although the concept of material numbers had at best a limited vogue, the cosmological significance of mathematics was strongly championed by Plato. For him this science surely seeks eternal truth rather than the knowledge of perishable and transient matter.¹⁵ True astronomers (mathematicians) properly lift up their thoughts to divinity in their studies. It is they who see the Creation in all its aspects as a mathematically perfect structure.¹⁶

It is understandable that these views were echoed by many neo-Platonic and neo-Pythagorean authors in late antiquity. Many examples of this might be offered, but few would be better than the remarks of Nicomachus of Gerasa (second century A.D.) in his *Introductio Arithmetica*:

All that has by nature with systematic method been arranged in the universe seems both in part and as a whole to have been determined and ordered in accordance with number by the forethought and the mind of him that created all things; for the pattern was fixed, like a

¹³ Aristotle, *Metaphysics*, Newly trans. as a postscript to natural science with an analytical index of technical terms, trans. Richard Hope (New York; Columbia U.P., 1952), p. 25 (989b).

¹⁴ *Ibid.*, pp. 15 f. (986a, b). It need hardly be said that the purpose of referring briefly to the Pythagoreans, Plato, Nicomachus and other pre-Renaissance authors is only to point out the persistent interest in cosmic harmony and the divine goal of mathematics. It is not our intent to examine in detail the views of any of these authors.

¹⁵ Plato, *The Republic*, in *The Dialogues of Plato*, trans. with Analyses and Introductions (4 vols., Oxford: Clarendon Press, 1871), 2, p. 362 (Book 7—526).

¹⁶ *Ibid.*, 2, p. 365 (Book 7—530). The concept of numerical perfection runs throughout the Platonic dialogues. The *Timaeus* is particularly important for this concept in reference to the universe. One Platonic theme which recurs regularly in the Renaissance chemical literature is the insistence that two extremes cannot exist without a mean. In the *Timaeus* this argument is used to show the necessity of a third element between Fire and Earth (31B—32C). This "argument of the mean" was used by the Paracelsians in proof of their three principles. Debus, *English Paracelsians*, pp. 93—94 and *passim*.

preliminary sketch, by the domination of number preexistent in the mind of the world-creating God, number conceptual only and immaterial in every way, but at the same time the true and eternal essence, so that with reference to it, as to an artistic plan, should be created all these things, time, motion, the heavens, the stars, all sorts of revolutions.¹⁷

Neo-Platonic thought was particularly persuasive to many early fathers of the Church. For St Augustine, Platonism was the philosophy which came closest to Christianity in truth,¹⁸ and it was not insignificant that Cusanus had called on his readers to read this Father for proof of the need of mathematics in the search for divine truth. At the same time, in his account of the Creation, Augustine, like other contemporary Platonists, referred specifically to the perfect qualities of various numbers, and he insisted that it had not been without reason that the world had been created in terms of number, weight and measure.¹⁹

The evident similarities between Platonism and Christianity recognized by Augustine and others had impressed elements of this philosophy on Christianity in late antiquity. As a result, neo-Platonism was given a degree of respectability not shared by other ancient systems of thought. Number mysticism is found in the works of Macrobius and Martianus Capella which enjoyed great popularity in the early medieval period, and the Pythagorean *De Institutione Arithmetica* and *De Institutione Musica* of Boethius were basic texts which continued to be frequently cited into the Renaissance.²⁰ Crombie has drawn our attention to Thierry of Chartres (twelfth century) who suggested that God had formed the universe in accordance with the mathematical ideas in His mind. Thus, only by mastering the mathematics of the quadrivium might a scholar properly understand the Creation account in *Genesis*.²¹ Similarly, the views of Roger Bacon fit in well with the earlier development of the subject. Of the four great sciences "the gate and key is mathematics, which the saints discovered

¹⁷ Nicomachus of Gerasa, *Introduction to Arithmetic*, trans. Martin Luther D'Ooge, with studies in Greek Arithmetic by F. E. Robbins and L. C. Karpinski (New York: Macmillan Co., 1926), p. 189 (Book 1, chap. 4).

¹⁸ St. Augustine, *The City of God* (Book 7, chap. 9). I have used the translation by John Healey with an introduction by Ernest Barker (3 vols., London and Toronto: J. M. Dent and Sons, Ltd., 1931), 2, pp. 46 ff.

¹⁹ *Ibid.*, 2, p. 215.

²⁰ Boethius is regularly referred to by authors interested in cosmic mathematics. The influence of both Cusanus and Boethius is to be found in the work of Jacobus Faber Stapulensis. An interesting example of this is his *Epitome/compendiosq introductio in libros Arithmeticos diui Severini Boetij: adiecto familiari commentario dilucidata . . . Insuper Astronomicon* (Paris: Volphgangus hopilius et Henricus Stephanus, 1503).

²¹ A. C. Crombie, "Quantification in Medieval Physics", *Isis*, 52 (1961), 145.

at the beginning of the world".²² For Bacon there are two types of mathematics corresponding to the two great divisions of the universe. "Terrestrial things will not be known without a knowledge of the celestial, and the latter cannot be known without mathematics".²³ But matter itself may be subjected to a geometrical investigation since by this method we may learn of the efficient and generating causes of those things which exist.²⁴ Above all—we hear once again—true mathematics

stirs us to reverence the Creator, and since there is no comparison in magnitude of things below with things celestial, the knowledge of things below will have no comparison with that of things above as regards their end, which is the praise and reverence for the Creator.²⁵

In short, even a most limited group of examples in the period prior to the Renaissance shows that the Pythagorean-Platonic-Christian influence emphasized the importance of mathematics as a key to the Creation epic and consequently, to all nature. Cusanus rightly called on the testimony of earlier philosophers, for even if he might disagree with them over details, his concept of the goal of mathematics differed from theirs.

B. OCCULT MATHEMATICS IN THE SIXTEENTH CENTURY

Although the observational-experimental implications of *Wisdom* 11:17 were eventually to become predominant, the mystical-theological goal of mathematics continued to be a matter of overriding concern to fifteenth- and sixteenth-century scholars. All might agree that mathematics had manifold practical values for the businessman, the surveyor and the artisan, but at the same time few would argue with Plato that the beauty of higher mathematical proofs could only serve to prepare the mind for greater and more divine truths. Yet, if mathematics truly dealt with the Creation of the world, the generation and corruption of matter and other topics beyond the ken of the ordinary scholar, how might it best be treated? The neo-Platonic and neo-Pythagorean texts of late antiquity had been filled with accounts of angels, demons and magic. Because of this a distrust of this science had developed early. Roger Bacon had found it necessary to defend the true mathematics (which he derived from *mathesis* with a short middle syllable—and meaning knowledge) from the false mathematics or magic (derived from *mathesi* with a long middle syllable

²² Roger Bacon, *Opus Majus*, trans. Robert Belle Burke (2 vols., Philadelphia, U.P.P., 1928), 1, p. 116.

²³ *Ibid.*, 1p, 129.

²⁴ *Ibid.*, 1, p. 165.

²⁵ *Ibid.*, 1, pp. 200-1.

—meaning divination).²⁶ The revived interest in neo-Platonic thought in the fifteenth century made this a question of vital interest. No one denied the existence of evil and demonic magic, but surely all forces in the universe must be natural in their operation since they all derive from the omnipotent Creator. It was only the goal of the magician which might be questioned. Most natural magicians of the Renaissance answered their opponents by affirming that their task was not to prepare spells, charms and incantations. Rather, they explored the wonders of God's created universe so that they might better comprehend their Creator. Since this was the meaning of the true magic, its practitioners could take pride in their goals and accomplishments.

Pico della Mirandola insisted that his only interest was in this type of magic.²⁷ But, essential to this is the true mathematics which is the formal part of physics.²⁸ Here kabbalistic number mysticism—a popular study of Renaissance scholars—played as strong a role as the more formal Pythagorean tradition.²⁹ We may be certain that with a knowledge of numbers we have

²⁶ *Ibid.*, I, p. 261. Such derivations from similar words with radically different meanings are common. Another example may be seen in Sir Christopher Heydon, *A Defence of Iudiciall Astrologie, In Answer to a Treatise lately published by M. Iohn Chamber* (Cambridge: John Legat, 1603), pp. 10–11.

²⁷ Ioannis Pici, *Mirandulae Concordiaque Comitiss, Opera quae extant omnia* (2 vols., Basil: Sebastianum Henricpetri, 1601), 2, p. 114.

²⁸ *Ibid.*

²⁹ Fifteenth and sixteenth century Christian scholars found a new stimulus for mystical numerical and geometrical studies in their fascination with the Hebrew *Kabbalah* and the Lullian system. In the kabbalistic tradition one may point to Reuchlin, Agrippa of Nettesheym and Georgius Venetus ("Zorzi") besides Pico. Because these studies were quickly applied to alchemical thought, they are of importance for an understanding of Paracelsian mathematics. Thus J. A. Pantheus (1518) discussed the art and theory of metallic transmutation in a kabbalistic system which assigned numbers to Latin, Greek and Hebrew letters. In a discussion of the four elements he gives each letter a number according to its place in the alphabet, adds the total, and then multiplies by eight. See J. A. Pantheus, *Ars et Theoria Transmutationis Metallica cum Voarchadumia, proportionibus, numeris, & iconibus rei accomodis illustrata* in *Theatrum Chemicum*, ed. Zetzner (6 vols., Argentorati: Zetzner, 1659–61), 2, pp. 459–549, especially p. 472. The Renaissance symbolic and kabbalistic thought is well treated in Desirée Hirst, *Hidden Riches* (London: Eyre & Spottiswoode, 1963), and of special significance is F. Secret, *L'Astrologie et les Kabbalistes Chrétiens à la Renaissance* (La Tour St.-Jacques, 1956).

Ramon Lull claimed that encyclopedic knowledge would be at one's fingertips by means of tables, movable circles and geometrical patterns. Although Lull himself had little patience with alchemy, his disciples wrote numerous alchemical tracts which are filled with Lullian geometrical figures to aid the scholar in his understanding of divine secrets. The authorship of these tracts was—in typical alchemical fashion—assigned to Lull. An example of this is the widely known *Testamentum Theoria & Practica* printed in the *Theatrum Chemicum*, 4, pp. 1–170. Here typical Lullian figures appear throughout the work. Giordano Bruno,

a key to the proper understanding of everything which may be learned by man.³⁰ Indeed, arising from mathematical books is a contemplative philosophy requisite for our further studies in theology.³¹ And since mathematics includes in its sphere the whole universe—things celestial and divine as well as things terrestrial and human—earlier philosophers were right in placing astronomy and astrology within its fold.³²

The equating of astrology, astronomy and mathematics is a persistent theme in Renaissance texts and one which is referred to by authors of widely differing views. For some, mathematics really meant iatromathematics, the use of astrology in medicine.³³ Leonard Digges opened a practical treatise on surveying with a defence of astronomy—or rather astrology—and mathematical sciences.³⁴ On the other hand, Porta, in his *Natural Magick*, explained that magic is essentially the search for wisdom and seeks nothing else but the “survey of the whole course of nature”.³⁵ In this legitimate and worthy search the Godly *magus* is told that he “must know the Mathematical Sciences, and especially Astrologie”.³⁶ Similar cosmic views are to be found in Agrippa’s *De Occulta Philosophia*. Here magic is depicted as the most perfect science, the consummation of philosophy.³⁷ A magician, however, can do nothing without mathematics since all things were made and continue to be ruled over by number, weight, measure, harmony, motion and light. These are mathematical studies which are necessary for natural philosophy. When they are mastered they may be put into practice with the mechanical arts with the

an enthusiastic Lullist, was to find a strong Lullist strain in the work of Paracelsus. Walter Pagel, *Paracelsus. An Introduction to Philosophical Medicine in the Era of the Renaissance* (Basel: S. Karger, 1958), p. 245. Indispensable here is Frances A. Yates, “The Art of Ramon Lull: An approach to it through Lull’s Theory of the Elements”, *J. Warburg Inst.*, 17 (1954), pp. 115–73.

³⁰ Pico. As quoted by John Dee in his “Mathematicall Preface” to *The Elements of Geometrie of the most auncient Philosopher Euclide of Megara*, trans. H. Billingsley (London: John Daye, 1570), sig. *i verso.

³¹ Pico, *op. cit.*, 2, p. 285.

³² *Ibid.*, 2, p. 488.

³³ On the history of this subject see Karl Sudhoff, *Iatromathematiker vornehmlich im 15. und 16. Jahrhundert* (Breslau, J. U. Kern, 1902).

³⁴ Leonard Digges, *A Prognostication of Right Good Effect, fructfully augmented, containyng, playne, briefe, pleasant, chosen rules, to iudge the wether for euer, by the Sunne, Moone Sterres, Cometes, Raynbowe, Thunder, Cloudes, with other Extraordinarie tokens, not omitting the Aspectes of Planets, with a brefe Iudgemente for euer, of Plentie, Lacke, Sicknes, Death, Warres &c.* . . . (London: Thomas Gemini, 1555), sig. A4 recto.

³⁵ John Baptista Porta, *Natural Magick* (London: Thomas Young and Samuel Speed, 1658), p. 2.

³⁶ *Ibid.*, p. 3.

³⁷ Henricus Cornelius Agrippa, *De Occulta Philosophia. Libri Tres* [(Cologne), 1533], p. 2.

production of marvels and wonders.³⁸ In addition, man himself might fruitfully be subjected to a numerical analysis. He is the most nearly perfect product of God's Creation and in him will be found the same composition according to weight, number and measure that we know exists in the macrocosm. Therefore, the proportions and harmonies we establish in the heavens and the earth we know must also be found by valid analogy in our own bodies.³⁹ For Agrippa, these truths may easily—and very properly—be related to kabbalistic studies.

There are few authors, however, whose work is more illustrative of Renaissance mathematics than John Dee. In his renowned "Mathematicall Preface" to the first English translation of Euclid, Dee proceeded to divide and subdivide the many disciplines which he felt belonged within the realm of mathematics. Modern historians of science have praised him for his description of *Archemastrie* which "is named of some *Scientia Experimentalis*. The *Experimentall Science*".⁴⁰ Dee was certainly not unaware of recent publications of significance. Rattansi, for instance, has pointed to Dee's recognition of the work of Benedetti who, through his knowledge of the mathematical science of *Statike*, had shown the error in the general belief that heavier bodies fall faster than lighter ones.⁴¹ Dee has been lauded also for his practical writings on astronomy, navigation and mathematics which seem to give an early indication of the significance and interrelation of technology and science.

If, however, we read his works in greater detail, we find a repetition of the now familiar Platonic arguments. Mathematics is a divine science because we know the Creation was essentially a mathematical process. The Creator's

³⁸ *Ibid.*, pp. 99-101.

³⁹ *Ibid.*, p. 160.

⁴⁰ Dee, "Mathematicall Preface", sig. Aiii recto. *Archemastrie* "teacheth to bryng to actuall experience sensible all worthy conclusions by all the Artes Mathematicall purposed, & by true Naturall Philosophie concluded: & both addeth to them a farder scope, in the termes of the same Artes, & also by hys propre Method, and in peculiar termes, procedeth, with helpe of the foresayd Artes, to the performance of complet Experiēces, which of no particular Art, are hable (Formally) to be challenged. . . . And bycause it procedeth by *Experiences*, and searcheth forth the causes of Conclusions, by *Experiences*: and also putteth the Conclusions them selves, in *Experience*, it is named of some *Scientia Experimentalis*. The *Experimentall Science*".

⁴¹ *Ibid.*, sig. of ci recto. "By these verities, great Errors may be reformed, in Opinion of the Naturall Motion of thinges, Light and Heauy. Which errors, are in Naturall Philosophie (almost) of all me allowed: to much trusting to Authority: and false Suppositions. As, Of any two bodyes, the heauyer, to moue downward faster then the lighter. This error, is not first by me, Noted: but by one *Iohn Baptist de Benedictus*. The chief of his propositions, is this: which seemeth a Paradox.

If there be two bodyes of one forme, and of one kynde, aequall in quantitie or unequall, they will moue by aequall space, in aequall tyme: So that both theyr mouynges be in ayre, of both in water: or in any one Middle".

"numbryng . . . was his Creatyng of all thynges, And his Continuall *Numbryng*, of all thynges, is the Conseruation of them in being".⁴² We find, therefore, that "The constant law of numbers . . . is planted in thyngs Naturall and Supernaturall: and is prescribed to all Creatures, inuolably to be kept".⁴³ The mathematical sciences then rightly become a means for us to learn of our Creator. Arithmetic is, indeed, a subject little less useful than Theology,⁴⁴ while the primary use of Geometry, as Plato teaches us, is

to conceiue, discourse, and conclude of thyngs, Intellectual, Spirituall, aeternall, and such as concerne our Blisse euclasting: which otherwise (without Speciall priuiledge of Illumination, or Reuelation frō heauen) No mortall mans wyt (naturally) is hable to reach unto, or to Com-
passe.⁴⁵

Christian scholars can—and should—study numbers so that

we may both winde and draw our selues into the inward and deepe search and vew, of all creatures distinct vertues, natures, properties, and *Formes*: And also, farder, arise, clime, ascend, and mount up (with Speculative winges) in spirit, to behold in the Glas of Creation, the *Forme* of *Formes*, the *Exemplar Number* of all thyngs *Numerable*: both visible and invisible: mortall and immortall, Corporall and Spirituall.⁴⁶

Surely with this admitted,

No man . . . can doute, but towards the atteyning of knowledge incomparable, and Heauenly Wisdome: Mathematicall Speculations, both of Numbers and Magnitudes: are means, aydes, and guides: ready, certain, and necessary.⁴⁷

Dee was a sincere alchemist and astrologer, and with this broader understanding of the primary purpose of mathematics his views in the "Mathematicall Preface" may be seen to fit in closely with his *Monas Hieroglyphica* (1564), which is a mystical alchemical text, dedicated to the penetration of divine mysteries through an occult explanation of geometrical figures.⁴⁸ Similarly Dee's description of astronomy relates this science to its major goal.

⁴² *Ibid.*, sig. *i verso.

⁴³ *Ibid.*

⁴⁴ *Ibid.*, sig. ai verso.

⁴⁵ *Ibid.*, sig. aiii recto.

⁴⁶ *Ibid.*, sig. *i recto and verso.

⁴⁷ *Ibid.*, sig. aiii recto.

⁴⁸ See the recent translation and commentary on the "Monas Hieroglyphica" by C. H. Josten, *Ambix*, 12 (1964), pp. 84–220. The first edition of this work appeared at Antwerp (1564) and the second at Frankfort (1591). Number mysticism in early alchemical texts has been discussed by H. E. Stapleton, "The Antiquity of Alchemy", *Ambix*, 5 (1953), 1–43.

It is true that astronomy teaches us the distances, magnitudes and motions of the stars and planets, but more important, we learn hereby of our Creator so that we may better glorify him.⁴⁹ As a science it may well be used "for Consideratiō of Sacred Propheties, accomplished in due time, foretold: as for high Mysticall Solemnities holding".⁵⁰ And if we pass on to a few of Dee's other mathematical sciences we see the familiar macrocosm-microcosm relationship develop. Astrology is such a science, for it treats quite simply of the "operations and effectes, of the naturall beames of light, and secret influence: of the Sterres and Planets: in euery element and elementall body".⁵¹ It is thus concerned with the actual connection of the celestial and terrestrial worlds. Anthropography, in turn, "is the description of the Number, Measure, Waight, figure, Situation, and colour of euery diuise thing, conteyned in the perfect body of MAN".⁵² This is the lesser world or microcosm which deserves a mathematical description no less than the greater world. Finally, natural magic called thaumaturgike by Dee, is devoted to the construction of "strange workes, of the sense to be perceiued, and of men greatly to be wondred at".⁵³ Dee's views here are not dissimilar to those of Roger Bacon, Agrippa and Porta. Natural magic is truly a mathematical science pursued by men who "seketh . . . in the Creatures Properties, and wonderfull vertues, to finde iuste cause, to glorifie the Aeternall, and Almighty Creator".⁵⁴ It is a wicked and blasphemous thing for the ignorant to call these pious men conjurers—a term he had been called himself.

C. THE MATHEMATICS OF THE PARACELSAINS

Paracelsian thought may be considered as a special case of the neo-Platonic-Hermetic philosophy of the Renaissance. With most Paracelsian authors the created universe remained mathematically inspired, but the major key to our understanding becomes chemistry, since the Creation is now considered primarily in terms of a chemical separation. With the divine mathematical Creation the scholar might progress in knowledge toward his Creator through a mystical concept of numbers. With the divine chemical Creation the Paracelsist might attain the same goal, but through his observations of natural objects and his chemical investigations by fire. The call for new experimental knowledge is common to most Paracelsians in the sixteenth and the seventeenth centuries. It was a plea which had its roots buried deeply in the past. In the

⁴⁹ Dee, "Mathematicall Preface", sig. bii recto.

⁵⁰ *Ibid.*, sig. bii verso.

⁵¹ *Ibid.*, sig. biii recto.

⁵² *Ibid.*, sig. ciii recto.

⁵³ *Ibid.*, sig. Ai recto.

⁵⁴ *Ibid.*, sig. Ai verso.

Hermetic texts the true philosopher is told to seek out knowledge as a form of divine worship—

... the student of philosophy undefiled, which is dependent on devotion to God, and on that alone, ought to direct his attention to the other sciences only so far as he may thereby learn to see and marvel how the returns of the heavenly bodies to their former places, their halts in pre-ordained positions, and the variations of their movements, are true to the reckonings of number; only so far as, learning the measurements of the earth, the depth of the sea, (the ... of air), the force of fire, and the properties, magnitudes, workings, and natures of all material things, he may be led to revere, adore, and praise God's skill and wisdom.⁵⁵

Alchemical theorists of the Middle Ages relied heavily on such references, and in addition they called on familiar Biblical quotations. Thomas Norton, for instance, writing at about the same time as Nicholas Cusanus, rhymed

For God made all things, and set it sure,
In Number Ponder and in Measure.⁵⁶

In short, traditional alchemy retained as its goal the glorification of the Creator, but because of its laboratory orientation there was less interest on the part of alchemists in the mathematical concept of Creation.

The shift in emphasis becomes apparent quickly when we turn to the works of Paracelsus. Here was a man who had no special interest in measurement and numbers. Yet, as Pagel has noted, Paracelsus relied on *Wisdom* 11:17 when he insisted that "disease stands on weight, number and measure", and we find in Paracelsian texts some of the earliest quantitative analyses of urine.⁵⁷ Similarly, Paracelsus frequently uses the terms "Kabbalah" and 'kabbalistic', indicating a general acquaintance with this literature even though specific references to the mystical numerical interpretation of letters are lacking in his work.⁵⁸ Nevertheless, it is primarily in the *Astronomia Magna* that the role of mathematics in philosophy is discussed in detail. Here we read that "Mathematica est *Magica, Nigromantica, Nectromantica Astrologia, Signata, Artium incertarum, medicinae adeptae, Philosophia adeptae*".⁵⁹ If mathematics

⁵⁵ Hermes Trismegistus, *Asclepius* in *Hermetica*, ed., trans. and notes by Walter Scott (vol. 4 with A. S. Ferguson) (4 vols., Oxford, Clarendon Press, 1924, 1925, 1926, 1936), 1, p. 311.

⁵⁶ Thomas Norton, *Ordinall of Alchimy* in Elias Ashmole (ed.), *Theatrum Chemicum Britannicum* (London, 1652), pp. 57-8.

⁵⁷ Walter Pagel, *Paracelsus. An Introduction to Philosophical Medicine in the Era of the Renaissance* (Basel: S. Karger, 1958), pp. 190-4, 281-2.

⁵⁸ *Ibid.*, p. 213.

⁵⁹ Paracelsus, *Opera Omnia* (3 vols. in two, Geneva: Joan. Antonii & Samuelis De Tournes, 1658), 2, p. 549.

is magic, true magic, in turn, may be equated with nature.⁶⁰ The godly magus may concentrate in himself celestial virtues which are the hidden powers of nature. He may then use these powers to work wonders and learn of his Creator.⁶¹

We must distinguish, Paracelsus continues, between elementary mathematics and the mathematics of the adept since only the latter may be called magic. Elementary mathematics is concerned with visible and tangible objects such as the growth of a tree, the motion of the sun and the phases of the moon. The mathematics of the adept goes beyond this and its adepts are enabled to study visible, but non-palpable, objects such as the image of the sun in a river or the moon in a well. Also called sidereal mathematics, this subject examines generation and creation as well as essences and archidoxies which the practitioner may then associate with their proper geometrical figures according to their height, profundity, amplitude and angles. There is thus a real division between the two mathematics. The sidereal mathematician is the master of a subject which would hardly be given that name today. He can show that paper is nothing but wood, discover the real substance of the sun, and learn the differences of type and species. Such studies are possible only for the "Adepta Mathematica, Philosophia & Medicina".⁶²

When late sixteenth-century Paracelsians mentioned mathematics other than in terms of weight measurements it was generally in these terms. Bostocke (1585) wrote that "the true and auncient phisicke" may be sought in nature "and is collected out of Mathematicall and supernaturall precepts". This is a sacred art properly called *Chymia*

Which sheweth forth the compositions of all maner bodies, and their dissolutions, their natures & properties by labour by the fire, following Nature diligently. So that Philosophie naturall and supernaturall, the Mathematics *Chimia* and *Medicina* be so combined together, that one of them can not be without the other.⁶³

Mathematics is truly a mystical science for Bostocke, and as the goals of the sidereal mathematics of Paracelsus would indicate, it may be easily equated with the mystical chemistry of the philosophical alchemists. Similarly Thomas

⁶⁰ *Ibid.*, 2, p. 558.

⁶¹ *Ibid.*, 2, p. 555. Nihil autem est aliud, quàm potentia, virtutes coelestes in Medium inducendi, & in illo operationis proficiendi. Medium hoc est centrum. Centrum est homo. Sic ergo per hominem vis coelestis in hominem induci potest, ita, ut in homine tali virtus, constellationi illi congrua, inveniat.

⁶² *Ibid.*, 2, pp. 577-8.

⁶³ R. B. Esq. (R. Bostocke), *The difference betwene the auncient Phisicke, first taught by the godly forefathers, consisting in unity peace and concord: and the latter Phisicke*. . . . (London: Robert Walley, 1585), sig. Bi recto.

Tymme (1605) pictures the divine Creation as a universal harmony which has been produced in terms of weight, number and measure. Yet, knowing the author is a Paracelsian, the reader is hardly surprised to see all of this described as "Gods Halchymie".⁶⁴

Among the early Paracelsians few authors were more concerned with numerical studies than Gerard Dorn. In his description of the Creation, and in his *Physics* of Trithemius, he continually referred to the power of mystical numerical analysis,⁶⁵ while his *Monarchia Triadis, in Unitate, Soli Deo Sacra* (1577) is a complex tract which attempts to show and relate the triune nature of divinity with the universe as a whole.⁶⁶ Beyond this, Dorn finds a correspondence between divine unity, the Paracelsian principles, and the medicine of the Paracelsians. On the other hand, the evil of a binary system is related to the devil and finds its expression in the corrupt medicine of the Galenists. Although elements of the thought of Cusanus are present,⁶⁷ the progression of geometrical figures which illustrate this tract are strongly reminiscent of John Dee's mystical *Monas Hieroglyphica*. Dorn's mathematical/geometrical theme is one which is recurrent among the Paracelsian authors.⁶⁸

With no author did the alchemical universe find greater support than with Robert Fludd (1574-1637). An Oxford trained physician, Fludd was an honoured member of the Royal College of Physicians and a friend of William Harvey and Mark Ridley. Yet, he was far from being a "modern". Fludd wrote with sincerity about the mystical alchemical Creation, and he considered kabbalistic analysis to be a proper method in the scholar's search for divine secrets. His publications were controversial in tone and widely discussed. As such, they engaged the attention of some of the best minds in Europe—a group which included Kepler, Mersenne and Gassendi.⁶⁹

In his first work, an apology for the Rosicrucians (1616), Fludd made a plea for a new learning. Nowhere did he feel that there was a more useless knowledge being spewed forth than at the Universities. These were the

⁶⁴ Josephus Quersitanus, *The Practice of Chymicall, and Hermeticall Physicke, for the preservation of health*, trans. Thomas Tymme (London: Thomas Creede, 1605), sig. A3 verso.

⁶⁵ The *Physica Genesi* and the *Physica Trithemii* form parts of the *Liber de Natura luce Physica, ex Genesi desumpta* which is printed in the *Theatrum Chemicum*, 1. Similarly see Dorn's preoccupation with the sphere and other geometrical figures in the *Clavis totius philosophiae Chemicisticae per quam potissima philosophorum dicta reserantur* in *Ibid.*, 1, pp. 192-361, p. 335.

⁶⁶ Gerard Dorn, *Monarchia Triadis, in Vnitate, Soli Deo Sacra* in Paracelsus, *Aurora Thesaurusque Philosophorum* (Basel: Palma Guarini, 1577), pp. 65-127.

⁶⁷ Pagel, *Paracelsus*, p. 135.

⁶⁸ The incompatibility of the "medicine ternarii" (or unity) with the "medicine binarii" was a major theme in Bostocke's Paracelsian apology of 1585 (see above, note 63).

⁶⁹ On Fludd see the references cited above in footnote 5.

strongholds of the classical scholars who felt that truth might only be found in the writings of the ancients. One could only shudder at their reliance on Aristotle in philosophy and Galen in medicine, for in the ancient world none set forth doctrines more opposed to Christianity than they. Aristotle and Galen had been heathens, and their followers were no better. The Universities must be reformed so that the divine light of Christian teachings could flourish. In a chapter on natural philosophy, medicine and alchemy, Fludd tells us that although innumerable authors have written on natural philosophy, they have presented to us only a shade of truth.⁷⁰ They fill whole volumes with definitions, descriptions and divisions, and they drone on about the four causes. They lecture on motion, the continuum, the continguum—of termini, loci, of space, vacui, time and number. This for them is the basis of physics. They go forth then to generation, corruption and descriptive accounts of the heavens and the universe.⁷¹ "But, good God, how superficial and equivocal this all is".⁷² It is impossible for anyone to attain the highest knowledge of natural philosophy without a thorough training in the occult sciences.⁷³

One must turn first to medicine, the most perfect science of all. There should not be understood by this term a simple description of diseases and the workings of the human body. Rather, it is the very basis on which natural philosophy must rest.⁷⁴ Our knowledge of the microcosm will teach us of the great world, and this, in turn, will lead us to our Creator. Similarly, the more we learn of the universe, the more we will be rewarded with a perfect knowledge of ourselves. The vulgar medicine of the Galenist, the Astrologer, and the Paracelsist fails since it treats only of descriptive material of little value—of principles, elements, humors, the body and its parts, temperaments, virtues and the motion of the pulse.⁷⁵ Yet, Hippocrates makes mention obscurely and mystically of a single medicine which cures all ills. From Pliny, Lull, Arnold, Rupescissa and others we learn that this medicine unites in peace the warring elements in the body.⁷⁶ It is this medicine which must be sought in our reformed science.

⁷⁰ Originally published as the *Apologia compendiaria, Fraternitatem de Rosea cruce suspicionis et infamiae maculis aspersam, veritatis quasi Fluctibus abluens et abstergens* (Leyden, 1616), I have used the enlarged second edition, *Tractatus Apologeticus Integritatem Societatis De Rosea Cruce defendens* (Lugduni Batavorum: Godfridum Basson, 1617). Here see p. 91. A German translation is available: *Schutzschrift für die Aechtheit der Rosenkreutzergesellschaft*, trans. AdaMah Booz (Leipzig: A. F. Böhme, 1782).

⁷¹ Fludd, *Tractatus Apologeticus*, pp. 91-3.

⁷² *Ibid.*, p. 93.

⁷³ *Ibid.*

⁷⁴ *Ibid.*, p. 89.

⁷⁵ *Ibid.*, pp. 95-7.

⁷⁶ *Ibid.*, pp. 97-9.

Even the art of alchemy from which we might expect so much, aids us little. Alchemists like Andreas Libavius do not call for a reform but rather describe calcination, separation, conjunction, putrefaction and all the other operations by which men are deceived and persuaded to part with their money.⁷⁷ True chemical authors are of a different sort and write of occult secrets. We need not vulgar, but natural fire, not artificial, but natural vessels. No miracles are performed when true alchemy is practised, only the work of nature.⁷⁸

Real wisdom may be found in the writings of the natural magicians, men who are in truth, mathematicians.⁷⁹ But if Fludd was distressed about the state of natural philosophy, medicine and alchemy in his day, he felt even more strongly about mathematics.⁸⁰ The texts of arithmetic were filled with definitions, principles and discussions of theoretical operations. We learn of addition, subtraction, multiplication, division, golden numbers, fractions, square roots and the extraction of cubes.⁸¹ But to the old wisdom and doctrines of the Pythagoreans the Arithmeticians pay little heed. These men of old were silent about the arcane arithmetic, and like mystical alchemists they hid their profound mysteries from the vulgar crowd.⁸²

And, Fludd continues, if we go beyond arithmetic to other mathematical studies, we find the same superficiality. Those who are really profound in these arts are considered impious and magicians.⁸³ Indeed, we can learn more from the silent wisdom of the Pythagoreans than we can from the useless books of the philosophers. The disciples of Pythagoras reached a certainty of belief in God through their profound study of numbers and their ratios. In the same way, we may learn of the unity of God in trinity, a theme continually stressed by these authors—and more, of the very fabric of the world.⁸⁴ But we look in vain for these secrets in the written records since there are no true remains of the Pythagorean teachings. It is a science which must be wholly restored.⁸⁵

And what of music? This is a subject which properly forms a division of

⁷⁷ *Ibid.*, pp. 100–1.

⁷⁸ *Ibid.*, p. 101.

⁷⁹ *Ibid.*, p. 23.

⁸⁰ *Ibid.*, p. 103.

⁸¹ *Ibid.*

⁸² *Ibid.*, p. 105.

⁸³ *Ibid.*

⁸⁴ *Ibid.*, p. 107. Fludd would have rejoiced in the publication in the same year of a book on mystical geometry by Fortunatus, *Decas Elementorum Mysticae Geometrae Quibus Praecipua Divinitatis Arcana Explicantur* (Padua: Peter Paul Tozzi, 1617). I am indebted to Walter Pagel for this reference.

⁸⁵ Fludd, *Tractatus Apologeticus*, p. 108.

mathematics. Are we to hear forever of harmonic systems, trite melodies, and sing *ad infinitum* the musical scales?⁸⁶

Good God, what does this have to do with the true and profound music of the wise, a subject through which the proportions of natural things are investigated, and the harmonic consensus and properties of the whole world are revealed. . . .⁸⁷

This science really deals with the joining of the elements, the proportions of light and weight in the stars, and their influence on our terrestrial world. Here we shall learn of the spiritual body of the sun and why the influence of Mars brings misfortune.⁸⁸ An exact knowledge of these things may be had only from speculation and revelation in the occult science of music which shows how the microcosmic palace agrees in celestial harmony with the macrocosm.⁸⁹

Therefore happy will be he who is well versed in such mysteries of occult music since without a knowledge of these things it is impossible for anyone to know himself. And without this he will be unable to reach a perfect knowledge of God, for he who understands himself truly and intrinsically perceives in himself the idea of the divine Trinity. . . .⁹⁰

Fludd's proposals for the renovation of the remaining branches of the mathematical quadrivium may be passed over fairly rapidly since his object is already quite clear. In geometry he was aghast to find the subject dominated by the theorems, axioms and propositions of Euclid. Surely this is all far removed from the true and perfect geometry which is concerned with hidden secrets.⁹¹ Like many of his contemporaries whom we today point to as forerunners of modern science, Fludd calls on Archimedes as our guide to a new science. Why?—because of his wondrous machines.⁹² In effect Archimedes is to be considered as the archetype of the perfect natural magician. Who

⁸⁶ *Ibid.*, p. 109.

⁸⁷ *Ibid.*, p. 109. Sed Deus bone quid hoc ad veram & profundam sapientis musicam, quā rerum naturalium proportiones investigantur, harmonicis consensus & totius proprietates revelantur. . . .

⁸⁸ *Ibid.*, p. 110. Similiter cur Mars etiam pro infortunio habetur, nisi propter extensionem suae consonantiae Diapason ad elementū suae naturae contrarium, videlicet Aquam.

⁸⁹ *Ibid.*, p. 111.

⁹⁰ *Ibid.* Foelix igitur erit qui in talibus Musices occultae misteriis benè est versatus, quippe sine quorum cognitione impossibile est, ut quis seipsum cognoscat; quod quidem nisi fiat ad perfectam Dei cognitionem attingere non potest; nam qui seipsum verè et intrinsecus intelligit, ideam in se divinae Trinitatis percipiet . . .

⁹¹ *Ibid.*, p. 113.

⁹² *Ibid.*, p. 114. For an example of Fludd's application of Arithmetic to nature see his demonstration of the mystery of the world's Creation "by way of an Arithmetically progression" in the *Mosaical Philosophy* (London: Humphrey Moseley, 1659), pp. 73-4.

today, he says, could build the masterworks of the past—the Colossus of Rhodes, the speaking birds and animals made of wood described by ancient authors, or even the brazen head of Roger Bacon? Similarly, in optics we now read descriptions of the membranes of the eye, the direction of rays and the refraction of colours. Instead we should be seeking the secrets of the mirrors which might destroy the Turks.⁹³ Such wonders are described in the writings of Roger Bacon, but the technique of their manufacture would appear to be irredeemably lost. In short, the state of geometry is so bad that we are faced with a problem of not simply correcting errors, but totally restoring the lost treasures of this subject.⁹⁴

The mathematical science of astronomy is really Astrology, but only pseudo-astrology is being cultivated today because the practitioners of the art are ignorant of the arcana of nature. They tell us of the motions of the stars, the divisions of the earth, and they prepare vast astronomical tables. They must learn instead of the arcane effect of the stars.⁹⁵ The celestial bodies are indeed the hieroglyphics of nature which man must learn to read.⁹⁶ Mystical alchemists embellish their works with symbolic drawings. How much clearer this is than descriptions with words or numbers which have no hidden meaning.⁹⁷ Yet, if scholars might once learn to properly read the message of the stars which has been written for us by the Creator himself, they will have a new and irrefutable guide to nature.

One can have no doubt that Fludd believed fervently in the use of mathematics for man's proper understanding of the universe. His meaning, however, derives ultimately from those mystical Pythagorean-Platonic and kabbalistic writings in which the subject assumes its major importance only when viewed as a key to cosmic mysteries. In this respect it is understandable that Fludd came into conflict with Kepler—a dispute which has been described so well by Wolfgang Pauli⁹⁸ and which forms no part of this paper. It is true that Kepler too was a spiritual descendent of the Pythagoreans.⁹⁹ He, too, seeks cosmic beauty in divine proportions, and his *Mysterium Cosmographicum* (1596) is famed for its relation of the planetary orbits to the regular solids. Pauli goes on to state that his ideas "reveal quite unmistakably the influence of Paracelsus and his pupils".¹⁰⁰ However, in spite of these similarities, it is quite

⁹³ Fludd, *Tractatus Apologeticus*, pp. 115–6.

⁹⁴ *Ibid.*, p. 114.

⁹⁵ *Ibid.*, pp. 116–8.

⁹⁶ *Ibid.*, pp. 32–3.

⁹⁷ *Ibid.*, p. 118.

⁹⁸ Cited above in footnote 4.

⁹⁹ Pauli, *op. cit.*, p. 156.

¹⁰⁰ *Ibid.*, p. 157.

understandable that the true meaning of mathematics for Kepler was something quite different than it was for Fludd. The latter sought mysteries in symbols according to a preconceived belief in a cosmic plan. His proportions and harmonies were forced to fit these symbols. Kepler, perhaps just as obsessed with his symbolic spherical picture of the world, insisted that his hypotheses be founded on quantitative, mathematically demonstrable premises.¹⁰¹ If his hypothesis could not accommodate his observations, he was willing to alter it. These two views were so separated from one another that the two men could not really understand each other. Fludd felt that he could honestly call Kepler one of the worst sort of mathematicians, one of the vulgar crowd who

concern themselves with quantitative shadows; the alchemists and Hermetic philosophers, however, comprehend the true core of the natural bodies.¹⁰²

D. THE IATROCHEMICAL REACTION: THE WORK OF VAN HELMONT

If the lofty and occult mathematics of the divine cosmology represents one stream of Renaissance thought which may be found in the writings of the Paracelsians, the influence of *Wisdom* 11:17 and other Biblical quotations led to other more mundane studies. In *The Idiot* Cusanus had additionally cited *Proverbs* 16:11 ("The weight and the Ballance are the judgements of that Lord, who hath created") and *Proverbs* 8:28 ("Who weighed the fountaines of waters, and the greatnesse of the Earth, in a Ballance, as the wise man saith").¹⁰³ And although such "quantification" could hardly compare with the search for the inner meaning of a divine mathematics, these Scriptural references alone were sufficient to indicate a divine sanction for such studies. Cusanus suggested that

Although nothing in this world can reach precision, yet wee finde by experience, the judgement of the Ballance, one of the truest things amongst us. . . .¹⁰⁴

¹⁰¹ *Ibid.*, p. 194.

¹⁰² *Ibid.*, p. 196.

¹⁰³ Cusanus, *The Idiot*, p. 172. From the Vulgate: *Prov.* 16:11. Pondus et statera iudicia Domini sunt: et opera eius omnes lapides sacculi. *Prov.* 8:28 Quando aethera firmabat sursum, et librabat fontes aquarum: *Prov.* 8:29 Quando circumdabat mari terminum suum, et legem ponebat aquis, ne transirent fines suos: quando appendebat fundamenta terrae. The neo-Platonic and Paracelsian background to Harvey's quantification (Cusanus, the Paracelsians, van Helmont) has been discussed by Walter Pagel, *William Harvey's Biological Ideas. Selected Aspects and Historical Background* (Basel/New York: S. Karger, 1967), pp. 73-82. Here Pagel shows that for Harvey also, mathematics is to be considered basically a tool for observation.

¹⁰⁴ *Ibid.*, p. 171.

With this justification he then proceeded to propose the analysis of spring waters, blood and urine by weight comparisons. The natural philosopher might attempt to weigh different samples of air, and similarly test the statements of the alchemists. Most famous of all, he is told to plant seeds in a weighed earthen pot. After they have grown,

hee woulde finde the earth but very little diminished, when he came to weigh it againe: by which he might gather, that all the aforesaid herbs had their weight from the water.¹⁰⁵

This type of quantification seemed in no way to conflict with Cusanus' grander scheme which involved a more direct search for divinity through the divine mathematical ideas.

One senses far less confidence among Paracelsians in the sixteenth and seventeenth centuries that cosmic mathematics should play as vital a role in science as Cusanus had suggested. As we have noted, mathematics was given a subservient role to chemistry in the writings of Paracelsus. In general, his followers—with the notable exception of Dorneus and Fludd—did not concentrate on the doctrine of the certainty of mathematical proof—even as they interpreted it. The chemical philosophers placed greater emphasis on weight determinations which were part of alchemical tradition and could be supported by Scriptural references in the fashion of Cusanus. Thus, we find a real interest on the part of sixteenth century iatrochemists in the weight analysis of mineral waters and urine,¹⁰⁶ and van Helmont was to carry out the plant experiment suggested by Cusanus with a tree. This mood may be seen in the work of the well known iatrochemist, Daniel Sennert, who paid little attention to the study of mathematics in his comparison of Aristotelian, Galenic and Paracelsian thought (1619),¹⁰⁷ and discussed the subject primarily as a practical art to be used whenever quantity is considered in his *Epitome Naturalis Scientiae* (1618).¹⁰⁸

Surely some chemical philosophers were reacting against an excessive use of theoretical mathematics in scientific investigations in the sixteenth century. We find Peter Severinus making this a major point in his rejection of Galenic medicine (1571).¹⁰⁹ Describing the decline of medical studies in antiquity, Severinus pictures Galen as a compiler faced with the task of putting order into the work of his predecessors. Seeking a unifying principle with laws and demonstrations, he at length came upon the writings of the geometricians.

¹⁰⁵ *Ibid.*, pp. 188-9.

¹⁰⁶ Allen G. Debuss, "Solution Analyses Prior to Robert Boyle", *Chymia*, 8 (1962), 41-61. Pagel, *Paracelsus*, pp. 190-4, 281-2.

¹⁰⁷ Daniel Sennert, *De Chymicorum cum Aristotelicis et Galenicis Concensu ac Dissensu Liber* (3rd ed., Paris, 1633).

¹⁰⁸ Daniel Sennert, *Epitome Naturalis Scientiae* (Paris, 1633), pp. 6-7.

¹⁰⁹ Petrus Severinus, *Idea Medicinae Philosophicae* (3rd ed., Hagae-Comitis, 1660), p. 2.

Seduced by their exquisite demonstrations, he attempted to make medicine a part of geometry with its own principles, axioms, and mathematical explanations. So influential had been his work that only in recent years had the fallacy of his approach been demonstrated. When Fernel tried Galen's methods and laws of cure he had found that they failed in the treatment of those new diseases which were ravaging the continent. We now know, Severinus continues, that the only true medicine is that to be found in the writings of Paracelsus,¹¹⁰ and far from being mathematically inspired, this science finds its roots in the experiments of the chemists.¹¹¹

Severinus had been the most important Paracelsian theorist in the sixteenth century. The work of van Helmont in the first half of the next century represents an even stronger protest against mathematical abstraction in theoretical science. This may be seen in his attack on Galen, Aristotle and Paracelsus. At one time strongly attracted to the work of Paracelsus, van Helmont eventually rejected many specific points of Paracelsian thought. Significantly he turned away from the macrocosm-microcosm universe in his later writings.¹¹² With this scheme discarded, and with a conviction—because of his study of Copernicus—that astronomy “was not worthy of the time bestowed on it”,¹¹³ much of the allure of the search for divine mathematical harmonies was lost.

Van Helmont's disillusion with Galen and Aristotle may be traced at least in part to his views on mathematics. Like Severinus, van Helmont writes of Galen's codification of the works of his predecessors and of his attempt to frame the whole science on the four elements.¹¹⁴ He, too, laboured over logic and the principles of Euclid which seemed to contain truth, but when he sought theorems and axioms in medicine, he found this quest quite hopeless.¹¹⁵ Medicine is a divine rather than an ordinary science because Scripture teaches us that the Lord created physicians.¹¹⁶ Rational, mathematically inspired

¹¹⁰ *Ibid.*, p. 3.

¹¹¹ *Ibid.*, p. 21.

¹¹² J. B. van Helmont, *Oriatrike or Physick Refined*, trans. John Chandler (London, 1662), p. 323. “The name therefore of Microcosm or little World is Poetical, heathenish, and metaphorical, but not natural or true. It is likewise a phantastical, hypochondriacal, and mad thing, to have brought all the properties, and species of the Universe into man, and the art of healing.”

On van Helmont see Walter Pagel's studies, *J. Bapt. van Helmont Einführung in die Philosophische Medizin des Barock* (Berlin: Julius Springer, 1930); “Religious Motives in the Medical Biology of the XVIIth Century”, *Bulletin of the Institute of the History of Medicine*, 3 (1935), 97–128, 213–31, 265–312; “The Religious and Philosophical Aspects of van Helmont's Science and Medicine”, *Supp. Bull. Hist. Med.*, No. 2 (Baltimore, The Johns Hopkins Press, 1944).

¹¹³ van Helmont, *Oriatrike*, p. 12. See also *Ibid.*, p. 126.

¹¹⁴ *Ibid.*, p. 3.

¹¹⁵ *Ibid.*, p. 13.

investigations may aid us in the study of physics, but not the chief goal of natural philosophy, medicine, for "to understand and favour these things from the spring or first cause is granted to none without the special favour of Christ the Lord".¹¹⁷ Neither the cosmic mathematics of the mystical alchemists and Pythagoreans nor the logical-mathematical method of the Galenist may help us here.

And if we turn to the mathematical physics of the Aristotelians we shall do no better than before. The teachings of Aristotle dominate our schools and turn the minds of our scholars into erroneous paths. Yet, if we examine his writings we shall unmask him. It is true that Aristotle had a most persuasive manner in arranging rules and maxims. In a later—and more lazy age—students willingly accepted these as a guide to truth while they prostrated themselves to him almost in worship.¹¹⁸ But the evidence shows, van Helmont adds, that Aristotle surely had little ability as a scientific observer. Therefore he relied heavily on mathematics in preparing his vast system simply because he was "far more skilful in this, than in Nature". And since this man had subdued nature under the rules of mathematics, our scholars are now cursed with an improper approach to science.¹¹⁹

In his examination of Aristotle's works, van Helmont's attention was arrested by the *eight books of Natural Instructions*. Here corporal matter is incorrectly combined with mathematical abstraction. Similarly, his books discuss the vacuum and the infinite—subjects which clearly do not belong to the knowledge of nature. And "they bring in local motion, as it serves to Science Mathematical or Learning by demonstration, alike foolishly, and with an undistinct indiscretion, into nature".¹²⁰ One reads the blasphemy which

¹¹⁶ *Ibid.*, p. 4. See *Ecclesiasticus* 38:1 "Honour the physician for the need thou hast of him: for the most high hath created him". Similarly, Paracelsus, stated "It was not the constellations that made me a physician; God made me. . . ." Paracelsus, *Sämliche Werke*, ed. Karl Sudhoff and Wilhelm Matthiessen (15 vols., Munich and Berlin, 1922-33), 8, pp. 63-5. From the *Paragranum*.

¹¹⁷ van Helmont, *op. cit.*, p. 4. On the same page we read ". . . the whole faculty of natural Philosophy is committed to man; and therefore this ought to respect both his life immediately, and all his defects. Therefore all natural Philosophy is limited to the use of life, the finding out of causes, the Disease and Remedies".

¹¹⁸ *Ibid.*, p. 33.

¹¹⁹ *Ibid.*

¹²⁰ *Ibid.*, p. 45. Van Helmont might have quoted Aristotle from the *Metaphysics*—"The minute accuracy of mathematics is not to be demanded in all cases, but only in the case of things which have no matter. Hence its method is not that of natural science; for presumably the whole of nature has matter". *Metaphysics*, Book 2, Chap. 3, as trans. by W. D. Ross and printed in *Great Books of the Western World*, ed. Robert Maynard Hutchins (54 volumes, Chicago/London/Toronto/Geneva: Encyclopedia Britannica, Inc., 1952), 8, p. 513.

"the Schools have taught, *That in every locall motion, a first unmoveable Mover is of necessity to be appointed*: Which thing I neither find true by Art, nor Nature".¹²¹ Really this "is a Paganish Doctrine drawn from Science Mathematical, which necessitates the first Mover to a perpetual unmoveableness of himself, that without ceasing he may move all things".¹²² We find, however, that the "most glorious Mover hath given powers to things whereby they of themselves, and by an absolute force may move themselves, or other things. Indeed, it is impertinent to run back to God the Mover to demonstrate the natural motion of Bodies".¹²³ Looking at nature with the eyes of a physician and vitalist, van Helmont sees a far different approach to local motion than the physicist. Sublunary bodies contain within themselves something which permits them to move. "They are moved by a certain will and pleasure or precept of nature, and have their own natural necessities, and ends: even as is seen in the beating of the Heart, Arteries, expelling of many superfluities, &c.". ¹²⁴ Thus, although we may find the maxims of Aristotle serviceable in the description of certain aspects of local motion and mathematical science, they have been given far greater weight than they deserve, and we may be certain that "the Rules of the Mathematicks, or Learning by demonstration do ill square to Nature. For man doth not measure Nature; but she him".¹²⁵

Thoroughly sickened by the logical-mathematical methods of the Schools, van Helmont could only hope—as did so many of his generation—for a new learning based upon a total reform. In his early work on the magnetic cure of wounds we see van Helmont's acceptance of natural magic as "the most profound inbred knowledge of things", and if he was to reject the most occult aspects of Paracelsian thought, we still find his emphasis on experiment and chemistry in his scheme for educational reform. No longer should young men waste their youth on Aristotelian thought—i.e. mathematical thought. In a seven year programme they may devote three years to arithmetic, mathematical science, the *Elements* of Euclid, and geography (which is to include the circumstances of seas, rivers, springs, mountains, provinces and minerals). In addition—in this three year period—they are to study the properties and customs of nations, waters, plants, living creatures, minerals, and the ring and astrolabe. Only then, van Helmont continues

... let them come to the Study of Nature, let them learn to know and separate the first Beginnings of Bodies. I say, by working, to have known their fixedness, volatility or swiftness, with their separation,

¹²¹ *Ibid.*, p. 176.

¹²² *Ibid.*

¹²³ *Ibid.*

¹²⁴ *Ibid.*, p. 177.

¹²⁵ *Ibid.*, p. 34.

life, death, interchangeable course, defects, alteration, weakness, corruption, transplanting, solution, coagulation or co-thickning, resolving. Let the History of extractions, dividings, conjoynings, ripenesses, promotions, hinderances, consequences, lastly, of losse and profit, be added. Let them also be taught, the Beginnings of Seeds, Ferments, Spirits, and Tinctures, with every flowing, digesting, changing, motion, and disturbance of things to be altered.

And all those things, not indeed by a naked description of discourse, but by handicraft demonstration of the fire. For truly, nature measureth her works by distilling, moystening, drying, calcining, resolving, plainly by the same meanes, whereby glasses do accomplish those same operations. And so the Artificer, by changing the operations of nature, obtains the properties and knowledge of the same. For however natural a wit, and sharpness of judgement the Philosopher may have, yet he is never admitted to the Root, or radical knowledge of natural things, without the fire. And so every one is deluded with a thousand thoughts or doubts, the which he unfoldeth not to himself, but by the help of the fire. Therefore I confess, nothing doth more fully bring a man that is greedy of knowing, to the knowledges of all things knowable, than the fire. Therefore a young man at length, returning out of these Schooles, truly it is a wonder to see, how much he shall ascend above the Phylosophers of the University, and the vain reasoning of the Schooles.¹²⁶

This is the Helmontian-iatrochemical programme for a reform in education. Students are to spend the bulk of their time learning the true facts of nature through observation and chemical operations with the fire. The purely intellectual pursuit of truth with mathematics here completely loses its value. Such mathematics is connected with Euclidean geometry, Aristotelian physics—especially the study of motion—and the theology of the Middle Ages. Truth may be attained only by disassociating ourselves from these errors of the past.

In contrast, the mathematics of real use for the natural philosopher is connected with experiments. Thus, it may be shown "mechanically, and mathematically that all solid Bodies are onely of water", and he suggests that urine should be examined by weight (as had Cusanus, Dorn, Paracelsus, and Thurneisser). Similarly, his willow tree experiment and his estimate of the weight of gas produced by burning 62 pounds of coal (a weight by difference based on the coal ashes) underline his belief in the value of weight determinations.¹²⁷ With van Helmont the more sublime mathematical road to divinity suggested by Cusanus has been completely discarded.

¹²⁶ *Ibid.*, p. 45.

¹²⁷ *Ibid.*, pp. 106, 109, 167, 1056. The quantitative analysis of urine described in the *Anatomia Corporum adhuc viventium* and ascribed to Paracelsus (printed in the *Aurora Thesaurusque Philosophorum Theophrasti Paracelsi accessit Monarchia Physica per Gerardum Dorneum* (Basel, 1577), pp. 129–91) was probably authored by Dorn. This is described in detail along with other early quantitative analyses of urine in Pagel, *Paracelsus*, pp. 189–200.

CONCLUSION

Cusanus had told the scholar to learn of his Creator through mathematics. Two paths were suggested by him—the first and most important being the contemplation of the divine mathematical ideas. These lift the seeker from particulars through an ascending scale to the divine infinite. This road to truth is in the tradition of the mystical neo-Platonic and Pythagorean sages. At the same time, Cusanus, in *The Idiot*, proposed a lesser road to truth in nature by quantitative weight measurements and the use of the balance. This, too, may be supported by appeal to Scripture.

Quantification and mathematical speculations were of considerable importance to some—if not all—iatrochemists in the sixteenth and seventeenth centuries and their views are worth study because of the contemporary general interest in their approach to nature. Within the ranks of these men we find advocates of both paths to truth. This becomes evident in the views on mathematics expressed by the contemporaries Robert Fludd (1574-1637) and J. B. van Helmont (1580-1644).

Fludd, perhaps the most renowned mystical alchemist of his generation, was a Pythagorean, kabbalist and Hermeticist who viewed the Creation in terms of a divine alchemy. He insisted that it is not the study of nature, but the search for divine mysteries which must claim our utmost attention. For him the greater and lesser worlds exist in a state of Platonic perfection which may be interpreted through musical harmonies and an alchemical-geometrical symbolism. All of this bears little connection with our concept of the use of mathematics in science, and even Kepler, influenced by many of the same themes, could not understand the approach of the English physician.

Van Helmont also based his work on religious convictions. Like Fludd, he insisted that the writings of Aristotle and Galen may be largely ignored because of their theological implications. Not only were their works to be rejected, even their logical-mathematical approach to nature was to be discarded and branded as blasphemous. Yet, van Helmont went further than this. Rejecting the mystical macrocosm-microcosm universe of his iatrochemical colleagues, he found no valid ground for the search for divinity in the numerical harmonies and symbols of heaven and earth. The true scholar will learn from his own observations and experiments. Here the second path of Cusanus is acceptable—measurements by weight applied to specific experiments. Beyond this the honest student cannot go, for the application of mathematical abstraction to nature is an unholy method which can only be associated with the Peripatetics in the Universities, not with the new science of the future.

The importance of all this may be seen less in the actual details of

iatrochemical mathematics than in the insight it gives us regarding the still unsettled role of mathematics in sixteenth and seventeenth century science. If the mystical alchemists and the Helmontians were of no influence, we would be justified in ignoring their views. We find, however, if we may judge by the number of books published, that their influence reached a high point in the mid-seventeenth century. We have already referred to the notice taken of Fludd's system by Kepler, Mersenne and Gassendi. The debate over Fludd's works was widespread and could not have helped but define the difference between the mystical alchemists and the Galileans on this point. In England in the decade of the 1650s we find more Paracelsian and alchemical translations than from the whole preceding century. It was just at this time that Robert Fludd's major work, the *Mosaicall Philosophy*, appeared in English translation (1659), and it was then, too, that John Webster proposed a reform of the Universities in terms which recall Fludd's Rosicrucian Apology of 1617.¹²⁸

Far more widespread was the appeal of van Helmont. Here was an approach to nature and divinity based on fresh observations and experiments which placed the study of man at the apex of natural knowledge. It is little wonder that physicians were attracted to this path to truth. Van Helmont offered a new experimental science founded on chemistry which allegedly was stripped of the mystical fantasies of his chemical predecessors. It is understandable that by the mid-seventeenth century his views could command a far greater audience than those of the more mystical Fludd. Yet, the rejection of the value of mathematical abstraction in the study of nature by van Helmont—as well as by Fludd and the Paracelsians—occurs precisely at the time when the power of mathematical analyses was being recognized by Galileo and his followers.¹²⁹ The rapid decline of the Paracelso-Helmontians in the period after 1670 may be attributed at least partially to the success of the mathematicized science which found no place in their schemes. This was an issue

¹²⁸ John Webster, *Academiarum Examen, or the Examination of Academies* (London: Giles Calvert, 1654). Webster praised the mystical anatomy of Fludd (p. 74), and suggested a reform of the mathematical sciences in Fluddian terms (pp. 40 ff.). He, too, strongly praised the Rosicrucian approach to nature (pp. 26 ff.). This text was strongly attacked by John Wilkins and Seth Ward.

¹²⁹ There is some similarity between the views of van Helmont and Francis Bacon on the extension of mathematics in the study of nature. The latter disliked the deductive nature of the subject, and he felt that some, by applying it to nature, were relying far too much on reason rather than on observation. Mathematical systems have been more acutely inquired into than other matters, because it is "the nature of the human mind, certainly to the extreme prejudice of knowledge, to delight in the open plains of generalities rather than in the woods and inclosures of particulars", with the result that logic and mathematics, which should be the handmaidens of science, exercise dominion over it. Francis Bacon, *Works*. Collected and ed. by J. Spedding, R. L. Ellis, D. D. Heath (14 vols., London: Longman & Co. etc., 1857-74), 4, p. 370. From the *De Augmentis*.

which had been decided by 1700, but it had not been decided half a century earlier. In the first half of the century it could still be seriously argued that the role of mathematics in science should be limited to the search for divine mathematical harmonies or calculations based on experimental measurements of weight.

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other Bodies as much rarer as he pleases, so that Light may find a ready passage through transparent substances. *The Magnet* attracts iron through all these

may find a ready passage through transparent substances. The Prismatic act, upon even shaped all their bodies not magnified nor red hot, of its bodies; as for instance through Gold, silver, lead, glass, water. The penetrating power of the Sun is transmitted through the body of the Planets without any diminution of its force. PROP. IX. so as to act upon all their parts according to the same law. In the air, creatures with the same force surrounded with the body of the

Bodies reflect and refract Light by one and the same power variously exercised in various circumstances.

This appears by several Considerations. First, Because when Light goes out of Glafs into Air, as obliquely as it can possibly do, if its incidence be made still more oblique, it becomes totally reflected. For the power of the Glafs after it has refracted the Light

the power of the Stars after it has reflected the Light as obliquely as is possible if the incidence be still made more oblique, becomes too strong to let any of its rays go through, and by consequence causes total reflexions.

Secondly, Because Light is alternately reflected and transmitted by thin Plates of Glafs for many fuccelfions

accordingly as the thickness of the Plate increases in an arithmetical Progression. For here the thickness

of the Glafs determines whether that power by which the Glafs acts upon Light ſhall cauſe it to be reflected, or to be tranſmitted. And Thirdly becauſe of the

particles which reflect or
as soon explained above.
Now if we conceive
luffer it to be transmitted. And, I hirdly, becaule thole
surfaces of transparent Bodies which have the greatest
refracting power. reflect the greatest quantity of Light

particulates of bodies to or refracting power, reflect the greatest quantity of Light, to dispose amongst them as was shewed in the first Proposition.

PROF. X.

smaller, which have as If Light be swifter in Bodies than in Vacuo in the
small empty space between the Sines which measure the refraction of the
be as equally all the proportion of the Sines which measure the refraction of the

magnitudes of these many Bodies, the forces of the Bodies to reflect and refract Light, particles; & that in like manner these matter particles are again composed of others much smaller all which together are equal to all the parts or

empty spaces between them; & so on perpetually. In some particles, instead
of empty spaces within them; and if in any gross body there is, for instance,
no pores or empty spaces like those of which air is solid; this body will have seven times
such degrees of solidity as that of four such degrees of particle the least of which are

will have fifteen times more pores than pentasolid parts. If there be five degrees, the body will have one hundred times more pores than solid parts. If six degrees, the body will have one hundred times more pores than solid parts. And so on perpetually.

After years of conceiving how Edith may be exceedingly poor, but what is her inward fear is not yet known to us.

Page 1 (continued). Newton states the rest shall be done. Page 10 of Book II.

PLATE I (reduced). Newton states the nut-shell theory. Page 70 of Book II of the 1704 *Opticks*, as revised in Newton's own hand for the 1717 printing. Reproduced from Newton's copy of the 1704 *Opticks* (Adv. b. 39. 3.) by permission of Cambridge University Library.