CHAPTER I

Tradition and Reform

Few events in world history have been more momentous than the Scientific Revolution. The period between the mid-fifteenth and the end of the eighteenth centuries witnessed the growing cultural and political influence of Western Europe over all other parts of the globe. The new science and technology of the West was a crucial factor in this development, a fact recognized by most scholars at the time. Thus, Francis Bacon (1561–1626) observed in the *Novum organum* (1620) that

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

For Bacon these discoveries were Western in origin and relatively recent in date. He was neither the first nor the last to make such a statement, but there were few whose works were read more avidly by those who hoped to erect a new science in the seventeenth century.

But if the importance of the Scientific Revolution is readily admitted by all, the more we study its origins, the more unsure we become of its causes. In this volume we shall be concerned primarily with the two centuries from 1450 to 1650, the first date coinciding roughly with the beginning of the new humanistic interest in the classical scientific and medical texts and the second with the years just prior to the general acceptance of the mechanistic science of Descartes (1596–1650), Galileo (1564–1642), Borelli (1608–1679), Boyle (1627–1691), and Newton (1642–1727).

These two centuries present an almost bewildering maze of interests, and only rarely will an individual be found whose scientific methodology would prove to be fully acceptable to a modern scientist. Some of the scholars, whose work contributed to our modern scientific age, found magic, alchemy, and astrology no less stimulating than the new interest in mathematical abstraction, observation, and experiment. Today we find it easy – and necessary – to separate "science" from occult interests, but many then could not. And we cannot relegate this interest in a mystical world view to a few lesser figures forgotten today except by antiquarians. The writings of Isaac Newton and Johannes Kepler (1571–1630) reveal a genuine interest in transmutation and a search for universal harmonies no less than the work of Paracelsus (1493–1541), Robert Fludd (1574–1637), or John Dee (1527–1608). For the most part it has been traditional among historians of science to view their subject by hindsight, that is, to ignore those aspects of an earlier natural philosophy that no longer have a place in our scientific world. However, if we do this we cannot hope to reach any contextual understanding of the period. It will thus be our aim to treat this period in its own terms rather than ours. As we proceed we shall find that controversies over natural magic and the truth of the macrocosm – microcosm analogy were then as important as the better-remembered debates over the acceptance of the heliocentric system or the circulation of the blood.

Renaissance Science and Education

The very words "Renaissance" and "humanism" have been employed with so many connotations that there is little hope of satisfying any two scholars with a single definition. There is no need to try to do so here. To be sure, the Renaissance did involve a kind of "rebirth" of knowledge – no less than it did a rebirth of art and literature. And it was surely the period of the development of a new science. But having granted this, it is necessary to be careful to avoid simplification. The new love of nature expressed by Petrarch (d. c. 1374) and other fourteenth-century humanists had more than one effect. We readily accept that it was instrumental in the rise of a new observational study of natural phenomena, but we also find that Petrarch and later humanists deeply distrusted the traditional scholastic emphasis on philosophy and the sciences. The rhetoric and history they preferred was a conscious reply to the more technical "Aristotelian" studies that had long been the mainstay of the medieval university. The humanists sought the moral improvement of man rather than the logic and scholastic disputations characteristic of traditional higher learning.

These shifting values were to result in a new interest in educational problems. Fourteenth- and fifteenth-century reform programs were to be directed toward elementary education rather than the universities. The humanist educator Vittorino da Feltre (1378–1446) established a new school where students were urged to excel at sports and to learn military exercises. In classrooms they studied rhetoric, music, geography, and history – and, taking their examples from the ancients, they were taught to value both moral principles and political action above the basic principles of the trivium (grammar, rhetoric, and logic) or the study of traditional philosophical and scientific subjects.

Many of the most renowned humanist scholars were to be affected by this movement in educational reform. The result may be clearly seen in the work of Erasmus (1466–1536). He thought it enough for a student to learn of nature through his normal course of study in the reading of the ancient literary authors. Mathematics was not to him of much importance for an educated man. And Juan Luis Vives (1492–1540), surely the best known of all Renaissance educators, agreed fully when he argued against the study of mathematics that it tended to "withdraw the mind from practical concerns of life" and rendered it "less fit to fuse concrete and mundane realities."

But can we then say that the universities remained the centers of scientific training? For the most part they did, but there was an ever-increasing number of scholars both in medicine and the sciences who rejected the overwhelming conservatism of many – and perhaps most – of the institutions of higher learning. Peter Ramus (1515–1572) recalled his own academic training with despair:

"After having devoted three years and six months to scholastic philosophy, according to the rules of our university: after having read, discussed, and meditated on the various treatises of the *Organon* (for of all the books of Aristotle those especially which treated of dialectic were read and re-read during the course of three years); even after, I say, having put in all that time, reckoning up the years completely occupied by the study of the scholastic arts, I sought to learn to what end I could, as a consequence, apply the knowledge I had acquired wih so much toil and fatigue. I soon perceived that all this dialectic had not rendered me more learned in history and the knowledge of antiquity, nor more skillful in eloquence, nor a better poet, not wiser in anything. Ah, what a stupefaction, what a grief! How did I deplore the misfortune of my destiny, the barrenness of a mind that after so much labor could not gather or even perceive the fruits of that wisdom which was alleged to be found so abundantly in the dialectic of Aristotle!"

Ramus was not alone in his frustration – and his complaints were not without grounds. Paris, for example, was acknowledged as a stronghold of Galenic medicine in the sixteenth and seventeenth centuries whereas in England both the Elizabethan statutes for Cambridge (1570) and also the Laudian code for Oxford (1636) maintained the official authority of the ancients. Nor were the early professional societies necessarily better. The London College of Physicians looked on innovation with distrust. Thus, when in 1559 Dr. John Geynes dared to suggest that Galen (129/130–199/200 A.D.) might not be infallible, the reaction was immediate and severe. The good doctor was forced to sign a recantation before being received again into the company of his colleagues.

The conservatism seen in many major universities in the sixteenth and seventeenth centuries may be partially balanced by a critical tradition that had been applied to the ancient scientific texts at Oxford and Paris in the fourteenth century. This work, associated with scholasticism, was to prove particularly beneficial to the study of the physics of motion. As a scholarly tradition it was still in evidence at Padua and other northern Italian universities in the sixteenth century. For many, however, scientific criticism was a curious kind of humanistic game in which the scholar was to be commended for having eliminated the vulgar annotations and emendations of medieval origin that marred the texts of antiquity. His goal was textual purity rather than scientific truth.

In short, the educational climate in the early Renaissance was of questionable value for the development of the sciences. University training in this period may be characterized for the most part as conservative. As for the reform of primary education accomplished in the fourteenth and fifteenth centuries, this was openly antiscientific.

Humanism and Classical Literature

Dedication to the ancients is a familiar characteristic of Renaissance humanism. The search for new classical texts was intense in the fifteenth century, and each new discovery was hailed as a major achievement. No account is better known than that of Jacopo Angelo (fl. c. 1406). His ship sank as he was returning from a voyage to Constantinople made in search of manuscripts, but he managed to save his greatest discovery, a copy of the *Geography* of Ptolemy hitherto unknown in the West. Not long after this, in 1417, Poggio Bracciolini (1380–1459) discovered what was later to be recognized as the only copy of Lucretius's (c. 99–55 B.C.) *De rerum natura* to have survived from antiquity. This was to become a major stimulus for the revived interest in atomism two centuries later. And, just nine years after the recovery of Lucretius, Guarino da Verona (1370–1460) found a manuscript of the encyclopedic treatise on medicine by the second-century author, Celsus. This work, *De medicina,* was to exert a great influence, an influence due perhaps less to its medical content than to its language and style. This was the only major medical work to have survived from the best period of Latin prose and it was to be mined by medical humanists who sought proper Latin terminology and phrasing.

The search for new texts – and new translations – resulted in a new awareness of the importance of Greek. To be sure, Roger Bacon (c. 1214–1294) had already underscored this need in the thirteenth century, but the situation had not materially improved a century later. At that time Petrarch had lamented his own inadequate knowledge of this language. In fact he was not alone. Few Western scholars were able to use Greek until the teacher Manuel Chrysolorus (d. 1415) arrived in Italy with the Byzantine Emperor Manuel Paleologus in 1396. But helpful though Chrysolorus was, much greater enthusiasm was stirred by another Byzantine, Gemistos Plethon, on his arrival at the Council of Florence in 1439. The Greek revival was to affect all scholarly fields in the course of the fifteenth century. In medicine the humanist Thomas Linacre (c. 1460–1524) prepared Latin translations of Proclus (410–485) and of individual works of Galen. Significant though this was, his plans – only partially fulfilled – were actually far more grandiose. He projected a Latin translation of the complete works of Galen – and, with a group of scholars, a Latin translation of the complete works of Aristotle as well. Hardly less industrious was Johannes Guinter of Andernach (1505–1574), whose translations from Galen place him in the front rank of medical humanists. As professor of medicine at Paris, Guinter became one of the most prominent teachers of the young Andreas Vesalius (1514–1564).

This quest for truth in the search for accurate manuscripts was not confined solely to the study of the ancient physicians. Georg von Peuerbach (1423–1461) recognized the need for an accurate manuscript of Ptolemy's *Almagest* while writing his textbook, the *Theoricae novae planetarum.* But Peuerbach died while he was in the process of planning a journey to Italy to accomplish this end. His pupil, Johann Müller (Regiomontanus) (1436–1476) completed his master's journey and published an *Epitome* of the *Almagest.*

But Renaissance humanism cannot simply be reduced to the recovery of a pure Aristotle, Ptolemy, or Galen. No less influential on the development of modern science – and certainly part of the same humanistic movement – was the revival of the neo-Platonic, cabalistic, and Hermetic texts of late antiquity. So important did these seem to be that Cosimo de' Medici insisted that Marsilio Ficino (1433–1499) translate the recently discovered *Corpus hermeticum* (c. 1460) before turning to Plato or Plotinus. These mystical and religious works – to be discussed later in more detail – seemed to justify the pursuit of natural magic, a subject of great popularity among the savants of the sixteenth and seventeenth centuries. Included in this tradition was the call for a new investigation of nature through fresh observational evidence.

Coincidentally, this search for the pure and original texts of antiquity occurred when a new means existed for disseminating this knowledge, the printing press. It is interesting that the earliest printed book from Western Europe dates from 1447, at the very beginning of our period. For the first time it became possible to produce standard texts for scholars at a moderate price. In the scientific and medical fields these incunabula were for the most part printings of the old medieval scholastic texts scorned by the humanists. Thus the first version of Ptolemy's *Almagest* to be printed was the old medieval translation (1515). A new Latin translation appeared next (1528) – and finally the Greek text (1538), just five years prior to the *De revolutionibus orbium* of Copernicus. Galen and Aristotle were to proceed through the same stages.

The Growth of the Vernacular

Latin and Greek were surely the primary keys to the world of the scholar, but the Renaissance world was also characterized by a rapid growth in the use of the vernacular languages in learned fields. This is seen most strikingly in the religious pamphlets of the Reformation, where the author had an immediate need to reach his audience. But the use of the vernacular also became increasingly important in science and medicine in the course of the sixteenth century. This may be ascribed partially to the conscious nationalistic pride seen in this period. It is a time when authors wrote openly of their love of their native land and of their own language. A second factor was the feeling on the part of many of the need for a decisive break with the past. This seems to be ever more evident after the second quarter of the sixteenth century.

Recent research indicates a rapid increase in the use of the vernacular in the medical texts of the late Middle Ages. This trend intensified in the sixteenth century when a medical pamphlet war divided the Galenists from the Paracelsian medical chemists. This debate had been brought to the university level when Paracelsus lectured on medicine at Basel in his native Swiss-German in 1527. The medical establishment attacked him in force not only for the content of his lectures, but also for his choice of language. The latter was to remain a sore point among his followers for generations to come. Thus, the English Paracelsist Thomas Moffett (1553–1604) admitted – in Latin (1584) – that

"it is true that Paracelsus spoke often in German rather than Latin, but did not Hippocrates speak Greek? And why should they not both speak their native tongues? Is this worthy of reprehension in Paracelsus and to be passed over in Hippocrates, Galen and the other Greeks who spoke in their own language?"

The situation was not appreciably different in mathematics and the physical sciences. Galileo's publications in Italian remain classics of Italian literature today and in England numerous authors presented both popular and technical subjects in Tudor English. Of special interest is John Dee, who took it on himself to compose a preface to the first English translation of the *Elements of Geometry* by Euclid. Here he thought it necessary to explain that such a translation would pose no threat to the universities. Rather, he argued, many common folk might well for the first time be able "to finde out, and devise, new workes, straunge Engines, and Instrumentes: for sundry purposes in the Common Wealth or for private pleasure and for the better maintayninge of their owne estate." Similar apologies for the publication of scientific and medical texts in the vernacular are to be found in the other major modern languages from this period.

Observation and Experiment

Any general assessment of Renaissance science must include a discussion of a number of seeming paradoxes. A recurring theme in the sixteenth-century literature is the rejection of antiquity. But, as we have already noted, this rejection most commonly was directed at scholastic translations and commentaries. Some scholars did call for a completely new natural philosophy and medicine, but many adhered to the ancient philosophy – provided that they were assured that their texts were pure and unadulterated. There were those such as William Harvey (1578–1657), who openly praised the Aristotelian heritage. Others – and here Robert Fludd is a good example – attacked the ancients viciously while integrating many ancient concepts in their own work.

Also characteristic of the period was a growing reliance on observation and a gradual move toward our understanding of experiment as a carefully planned – and repeatable – test of theory. Older classics of observational science and method were recognized and praised by Renaissance scholars, who saw in them a model to be emulated. Thus many who rejected Aristotle's physics pointed to his work on animals as a text of major importance. Because of his use of observational evidence, Archimedes (287–212 B.C.) had great weight, whereas among medieval authors Roger Bacon, Peter Perigrinus (of Maricourt) (fl. c. 1270), and Witelo (Theodoric of Freiburg) (thirteenth century) were cited for their "experimental" studies.

Yet even though Roger Bacon and others might speak of a new use of observation as the basis for an understanding of the universe, it was far more customary to rely upon fabulous accounts related by Pliny the Elder (23–79 A.D.) or other ancient encyclopedists. Even the brilliant critique of the ancient physics of motion carried out at Oxford and Paris in the fourteenth century had been based more upon deductive reasoning and the rules of logic than upon the results of any new observational evidence.

The scientists of the sixteenth century did not immediately develop a modern understanding of the use of experiment, but there is evident in their work a more general recourse to observational evidence than existed before. Thus Bernardino Telesio (1509–1588) founded his own academy at Cosenza, which was dedicated to the study of natural philosophy. Rejecting Aristotle, whose work seemed to disagree with both Scripture and experience, he turned instead to the senses as a key to the study of nature. Of equal interest is John Dee, who numbered among his mathematical sciences *Archemastrie,* which "teacheth to bryng to actuall experience sensible, all worthy conclusions by all the Artes Mathematicall purposed. . . . And bycause it procedeth by *Experiences,* and searcheth forth the causes of Conclusions, them selues, in Experience, it is named of some *Scientia Experimentalis.* The *Experimentall Science.*" Here the word "experimental" may best be understood as "observational." The concept of the modern controlled experiment was not part of Dee's methodology.

Mathematics and Natural Phenomena

Surely no less important than the new appreciation of observational evidence was the development of quantification and the increasing reliance on mathematics as a tool. Plato had stressed the importance of mathematics, and the revived interest in his work did influence the sciences in this area. In our period Galileo stands as the key figure in this development. Viewing mathematics as the essential guide for the interpretation of nature, he sought a new description of motion through the use of mathematical abstraction. In doing so Galileo was acutely aware that he was departing from the traditional Aristotelian search for causes.

Combined with the novel use of mathematics in natural philosophy, there were dramatic new developments within mathematics itself. The work of Tartaglia (1500–1557), Cardano (1501–1576), and Viète (1540–1603) in algebra did much to advance that subject in the sixteenth century – and tedious arithmetical calculations were greatly simplified through the invention of logarithms by Napier (1550–1617). And only slightly beyond our period comes the invention of the calculus by the independent efforts of Leibniz (1646–1716) and Newton. All these tools were quickly seized upon by contemporary scientists as aids to their work.

If one were to ask the reasons for this use of mathematics in the sixteenth century, one might arrive at a variety of answers. One would surely be the new availability of the work of Archimedes, the Greek author whose approach most closely approximated that of the new science. His texts had never been completely lost, but there is clear evidence of a new Archimedean influence in the mid-sixteenth century with a series of new editions of his work. Another factor of importance is the persistence of interest in the study of motion initiated by the fourteenth-century scholars at Oxford and Paris. There seems little doubt that Galileo was as a student the beneficiary of this tradition. A third factor was surely the Platonic, neo-Platonic, and Pythagorean revival. This influence often had a mystical flavor, but whatever its form, it was an important stimulus for many scientists of the period. And finally, one might point to the need for practical mathematics associated with the practical arts and technology.

Technology

It is rewarding to pause momentarily to examine this new interest in technology. While the extent of the relationship is open to debate, it is clear that at the very least those interested in warfare required mathematical studies in their use of cannon, and the navigator had to perform calculations to determine his position at sea. This was a period that witnessed impressive advances in instrumentation, ranging from practical astrolabes for the mariner to the massive astronomical instruments built by Tycho Brahe. The telescope, the microscope, the first effective thermometers, and a host of other tools were developed by artisans and scientists alike. Indeed, the scientists were taking an active interest in the work of the tradesmen for the first time. This may be interpreted partially as a revolt against the authority of the ancients, as most ancient and medieval studies of nature were totally divorced from processes employed by workmen. The scholastic student of the medieval university agreed with the ancients and rarely left his libraries and study halls. In the Renaissance, however, we witness a great change. There may be few descriptions of the practical arts in the books of the fifteenth century, but handbooks of mining operations began to appear from the presses as early as 1510 and similar works relating to other fields appeared shortly thereafter.

In contrast to earlier periods the scientists and physicians now acknowledged openly that the scholar would do well to learn from the common man. Paracelsus advised his readers that

"not all things the physician must know are taught in the academies. Now and then he must turn to old women, to Tartars who are called gypsies, to itinerant magicians, to elderly country folk and many others who are frequently held in contempt. From them he will gather his knowledge since these people have more understanding of such things than all the high colleges."

And Galileo candidly began his epoch-making *Discourses and Demonstrations Concerning Two New Sciences* (1638) with the following statement:

"The constant activity which you Venetians display in your famous arsenal suggests to the studious mind a large field for investigation, especially that part of the work which involves mechanics; for in this department all types of instruments and machines are constantly being constructed by many artisans, among whom there must be some who, partly by inherited experience and partly by their own observations, have become highly expert and clever in explanation."

This list could be greatly amplified if we took into account the great mining treatises of Agricola (1494–1555) and Biringuccio (fl. c. 1540), the views of Francis Bacon on the practical purpose of science, and the stated practical goals of the early scientific societies. There is little doubt that some areas of science progressed because the contribution of artisans and scientists fostered the study of practical processes. Johann Rudolph Glauber (1604–1670) was so encouraged by the developments he had witnessed that he forecast the supremacy of Germany over all Western Europe if its rulers would only follow his plan outlined in the *Prosperity of Germany*. And yet, even if we grant this belated recognition of technology by the scientist, there was no appreciable feedback from the small scientific community to technology until well into the eighteenth century.