Chapter One
"What was Worth Knowing" in 1500

I The universe of the university

In 1500 the universities reigned over European intellectual life. Their organizational structures were closely modelled on the thirteenth-century prototypes from which they derived, and the content of their philosophical instruction generally conformed to the tenets of scholastic Aristotelianism already described. Those tenets engaged with more than just the formal characteristics of explanation, however; they were also tightly entwined with a picture of the structure and make-up of the physical universe.

Aristotelian philosophy spoke of a spherical universe at the centre of which was found the spherical earth. Aristotle's world, rooted in sense-experience, was always addressed to the position of human observers, not to that of some transcendent, godlike being viewing the whole from the outside. Accordingly, the heavens, above our heads, obeyed different regularities from those observed by things around us on the earth's surface. The heavens revolved around the central earth, cyclically generating the periods of time that structured both the calendar and the daily round. The heavens did not fall down; nor did they recede from us. By contrast, on earth we are surrounded by heavy bodies that fall, and light bodies that tend to rise. Thus the characteristic motions found naturally in the terrestrial realm were either towards the centre or away from the centre; those of the heavens, by contrast, took place *around* the centre.

That way of perceiving things was integrated with a theory of matter. How do we know what things are made of? For Aristotle, the answer is that we see how they behave. On the surface of the earth, there are bodies that fall. These bodies therefore have a characteristic property of heaviness. But not all bodies that fall are the same. Solid bodies that fall are said to be composed primarily of the element "earth," while liquid bodies that fall are said to be composed primarily of the element "water." Both move as

they do when they are displaced from their proper locations in the universe. The natural place of earth is at the centre of the universe, whereas the natural place of water is around the natural place of earth – which is why the oceans tend to surround the solid earth. Corresponding to the two heavy elements are two light elements, air and fire, which possess, rather than "gravity," the property of "levity." Thus we see that air-bubbles and flames rise. Air occupies the region above that of water, while fire occupies that above air. The four together exhaust the number of elements making up terrestrial matter.

This terrestrial onion, earth at the centre, water, air and fire in successive shells, occupies only a small proportion of the universe. The vast region beyond the sphere of fire constitutes the heavens, moving cyclically around the centre. Because of that characteristic motion, categorically different from that of the terrestrial elements, the heavens are said to be composed of a single element, the "aether," the natural motion of which is precisely this circular rotation. Indeed, it is on the basis of this routinely observed motion that the existence of aether is inferred to begin with.

The visible celestial bodies, consisting of the moon, sun and five planets (those visible to the naked eye) are carried around the earth by transparent, invisible spheres. These spheres continue the onion motif: they are nested one within the next around the centre, each celestial body being embedded in the side of a distinct sphere. The spheres revolve, carrying the visible bodies around. The stars are out beyond Saturn, the furthermost planet, on the surface of an enormous sphere. The point of the arrangement, again, is to account for what we, inhabitants of the earth's surface, see. The invisible celestial spheres must be there, because the visible celestial bodies have to be moved somehow. Experience-based knowledge, for Aristotelians, is not just a matter of what can be sensed directly, but also a matter of what can be *inferred* from experience.

There were further, more consequential aspects of the heavens that flowed from these considerations. Elements, as we have seen, are characterized by their natural tendencies towards motion, whether up, down, or around. But they could also change into one another, because that is a commonly experienced behaviour: liquids become solids, solids burn to produce fire, and so forth. Part of the concept itself, therefore, implied the possibility of change – at least as far as the terrestrial elements were concerned. The heavens, however, were immune from this kind of transmutation. They were composed of a single element, the aether, a point that necessarily precluded substantial change. Things made of aether could be denser or rarer, but there was no other celestial element for them to change into. Nothing in the heavens came into being, or ceased to exist; celestial motion itself was cyclical, and no genuine novelty had ever been observed beyond the confines of the terrestrial region. Such ephemera in the skies as comets were accounted, almost by definition, as terrestrial. Aristotle held comets to be meteorological phenomena in the upper atmosphere, below

Figure 1.1 *The Aristotelian universe in the sixteenth century, from Petrus Apianus,* Cosmographia *(1539). The order of the planets in distance from the earth is that due to the astronomer Ptolemy, which differs slightly from that of Aristotle himself.*

the lowest sphere which carries the moon around the earth. Terrestrial and celestial were distinct regions, therefore, governed by different physical constituents and correspondingly different physical behaviours. Terrestrial and celestial physics were both part of natural philosophy, but they were different domains.

This was the world promulgated by the university arts curriculum; the world seen, contemplated, and explained by the scholastic natural philosopher. It was a complex universe, but it was also finite in at least two senses. Not only was it of limited spatial dimensions – a huge but bounded globe enclosing all of Creation – but the *kinds* of things that it contained, and the ways in which it behaved, were also strictly limited. Aristotelian natural philosophy specified the categories of things contained in the world, and exhaustively catalogued the ways in which they could be understood. The reason for the absence of innovation and discovery as a significant part of this worldview is that there was no real sense of the natural world as a vast field to be explored; there was nothing genuinely and fundamentally new to be found in it.

It is therefore of relevance to consider that in 1500, at the start of our period, Christopher Columbus's first voyage was only eight years in the past and the Americas had not yet received their name. The availability of geographical discovery-metaphors was much greater in the sixteenth and seventeenth centuries than had been the case previously: Europeans were looking outwards on a world that no longer corresponded to the classical geography found in the much-reprinted standard ancient text on the subject, Ptolemy's *Geography*. The new sense that the world was large, and largely unknown, was not, therefore, purely philosophical.

The sharply defined quality of Aristotle's physics, which provided such a preordained field for natural philosophy, arose from the four causes into which he analysed the categories of human explanation. His basic question amounted to asking "How do we understand things?" His answer was that we, as a matter of fact, understand or explain things according to four models, designated "causes." Together, the four causes are intended to exhaust all the possible ways in which people explain or understand. "Final cause" explanations make sense of the behaviour or properties of something by invoking its purpose: I walk because I'm going towards a destination; a sapling grows because it strives to be a fully-grown tree. The "final cause" is "that for the sake of which" something occurs, in the case of events or processes, or is the way it is – such as explaining the arrangement of teeth in the mouth by reference to their chewing function (this second kind is called "immanent teleology"). The "material cause" adduces what a thing is made of: my chair burns when ignited because it is made of wood, an inflammable material. The "efficient cause" (sometimes called the "moving cause") is closest to our modern understanding of that word: it is the action by which something is done or brought about. Thus the efficient cause of a gun firing might be the pulling of the trigger; or of a snooker ball rolling into a pocket, the preceding collision between it and the cue-ball.

The trickiest, and at the same time most characteristic, of Aristotle's four causes is the "formal cause." This accounts for the kind of explanation that makes reference to the nature of the thing in question. Consider again this classic medieval syllogism:

All men are mortal
Socrates is a man
Therefore Socrates is mortal.

The formal cause of Socrates' mortality is the fact that he is a man – that is the *kind* of thing that he is – and it is in the nature of men to be mortal. The reason for this kind of "cause" being called "formal" is that Aristotelians referred to the kind of thing that something is as its "form."

The concept of forms is central to Aristotelian thought. It arose from a reinterpretation of a general philosophical problem considered by Aristotle's teacher, Plato. How does one recognize what an individual thing is? How does one know, for example, that this tree *is* a tree rather than a bush, or even a helicopter? Plato's answer, in which he was followed by Aristotle, was to say that one must *already know* what a tree is in order to recognize one. And what one already knows, namely what a tree is in general (that is, what *sort* of thing a tree is), Plato describes as knowledge of a tree's *form*. Forms, for both Plato and Aristotle, are in effect categories into which individual objects can be sorted. The category into which something fits (tree, bush, helicopter) represents what kind of thing that object is: Socrates, in the earlier example, is a man. Thus the world is seen as being made up of categories, or classificatory boxes, that take account of everything that exists or could exist. Aristotle's is a vision of the world that sees it as a taxonomic system, in which there is a place for everything. True philosophical knowledge of the world amounts to locating everything in its place. Furthermore, causal properties are important parts of properly categorizing things.

The purpose of this philosophical scheme, therefore, was to understand in the most fundamental way what things *were* and why they *behaved* as they did. And Aristotle's taxonomy of causes determined, as taxonomies tend to do, what could and could not be said of natural phenomena, and what was *worth* saying. At the same time, it should be remembered that, to a greater or lesser extent, this is a property of any classification system, and by extension any framework within which to locate knowledge of nature. It is not the case that Aristotelian philosophy restricted the sciences of nature whereas its replacements extended their scope. Any single system would have had these same structural characteristics, some of which we will see in later chapters. But the abandonment of scholastic Aristotelianism, especially during the seventeenth century, was accompanied by a proliferation of alternatives which, collectively, greatly expanded the possibilities – even if most of those possibilities, different in each case, would have been rejected from within any particular philosophical scheme. In the case of those new systems which were presented in the seventeenth century as something new, there was in addition the prospect of unpacking their implications and following their precepts for the first time, in contrast to the well-surveyed territory of their chief predecessor.

II Natural knowledge and natural philosophy

The scholastic Aristotelianism prevalent in Europe at the start of the sixteenth century differed in some significant respects from the philosophy found in the writings of Aristotle. That philosophy, and particularly its natural philosophical components, had first been assimilated into the academic world of Roman Catholic (or Latin) Europe in the twelfth and thirteenth centuries. The assimilation wrought its own changes, which sprang from the settings in which Aristotle was seen as being of interest to begin with. Scholars tended overwhelmingly to be clerics, since they were the ones who were much the most likely to be literate. The Church, as the dominant institution throughout Western and Central Europe, played a major role in determining intellectual priorities: Aristotle came to be interesting because he could be used to illuminate matters of theological interest. After conflicts and disagreements during the thirteenth century, especially at the University of Paris, the works of Aristotle on a whole range of subjects from logic and rhetoric to meteorology were securely ensconced in the curricula of the new universities, even while official Church dogma still tended to circumscribe some aspects of their interpretation. The theological value of natural philosophy stemmed straightforwardly from its topical focus: interpreted from a Christian standpoint, it concerned God's Creation. Learning about God by learning about what He had made, and understanding the whys and wherefores of its fabric, was seen by many as an eminently pious enterprise. Natural philosophy had become a religious endeavour, and it remained so for many centuries. In the early eighteenth century, Isaac Newton wrote that "to treat of God from phenomena is certainly a part of natural philosophy."[1]

This is not to say, however, that natural philosophy in medieval and early-modern Europe was *always* understood as dealing explicitly with the natural world as God's Creation. Usually it was, but, as Newton's protestation suggests, the connection was not a necessary one. In sixteenth-century Padua (a leading university centre), as also in thirteenth-century Paris, so-called "Averroïsm" caused great controversy by purporting to discuss Aristotelian natural philosophy in isolation from a Christian theological context. The twelfth-century Arab philosopher Averroës had written extensive commentaries on Aristotle's natural philosophical writings that attempted to explicate their content independent of extraneous religious doctrines (in Averroës' case, Islamic). In the thirteenth century some Christian scholars at Paris followed Averroës' lead, developing his interpretations of Aristotle in sometimes flagrant disregard for theological controversy. Their frequently condemned attempts to get away with this relied on the possibility of representing their endeavour as being natural philosophy and *not* theology. Natural philosophy was clearly not invariably seen as a study of the divine. Their position was, however, opposed by such alternatives as Thomas Aquinas's. Aquinas made an extremely influential attempt in the thirteenth century explicitly to disallow Averroïsm; his view of natural philosophy as a "handmaiden" to theology quickly became commonly accepted, and coloured the conception of the discipline thereafter. In practice if not always in principle, natural philosophy and theology had become inextricably linked.

The university world of 1500 had expanded significantly since the foundation of the first such institutions around 1200. The word "university" is an English version of the Latin *universitas*, a term routinely applied in the medieval period to legal corporations. Only over the course of centuries did "university" come to be associated specifically with those corporations (whether of scholars or of students) devoted to educational purposes and offering various grades, or "degrees," through which the student attempted to pass. The fifteenth century saw a rapid increase in the number of universities across Europe, largely due to the foundation of new institutions in the eastern parts of Catholic Europe, such as Poland (Nicolaus Copernicus studied at Krakow in the 1490s). The new foundations retained the same basic organizational structure as their medieval prototypes, however. Their basic component was the so-called Arts faculty, the division that dealt with the "liberal arts" of which philosophy (natural, metaphysical, and moral) was the major component. Following successful passage through the degrees of Bachelor and then Master of Arts, students aiming at a doctorate in a professional discipline went on to study in one of the three "higher" faculties of medicine, law, and theology. In the non-Italian universities, north of the Alps, theology was usually the most important of the three. This vocational direction tended to affect the treatment accorded to natural philosophy, reinforcing its perceived role as a handmaiden to theology.

A characteristic shared by all three of the higher faculties, however, and not just theology, was that they served vocational directions that were not open to women. It is therefore unsurprising that there was virtually no place for women in the universities; the basic purpose of the university was to train young men in one of the professions. The most characteristic, and important, vocation in the Middle Ages lay in the church – perhaps the exemplar of a major social institution restricted to men only. Clerics could in principle, and to varying extents did, come from all social classes; but they could never be female. This fact is probably too deeply rooted for its implications to be easily and unequivocally traced, but it has been suggested that the longstanding domination of western science by men may owe something to the clerical character of its academic and scholarly origins. What effect that may have had, in turn, on the conceptual and ideological structure of the sciences cannot be clearly stated, owing to the vast number of mediations that would have to be traced to make the relevant connections. Nonetheless, it will be important to bear in mind this basic sociological fact about the knowledge enterprises of medieval and early modern Europe in what follows.

Besides natural philosophy itself, there were other subjects of study concerning knowledge of the natural world that were also taught in the universities. Medicine, one of the higher faculties, involved study of such components as anatomy and *materia medica*. The anatomy of the human body was increasingly, by 1500, being taught to medical students at northern Italian universities and elsewhere in part through demonstration-dissections, whereby a corpse would be dissected over the course of several days for the benefit of onlookers. The textual accompaniment to these displays was typically a digest of the anatomical teachings of the ancient physician Galen (late second century AD), such as the early-fourteenth-century handbook by the Italian Mondino de' Liuzzi. The purpose, however, was not to conduct research; it was wholly pedagogical, intended to familiarize students with the internal structure of the human body according to Galenic doctrine. The area of *materia medica* concerned such things as drugs and ointments, together with their preparation from mineral and especially botanical sources. It therefore included natural historical knowledge of plants and their medicinal properties. It might be noted that neither of these studies, anatomy or *materia medica*, purported to deal centrally in philosophical content. Although the human body and its parts were to be understood in terms of Galen's theoretical (really, natural philosophical) views, the study of anatomy itself concerned detailed morphological description rather than being focused on explanation. *Materia medica* was also a field that presented practical know-how rather than theoretical understanding. When dealing with plants, for example, the physician was not concerned with the causal science (in Aristotle's sense) of botany, but with empirical knowledge of a plant's properties. While the language of natural philosophy was often used to characterize the medicinal properties of a drug, it was an auxiliary aid to medical knowledge rather than an end in itself.

The other main area of natural knowledge that was separate from natural philosophy, this time in principle as well as in practice, was that of mathematics. The chief mathematical sciences practised in the medieval university were astronomy and, to a lesser extent, music. These were both members of the medieval *quadrivium*, comprising the four mathematical sciences of arithmetic, geometry, astronomy and music. The theoretical justification of this grouping conformed once again to Aristotelian expectations: the first two were the branches of "pure" mathematics, dealing with abstract magnitude as their proper subject matter. Arithmetic was concerned with discontinuous magnitude – numbers – whereas geometry concerned continuous magnitude, in the form of spatial extension. The third and fourth members of the quadrivium represented the branches of "mixed" mathematics. That term signalled that their proper concern was magnitude *combined with* some specific subject matter. Thus astronomy was geometrical extension as specifically applied to the motions of the heavens; music was numbers as specifically applied to sounds.

These last two disciplines were thus sciences of the natural world, but were explicitly denied the status of natural philosophy. Aristotle himself had characterized such subjects as mathematical, distinguished from natural philosophy by their supposed lack of causal explanations. The mathematical astronomer, on this view, merely described and modelled the motions of the celestial bodies; it was the job of the natural philosopher to explain *why* they moved. Similarly, the mathematical musician codified the number-ratios corresponding to particular musical intervals (number-ratios that found their typical physical instantiation in musical string lengths). The natural philosopher was left with the task of explaining the underlying *nature* of sound.

This Aristotelian characterization of the mathematical sciences informed the curricular structure of the European universities of 1500. Natural philosophy was taught as an important component of an arts education, while mathematical studies, when they were given any significant place, tended to be presented as independent, specialized disciplines that were chiefly aimed at practical ends involving computations of various sorts. Astronomy was the most important such science in the universities, for a number of reasons. First, its practical functions were highly regarded: these included calendrical uses, such as computing the dates of moveable church feasts (although this had become routine and unproblematic by the time of the foundation of the first universities), and the casting of horoscopes. Astrology was not a specialty definitively distinguished from astronomy; the astronomer was also an astrologer, while the astrologer always had to have command of astronomy, the science of the motions of the heavens. The high practical importance of astrology stemmed from its use in learned medicine, where the casting of horoscopes was a routine procedure in making prognoses regarding the future course of an illness. Indeed, astronomy was a particularly prominent study at the University of Padua during the Middle Ages because the faculty of medicine was the major of the three higher faculties there, a priority that reflected back onto the preparatory arts training.

III Astronomy and cosmology

The relationship between astronomy and cosmology in the medieval university tradition was an uncertain one that only began to change in major ways in the generation or so preceding Copernicus. The word "cosmology" in its modern sense dates from the eighteenth century, but it is useful to apply it to earlier conceptions of the physics of the heavens and to related natural philosophical ideas about the overall structure and workings of the universe. The cosmology found in the university world preceding

Copernicus's work was broadly Aristotelian, as we saw above, and as such it restricted the heavens to motions that were perfect, uniform, and circular – the kind of natural motion appropriate to spheres composed of aether. The foremost astronomical authority of Antiquity, Claudius Ptolemy (second century AD), had written the work that became the bible for subsequent astronomers in the Greek, then Arabic and Latin traditions. It was known in the Middle Ages as the *Almagest*, a corruption of the usual title in Arabic; in Greek it was the *Syntaxis*, or "compilation." Ptolemy had commenced the *Almagest* with a brief treatment of the physical framework that constrained his accounts of the motions seen in the heavens, and it was a framework derived from the natural philosophy of Aristotle. Ptolemy followed in the tradition of previous Greek astronomers in restricting the elementary motions from which actual observed motions were to be synthesized to uniform, circular motion, and that restriction (held to have originated with Plato) itself seemed to conform to Aristotle's account of celestial physics. While the physics to which Ptolemy deferred was Aristotelian, the vast bulk of the *Almagest*, having adopted Aristotle's cosmological ground rules, followed the autonomous mathematical traditions of Greek astronomy. Ptolemaïc astronomy as it was practised in the Latin Middle Ages was therefore easily cordoned off from natural philosophy in the universities.

Not all the complexities of Ptolemy's achievement, let alone the refinements and improvements furnished by several intervening centuries of Arabic astronomy, were adopted by Latin astronomy following the translation of the *Almagest* from the Arabic in the twelfth century. Ptolemaïc astronomy, having justified its central, stationary spherical earth with Aristotelian arguments, arrayed the heavenly bodies in orbits around it, accounting for the details of their paths by using an array of subsidiary circles. A (very) simplified Ptolemaïc model of the motion of a planet would look like Figure 1.2. (This diagram discounts the daily motion of the heavens; strictly speaking, the entire diagram ought also to revolve around the central earth once a day.) A simple circular path around the central earth would not have fitted observation: although, in general, the heavens appear to roll around the earth in circular paths (hence the characteristic properties of Aristotle's elemental aether), the planets show anomalies. Mars, Jupiter, and Saturn, for example, periodically slow up in their overall course from west to east through the stars, and double back away before continuing in their original direction; the doubling-back is called "retrograde" motion, the phenomenon itself "retrogression." The smaller circle in Figure 1.2 allows this appearance to be mimicked. The planet moves uniformly around the small circle (called an "epicycle"), while that circle's centre revolves uniformly around the larger circle (called a "deferent"). If the lesser circular motion completes several revolutions for each single revolution of the greater circle, the appearance from the centre will be of the planet looping back in its motion whenever it passes around that part

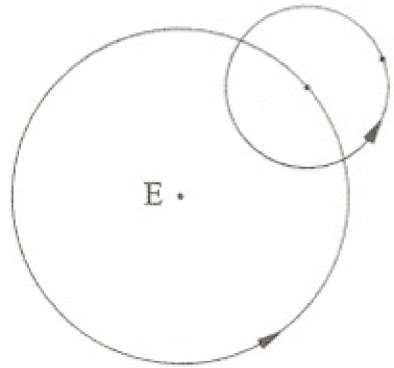

Figure 1.2 *Simplified basic planetary model, as used by Ptolemy. An epicycle, around the centre of which the planet is carried, itself in turn revolves on its deferent circle around the central earth.*

of the small circle which is on the side closest to the system's centre (Figure 1.3). This conception formed the basis of Ptolemy's explanations of planetary motions around the earth. To achieve the greatest possible accuracy, many refinements, including additional subsidiary circles, needed to be made to models of this kind.

From the point of view of a natural philosopher, however, this approach would have been questionable if presented as an *explanation* of planetary motions. Not only is there no attempt to explain *why* such circles move as they do, or what those circles are composed of; the circles themselves (in this case, the epicycle) routinely have as their centres of revolution points displaced from the centre of the earth (and hence of the universe). By contrast, Aristotle's concept of the circularity of celestial motion involved an understanding of that motion as being centred on the earth. What, then, was the physical status of Ptolemaïc models in the Middle Ages?

From one perspective, they were simply calculating devices. As long as the numbers that they generated corresponded to observed celestial positions, it mattered little to the mathematical astronomer whether the details of the models represented real motions in the heavens or were fictitious. Were epicycles and deferent circles real objects, or figments of the astronomer's imagination? From a practical standpoint, the astronomer did not need to worry about it; a resolution of the question would not improve his calculations. But for the natural philosopher, things were less simple. While the astronomer ought not to worry about physical causes, such questions were the natural philosopher's stock-in-trade.

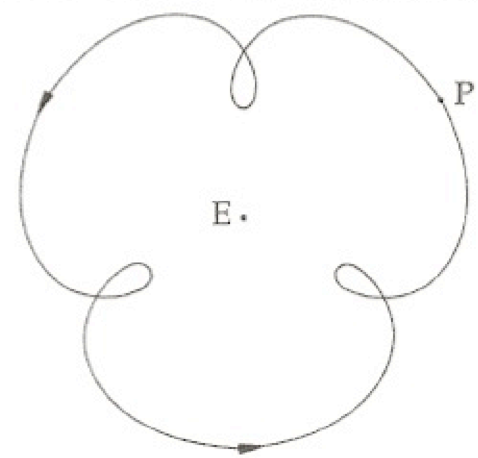

Figure 1.3 *The epicycle in the Ptolemaïc planetary model accounts for the periodic appearance of retrograde motion as seen from the earth, during the times at which the planet is at its closest approach.*

Usually, however, medieval cosmology concerned itself with general questions of the nature of the heavens and the causes of celestial motions, leaving the details of those motions to the astronomers as if it made little difference. Only very seldom did medieval natural philosophers so much as consider questions concerning the physical status of the astronomer's complex systems of circles. It was easy to ignore them, evidently, in light of the hierarchy of the disciplines in the universities: natural philosophy, dealing with causes and the natures of things, was more highly regarded than the more practical craft of astronomical computation.

Physicists were in a position, therefore, largely to disregard the concepts used by astronomers, much as a botanist might ignore the practical wisdom of the gardener. For their part, astronomers ignored the same issues of the compatibility between the physics and the mathematics of celestial motions even more completely than did the physicists; astronomical treatises of the Middle Ages do not broach the subject at all.

This was the situation from the introduction of the *Almagest* into Latin Christendom until the second half of the fifteenth century – the generation before Copernicus. Since the thirteenth century, one of the major teaching texts on astronomy had been an anonymous work called *Theorica planetarum*, or *Theoric of the Planets*. The title's first word, usually translated into English as "theories," refers rather more specifically to the particular geometrical models of the motions of celestial bodies that the book contains; *theorica*, or "theoric", here means something like "theoretical modelling." The work contains such models for the sun, moon, and the five planets, together with instructions on how to use them for computation. It is important to note that, although clearly derived from the models given in Ptolemy's *Almagest*, those of the *Theorica* are distinctly simpler, eschewing much of the complexity that Ptolemy had used to achieve a high level of accordance with observational data. In this connection, it is also relevant to note that the *Alfonsine Tables* (*c*.1272), the standard numerical tables used in the Middle Ages for determining celestial positions, had been computed for each of the celestial bodies from geometrical models that were enormously simplified compared with their Ptolemaïc prototypes. As long as the predictions that could be made were good enough, precision for its own sake was not a desideratum – another indication of the practical bent of medieval astronomy.[2]

In the 1450s, however, a German astronomer in Vienna, Georg Peurbach (or "Peuerbach"), wrote a new teaching text bearing the title *Theoricae novae planetarum*, or *New Theorics of the Planets*, finally printed in 1475. As the title suggests, it was intended as an improved replacement for the old *Theorica planetarum*. It presented the same kind of material as its predecessor, endeavouring only to improve certain features of the individual models but in no way attempting to present models of the same complexity as those found in the *Almagest*. Perhaps the most radical innovation, however, lay in its presentation of those models themselves. Rather than showing diagrams made up of geometrical lines representing distinct motions, as in Figure 1.2, above, Peurbach displayed solid spheres of a finite thickness (Figure 1.4).

The sun moving on a deferent has turned into a body embedded within the walls of a deferent sphere which itself is embedded within a much larger, hollow sphere that encompasses the earth. This unquestionably *physical* picture was much more compatible with the physical spheres spoken of by Aristotle and the scholastic natural philosophers than was an abstract, computational geometrical model. It is the first time that an astronomer, rather than natural philosopher, in the world of Latin Christendom had confronted the issue of the physical status of his models: Peurbach wished to interpret his mathematical devices as having physical referents. Observational niceties had led mathematical astronomers to add circle upon circle to the basic Aristotelian picture of the heavens; now Peurbach insisted on regarding those circles as physical things that astronomy had, in effect, discovered – *discovered*, because these were circles that apparently needed to exist in order for the appearances in the heavens to be as they were. He declined, that is, to regard mathematical astronomy as purely instrumental, like most navigational calculations today, which are still conducted, for convenience, according to the fiction of a stationary earth because they give the right answers.

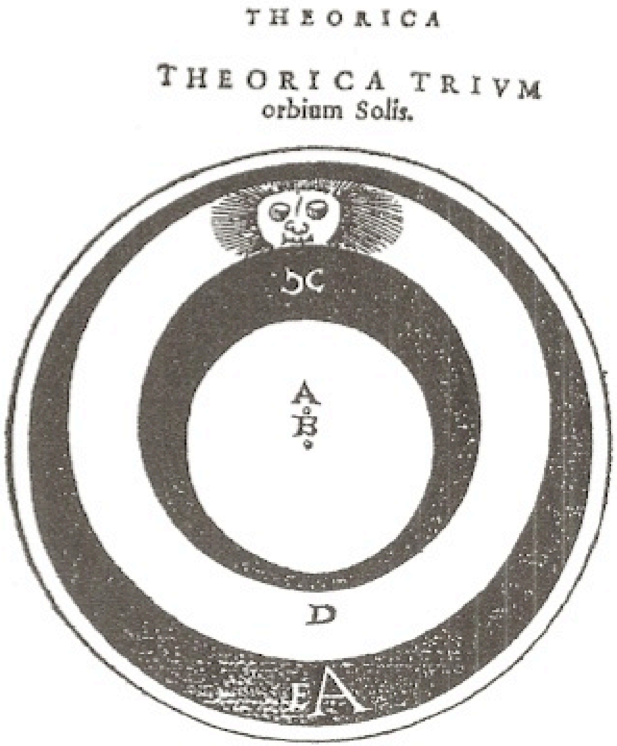

Figure 1.4 *Peurbach's conception of the physical reality of Ptolemaïc astronomical models, from his* Theoricae novae planetarum: *each circle in the geometrical model is here interpreted as a three-dimensional solid in the heavens. B represents the central earth; A is the point (axis, normal to page) around which the eccentric sphere D, which carries the sun, rotates. The planets are handled using similar, but more complicated, techniques.*

Ptolemy's astronomy reached Copernicus, at the close of the fifteenth century, through accounts such as Peurbach's; that is, accounts at one remove from the *Almagest* itself. His most detailed source was a work by Peurbach and his collaborator Regiomontanus, called *Epitome of the Almagest*. Although completed in the early 1460s, this work was not printed until 1496 (in Venice), by which time Copernicus had begun his university studies of astronomy. The *Epitome* is what its name suggests: a digest of the *Almagest* intended to illuminate the niceties of Ptolemy's geometrical models for celestial motions. Much more elaborate than either the *Theorica planetarum* or even Peurbach's *Theoricae novae*, the *Epitome of the Almagest* represented the peak of Latin astronomical science in 1500. But it was an astronomical science that already threatened encroachment on the domain of causal natural philosophy by implying its competence to speak of the true workings of the heavens.

IV Beyond the university

A scholar's life by 1500 was as much material as intellectual. The end of the fifteenth century saw a European learned culture that was busily absorbing the impact of a new technology, that of printing with moveable type. First appearing around 1450 in the German city of Mainz, printing rapidly spread from Johann Gutenberg's original press throughout the German territories and northern Italy, most notably Venice. This establishment, during the second half of the century, of scores of print shops corresponds to two related features of European, especially Western European, society at that time. The first is the fairly high rate of literacy on which the market for books and pamphlets was based. The second is the quite sudden wide availability of a multitude of philosophical and general intellectual options. Together, these two features created a situation in which knowledge for very many people was no longer so chained to the texts of the university curriculum. This was a new situation practically without parallel.

In 1500 the variety of intellectual options being sought in the new literary environment was still relatively limited. Perhaps the most influential among them at the time was the so-called neo-Platonism of Marsilio Ficino in Florence. In the 1460s Ficino undertook to translate into Latin the works of Plato, which had received relatively little attention during the Middle Ages.[3] Prior to this task, he had translated in addition a number of texts nowadays reckoned to date from the early Christian era, but which were believed by Ficino and most others to be among the oldest texts of antiquity, predating by centuries the writings of Aristotle, Plato, and all the other luminaries of classical culture. These were texts of the so-called hermetic corpus, held to have been written by an ancient sage in Egypt called Hermes Trismegistus (thrice-great Hermes). Their most notable feature (apart from reports of ancient Egyptian temple magic, in a hermetic text already known to the Latin Middle Ages) was their metaphysical conception of the universe. This, not surprisingly, resembled closely the neo-Platonic doctrines of late antiquity, the period now reliably believed to have produced the "hermetic" corpus as well. Since the late-antique neo-Platonic writers, such as Plotinus (third century), regarded their own teachings as expositions of the more arcane and mystical implications of Plato's own work, Ficino believed that all three together – Plato, the hermetic

corpus, and the neo-Platonic texts – represented an ancient mystical tradition of profound wisdom dating back to before the time of Moses in the Old Testament.

The overall thrust of these doctrines was a picture of the universe as a spiritual unity, in which the various parts were related by spiritual sympathies and antipathies. Astrology was a characteristic aspect of these views, one that was widely shared. Astrology had, of course, been a standard part of the learned beliefs of the preceding centuries too. Its novel aspect in the new neo-Platonic or hermetic form championed by Ficino, however, involved the ambition to use the astrological influences of the stars for human ends, rather than simply to predict and document passively their effects. In other words, this was a kind of astrology that held out the dream of magical domination of nature. The astrologer-magus – of whom another good example from the late fifteenth century is the Florentine Giovanni Pico della Mirandola – dreamed of harnessing the powers of the stars in their psychical interaction with things on the earth.

It can be noted right away that this neo-Platonic magical strain in Renaissance thought, clearly distinct from the usual teachings found in the university, does not strictly count as a non-Aristotelian *natural philosophy*. This is because it endeavoured to be more than that. To the extent that its view of nature was directed towards achieving operational control over nature, it was centrally a form of *magic*, a kind of technology intended for practical ends, and not a philosophical study devoted to understanding for its own sake. However, at the same time, because it did implicate non-Aristotelian philosophical ideas about the workings of the universe, it was one route (among many) by which non-Aristotelian natural philosophies became established in competition with orthodoxy. Magic was certainly known in the Middle Ages too, but it was usually presented as, at the least, not incompatible with Aristotelian natural philosophy. The Aristotelian world was a world of regularities, but not a world of rigid determinism. Unusual things could sometimes happen, and magic attempted to operate in that rather lawless hinterland left out of account by Aristotle's emphasis on what *usually* happened.

Magic itself could be a treacherous category. At its most fundamental level, the term referred to an art of manipulation, of doing things that, specifically, tended to provoke wonder, or that were marvellously out-of-the-ordinary. There was, in consequence, a variety of practices that properly bore that label. They included spiritual magic, which worked by invoking the aid of spirits, whether angels or demons (the latter then being known as "demonic" magic, associated with witchcraft); and "natural" magic. The latter was supposed to work by exploiting, rather than the abilities of spiritual agencies, the hidden ("occult") powers found in nature. The action of a magnet upon iron, for example, manifested one fairly common such power. Magic was an art of doing things, a technology, and the magus was someone who knew how to use it. It therefore represented a quite different kind of knowledge from the Aristotelian contemplative ideal.

Operational knowledge manifested itself in other ways too. The advent of printing saw the appearance not only of Latin treatises on magic, accessible to the learned, but also texts in the vernaculars, such as dialects of Italian and German. These vernacular texts had, of course, a much wider potential readership. Literacy was required, but not the scholarly training that would render Latin texts accessible. The new "books of secrets" therefore presented practical, but usually rather recondite, information to people with only a middling education. The genre, which really took off in the sixteenth century, seems to have been very much a creature of printing; the demand for such books was fed and encouraged by printers who could promise their readers all manner of practical tips that had hitherto (or so it was claimed) been the preserve of closed guilds of practitioners. Medical advice was particularly popular, with books presenting recipes for the treatment of a wide variety of ailments. In the first half of the sixteenth century one of the most prominent authors of such vernacular medical texts was Walther Hermann Ryff, a man with some training in medicine and the arts of the apothecary. Ryff published a multitude of popular works in German, largely drawn from the writings of others in the same fields, and including material taken from the learned Latin treatises of the university medical schools. In 1531 and 1532 there first appeared a group of small booklets, known as *Kunstbüchlein* ("little craft-books"), on a variety of practical craft and technical subjects. These anonymous books were produced from the shops of printers in a number of German cities, and catered to what they revealed as an eager appetite for such things not just among German craftsmen, but among literate people of the middling sort in general. They broke the perceived monopoly of the craft guilds over possession of such practical knowledge as made up metallurgy, dyeing or other chemical recipes, pottery or any of a multitude of potential household requisites.

The historian William Eamon, in his studies of such literature, has characterized these "technical recipe books" as a means whereby the "veil of mystery" that had hitherto surrounded the practical crafts was lifted, so that ordinary people could see that the craftsman was not possessed of some arcane wisdom, but simply had knowledge of a set of techniques that, in principle, anyone could apply.[4] This is not a notion that should be taken for granted, however. Studies in recent decades of the ways in which expert knowledge is constituted and passed on suggest that practitioners do indeed possess skills that are communicated only with difficulty. Their practical knowledge is often unlearnable from the eviscerated accounts that appear in the pages of experimental papers (in the sciences) or technical manuals (in skilled craftwork in general).[5] Thus, if Eamon is right, the growing sense that developed during the sixteenth century, as a consequence of printing and its uses, that practical craft knowledge ("know-how") can be reduced to straightforward rules of procedure that can be acquired readily from books, was to a large degree an illusion. If this is so, it is an illusion that we have inherited.

Two additional items to the emerging cultural mix deserve mention. Alchemy was to gain more adherents as time went on, until we find Isaac Newton, towards the end of the seventeenth century, as one of its principal exponents – at least judging by the amount of surviving manuscript material. Alchemy, as the name suggests, had been known to the Middle Ages originally from Arabic sources. By the start of the sixteenth century, it had appeared in some printed discussions, albeit generally in an equivocal way. One of the hallmarks of alchemy was its secrecy; writings on the subject were intentionally allusive and obscure, since this arcane knowledge was not to be made available to everyone. Only those who were already in the know were supposed to be able to benefit from texts on the subject. However, so-called alchemy did sometimes appear in the new printed genre of "books of secrets." This kind of alchemy differed, however, from the mystical alchemy practised by magicians, the kind of alchemy that had close ties to astrology.[6]

Thus the first of the *Kunstbüchlein*, appearing in 1531, was entitled *Rechter Gebrauch d'Alchimei* ("The Proper Use of Alchemy"). Based on a genuinely alchemical treatise that concerned itself with such matters as transmutation, this printer's compilation restricted the contents largely to practical metallurgical and chemical techniques; a kind of workshop *vade mecum*. Clearly, from this perspective, the "proper use" of alchemy was one that divested it of its more speculative and mystical aspects.[7] Despite this, right through to the time of Newton alchemy remained closely identified with spiritual and mystical dimensions. Thus, famously, one of the factors supposedly affecting the outcome of an alchemical preparation was the spiritual state of the alchemist; failure in such work did not necessarily reflect upon the techniques used, but might simply mean that the alchemist's soul had not been sufficiently pure. A transmutation could only be effected if the alchemist's spiritual rapport with the materials being manipulated was of the correct kind. Alchemy was usually by its nature a secretive practice, rather than a publicly available set of techniques suitable for publication in a handbook; witness the radical editing performed for the 1531 text.

Another secretive and magical domain of knowledge around this time was cabalism. Adverting, like neo-Platonism, to the clandestine knowledge of late antiquity, cabalism had originally been a Jewish practice, of which the Renaissance saw the emergence of a Christianized version. It rested on the investing of words, typically names, with occult significances and interrelationships based on the letters (in the original form, Hebrew) by which they were written. A word could be assigned a numerical value given by the sum of the numbers that conventionally corresponded to its individual letters; two words that had the same numerical value were deemed to have some hidden, deep correspondence. Thus the Christian cabala endeavoured to show that the name of Jesus really did correspond to "messiah," by showing that those two words had the same value – a matter in this case of trying to turn Jewish mysticism to the task of convincing Jews themselves of the truth of Christianity. From the 1490s the most prominent writer in this tradition was the German mystic Johannes Reuchlin.

This considerable variety of intellectual options, closely associated with the new technology of printing, meant that Europe around 1500 was preparing itself for a battle over intellectual authority of epic proportions. The sixteenth century was to see one of the great upheavals of European history with the Protestant revolt against the Catholic Church, a rejection of ideas and systems of authority that had held most of the continent for centuries. Placed alongside the questioning of papal authority, challenges to Aristotelian philosophical approaches seem of small significance by comparison. Both, indeed, can be seen as facets of the same process: Martin Luther and Jean Calvin, the most prominent of the religious reformers, both put a stress on the text of the Bible, which was to be made available to all Christians in their own languages, as the cornerstone of the Christian religion. Products of the printing press were to circumvent the elaborate structure of the Catholic Church, to put believers into direct communion with the word of God.

V Learned life and everyday life

It is important to remember the sort of ideas about knowledge of nature that are at issue here. In the case of religion in the sixteenth century, the changes due to the Protestant Reformation and the Catholic response of the Counter-Reformation affected, to a greater or lesser extent, everyone in Latin Christendom. The Counter-Reformation, however, was much more driven by the church hierarchy than was the Reformation, which had involved a great deal of popular religious upheaval in addition to the organized dissent stemming from religious leaders like Luther. The new options in the study of nature in this sense resemble the former more than the latter: the intellectual élite (those who presumed to define "what was worth knowing") fomented or opposed the struggles of the period, with little resonance at the popular level. Indeed, it is unclear how much difference the classic "Scientific Revolution" of the sixteenth and seventeenth centuries made to ordinary people. Its innovations left most features of their everyday lives unchanged; the changes that occurred are usually attributable to identifiably different causal factors, such as religious beliefs and practices themselves.

A longstanding view of the classic Scientific Revolution has emphasized the "decline of magic" by the end of the seventeenth century.[8] This view held that belief in witchcraft and other magical, supposedly "irrational" components of the European world-picture crumbled in the face of advancing scientific rationalism. It is, however, a view that carries much less credibility in light of the historical researches of recent years. The popular credibility of such things as witchcraft and astrology remained strong well into the eighteenth century, and there was a significant level of belief in them even on the part of scholars right through to, and beyond, the end of the seventeenth century. The traditional notion of rising "scientific" attitudes sweeping away the relics of superstition no longer seems very satisfactory. An indication of this point may be had from consideration, once again, of the claims made by those eighteenth-century figures who were the first to characterize the preceding couple of centuries as having seen a philosophical "revolution." The motivations driving so noisy a set of protestations stemmed from a desire to defeat utterly those institutions and ways of thought that many such eighteenth-century thinkers opposed. The most visible and powerful upholder of the supernatural was, of course, the Church (in France, the established Catholic Church). With its miracles, demons, and angels, this was therefore the main target of the "rational" philosophers of the new century: if there had not in the eighteenth century still been widespread belief in such things, there would have been no need to proclaim their outdatedness with such ferocity.

It is worth bearing this in mind from the outset, because the picture of a superstitious and credulous Europe in 1500 giving way, by 1700, to a cool, rationalistic, scientific Europe continues to have a strong hold on our views of the past. The astrology, demonology, and so forth of fifteenth-century figures like Ficino were ingredients of the intellectual ferment of the next couple of centuries; they were not photographic negatives of a new rationality that would sweep them away. History is seldom so neat.

Chapter Two
Humanism and Ancient Wisdom: How to Learn Things in the Sixteenth Century

I Language and wisdom

The new challenges to scholastic philosophical orthodoxy in the universities appeared from what seems at first an unlikely source. One of the usually unstressed aspects of an arts education in the medieval university had been the teaching of the subjects comprising what the early Middle Ages (*c.*600 AD onwards) had dubbed the "trivium." The three parts of the trivium consisted of grammar, logic, and rhetoric. The three went along with the so-called "quadrivium" – the mathematical subjects of geometry, arithmetic, astronomy and music – to make up the "seven liberal arts." These had been the basis of higher education in classical antiquity, and their echoes (with the new names "trivium" and "quadrivium") informed the educational norms of the early medieval period in the west.

The seven liberal arts only loosely structured the curriculum in the new universities of the thirteenth century. Logic, with its newly-available Aristotelian texts rather than just early-medieval digests, blossomed in importance alongside natural philosophy and metaphysics in the university arts curriculum. The quadrivium, meanwhile, enjoyed varying fortunes at different periods and among different institutions, but was never (with the very partial exception of astronomy, as we have seen) strongly emphasized. The other subjects of the trivium, grammar and rhetoric, received similarly short shrift. Latin grammar had evidently become the province of pre-university education (it was in effect a prerequisite to university study, since all instruction took place in Latin). Rhetoric, a discipline concerned with modes of persuasion, occupied a minor place, since the study of argumentation was regarded almost exclusively as the province of logic. But the academic status of rhetoric came to change radically in the fifteenth century.

The learned culture that underpinned the period of the Renaissance (dating from around 1400 or so onwards) is usually designated by the term

"humanism." "Humanism" is a much later historians' term derived from the contemporary Latin expression *studia humanitatis*. In Italian universities in the fifteenth century, the *studia humanitatis* were those disciplines concerned with language usage – grammar, rhetoric, and poetics. They placed at their core correct Latin (in time, Greek was added), and elegant literary style in composition. The expansion of these studies at a number of the universities of northern Italy went along with an increasing self-assertion on the part of those who taught them. These teachers, the original "humanists," claimed with increasing volubility the importance of their subjects in the arts curriculum as against the scholastic Aristotelian philosophy that had hitherto dominated it.

The local conditions of northern Italy played a considerable part in bringing this situation about and in fostering its success. The entire Italian peninsula was a patchwork of small states, the typical model in the north being the city-state, such as Milan, Venice, or Florence. Each city, with its surrounding territory (often, as in the case of Florence, considerable and enveloping a number of other major towns), thus exercised a high degree of political autonomy, and civic life within them often involved the participation of their leading citizens rather than being subject to the power of a prince. The early humanists took advantage of this situation by stressing the value of a humanistic education to the creation of an active, politically responsible citizen. A training in the *studia humanitatis*, they proclaimed, was a much better preparation for the future citizen than the dry logic-chopping offered by the Aristotelian philosophers. The humanists taught, as the real pay-off of the education that they offered, skill in rhetoric that would serve well the budding political orator, not just in teaching him tricks of delivery but in developing within him the wisdom and judgement required of a statesman.[1] The great model for such a person was the ancient Roman orator and senator from the first century BC, Cicero.

To the humanist educator, Cicero embodied all the virtues of the good republican statesman. During the latter days of the Roman republic, Cicero had been a political leader whose speeches to the senate, regarded by all as classics of effective oratory, still survived to be studied. Furthermore, Cicero had written on the art of oratory, laying down advice and rules on how to compose and deliver a successful public address. Thus both the theory and practice of rhetoric could be found in Cicero's writings, which to the Renaissance humanists were a treasure-trove to be exploited in the present day. Cicero, in short, could show modern society how public life ought to be conducted. The essential trick to be accomplished here, of course, was bridging the gap between effective speaking and the sound policy judgements that political oratory should, ideally, deliver. Again Cicero was a convenient model. Not only had Cicero spoken and written well; his speeches were also admired for the wisdom of their content. The new humanist ideology contended that the two were, in fact, inseparable: one could only match Cicero's eloquence if one had acquired his wisdom since only true wisdom could give rise to such eloquence. The art of Ciceronian oratory thereby acquired an almost mystical quality, and by equating the medium with the message, humanist educators attributed to the education that they provided a privileged role in creating good citizens. In practice, this meant that pupils were trained to *imitate* Cicero's Latin style, as well as imitating the styles of other good classical authors. An eloquent fool was not to be entertained; it would be an oxymoron, or so humanist educators maintained.

The fifteenth century had seen the gradual spread of the humanist educational agenda. It crossed the Alps around the middle of the century, and by the 1490s strongly coloured the style and content of university curricula in countries as far afield as Poland. During the sixteenth century, humanist education created a common cultural style among élite classes everywhere, becoming firmly established in the universities as well as in other kinds of advanced schooling. During the fifteenth century, humanist reformers, most notably Lorenzo Valla, had often attacked scholastic philosophy and theology on both scholarly and moral grounds. They castigated the language of the scholastics for deviating from classical norms – medieval scholastic Latin having drifted away from Ciceronian standards in both vocabulary and grammar – and argued that this barbarism was compounded in the case of theology (especially the "Thomist" theology of Thomas Aquinas). There, bad Latin was deployed in the service of Aristotelian logical niceties regarding metaphysics, to yield a form of theology that seemed far removed from the simple faith represented in the New Testament.

The picture that emerges in the sixteenth century, by contrast, is one of coexistence rather than conflict. In effect, the humanists won their battle for recognition without vanquishing their erstwhile rivals, the scholastic philosophers. Instead, the values of humanism pervaded scholarship as a whole, drifting up from the renewed emphasis on the "trivial" values of rhetoric and classical literature, the revivified remnants of the old trivium. Philosophers had by now routinely received humanistic training under the new educational dispensation. As an almost inevitable result, one finds in the sixteenth century scholastic commentaries on the works of Aristotle that are written in humanistic, classical Latin instead of the barbarous Latin of the medieval scholastics, and consider the niceties of the original Greek texts rather than concentrating solely on medieval Latin translations (themselves "barbaric").

There was much more to the new humanistic scholarly ethos of the sixteenth-century universities than elegant Latin, however. Cicero was a role model for the humanist rhetorician because he had combined eloquence with wisdom in the conduct of civic affairs. His perceived pre-eminence rested on the assumption that classical antiquity had seen the highest achievements in all areas of culture, achievements that had not since been equalled, much less surpassed. So the greatest orator-statesman of antiquity was, practically by definition, the greatest orator-statesman of all time. By the same token, the greatest practitioners or authorities in practically all other areas of endeavour themselves served as pre-eminent models. Thus the improvement of present-day cultural and scholarly activities came increasingly to be seen as a matter of restoring the highest accomplishments of the ancients. Not progress, but *renewal* was the humanist watchword. The wisdom of the ancients should be sought, in order to reverse the decline that had been occurring ever since the last days of the Roman empire.

II The scientific renaissance

The word "renaissance" means "rebirth." The humanists liked to characterize their own time by using such terminology, because they pretended to be bringing about a rebirth of classical culture. In doing so, they were rejecting the barbarism of the period that intervened between classical antiquity and its rebirth in the present – the "Middle Ages"; it is to the humanists that we owe that name.

The ideal of renewing culture by a return to antiquity first appears in the sciences with any prominence in the mid-fifteenth century. The central figure here was Regiomontanus, a.k.a. Johannes Müller, whose preferred appellation was a self-consciously classicized version of the name of his home town, Königsberg. Regiomontanus was a mathematician and astronomer, but he was also a humanist specialist in Latin literature (especially Vergil). The attendant attitudes towards antiquity determined his other scholarly work, and appear with stark clarity in the *Epitome of the Almagest*, the work that he wrote with his older contemporary Georg Peurbach, another humanist and astronomer in Vienna.[2] The preface to this work, written in the early 1460s, is a humanist paean to the glories of antiquity and the contrasting cultural poverty of the present. Regiomontanus harangues his audience on the sad state of mathematical studies, and on the only proper way forward – the one that he promoted. He took this material on the road in the 1460s, most notably addressing university audiences at Padua in 1464 in a surviving lecture on the history of mathematics, the *Oratio introductoria in omnes scientias mathematicas* ("Introductory oration on all the mathematical sciences"). Regiomontanus's approach in the *Oratio* is designed to place him in a mathematical tradition that can be traced from the Egyptian origins of geometry, through the ancient Greek mathematicians and the successive translation of their work into Arabic and then Latin, to yield the present-day mathematical enterprise. This last, continuous with antiquity, is that in which Regiomontanus himself participated (again through forms of translation). And he regarded astronomy as the highest of the mathematical sciences.

Regiomontanus thus transferred the language of the humanists, on decline and renewal, to the specific arena of the mathematical sciences. The

Oratio and his preface to the *Epitome* are typical statements of humanist ideology, and can be found echoed in major texts of the sixteenth century that similarly address scientific matters. The *Epitome* had a large influence on astronomical training at the end of the fifteenth century, after its eventual printing in 1496, and its humanist rhetoric of "restoration" clearly found a receptive audience. Perhaps the most important of all the astronomical practitioners who followed in Regiomontanus's footsteps was the Polish canon familiarly known in Latin as Nicolaus Copernicus. In the early 1490s Copernicus studied at the University of Krakow, one of the new Polish universities of the fifteenth century and an institution with a quite vigorous tradition in astronomy. In addition to its astronomical status, however, Krakow had also become, by the end of the century, something of a centre for the new humanist learning, stressing the importance of the classical languages and the value of erudition in the texts of antiquity. Copernicus was studying in Italy when the *Epitome* came off the presses in Venice (he returned to Poland with some expertise as a medical practitioner, although he never took a medical doctorate). A few years later, in 1509, his first published work appeared: a Latin translation of a Greek poem. By around 1512, he had produced the first version of a new astronomical system intended to replace the world-system of Ptolemy. This text, known as the *Commentariolus* ("little commentary"), began with a consideration of Ptolemaïc astronomy and its supposed shortcomings; all the evidence suggests, however, that Copernicus's detailed knowledge of Ptolemy's astronomy at this time was still dependent on the account given in the *Epitome of the Almagest* rather than on Ptolemy's *Almagest* itself – a text that remained unprinted until a medieval Latin version from the Arabic was published in 1515, the original Greek text itself not appearing in print until 1538. The *Commentariolus* came to be known quite widely in astronomical circles during the sixteenth century, but only in manuscript form. The printed account of Copernicus's new system did not appear until much later, in 1543.

That later work, *De revolutionibus orbium coelestium* ("On the Revolutions of the Celestial Spheres"), which turned the earth into a planet that orbits the sun, was presented explicitly as a renovation of the ancient Greek astronomical tradition. In the preface to the work (dedicated to Pope Paul III), Copernicus tells of the route he had taken in arriving at his new ideas. They centred above all, as had his much briefer remarks at the beginning of the *Commentariolus*, on the shortcomings to be found in the current state of astronomical practice. Declaring that his intention was to improve matters, Copernicus makes the typical humanist move – he canvasses the available ancient authorities.

> I undertook the task of rereading the works of all the philosophers which I could obtain to learn whether anyone had ever proposed other motions of the universe's spheres than those expounded by the teachers of astronomy [lit. "mathematics"] in the schools. And in fact first I found in Cicero that Hicetas supposed the earth to move. Later I also discovered in Plutarch that certain others were of this opinion. I have decided to set his words down here, so that they may be available to everybody . . . [there follows a quotation from the Roman Plutarch's *Opinions of the Philosophers*].[3]

Copernicus's conclusion to this apparent digression is instructive. He says: "Therefore, having obtained the opportunity from these sources, I too began to consider the mobility of the earth. And even though the idea seemed absurd, nevertheless I knew that others before me had been granted the freedom to imagine any circles whatever for the purpose of explaining the heavenly phenomena."[4] Finding ancient precedent for the suggestion that the earth might move was essential to justifying his own consideration of the matter: it provided him with an "opportunity" that he would otherwise have lacked. Presenting one's work as innovative was seldom regarded as the best way to be taken seriously; innovations were light and insubstantial.

It needs to be stressed, however, that we cannot regard Copernicus's way of speaking as mere packaging. There is no basis whatever for thinking that Copernicus did not see his "new" astronomical system as a legitimate continuation of the ancient legacy represented by Ptolemy, and his own work as that of restoration. Furthermore, we have good evidence from a reliable source that this was indeed Copernicus's view of his own endeavour. The first printed discussion of Copernicus's sun-centred astronomy appeared in 1540, written by Georgius Rheticus, a mathematics professor from the University of Wittenberg. Rheticus (a Lutheran) had travelled to Thorn, or Toruń, in western Poland, to visit Copernicus (a canon in the Catholic church) in 1539. Rheticus was evidently drawn there by the high reputation that Copernicus had acquired over the years as a mathematical astronomer (he was never much of an observer) and by rumours of Copernicus's new astronomical system. Rheticus wanted to learn more, and the work of 1540, called *Narratio prima* (the "first account" of Copernicus's system), contains an outline of Copernicus's ideas and praise for their virtues – which for Rheticus amounted, when all was said and done, to their being *true*. Rheticus refers frequently in *Narratio prima* to the as-yet-unpublished text of *De revolutionibus*, which he was instrumental in persuading Copernicus to have published; in a letter he mentioned that Copernicus's great work had been written "in imitation of Ptolemy".[5] The word "imitation," unquestionably used by Rheticus as a term of approval, shows once again how Copernicus and his astronomical contemporaries viewed his work. Copernicus imitated Ptolemy just as a budding humanist rhetorician imitated Cicero; it was the way to acquire their skills. Hence Copernicus's greatest achievements in the eyes of his mathematical contemporaries lay in his consummate skill in devising geometrical models of

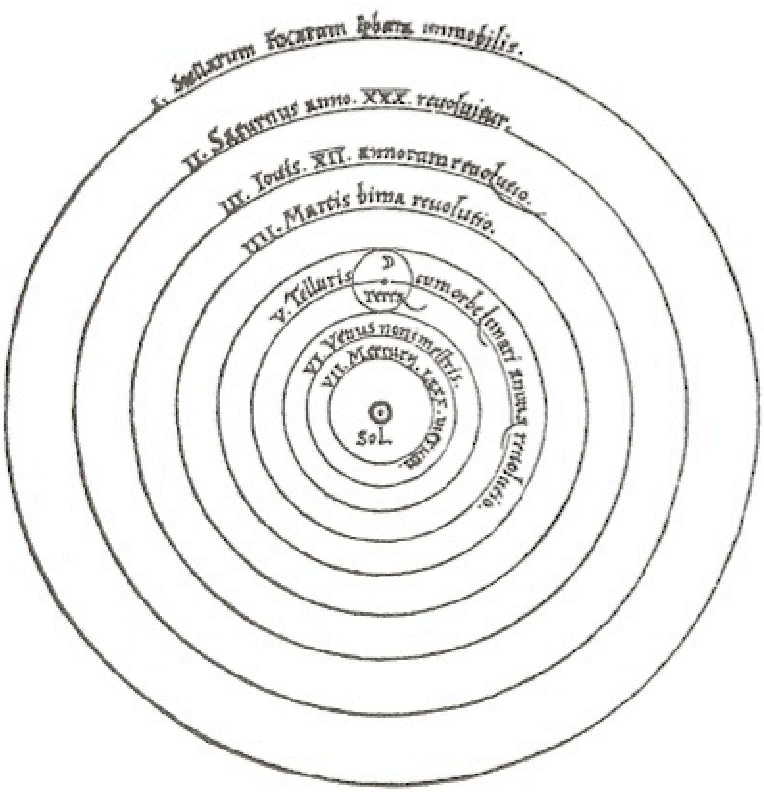

Figure 2.1 *Copernicus's basic world-system, without the additional circles needed for accuracy. From Copernicus,* De revolutionibus.

celestial motions using the same techniques as Greek astronomers themselves – including the firm restriction to uniform circular motions as the models' components. (See Figure 2.1.)

All this was despite the fact that Copernicus departed from Ptolemy radically, by setting the earth in orbit around a now-stationary central sun. This reformulation was more than simply astronomical, a new way to calculate the motions of lights in the sky; it also possessed *physical*, cosmological significance if taken literally. A moving earth that was no longer at the centre of the universe undermined many of the central tenets of

Aristotelian physics. As we shall see shortly, however, one way for the astronomer to stop short of drawing unwelcome physical implications from Copernican astronomy was precisely to *be* an astronomer, and *not* a natural philosopher.[6]

In pursuing a technical enterprise by hailing a return to the practices of the ancients, Copernicus was participating in the great scholarly cultural movement of his time, that of renaissance humanism. We should not, therefore, expect him to be alone in this kind of enterprise. The norms and conventions of humanist discourse conditioned not only the forms of presentation used in various of the sciences, but also the nature of those enterprises themselves, as we have just seen in the case of Copernicus. The goal of restoring modern society by returning to the cultural practices of antiquity could not be cleanly separated from the procedures of those sciences themselves. The "Scientific Renaissance," as we have called it, spans the sixteenth century precisely to the extent, and in the same way, that humanist education infused the scholarly perspectives and judgements of practically all those educated to anything near university standards.

III Finding out how the ancients did it

The anatomist and physician Andreas Vesalius of Brussels affords another striking instance of a renowned figure in the history of science who must be seen as a part of this same cultural movement. Vesalius is best known for his influential publications – printing being, again, an integral part of the story. His greatest work is *De humani corporis fabrica* ("On the Fabric of the Human Body"), published, like Copernicus's *De revolutionibus*, in 1543. Vesalius had been trained as a physician at the University of Paris, and subsequently taught at the universities in Louvain, Paris, and then Padua. Most of the specifics of what can be said about his early career depend on his own account of them, an account that was itself fashioned with particular, interested aims in mind. Fortunately, enough is known independently about the universities with which he was associated to allow checks on some of his claims. But one of the things of which we can be sure is that Vesalius had the technical skills and the intellectual sympathies required to make him a humanist scholar.

Vesalius was born in 1514. In the 1530s he was drawn into collaborating on the production of a new, scholarly edition of the works of the pre-eminent medical authority of antiquity, Galen, an edition that appeared in 1541. This edition was intended to publish Galen's many Greek texts in good new Latin versions, with all the appropriate scholarly apparatus commenting on and explicating the philological niceties of Galen's language and terminology. Such an enterprise stood at the centre of humanist scholarship; classical culture could not be revived without intimate understanding of the sources. In introducing the *De fabrica*, Vesalius availed

Conclusion
What was Worth Knowing by the Eighteenth Century?

By the time of Newton's death, the educated European outlook on the natural world had changed beyond all recognition from what it had been in 1500. The new ideology of natural knowledge was now one firmly, though not exclusively, associated with practical, operational capabilities. The greatest physico-mathematicians of the later seventeenth century, Huygens and Newton, both took an active interest in practical, non-contemplative matters. Significantly, in the 1650s, Huygens had devoted much attention to the problem of the determination of longitude at sea, a problem of especial concern to the new mercantile states of Western Europe such as Huygens's own nation of the Netherlands (United Provinces). In addressing it, Huygens not only dealt with the theoretical problems relating to pendulum motion (the use of the pendulum as a timekeeper had earlier been suggested by Galileo), but also worked on the details of actually constructing a marine chronometer that would continue to keep regular time on ocean voyages: Huygens's chronometers were actually put to practical trial on long voyages by French naval vessels. The incessant rhetoric of Baconian practicality that dominates the first decades of the Royal Society was also important for Huygens and the Royal Academy of Sciences in Paris, and it remained crucial in the early decades of the eighteenth century with the establishment of a Newtonian natural-philosophical ideology.

The major development of the two centuries covered in this book was, therefore, the rise to a position of prominence of a "natural philosophy" that was directed towards control of the world. European knowledge in 1500, as it existed in formal, official settings such as universities, placed a premium on abstract, contemplative understanding. This is not to say that there were no social implications of such a focus, but it is to say that those implications were mediated through institutions (especially the Church) whose power did not noticeably involve ambitions to increase the means of control over the natural world itself. During the sixteenth and seven-

teenth centuries, however, European nations began to spread their power to other parts of the world to an extent unprecedented in history. Consequently, valuations of knowledge began very gradually to shift towards those kinds of knowledge that could bring the world beyond Europe back home (as with geography and natural history), or that would enable a more effective reaching out to other parts of the world with the intention of material and cultural domination (as with such sciences as navigation or mechanics – or even with Matteo Ricci's use of mathematics to impress the Chinese court). The rise of a Baconian rhetoric of utility during the seventeenth century, associated with the welfare of the state, mirrored closely these large-scale changes in European life.

Significantly, it was the mercantile states of western Europe that played the greatest role in revolutionizing the sciences during this period. Spain, the greatest colonial power of the period in terms of wealth acquired and land conquered, but not the greatest as an active mercantile power, did not follow the same direction as countries such as France, England, or the Netherlands, except perhaps in studying the natural history of the New World. England and the Netherlands in particular illustrate well the associations between mercantile colonial expansion and the new ambitions of European knowledge in these centuries.

Concomitantly, while the sixteenth century had witnessed a form of intellectual endeavour that was dominated by humanism, and by the explicit aim of recovering the civilization of classical antiquity, the seventeenth century saw the appearance of a new ambition, exemplified by Descartes and Bacon, to forge ahead with professedly novel intellectual programmes. The sanction of antiquity remained an important rhetorical resource for many, but it now competed with claims of novelty that often justified approaches to nature by talk of "method" instead of talk about classical precedent. The evidence that such methods were efficacious was argued to reside in the practical achievements that the method supposedly enabled, whether it was Bacon's inductive method leading to "works," or Descartes's method leading to improved optical lenses (as in his essay "Dioptrics") or, as Descartes also hoped, to lengthened human lives.

All the same, the category of endeavour known as "natural philosophy" retained certain fundamental features right through all the changes that occurred during this period. From beginning to end, natural philosophy involved God, whether Thomas Aquinas's medieval God of an Aristotelian universe or the God of the Newtonians, free to do whatever He wanted and continually, providentially aware of everything in the universe due to His omnipresence throughout all of (absolute) space – what Newton called God's "universal sensorium." Natural philosophy bred very few genuine atheists in the sixteenth or seventeenth centuries, although matters changed in the eighteenth.

It would be foolish to see the so-called Scientific Revolution as nothing but a straightforward product of European expansion. The emergence in the seventeenth century of the infinite universes of Descartes and of Newton, with the earth a planet orbiting a star called the sun, can stand for enormous intellectual shifts in the kind of universe that educated Europeans saw themselves as inhabiting. Nonetheless, at the heart of these shifts are the operational, mathematical, and (in the case of natural history) enumerative or cataloguing enterprises of the period, enterprises that underpinned the creation of a new universe and a new natural philosophy. European learned culture, in regard at least to an understanding of the natural world, had undergone a shift from a stress on the *vita contemplativa*, the "contemplative life," to a stress on the *vita activa*, the "active life," to use a Latin terminology familiar to the humanist scholars of the period.[1] "Knowing *how*" was now starting to become as important as "knowing *why*." In the course of time, those two things would become ever more similar, as Europe learned more about the world in order to command it. The modern world is much like the world envisaged by Francis Bacon.

Notes and References

Introduction

1 See, e.g., Jean d'Alembert, *Preliminary Discourse to the Encyclopedia of Diderot* [1751], trans. Richard N. Schwab (Indianapolis: Bobbs-Merrill, 1963), p.80.

2 See below, Chapter 3, section IV.

3 Aristotle, *Posterior Analytics* II.19, in Jonathan Barnes (ed.), *The Complete Works of Aristotle*, 2 vols (Princeton: Princeton University Press, 1984), vol.1, pp.165–6 (trans. Barnes).

4 It is in the nature of heavy bodies to fall downwards. This in turn is understood in terms of "final causes": their natural place (i.e., their destination) is the centre of the universe, towards which they therefore tend to go. See Chapter 1, section I, below.

5 Francis Bacon, *The New Organon*, ed. and trans. Lisa Jardine and Michael Silverthorne (Cambridge: Cambridge University Press, 2000), Book I, aph.93. Bacon refers here to the voyages of discovery, using the image of passing through the Straits of Gibraltar into the great ocean beyond.

6 An insightful recent discussion of this very point is Peter Pesic, "Wrestling with Proteus: Francis Bacon and the 'Torture' of Nature," *Isis* 90 (1999), pp.81–94.

7 Hence the title of Marie Boas Hall's book *The Scientific Renaissance, 1450–1630* (New York: Harper & Row, 1962).

8 Nonetheless, important exceptions still remained, including features of the work of Isaac Newton: see J. E. McGuire and P. M. Rattansi, "Newton and the 'Pipes of Pan'," *Notes and Records of the Royal Society of London* 21 (1966), pp.108–43.

Chapter 1: "What was Worth Knowing" in 1500

1 Isaac Newton, *The Principia: Mathematical Principles of Natural Philosophy. A New Translation and Guide*, trans. I. Bernard Cohen and Anne Whitman (Berkeley, etc.: University of California Press, 1999), p.943.

2 Generally, the desideratum was to locate planets within the correct zodiacal sign, i.e. to within fifteen degrees, for astrological purposes.

3 Theology and philosophy during the Middle Ages themselves exhibit many "Platonic" strains, but there was little close study of Plato's own texts. Medieval Platonism had typically been refracted by other authors, especially the Christian Church Father St Augustine (*c*.400 AD).

4 William Eamon, *Science and the Secrets of Nature: Books of Secrets in Medieval and Early Modern Culture* (Princeton: Princeton University Press, 1994), p.113.
5 On the importance of "tacit knowledge" in science, see H. M. Collins, *Changing Order: Replication and Induction in Scientific Practice*, 2nd edn (Chicago: University of Chicago Press, 1992).
6 The astronomer Tycho Brahe, in the late sixteenth century, was also an alchemical practitioner.
7 Eamon, *Science and the Secrets of Nature*, pp. 114–15.
8 The classic exposition of this view is Keith Thomas, *Religion and the Decline of Magic: Studies in Popular Beliefs in Sixteenth- and Seventeenth-Century England* (London: Penguin Books, 1978).

Chapter 2: Humanism and Ancient Wisdom: How to Learn Things in the Sixteenth Century

1 Separate humanist schools were also set up, seldom but sometimes including such education for girls.
2 Regiomontanus completed the *Epitome* after Peurbach's death in 1461. See also Chapter 1, section III, above.
3 Nicholas Copernicus, *On the Revolutions*, translation and commentary by Edward Rosen (Baltimore: The Johns Hopkins University Press, 1992), p.4.
4 Ibid., p.5.
5 Quoted in Alexandre Koyré, *The Astronomical Revolution: Copernicus – Kepler – Borelli* (London: Methuen, 1973), p.29.
6 See Chapter 1, section III, above.
7 Translated in C. D. O'Malley, *Andreas Vesalius of Brussels 1514–1564* (Berkeley, etc.: University of California Press, 1964), p.320.
8 Ibid.
9 Galen was particularly concerned to give explanations for anatomical features in terms of final causes.
10 Vesalius, in O'Malley, *Andreas Vesalius*, p.322.
11 Ibid.
12 "Coss" from the Italian "cosa," meaning "thing" – what we would call the "unknown" in an algebraic equation.
13 René Descartes, *The Philosophical Writings*, vol.1, ed. John Cottingham, Robert Stoothoff and Dugald Murdoch (Cambridge: Cambridge University Press, 1985), p.17 (trans. Murdoch).
14 That is, with a *stationary* sun, but not strictly helio*centric*, with the sun at the *centre* of the system – as Kepler later noted. In Copernicus's complete system, the sun was slightly off to one side of the centre of the earth's orbit, which provided the actual fixed point with which the other planetary motions were coordinated.
15 See Chapter 1, section III, above.
16 Copernicus, *De revolutionibus*, trans. Rosen, p.xx.
17 Ibid.
18 As long as the stars are now taken as being enormously distant compared to the size of the earth's orbit.
19 Guidobaldo's most important work was his *Liber mechanicorum* ("Book of Mechanics") of 1577.
20 Quoted in Paul Lawrence Rose, *The Italian Renaissance of Mathematics: Studies on Humanists and Mathematicians from Petrarch to Galileo* (Geneva: Droz, 1975), p.230.

Chapter 3: The Scholar and the Craftsman: Paracelsus, Gilbert, Bacon

1 These are the Latin forms of their names, by which they were known in the universities.
2 Blood was hot and wet, phlegm was cold and wet, black bile was cold and dry, and yellow bile was hot and dry. The Aristotelian elements were also associated with these pairs of qualities.
3 Quoted in Walter Pagel, *Paracelsus: An Introduction to Philosophical Medicine in the Era of the Renaissance*, 2nd rev. edn (Basel and New York: Karger, 1982), p.71.
4 Ibid., p.84.
5 And see above, Chapter 1, section IV.
6 Cf. Chapter 2, section IV, above, on Pliny and Lutheran pedagogy. Agricola's book is also the chief literary source, through his presentation of traditional miners' lore, of the association between mining and dwarfs, the gnome-like beings that were believed to lurk in the mines: Georgius Agricola, *De re metallica*, trans. Herbert Clark Hoover and Lou Henry Hoover (New York: Dover, 1950), p.217 n.26.
7 See also Chapter 4, section IV, below.
8 William Gilbert, *De magnete*, trans. P. Fleury Mottelay (New York: Dover, 1958), pp.14–15.
9 Ibid., p.15.
10 Ibid., p.47.
11 Ibid., p.22.
12 See, e.g., Gilbert's self-presentation in ibid., "Preface," pp.xlvii-li.
13 For example, Francis Bacon, *The New Organon*, ed. and trans. Lisa Jardine and Michael Silverthorne (Cambridge: Cambridge University Press, 2000), Book I, aph.63, comparing Aristotle unfavourably to the Presocratics.
14 Ibid., aph.32.
15 Ibid.
16 Ibid., aph.122.
17 Ibid., aph.79.
18 Ibid., aph.71.
19 Ibid., aph.79.
20 Ibid., aph.33.
21 Ibid., aph.124.
22 Note the Aristotelian concepts here.
23 Bacon, *New Organon*, Book I, aph.66 (end); my emphasis.
24 Ibid., aph.81.
25 Ibid., aph.129 (end).
26 On the syllogism, see Introduction, section II, above.
27 Bacon, *New Organon*, Book I, aph.11.
28 Ibid., aph.8.
29 Ibid., aph.12.
30 Ibid., aph.105.
31 Ibid., aph.106.
32 For example, ibid., aph.100.
33 Ibid., aph.101. Bacon's term for this is, in Latin, *experientia literata*: "literate experience."
34 For more on Harvey, see below, Chapter 7, section IV.
35 Francis Bacon, *The Works*, 7 vols, edited by James Spedding, R. L. Ellis and D. D. Heath (London, 1857–61), vol.3, p.156.
36 Bacon, *New Organon*, Book I, aph.96.