The Scientific Revolution and the Origins of Modern Science

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John Henry

palgrave

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1 The Scientific Revolution and the Historiography of Science

The Scientific Revolution is the name given by historians of science to the period in European history when, arguably, the conceptual, methodological and institutional foundations of modern science were first established. The precise period in question varies from historian to historian, but the main focus is usually held to be the seventeenth century, with varying periods of scene-setting in the sixteenth and consolidation in the eighteenth. Similarly, the precise nature of the Revolution, its origins, causes, battlegrounds and results vary markedly from author to author. Such flexibility of interpretation clearly indicates that the Scientific Revolution is primarily a historian's conceptual category. But the fact that the notion of the Scientific Revolution is a term of convenience for historians does not mean that it is merely a figment of their imaginations with no basis in historical reality.

Certainly, knowledge of the natural world can easily be seen to have been very different in 1700 from the way it was in 1500. Undoubtedly, during this period, highly significant and far-reaching changes were brought about in all aspects of European culture concerned with the nature of the physical world and how it should be studied, analysed and represented, and many of these developments continue to play a significant part in modern science. It is perfectly clear, also, that many of the leading innovators in the period saw themselves as doing something new. Indeed, the word 'new' occurs time and again in the titles of many of the books written by the leading figures in the Revolution. Francis Bacon (1561–1626) announced his intention to replace the doctrines of Aristotle's *Organon* in his *New Organon* (1620), Galileo (1564–1642) wrote a book about *Two New Sciences* (1638), and Johannes Kepler (1571–1630), who had earlier noted that the Paracelsians had invented a new medicine and that the Copernicans had invented a new astronomy, presented a book on his own discoveries which he also saw as *A New Astronomy* (1609). There were many similar examples. The concept of the Scientific Revolution can be seen, therefore, to refer to a very real process of fundamental change. If we wish to understand the nature and causes of these changes we must try to pinpoint the fundamental issues for past thinkers, their most significant switches in ways of thinking, the clearest shifts in their social organization, the most far-reaching changes in their scientific practice, and the implications of the most significant discoveries and inventions. We need not detain ourselves, however, in discussions about the correct starting date, about precisely what kind of revolution it was, or about the best way of defining revolutionary change in science. To do so is mistakenly to regard what is nothing more than a convenient term of reference for a wide range of major social and intellectual changes as though it somehow grasps the putative essence of those changes [6; 38; 205; 235].

The reification of the Revolution, as a revolution, has, however, given rise to one important historiographical debate; one which continues to be disputed. A number of historians have argued that the very concept of a revolution in early modern science, with its implication of a radical break with the past, is misplaced or misconceived. The issue depends, of course, entirely upon whatever criteria are used to circumscribe the debate [51; 50; 210]. The current consensus seems to be that the 'continuist' view of scientific development has been overstated in the past, but remains valuable for pointing to the many and various antecedents of later developments during the medieval period [167; 68; 26]. As a number of recent surveys of medieval science have made abundantly clear, medieval natural philosophy provided the foundations upon which the Scientific Revolution was built. But these recent works are not strictly continuist in their historiography because they do acknowledge that something significantly different did take place in the period of the Scientific Revolution. There was a change in the edifice of European knowledge which enables us to see where the foundations end and the superstructure begins. The fact remains, however, that where once the Middle Ages could be presented as a period of scientific sterility and stagnation, thanks to the excellent work of continuist historians, we can now see the undeniable achievements of medieval thinkers, particularly in the fields of astronomy and cosmology, optics, kinematics, and other mathematical sciences, as well as in the development of the notion of natural laws and of the experimental method [109; 110; 50; 51; 167; 210; 68].

Moreover, continuist historiography has played an important part in making historians of science aware of the dangers of what is called whiggism. There is a tendency in the history of science to look back with hindsight about what is known to be important later. To judge the past in terms of the present is to be whiggish. In the early decades of the formation of the discipline it was common for a historian of science to pick out from, say, Galileo's work, or Kepler's, those features which were, or could most easily be made to look like, direct anticipations of currently held science. The resulting history was often a lamentable distortion of the way things were. But the very notion of the Scientific Revolution, it's easy to see, has something rather whiggish built into it. The science of that era was revolutionary because, unlike previous science, it was like our own, or so we think. It's almost as if what we want to say is not just, here are the origins of modern science, but here is the beginning of current science.

There is a sense in which this kind of whiggism still thrives in history of science. The *raison d'être* of history of science is, essentially, to try to understand why and how science became such a dominant presence in our culture [161; 152; 41; 52; 139]. As such, all our history is directed towards the present. So, although the vigorous repudiation of whiggism has now become a shibboleth which must be uttered to gain entry into the ranks of serious scholars, whiggism lurks within all of us [116]. The distinguished intellectual historian, Richard H. Popkin, once wittily announced that he intended to study the reasons why 'one of the greatest anti-Trinitarian theologians of the seventeenth century', Isaac Newton (1642–1727), should take time off to write works on natural science [204]. Why do I describe this as witty? Because I find it impossible to take seriously the suggestion that Newton's historical significance derives from his standing as a theologian. To this extent I have to confess to whiggism. I believe that we study Newton because he made such exceptional contributions to our scientific culture. Nothing else about this fascinating man is quite so interesting as that.

Continuism can be seen, however, at least to some extent, as an antidote to whiggish tendencies because it tends to be backward-looking, rather than inherently forward-looking. The attempt to see Galileo as a latter-day *impetus* theorist is intrinsically less whiggish than presenting him as one who prefigured Newtonian inertia, and should lead us closer to Herbert Butterfield's suggestion (before he himself became a Whig historian by writing a book about the Scientific Revolution! [116: 58; 26]) that we should attempt 'to see life with the eyes of another century than our own' [quoted in 116: 48]. Virtually all historians of science now try to avoid overt forms of whiggism, revolutionists and continuists alike, but it seems safe to say that historians of the Middle Ages were among the first to show the way [50; 51; 68].

Another indicator that the concept of the Scientific Revolution is inherently whiggish is the very word 'scientific'. Our present use of the word 'science' was first coined in the nineteenth century and, strictly speaking, there was no such thing as 'science' in our sense in the early modern period. To talk as though there was, as I have been doing, is an obviously whiggish distortion. Part of our aim, in looking at the historical development of what we think of as science, should be to understand how the very concept 'science' arose; we simply beg the question if we talk about 'science' as though it always existed.

So, if there was no 'science' at the time of the Scientific Revolution what was there? There was something called 'natural philosophy', which aimed to describe and explain the entire system of the world [110]. There were a series of technically developed disciplinary traditions, either mathematically based like astronomy [73; 163], optics [215; 50], mechanics [68; 159; 165;] and what was called music, but which we would see as a rather more mathematical study based on principles of ratios and other aspects of proportion [36; 40; 108]; or medically based like anatomy [27; 91], physiology [119; 271; 18], and pharmacology or the study of *materia medica*, those things from which medicines could be made [7; 18; 66]. And finally, there were a range of practical arts like navigation, cartography, fortification and other military arts, mining, metallurgy, and surgery [235: 225–7; 164; 159; 165]. The relationship between these technical disciplines and natural philosophy requires careful elucidation and work in this area is continuing.

Some of the most exciting research in the history of science has been concerned to show how changing interactions between the specialist disciplines and natural philosophy, through practitioners in either or both camps, has given rise, not only to new developments in knowledge and practice, but also to something which looks closer, or more directly related, to our present-day demarcation of scientific disciplines. Galileo's endeavour to bring together kinematics and natural philosophy resulted in what he called the new science of motion, which historians still regard as an influential step towards subsequent theories [247]. Similarly, the new and highly influential natural philosophy of René Descartes (1596–1650), the mechanical philosophy, was forged out of his attempts to base natural philosophy upon the certainties of geometrical reasoning [103]; and Newton's new natural philosophy was based, as the title of his book proclaimed, on mathematical principles [95]. The development of atomistic theories of matter grew at least partly out of the efforts of medically trained natural philosophers to extend Aristotle's natural philosophy to account for the empirical knowledge of chemists [77; 178; 266]. The new experimental philosophy, developed in late-seventeenth-century England by Robert Boyle (1627–91) and others, was intended to demarcate new discipline boundaries around correct natural philosophy, and to exclude what had previously been regarded as correct practice [243].

A simple but essentially accurate way of summing up what took place in the Scientific Revolution, then, is to say that the natural philosophy of the Middle Ages, which had tended to remain aloof from mathematical and more pragmatic or experiential arts and sciences, became amalgamated with these other approaches to the analysis of nature, to give rise to something much closer to our notion of science. The Scientific Revolution should not be seen as a revolution *in* science, because there was nothing like our notion of science until it began to be forged in the Scientific Revolution out of previously distinct elements [6].

It should be clear from this that it is by no means ideal to use the term 'natural philosophy' instead of 'science' when dealing with the early modern period. The terms are by no means equivalent. One of the revolutionary things about the Scientific Revolution is precisely the fact that, throughout the period, natural philosophy was being changed beyond all recognition, and approaching closer to our concept of science. Even so, the term natural philosophy was the one which was most used at the time to refer to an understanding of the physical world, and continued to be until the nineteenth century (when the word ‘science’ acquired its present meaning). Accordingly, I will use ‘natural philosophy’ and ‘science’ quite interchangeably, meaning in both cases nothing more than the endeavour to understand, describe or explain the workings of the physical world (I will also use the adjectival forms, ‘natural philosophical’ and ‘scientific’ in the corresponding way). I hope neither anachronism will prove too distracting.

It is possible to acknowledge a whiggishness in one’s reasons for looking at the history of science without, however, allowing whiggism to intrude into our historical narratives. Rather than imposing our own views, our aim as historians should be to strive for as full an understanding as possible of the contemporary context. For example, if we wish to understand the contemporary response to a little book like Galileo’s *Siderius Nuncius* (*Starry Messenger*, 1610), in which Galileo presented the discoveries he had made by turning the newly invented telescope to the night sky, it is obvious that we cannot simply read Galileo’s text [97; 255]. Nor will it be enough to familiarize ourselves with the technical astronomy and cosmology of Galileo’s time. It is well known, for example, that some of Galileo’s contemporaries refused to look through his telescope. Why did they respond that way? Obviously not because of any astronomical technicality [265]. Part of the answer is that magicians, and even common conjurors, used combinations of mirrors and lenses to fool people [122]. An understanding of the implications of what Galileo wrote is also relevant. A contemporary reader would have responded differently to a work which was likely to have no impact beyond its immediate area, than to one, like Galileo’s, which could be seen to run counter, not only to current astronomy and cosmology, but also to the wider natural philosophy, and to religious belief [16; 246; 171; 133]. A really full account would also require some knowledge of contemporary understanding of who Galileo was: his reputation, his presumed or perceived motivation, and whether he could be held to speak disinterestedly, and so forth [15; cf., for similar considerations about other thinkers, 13; 170; 240; 242; 243]. Of course, there are no definite limits to an enterprise of this kind, which is why no single historian can have the last word on any given topic. It is always possible to point to something else in the subject's milieu which may be relevant to our attempt to reconstruct the past.

A striving for an ever richer contextualization can be seen, then, as the driving force in current historiography of science. This contextualism can be seen as the outcome of an eclecticism which combined what used to be seen as opposite approaches to the history of science. The discipline of the history of science used to be riven by warfare between internalists and externalists (*c.*1930–59). The internalists were supposed to have believed that science, or possibly an individual sub-discipline within science, was a system of thought which was self-contained, self-regulating, and developed in accordance with its own internal logic. The externalist, on the other hand, was supposed to believe that the development of science was determined by the socio-political or socio-economic context from which it emerged. In fact, neither position seems to have been properly established as valid or viable [241: 345–51], and it wasn't long before a professed eclectic approach became all the rage (*c.*1960). Effectively, this eclectic approach is still dominant, and what this means in practice is that virtually all recent work can be located somewhere upon a spectrum from the more internalist [e.g. 68; 77] shading through to the more externalist [e.g. 194; 150]. But the new eclectics, unlike externalists, recognise that scientific judgements about pertinent experimental or analytical results, or about correct theory, can sometimes only be understood in terms of the technical tradition within which they play a part, and may be insulated from wider social considerations. This is not tantamount to internalism, however, since eclectic historians of science would argue (or assume) that in such cases the technical tradition itself is a socially constructed, or culturally determined, phenomenon and that work within that tradition is affected by social interactions between the relevant specialists [241: 352–3; 235: 222; 237, 90; 61; 254].

The important thing to note about the historiography of science, then, is that ever richer contextualization has been the main ambition of the majority of its practitioners for a number of decades. The result is a sub-discipline of history which is flourishing in its own terms, and which more generally is making a major contribution to our understanding of how and why science has become such an overwhelming feature of Western culture. Within this general effort to understand the cultural dominance of science, accounts of the Scientific Revolution play a major role. But it is important, whenever we consider these accounts, to bear in mind the complex historiographical issues which have helped to shape them.

6 Religion and Science

There is still a lingering tendency to see science and religion as thoroughly opposed and incompatible approaches to the understanding of fundamental truths about the world. There has been conflict between these two worldviews, but that is far from the whole story [19]. Even the so-called 'Galileo affair', probably the most well-known example of scientific knowledge coming into conflict with religion, was by no means the inevitable outcome of two supposedly contradictory perspectives.

Certainly, the Copernican theory was opposed on religious grounds (by Catholics and Protestants alike) from its first appearance [285], but there was no official pronouncement upon it for over seventy years, and then (1616), in spite of the agreement of a group of consultors that heliocentrism was 'formally heretical', the Catholic Church merely suspended its approval of Copernicus's book 'until it should be corrected' [246; 246; 16]. The Church of Rome only really insisted upon the heretical nature of Copernicanism with the condemnation of Galileo in 1633. Historical research has now made it abundantly clear that, far from being the inevitable outcome of a clash between scientific and religious mentalities, the condemnation of Copernicanism and of Galileo was the entirely contingent result of a number of highly specific factors.

The delicate balance which kept Copernicanism away from the serious concern of the Inquisition was disturbed by the talent of Galileo, courtier, for making enemies. He made enemies in the 1610s and 1620s of powerful groups of Dominicans and Jesuits, and a characteristic arrogance displayed in his *Dialogue on the Two Chief World Systems* (1632) succeeded even in alienating his erstwhile supporter, Pope Urban VIII [15; 16; 80; 226; 246; 248]. The situation was not helped by Galileo's insistence upon entering into public discussion of biblical interpretation (to show how Copernicanism could be made compatible with various biblical statements), at a time when the counter-reforming Catholic Church was trying to restrict free interpretation of Scripture. Furthermore, a series of circumstances in the printing and publication of the *Dialogue* drew (unfounded) suspicion on Galileo as a sympathizer with anti-papist factions, at a time when Urban VIII was feeling extremely beleaguered [15; 80; 246; 249; 60]. If the outcome was inevitable it was so only because of these highly specific circumstances. The Galileo affair should not be taken as a general indicator of relations between science and religion in the early modern period.

This becomes all the more obvious if we look at almost any other major contributor to the Scientific Revolution. Time and again we can see the importance of religious concerns to the leading thinkers, in providing a general motivation for, and in shaping the precise details of, their natural philosophies.

Kepler, for example, saw himself as a priest 'of the Most High God with respect to the Book of Nature' who, by discovering the pattern which God had imposed on the cosmos, was 'thinking God's thoughts after Him' [19: 19–22; 85]. Francis Bacon described his plans for the reform of natural philosophy as a work of preparation for the Sabbath. The Sabbath he had in mind was the ultimate, everlasting Sabbath after the Day of Judgement, which he believed would be ushered in, according to a biblical prophecy, after the augmentation of the sciences [19: 22; 274; 115; 208: 390–2]. The natural philosophies of Pierre Gassendi [196], René Descartes [196; 104], Robert Boyle [144; 161; 242; 243], Isaac Newton [70; 63; 204; 282] and Gottfried Wilhelm Leibniz [21; 99; 217] were each carefully developed in order to provide support for the individual theological views of their respective authors. Precisely the same could be said of the natural philosophies of a host of lesser figures from Paracelsus [278] to Blaise Pascal [9; 59], from Joan Baptista van Helmont [161; 198] to William Whiston (1667–1752) [88], from Marin Mersenne [9; 58; 137] to Nicolas Steno (1638–86) [9]. All in all, there can be little doubt of the importance of religious devotion in motivating and shaping early modern science.

One of the major concerns of the mechanical philosophers, for example, was to show how God interacted with the mechanical world. Because of its dependence on quasi-atomist concepts of matter, the mechanical philosophy was easily associated with the supposedly atheistic atomism of the Ancient Greek, Epicurus. According to Epicurus, matter was inherently self-moving, and all things could be explained in terms of the necessary consequences of chance collisions by atoms. Gassendi, who actively sought to rehabilitate Epicureanism for Christian readers, rejected this aspect of Epicurus's matter theory and insisted that God had endowed matter with an internal principle of motion at the Creation [24; 196]. This stratagem was taken up by a number of other mechanists, including Boyle and Newton. In this way God's existence could be proved by pointing to the activity of matter. The argument went like this: matter must necessarily be extended (we cannot imagine matter without extension), but it does not have to be active, on the contrary, matter seems on a superficial consideration to be inert and passive. If there is activity in matter, therefore, and gravitational attraction shows that there is, then it must have been put there by God. The activity in matter, it was believed, could be explained only by recourse to God's creative power [130].

Descartes, whose system was based on the (rationally argued) assumption that matter was completely passive and inert, had to develop a different stratagem. Since matter was characterized in terms of extension, and he wished anyway to avoid suggestions that matter might have intrinsic powers, Descartes turned directly to God to explain the various interactions of matter. God, according to Descartes, not only set the different parts of matter in the world in motion at the creation, but he also maintains the amount of motion in the world, ensuring that motions are transferred from one parcel of matter to another in accordance with the three laws of nature and seven rules of impact. God obeys the laws which He Himself has established. The amount of motion must be conserved, and it must always be transferred in accordance with the same laws of nature in order, Descartes supposed, to maintain God's perfect immutability [98; 126; 104: 248–9]. A perfect being does not change, and so God does not change his mind. Once God had set the universe in motion, therefore, it stands to reason that he would maintain the amount of motion that he first established. Similarly, he would ensure that all bodies always behave in accordance with unchanging laws of nature. There can be no doubts about Descartes's religious devotion and sincerity, but considering how important God's immutability is to Descartes's system, it is hard to resist the conclusion that Descartes's God was conceived to underwrite Cartesian physics [126]. Certainly, many devout English thinkers, like Robert Boyle, were repelled by a notion of divinity which seemed to turn God into a cosmic drudge.

Descartes's views on force, grossly simplified here, continue to cause controversy among specialist historians of philosophy, and, more importantly for us, they were often overlooked by contemporaries. Many believed that Descartes's laws of nature and rules of impact were supposed to be sufficient to explain the workings of the world without any recourse to God, once it was acknowledged that he had set the system rolling. It was all too easy, however, to develop an atheistic version of this account, simply by assuming, as Aristotle had done, that the world was eternal and had always existed the way it does now. If the system had no beginning, God was not necessary at all [140: 173–7].

Perhaps for this reason, a number of Descartes's followers developed the notion of occasionalism, in which God is the only efficient cause at work in the world. The most influential occasionalist was the Oratorian priest Nicolas Malebranche, who argued that the laws of nature do not express genuinely causal relationships: when a stone hits a window it is simply the occasion on which God exercises his causal power; the stone itself has no power to break the window [157: 404–5; 176]. For a number of contemporaries this seemed to make God directly responsible not only for the utterly trivial but also for the downright evil [176].

Leibniz objected to the occasionalist implication that all physics is a perpetual miracle, insisting upon a return to a natural philosophy in which bodies have their own forces by which they can affect things (in accordance with divinely imposed laws of nature). It was evidently important to Leibniz to preserve the transcendence of his God and this necessitated, he believed, making all bodies the source of their own activity. We saw earlier that he revived the scholastic notion of substantial form to enable him to characterize bodies in terms of passive matter combined with primitive active force (see Chapter 4), but he was also convinced of the truth of another scholastic dictum: that only a genuine individual can be self-active. This presents difficulties for the corpuscularist conception of bodies in the mechanical philosophy. Can a body which is composed of atoms or corpuscles be a genuine individual?

Considerations like these, together with a number of other metaphysical complexities, led Leibniz to his mature philosophy in which the world was constituted not of atoms but of monads, essentially living creatures with both bodies and souls (and therefore genuine individuals, like human beings) and so capable of being self-active [21; 99; 217].

The nature of force and the activity of bodies (or their lack of activity) was only one aspect of God's relationship with the physical world. Concepts of space were another prime site for discussions of God's place in the world. For Newton, always influenced by Platonic ways of thought, space was 'an emanent effect of God', an outpouring from God's being which provided the immensity of the world. He saw space, therefore, as a real existence and infinite in extent. Indeed, he seems to have gone so far as to later identify space with the immensity of God, so that the biblical pronouncement that 'In Him we live, and move, and have our being' (Acts 17:28) was taken quite literally [109]. Newton's concept of absolute space, so important to the elaboration of his *Principia mathematica* (1687), was not dictated by the requirements of his geometrical analysis of the world system, but by his concept of God.

Leibniz begged to differ. Seeking once again to preserve God's aloof transcendence, Leibniz insisted that space, or dimensionality, could not be an attribute of God. If it were, it would mean that God consisted of parts which he took to be absurd. But Leibniz was never content to deny when he could refute. Accordingly, he developed his notion of space as a mere relational concept; an order of coexistences. Extension, shape and motion are only apparent and to a large extent imaginary. It is we, as observers, who impose extension on to the world. Clearly, therefore, it makes no sense to link the absolute God to such a relative space [109].

Natural philosophies which differ fundamentally can often be seen to be grounded in opposed basic assumptions about the nature of God's providence. Voluntarist theology supposes God's will to be his dominant attribute, while intellectualist theology emphasizes God's reason. The voluntarist refuses to acknowledge anything which might circumscribe God's omnipotence, while the intellectualist believes that there are some eternal or pre-existing truths which lead God through his reason to act in certain ways. Voluntarists suppose that what God wills is good, but intellectualists believe that God wills what is good. The voluntarist does not accept that the world can be rationally reconstructed. God's arbitrary will may have introduced any contingency into it, so the system of the world must be discovered empirically. The intellectualist, by contrast, believes that it is possible, at least to a limited extent, to 'think God's thoughts after him' and so arrive at a rational understanding of the world [168; 193; 196].

A number of studies have shown how theological voluntarism or intellectualism has informed the natural philosophies, not only of individual philosophers like Gassendi [196], Descartes [196], Boyle [161; 193; 242], Newton [70; 282] and Leibniz [168; 193], but also of a whole group of like-minded English thinkers [130; 132]. These studies have shown the powerful interconnections between the underlying theological position on the one hand, and on the other, theories of force and matter, as well as more general epistemological and methodological views. For example, the experimentalism of English natural philosophers, so different from continental attitudes to experiment, can be seen to dovetail perfectly with the voluntaristic commitment to the unlimited omnipotence of God. Where Descartes, the intellectualist [196], feels he must insist upon the utter passivity of matter, English voluntarists may suppose that God might have endowed matter with intrinsic principles of activity. While Descartes believes that the passivity of matter can be established by the power of reason, English natural philosophers insist upon the experimental investigation of the powers of matter [130; 132].

Another major religious concern of the early mechanical philosophers was the concept of the soul. Each of the first generation of mechanical system builders, Gassendi, Descartes, Sir Kenelm Digby (1603–65) and Walter Charleton, claimed that their mechanical philosophy provided a much better assurance of the immortality of the soul than could Aristotelianism. (Hobbes, missing from this list, rejected the possibility of a disembodied soul.) Their general approach was essentially the same. Having established that all change and dissolution was merely the result of rearrangement or dispersal of the material particles which make up a body, the mechanists could then infer that the rational soul was incapable of change and immortal by virtue of the fact that, being immaterial, it was not composed of material particles [196: 72–3]. It is important to note, however, that this argument only applies to the rational soul which was held to distinguish humans from other creatures.

The mechanical philosophers tried to explain the functioning of the so-called vegetative and animal souls in terms of the movements of particularly subtle particles [119; 128; 196: Chs 2, 9].

Descartes used his mechanical philosophy to underwrite an extreme dualism in which there were two kinds of substance in the world, *res extensa* (an extended thing, or body) and *res cogitans* (a thinking thing, mind or soul). The mind was held to be beyond the bounds of the mechanical philosophy, and Descartes remained essentially silent upon matters which were to tax his followers. How could this immaterial substance cause the body to perform deliberate acts of the will? And whenever it did so, did it not result in an increase in the amount of motion in the world? These were problems for Cartesianism but not, it seems, for Descartes himself [104]. Similarly, Descartes's metaphysical arguments for supposing the existence of a disembodied soul or mind were also fraught with difficulties, being based on little more than our entirely subjective experience that we exist as thinking beings located within a body that is separate, and separable, from ourselves as we really are [104]. The fact that, in spite of these difficulties, Descartes never wavered in his commitment to his dualist system, and always seems to have seen it as a way of demonstrating the immortality of the soul, should suggest to us the influence of religious preoccupations on his thinking. The same could certainly be said of the other mechanical philosophers concerned with the nature of the soul. The differences in detail of the various accounts can always be related to differing religious perspectives [196; 19].

If Descartes's theory of the soul caused internal difficulties for his system, his theory of matter caused difficulties for his Church. The daily miracle of the Eucharist, in which bread was transformed into the body of Christ, was easily explained in Aristotelian terms. Substances (a combination of matter and form) always carried a number of accidental (non-essential) attributes, such as colour, taste and other sensible properties. In the miracle of the Eucharist the accidental properties of the bread remained but the substance was held to have changed. Having done away with this view of body, Descartes attributed properties like colour and taste to the configuration of the particles which made up the body. If bread became flesh it surely had to undergo a change in the configuration of its particles and that must result, by definition, in different sensible properties.

Given the power of the Church, and Descartes's loyalty to his religion, this required some intellectual escapology. Descartes tried two ways of wriggling out of this difficulty. First, he suggested that the surfaces of the bread might remain the same in the Eucharist, thus providing the senses with an unchanged source of sensory information, while the inside turned to flesh. Alternatively, he reverted back to a scholastic explanation in which the substantial form of Christ was said to inform the matter of the bread, in which case, by a Scholastic definition, the bread was the body of Christ. For good measure, he suggested a combination of both of these explanations [60].

Descartes was extremely influential, and his philosophy quickly gained numerous adherents and even made substantial inroads into the curriculum at a number of universities. The problem of transubstantiation in the Eucharist, however, led to the prohibition of his works by the Congregation of the Index of Forbidden Books in 1663. In 1671 a royal ban on teaching Cartesianism in French universities was issued by Louis XIV. Catholic opposition seems to have been orchestrated to some extent by Jesuits, but in 1678 the Oratorians imposed a ban on teaching Cartesianism in their colleges. Opposition to the philosophy of Descartes was the Catholic Church's most vigorous interference with natural philosophy since the Galileo affair [9]. Unlike Galileo, however, Descartes also invoked the wrath of Protestant authorities. Gisbert Voetius (1588–1676), Calvinist rector of the University of Utrecht in the Netherlands, outraged by some of the Cartesian doctrines of Henricus Regius (1598–1679), campaigned successfully against Cartesianism, as did two theologians at the University of Leiden [104; 157].

Perhaps we should conclude, after all, that science and religion are worldviews which are fundamentally at odds with one another? No, again we must resist such a conclusion. There can be no doubt that his religion was a major stimulus to Descartes's philosophizing and a profound influence upon the details of its development and final form [104; 127]. The same could equally be said of virtually every other leading thinker in the Scientific Revolution. There can be no fundamental incompatibility, therefore, between religious and scientific thought. Nevertheless, major religious institutions, as internally complex and as widely interconnected with other political and social institutions as they are, must respond to a bewildering array of social and intellectual factors. Small wonder that in the politically unstable atmosphere of post-Reformation Europe, religious institutions were sometimes made to act against the burgeoning institution of the new science.

According to a vigorous historiographical tradition, however, there is also a strong case to be made for the positive effect on the burgeoning of science by a particular religious institution. It has been suggested that the undeniable success of natural philosophy in seventeenth-century England was due, at least in some large measure, to the rise of Puritanism [182; 39; 273; 274]. This claim has met with considerable opposition, however, and continues to stimulate heated debate.

Part of the difficulty that historians have with the Puritanism-and-science thesis, particularly in the form stated by its principal founder, Robert K. Merton, is that it is hard to see why Puritanism, especially, should have provided a stimulus to science. Suggested factors, such as a concern with socially useful work, 'for the relief of man's estate', as a means of glorifying God and indicating one's state of grace, a concern with rationalism tempered by empiricism [182], rejection of authority in favour of individualistic search for the truth [138], and increased millennial expectations linked to Baconian social ameliorationism [274], can all be seen to be relevant to non-Puritan groups, and in some cases, even to Catholics.

Charles Webster has made the strongest case for links between Puritanism and new attitudes to natural knowledge, agriculture, husbandry, chemistry, medicine and education during the Civil Wars and the Interregnum [228], but he acknowledges that his study focuses upon a set of rather pragmatic concerns which do not always coincide with present-day notions of what is proto-scientific [274: 517]. Indeed, Webster accepts that the origins of what most of us would recognize as modern science owe more to an ideology alien to Puritanism, but does not say what that ideology is [274: 520]. On the other hand, more recently he has pointed out that a view of 'science' restricted (whiggishly) by present-day concerns is bound to exclude the activities and influence of the Puritan groups which have been at the centre of his research [277: 193]. If, therefore, we accept Webster's definition of science during the Interregnum, we will undoubtedly receive a much fuller understanding of seventeenth-century English attitudes to the natural world than if we choose a definition closer to our current concerns.

Even so, it is not always possible to see from Webster's work why (or even whether) the reformers he discusses should be regarded as Puritans [189]. But this is to open up another major problem with the Puritanism-and-science thesis, namely, who was a Puritan and who was not [189]. Merton's original thesis presented the reader with a 'crucial experiment', designed to test the thesis. It consisted of counting the numbers of Puritans in the early Royal Society (founded just after the restoration of the monarchy in 1660) [182: Ch. 6], but critics were quick to point out that Merton was not an unbiased sampler. Certainly, more careful scholarship has concluded against Merton's view of the early Royal Society [141], and Webster has declared 'headcounting' to be counter-productive in settling the issue [277: 199].

In spite of the difficulties of the Puritanism-and-science thesis, it still survives as a potent historiographical force. A major reason for this is that opposing views, emphasizing the role of Laudian Anglicanism [262], royalism [188], or a hedonistic–libertarian ethic [84], are even less plausible. Moreover, those alternative views which have seemed plausible seem like mere refinements of Merton's and Webster's views, rather than refutations. In each of these refinements of the Puritanism-and-science thesis, Latitudinarian Anglicanism plays the dominant role. Barbara Shapiro and others have argued that the sceptical epistemology of the Latitudinarians, which derived from their disgust at the divisiveness of dogmatic pronouncements about the true faith, gave rise among like-minded Anglican natural philosophers to a similar sceptical epistemology in science and a concomitant empirical methodology. The Baconian empiricist distrust of preconceived theorizing and emphasis on matters of fact which was characteristic of English natural philosophy at this time can be seen, therefore, to be an emulation of the doctrinal minimalism and emphasis on uncontentious matters of faith of the irenic theology of Latitudinarianism [132; 244; 290; 149; 243].

One merit of these claims is that they provide a continuity for the undeniable association between Latitudinarianism and the new philosophy which can be discerned after the Glorious Revolution of 1688. In this later period there was a particular emphasis on the natural philosophy of Isaac Newton, and there can be little doubt that the extraordinary pre-eminence of Newton and his natural philosophy in the cultural life of eighteenth-century Britain owed a great deal to the success of what has been called the 'holy alliance' between that philosophy and the apologetics of low-church Anglicanism [100; 150; 253; 194].

We have been looking at ways in which religion might be said to have promoted the development of natural philosophy and so contributed to the Scientific Revolution (in spite of seeming counter-examples like the Galileo affair and local bans on Descartes's writings on religious grounds). There is another facet to the story, however. There can be no doubt that the late sixteenth and early seventeenth centuries saw not only the origins of modern science, but also the origins of modern atheism. Although it is hardly possible for the historian to point to an out-and-out atheist at this time, there was undoubtedly genuine concern among contemporaries that atheism was becoming increasingly prevalent [143]. It is also clear that the new philosophies were often associated with atheism [280; 143; 63; 130; 132; 19]. It is hardly surprising, therefore, that leading natural philosophers, many of whom, as we've seen, were extremely devout, tried to use their natural philosophies either to defeat atheism, or at least to demonstrate that their philosophies were not atheistic.

This can be seen most clearly in the rise to prominence of the essentially new tradition of physico-theology, or natural theology [19; 280; 44; 105; 212; 221]. Although attempts to prove the existence of God by pointing to the beauty, complexity and order of the natural world – the so-called 'argument from design' – had existed since at least the thirteenth century, it was only in the seventeenth century that whole works of natural history aimed to establish the wisdom and omnipotence of God by scrutinizing the creation. As the new tradition burgeoned, readers were repeatedly told that Nature was God's other book, and that the dedicated student of nature was like a priest.

Natural theology primarily drew upon natural history (see Chapter 3(ii)), but natural philosophy soon came in on the act. The latest developments in natural history often derived from studies using the newly invented microscope, and these seemed to provide powerful circumstantial evidence for the truth of corpuscularist, and therefore mechanical, natural philosophies [288; 44; 199;

222; 223; 105]. Besides, as we've seen, each of the founders of the new systems of mechanical philosophy specifically intended their respective philosophies to provide an underpinning to religion. If a new philosophy was intended to entirely replace the traditional, comprehensive Aristotelianism, it had to be seen to be capable of taking over the role of handmaiden to religion. Gassendi, accordingly, took great pains to 'baptize' Epicurus, most notorious of ancient atheists [196].

Concern about the increasing prevalence of atheism ran particularly high in England during the Interregnum and the Restoration, and leading natural philosophers often took an apologetic and highly defensive line in the presentation of their natural philosophies [143; 280; 140: Ch. 7]. Even Robert Boyle, whose orthodoxy was never in question, felt obliged to defend his promotion of the new philosophy against charges that it was inherently atheistic [143; 228; 144]. Boyle was so concerned about this that he established just before his death in 1691 an annual series of monthly lectures (the Boyle Lectures) to combat infidelity of various sorts, but first and foremost, atheism [150; 253].

For the most part the defence of the new philosophies against charges of atheism concentrated on the argument from design, pointing to the beauty and complexity of nature, and trying to demonstrate the impossibility of such intricacies without the creative intervention of a supreme artificer [19; 44; 105; 212; 280; 288]. But there were one or two less predictable developments. Drawing upon the still highly respected humanist tradition of historical scholarship, for example, a number of natural philosophers tried to establish that atomism was not an invention of pagan Greek philosophy but a more ancient philosophy in the Judaeo-Christian tradition. A Phoenician by the name of Mochus was increasingly discussed in works of classical scholarship as the founder of atomism, and on at least one occasion he was identified with Moses himself [225]. This tradition was repeatedly invoked in defence of atomism by English natural philosophers throughout the seventeenth century.

Less widespread, but certainly noticeable in the historical record, was the attempt to affiliate the new philosophy to belief in witchcraft and demons. To deny the Devil and all his works was also to deny God. A minority among the natural philosophers, in their concern to dispel charges of atheism, discussed famous and not so famous cases of witchcraft, hauntings and all other evidence of a supposedly spiritual realm. As with arguments to prove the immortality of the soul (see above), the spirituality of these phenomena could be established by showing that they could not be explained in terms of the mechanical philosophy. By showing the reality of the spiritual world, the benefit to religion of the mechanical philosophy was conveniently displayed [143; 156; 276; 230; 245: Ch. 6; 243]. Additionally, by defining all the correctly attributable forms of physical causation in the world, the mechanical philosophy made it easier to determine which explanations were illegitimate. Anyone who believed in the efficacy of causal links which mechanical philosophers rejected as unworkable, such as an ointment capable of making someone fly, could be held to be misled, either by their own superstition or by the Devil, and therefore guilty (in either case) of turning away from God. The mechanical philosophy thus showed itself to be useful in the war against irreligion [30; 31].

The various apologetic stratagems developed by English natural philosophers as a result of contemporary fears of atheism cannot entirely be separated from the more positive religious intentions which thinkers like Bacon, Boyle, Newton and a host of others cultivated. The result is a subtle and complex set of interactions, often differing from one individual to another [143]. It is important, therefore, to be aware of the interplay of evangelism and apologetics in the natural theologies of seventeenth-century natural philosophers [19]. There can be no doubt, however, that religion and theology played a major part in the development of modern science.