Theology and Modern Physics

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CHAPTER 1

Theology, Philosophy and Physics

Introduction

At the end of the nineteenth century it was generally believed that physics was essentially complete. Newton's dynamics enabled the motions of the moon and the planets to be calculated with great accuracy, and Maxwell's electromagnetic theory unified electric and magnetic phenomena. There were a few problems that still remained, but it was confidently expected that they would soon be cleared up. The future truths of physics, an eminent scientist remarked, are to be looked for in the sixth decimal place. The young Planck was undecided whether to devote his life to physics or to philology; he was advised to choose philology because there was nothing much left to discover in physics.

The twentieth century, however, has seen an unprecedented increase in our knowledge of the world. In a few years there came Planck's discovery of the quantum and Einstein's theory of relativity, the discovery of the nucleus and the formulation of quantum mechanics. The structure of matter has been probed to reveal finer and finer detail: first the structure of the atom, then of the nucleus and finally of the nuclear particles themselves. At the other end of the scale, the universe as a whole has become the object of scientific study, and the knowledge of nuclear and elementary particle physics has been used to reconstruct the processes occurring in the first few instants after what is called the big bang. Our knowledge of space and time has been profoundly changed by Einstein's theory of relativity, and experiments have revealed the strange phenomena of the quantum world. Taken together, these advances in understanding that constitute the new physics have changed our view of the world.

This scientific knowledge of the world has led to a vast range of technological developments that have changed our lives beyond all recognition. Communication and transport have brought people throughout the world closer together, and electronic computers enable us to perform with ease complicated tasks quite beyond the resources of previous generations.

More profoundly, science has altered the way we think about ourselves and our world. We know that we live on a relatively small blue ball, poised in space, orbiting the sun. Our resplendent sun is a rather undistinguished star in one of the spiral arms of a vast galaxy of about two hundred thousand million stars, and that galaxy is but one of many billions of such galaxies spread through the unimaginable vastness of space. We understand to some extent how we have arrived here by a long process of cosmic and biological evolution. This is the stage on which the drama of our salvation is enacted. Our ideas of space and time, determinism and causality, have been changed, inevitably affecting the imagery of theology.

People have always, in quiet moments, thought about the meaning of existence, why we are here and what will become of us all. Answers have been proposed by the great religions, using the language and concepts derived from the cosmology of the times. The ancient Hebrews thought of the world as a flat surface with the stars fixed to the underside of an upturned dish. Each day the sun travels from the east to the west, and then returns to its starting point by voyaging through the underworld. The Bible implicitly accepts this world view, speaking about the sun moving around the earth. The heavens above the earth are the abode of the saints, and the wicked are thrust down into the hell below the earth. Not only was the earth at the centre of the universe, but also Jerusalem was at the centre of the world, as indeed is often shown in old maps. The Crucifixion thus had a central place in space as well as in time.

The Greeks also developed a cosmology, and Pythagoras taught that the earth is a sphere in the centre of the universe. Faced with the challenge of Hellenistic philosophy, the theologians of the Alexandrine school maintained that it is the duty of Christians to study the new ideas, and not to fear them.

A serious challenge came with the heliocentric theory of Copernicus and Galileo. This seemed to many theologians to be quite contrary to the evident meaning of Scripture. It deposed the earth from its central position in the universe and with it the centrality of Jerusalem. Eventually it was realized that passages such as that in Joshua simply use the familiar manner of speaking and were not intended to imply any specific cosmological theory.

Over the ages, the cosmologies and the ways of thinking about the world have changed, and with them the ways we express the accompanying theology. The more we learn about the universe, the more we know about our situation in it. At a deeper level, new scientific advances often bring with them new concepts, thus expanding our mental horizons, and this again affects our theology. More subtly, it affects the very words and concepts we use. Modern physics has changed the way we think about nature and about ourselves, and this has raised many questions about human freedom, our responsibility for our actions, miracles and the providence of God. To explore these questions we have to study the relation between theology and science.

Many answers have been proposed. At one extreme it could be said that the new physics has no effect whatever on our theological ideas. We can hold fast to our traditional beliefs and lead our lives just as in the previous centuries. This is indeed possible, but it carries with it the hazard of living in a time capsule, insulated from the new ideas, speaking a language that becomes more and more isolated from contemporary thought, and defenceless against attacks on traditional beliefs made in the name of the new physics.

The opposite extreme is to maintain that 'the knowledge of God and His designs can only be obtained through a knowledge of his works' (Weber, quoted in Basalla, 1968). More recently Davies (1983) has claimed that the new physics provides a surer road to God than the ancient religions. The more we learn about the universe, the more we will know the mind of God. Some believe that age-old problems will be solved by the application of modern physics, and old arguments will be shown to be invalid. Thus it has been suggested that the indeterminism of quantum mechanics and the unpredictability of chaotic systems implies a breakdown of causality, and with it one of the traditional ways to God, and that the Heisenberg uncertainty principle provides a loophole for the exercise of free will. These and similar questions must be critically examined.

The first requirement for such discussions is a knowledge of the physics on which they are based. Physics is first of all an experimental science, and it was a series of key experiments, together with the theories that were developed to account for them, that led to modern physics. Then there are the interpretations of these theories in terms of more general philosophical categories, and finally the theological implications.

Theology, Philosophy and Physics

Before considering the relations between theology and the new physics it is desirable to summarize briefly the relations between theology, philosophy and science that lie behind the above remarks. This is a highly complex and disputed matter, and it might be thought more appropriate to wait until the end of the book to do this. However, to avoid misunderstandings, what follows is an attempt to outline as clearly as possible the presuppositions underlying the discussion. This is not intended to be a definitive statement, but an indication of the meanings that I attach to the words. At the end we may be able to see how useful they are.

Theology

Theology is the result of our rational attempts to understand God and His relations with us and with the natural world. It is based on Divine Revelation and on the teaching of the Church as contained in the Old and New Testaments, the decrees of church councils and other church documents.

Theology is thus unchanging in essence, although it is inevitably expressed in terms of philosophical concepts initially derived from the Hebrews and the Greeks. From time to time the Church, through the medium of councils, defines theological beliefs more precisely in order to remove erroneous ideas. Our understanding of the truths of theology has developed over the centuries (Newman, 1960). Theologians sometimes use terms derived from the sciences and inevitably accept the current scientific world view. This has to change when the science changes, for otherwise the theology will appear outdated. Such accommodation is not easy, and takes time, so that there is often a lag between the establishment of a new world view and its assimilation by theology. A particular difficulty is that often a new scientific idea is generally accepted long before it is definitively established. It is also unwise for theology to move too rapidly because the new scientific idea may not long survive.

Philosophy

Philosophy initially arose from attempts, particularly by the ancient Greeks, to make sense of the whole of life, our origin, our experiences, our hopes and our destiny. Starting from self-evident principles, and applying reason to our experiences, natural philosophers, as they were called, built up a theory of the natural world. Primarily this was the work of Aristotle, and it endured with some developments for two millennia. During the Renaissance several philosophers, in particular Bacon, Galileo and Descartes, realized that such activities are often sterile and that a new approach is needed based on careful measurements that show the interrelationships between various measurable properties. At this point science separated from philosophy and became a distinct activity, although it was still based on philosophical beliefs about the world. This implies a radical distinction between philosophical and scientific knowledge: in principle philosophical knowledge is exact and certain, whereas scientific knowledge is always subject to uncertainties due to the inevitable inaccuracies of measurement. Over the centuries various parts of knowledge become specialized into separate disciplines; thus for example science became natural philosophy and then divided into physics, chemistry and biology.

Historically, there are many philosophical systems that are based on certain fundamental presuppositions. A great philosopher is one who has worked out the consequences of the starting point with thoroughness and consistency to the (often bitter) end. Whether the philosophical system is true is another matter, though that is usually settled by the examination of its fruits. A connected function of philosophy is to examine critically the words and concepts we use, and how they are related to each other. It is concerned always to ask what we mean by what we say, how we know it is true, what criteria we apply, how we justify our criteria and so on. It addresses these questions to the theologian and to the scientist.

There is an important connection between theology and philosophy. Some truths may be obtained with difficulty by purely philosophical reasoning, but can be reached more fully and easily from theological considerations (Gilson, 1955). This is particularly relevant to the origin of the philosophical truths underlying science.

As an example of philosophical reflection, consider a man who writes a book denying realism, purpose, cause and free will. However, the book itself is a real object. It is written with a purpose, namely to cause other people to modify their beliefs, an activity that makes sense only if they have free will. Thus the very means by which the author conveys his message contradicts that message (Jaki, 1999b).

The fundamental philosophical activity is the immediate grasp of external reality by the mind. As Duhem emphasized, we 'grasp reality and its lawfulness in a spontaneous natural way' (see Jaki, 1984, pp. 321–2; all other quotes from this source). Jaki comments that 'objective reality for Duhem is an unquestioned and unquestionable truth which man grasps in the very act of knowing a realm external to him'. 'There is thus no need for any metaphysical elaboration of what reality is meant by words such as body, law, extension, time and motion'. 'These notions appear to our intelligence sufficiently certain, so that we may, without fear of confusion and error, make them operate in the experimental method'. This certainty cannot be found in physical theories because these are interpretations of facts, and there is no one-to-one correspondence of theory with reality, of formalism with facts. Thus physical theories, and their associated formalisms, serve only as convenient summaries of facts, and may not correspond exactly to reality, although as physics advances they approach closer to this ideal. In all these discussions, philosophy carries out its perennial task of critically analysing and assessing the validity of the arguments used.

The ancient Greeks provided many of the beliefs about the material world that are essential for science, in particular that it is worthy of study and also rational and orderly, and open to the human mind. Additional beliefs essential for modern science came from the Hebrews and from Christian theology, as suggested in Chapter 2. To be efficacious in this way, a belief needs to be firmly held by the whole community, to the exclusion of other beliefs. Among the Greeks, many different beliefs were held by different philosophers, whereas the Hebrew and Christian belief in the orderly creation of the world by God was century by century hammered into the European mind to the exclusion of all other beliefs until in the High Middle Ages it provided the fertile ground for the birth of modern science.

It may be asked whether it is possible to argue from the success of science to the philosophical principles on which it is based. Certainly not in a strictly deductive sense, because scientific theories are subject to change and revision. Nevertheless it is possible to find the philosophy behind physics by examining the consequences of the denial of any of these tenets. Furthermore, examination of the way science is actually done shows that scientists, often unconsciously, make certain assumptions about the natural world and, to the extent that science based on them is successful, they are retrospectively justified. This may not be logically conclusive, since it is conceivable that successful science can be carried out within the framework of different philosophies of the natural world. However, in cases where there is a simple choice between two alternatives, such as that between realism and idealism, this retrospective inference is justified (Brody, 1993).

The further question whether, if we admit that science is based on Christian beliefs, the success of science provides evidence for the truth of Christianity must be answered in the negative, because we cannot prove that science could not have arisen in the context and on the foundations provided by other beliefs. However, as a matter of historical fact, it has never done so.

Physics

Science may conveniently be divided into empirical knowledge obtained by observation and experience, and the much more detailed knowledge we have today. The former, which may be called primitive science, describes knowledge about the properties of materials gained by craftsmen working with wood, stone and metals, and that of plants and animals obtained by observation and experiment. It includes also the observational knowledge of the planets and stars. This primitive science is found in all human societies, including past civilizations, and is to be distinguished from the knowledge we have today. As our knowledge of the world increases, it is convenient to divide it into the physical and the biological sciences; it is only the former that are considered here.

Our own civilization is unique in that it has a detailed knowledge of the natural world that goes far beyond primitive science. Science proceeds by observation and experiment, whenever possible under controlled conditions, accompanied by attempts to make sense of the results by speculations, hypotheses, models and theories, expressed mathematically wherever possible. The first observations of a new phenomenon sometimes suggest ideas about the underlying process that may eventually form a theory. This theory may suggest further observations that serve as a test, and the result of the new observations or experiments may suggest some modification of the theory, which may itself be tested in turn. Most physical theories can be expressed mathematically, and predict very precisely what will happen in given circumstances; thus precise measurements enable a very sharp test to be made.

This continuous dialectic between experiment and theory is the life-blood of science. New scientific advances may be stimulated in a variety of ways, and even by extra-scientific ideas that are bizarre or even false. Thus Kepler was practically a sun-worshipper and so believed that the sun was at the centre of the universe. The success of a scientific idea does not validate the beliefs on which it is based.

The difficulty of experiments in physics is often underestimated. Anyone who has ever tried to perform an experiment of even moderate complexity knows very well that if anything can conceivably go wrong, it probably will (Murphy's law). It requires extraordinary skill to perform a reliable experiment. It is often necessary to make a number of corrections to the result to allow for unwanted extraneous disturbing influences, and it requires great skill to identify and evaluate them. There are numerous examples in the history of physics of experiments that have been made with great care, but which are now recognized to have given wrong results. When reading about the history of science it is well to realize that many stories of events in the history of science that are frequently repeated in popular accounts are now known to be false.

Particular care was devoted to the accurate determination of the fundamental constants such as the velocity of light and the charge on the electron. Many of these determinations gave results that are quite outside the uncertainties associated with the values that are now believed to be correct, which shows the difficulty of obtaining accurate results. A connected problem is to know which observations to discard as spurious. Thus Millikan (1911, 1913), in his account of his determination of the charge on the electron, stressed that every single measurement gave essentially the same result. Yet examination of his laboratory notebooks showed that many measurements in fact gave different results, and Millikan discarded these with the comment: 'not an electron'. This was initially regarded as rather sharp practice on Millikan's part, but properly understood it shows the strength of his physical intuition (Holton, 1978, 1996; see also Kohn, 1986, pp. 57–62; Franklin, 1986, pp. 138–64).

Each stage in this process is fraught with difficulties. The history of physics provides many examples of reports of phenomena now regarded as completely without foundation. In this category come Blondlot's N-rays (Klotz, 1986, pp. 39–65, Gratzer, 2000, ch. 1), polywater (Klotz, 1986, pp. 67–75) and the planet Vulcan postulated by Le Verrier in 1859 to explain the shift in the perihelion of the planet Mercury that was subsequently shown to be given by Einstein's general theory of relativity (Peterson, 1993, p. 114; Baum and Sheehan, 1977; Cushing, 1998, p. 154). Such examples, and many others, show that one of the great strengths of physics is that such errors are eventually identified and removed (Kohn, 1986). They also show, however, that new results should be treated with some caution, and that they should be tested most rigorously before being accepted.

The acceptance of an experimental result may depend on current theories: if it is completely outside their scope it is likely to be disregarded, however cogent the evidence. This happened to the experiments made by Cox et al. (1928) and by Chase (1930) that strongly suggested that parity is not conserved in weak interactions. Many years later, when Lee and Yang (1956) had prepared the way by reviewing all the available evidence (except that of the authors just mentioned), the result of Wu et al. (1957) providing experimental evidence for parity non-conservation was immediately accepted.

There have been many reports of experiments, often with results of impressive statistical accuracy, that show the possibility of extra-sensory perception, the effect of prayer on the growth of plants and similar unexpected phenomena. These are not accepted by physicists because there seems to be no mechanism by which such effects can occur. However, non-local quantum interactions are considered seriously despite the lack of a mechanism and even though they appear to be in contradiction to special relativity. Acceptance in such cases is because the effect can be expressed mathematically, even though the mechanism is unknown. A cautious scepticism would seem to be the appropriate reaction here, since it has not been proved that such effects cannot occur.

The next stage is to make sense of the experimental results by theories. The results of observations and measurements have to be interpreted before they can give knowledge of reality. This act of interpretation requires the belief that there is a meaning to be found, and the background knowledge to put it into context. Science does not advance by a series of logical steps, but by leaps of the imagination. Of course what is imagined must afterwards be checked and verified logically, but logic alone would never get there. Scientific theories cannot be deduced or induced from the experimental facts (Duhem, 1954, ch. 6, sections 4 and 5); they are free creations of the human mind, and stand or fall by their internal and external consistency and by the agreement of their consequences with the experiment. The phrase 'scientific method' might be taken to imply that anyone who follows a prescribed set of rules can make scientific discoveries. This is far from the truth. Scientific discovery depends on the creative genius of the individual scientist, and often he himself cannot describe how it happens.

The scientist uses basic notions such as space and time, mass and inertia, and these can in a qualitative way be obtained directly from our experiences. This is, however, insufficient for the precise formulation required for a physical theory. Such formulations can be based on different principles and yet still agree with a wide range of experimental facts, as shown for example by the dynamics of Newton and Einstein. Scientific theories, though they may be suggested by our experiences, are free creations of the mind and require precise experimental tests to validate them. Even then, there always remains the possibility of further changes as new facts become known (Einstein, 1954, p. 270).

When a scientist first studies a problem, it often makes little sense. He gathers together all the results of observations and experiments and thinks about them. Newton was once asked how he made his great discoveries. 'By setting my mind continually unto the problem', he replied. And then, quite suddenly, and often when the scientist is thinking about something entirely different, the light dawns and all become clear. He knows that everything will fall into place and it is then just a matter of putting it all together and tidying up the details. This faculty of seeing the truth directly is sometimes called intuition. Great scientists 'know, without analysis, without reasoning, what is important for them to know'. They 'instinctively take the path leading to a discovery' (Carrell, 1961, pp. 85–6). Nevertheless, intuition can be mistaken, so it always remains essential to test the new insights experimentally.

There are many examples of this process of discovery in the history of science, such as Kekulé's discovery of the structure of benzene, Hamilton's discovery of quaternions and Poincaré's discovery of the Fuchsian functions. In each case there was an extended period of intense work when all the information was collected together, followed by a period of relaxation. Then suddenly and unpredictably the solution comes, Kekulé's in a dream,[1] Hamilton's when he was crossing a bridge and Poincaré's[2] when he was putting his foot on a step (Gill, 1944). It should be remarked that sometimes two quite different theories fit the available facts equally well. This, incidentally, shows how hazardous it is to try to obtain theological consequences from scientific theories.

In physics, theories are expressed mathematically, and this enables them to be tested very accurately by comparing their predictions with the experimental data. Sometimes it happens that experimental results are not accepted until they have a theoretical explanation. This is in opposition to the more familiar statement that a theory is not accepted until it is shown to be in accord with experiment. This is true in general but also requires caution. A theory is always at the mercy of future experiments, and all that is usually established is that the

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[1] There is now evidence that this story is a fiction invented by Kekulé to avoid giving credit to non-German scientists, who preceded him in using cyclic structures. See Kohn (1986), pp. 214–16.

[2] See Poincaré (nd), ch. 3.

theory is valid for some specified range of phenomena to a certain degree of accuracy, as, for example, Newtonian dynamics is valid only for velocities much less than that of light. Further experiments may limit the scope of a theory without affecting its validity in a certain domain. The possibility that a completely different theory may also account for the same range of experimental data is a reminder that theories can never be established in the same way as facts. This throws serious doubt on the very possibility of drawing philosophical conclusions from physical theories. If the theory is interpreted philosophically, this validates neither the physical theory nor the philosophical ideas that are used. Philosophical systems must be established by the proper methods of philosophy, and the same applies to theological beliefs. It cannot be too strongly emphasized that theories, however well they predict experimental results, must be sharply distinguished from the reality they try to describe. It is always possible that further research will show that they fail for new types of phenomena and are therefore only partial accounts of reality. Many examples of this occur: a most notable one is the distinction between what is called the quantum world described by quantum mechanics and the real world in which we live.

In spite of all these difficulties, it is possible to describe the behaviour of matter in a precise quantitative way by differential equations. Once the initial conditions are specified, solution of the equations gives all the subsequent behaviour of the system. Thus Newton's laws, together with his theory of gravitation, enable the motions of the planets and other celestial bodies to be calculated to high accuracy. Maxwell's equations similarly describe electromagnetic phenomena and Schrödinger's equation the phenomena of the atomic and nuclear realms. This understanding of nature is the unique achievement of the Western European civilization.

It is not always possible to find out about the results of scientific research just by reading books. One can easily find descriptions of experiments, complete with results, that omit to mention that the experiment exists only in the imagination of the writer, and has never in fact been done. Thought experiments have indeed a valuable place in physics, since they often help to clarify concepts, but they should not be confused with real experiments. Any discussion should therefore be based on an experiment that has indeed been done.

Many popular books fail to distinguish clearly between well-supported theories and speculations that have not been subjected to any serious experimental test. Theories are sometimes expressed using particular philosophical terms and ideas, and this can lead to their acquiring a spurious validity if it is believed that they are in some way endorsed by their use in describing physical theories. Critical attention to what has really been established and what has not is essential to any discussion of the relation of theology to modern physics.

Another source of confusion is that the arguments in favour of a particular theory or result may be strong but not compelling. Someone who, perhaps for quite other reasons, is unwilling to accept the theory is then quite justified in emphasizing that it has not been proved beyond doubt. It is almost always possible to formulate quite plausible objections, but ultimately the time comes when it is obvious to all but a few diehards that it is a lost cause. On the other hand, the pioneers of science are quite often convinced of the correctness of their views long before an unassailable proof is forthcoming and so they are naturally exasperated by opponents who do no more than draw attention to the difficulties.

Disagreements can also arise if the theory is such that a complete proof can never be forthcoming. The opponents are then on very strong ground, but they may still be acting in an unscientific way if there is no real scientifically acceptable alternative. The theory of evolution is an example of this, typified by the myth of the Huxley–Wilberforce debate (Lucas, 1979).

As scientists advance into the unknown, they encounter new phenomena. To describe these, scientists sometimes coin new words such as 'electron' and 'gene', but more frequently they continue to use the old words with a new but related meaning. This is a trap for the unwary, who may assume that words such as space and time, energy and force, have the same meanings as in common speech. It requires familiarity with science itself to understand the meanings of familiar words in a new context. As Oppenheimer (1954, p. 3) remarked, 'often the very fact that the words of science are the same as those of our common life and tongue can be more misleading than enlightening, more frustrating to understanding than recognisably technical jargon. For the words of science, – relativity, if you will, or atom or mutation or action – have been given a refinement, a precision and in the end a wholly altered meaning.'

A revealing example is provided by the use of the concept of wave in quantum mechanics. The familiar waves in the ocean are collective phenomena with many molecules acting together in a collective way. However, the so-called interference patterns observed in quantum systems, such as the double slit, are built up by a large number of electrons acting completely independently of each other. It is seldom recognized that quite different phenomena can be described by the same equation, so care is needed when words describing one are used for the other.

This provides a further illustration of the need for a thorough understanding of the science itself before embarking on philosophical reflections or theological speculations. It is fatally easy for those not familiar with science, and even for those who are, to misinterpret the words used to describe a new scientific advance and to use them to promote views that are not supported by the scientific evidence but may well come from some implicitly held philosophical views that have nothing to do with science.

There is thus a hierarchy of knowledge – theological, philosophical and scientific. Knowledge flows easily from theology to philosophy to science, but only partially and with difficulty in the reverse direction. Thus, for example, some knowledge of God can be obtained by purely philosophical means, but the theology of creation immediately implies a really existing world and with it a realistic philosophy. In turn, realism is instinctively accepted by working scientists and its correctness is confirmed by its continuing fruitfulness.

Interactions between Theology and Science

The most important interaction between theology and science is that theology can provide at least some of the essential beliefs about the natural world on which modern science is based. Thus Catholic theology, based on the Old and New Testaments, teaches us that the world is good, rational, contingent and open to the human mind. This all follows from the belief that God created the world and gave each particle the properties which determine its movements and its interactions with other particles until the end of time. Many of these beliefs were also formulated by philosophers from the time of the Greeks onwards. Without these beliefs modern science could not exist.

Theologians live in a particular cultural setting, and they inevitably accept the current world view and use its concepts and terminology in expressing theological truths. Thus they speak of Christ's ascension into heaven and descent into hell. Taken literally, this implies that heaven is up in the sky and hell in the bowels of the earth. Behind this is the geocentric world of Aristotle and Ptolemy, with the central earth surrounded by the spheres of the planets and the stars, surmounted by the empyrean realm. Scripture speaks of the sun standing still, implying that normally it moves around the earth, so that Scripture apparently supports the geocentric theory and not the heliocentric theory. The passage most often quoted is from the book of Joshua (10: 12–13): 'The sun stood still in the middle of the sky and delayed its setting for almost the whole of the day.' When a theologian has expressed the truths of his faith in the context of the current world view, he can easily come to see a threat to that world view as a threat to his theology, and react accordingly.

Science and the Bible

Such problems raise the question of the correct way to interpret the Bible. Those who hold that the surface meaning is true have difficulties when it appears to say something that is contrary to the results of scientific research. This problem has been studied for centuries, and Augustine laid down some principles that have been followed and developed by subsequent authors (see McMullin, 1998). In this view it is accepted that the Bible is literally true, which means that it is true in the sense intended by God, which may or may not be the surface or bare meaning of the words. Augustine emphasized that it simply invites ridicule to interpret the Bible in a way contrary to established scientific knowledge. Indeed, such knowledge can guide us in the interpretation of difficult passages. The Bible is given to us for our salvation, not to teach us things about the world that we can find out by ourselves, and often uses expressions adapted to the minds of its readers. This is obvious when it speaks of God's right hand, or God walking in the garden. It is also true when it adopts modes of common speech, as when it speaks of the rising and setting of the sun. Ultimately, it is the Catholic Church, which was responsible for certifying the definitive text of the Bible at the Council of Trent in 1545, that has the authority to decide on its interpretation.

This problem of biblical interpretation arose in a particularly acute form when Galileo vigorously supported Copernicus' heliocentric theory of the earth and planets going round the sun, which appears to contradict several passages in the Bible. This came to the notice of the leading Catholic theologian of the time, Cardinal Bellarmine, who was head of the Holy Office. Following Augustine, he told Galileo that if a scientific result is established beyond doubt, then any passage in Scripture that it appears to contradict must be re-examined, for truth cannot contradict truth. The Bible may well use phrases from the current world view without making a scientific statement, as indeed we all do when we speak of the sun rising and setting. Thus the use by theologians of the current world view does not imply that they endorse it. Bellarmine also told Galileo that since heliocentrism was not then established beyond doubt it should be taught as a hypothesis (Finocchiaro, 1989, 2001; Sharratt, 1994, p. 114).

All this is not as easy as it at first sounds. At what point can we say that a scientific result is established beyond doubt, and what criteria do we apply to do this? Bellarmine did not specify what he meant by proof, but almost certainly he had in mind the Aristotelian definition as certain knowledge through causes, which is not quite what would be accepted by scientists today. Very often the recognition of truth in science (as in other areas) comes through the interpretation of many different signs that fit together in a convincing way. This is the illative sense of Newman (1947). It is open only to those who have a mastery of all the relevant facts, and so it is virtually impossible for scientists to convince others of the truth that they can clearly see. Thus scientists can achieve practical certainty long before a simple irresistible proof is available; in the case of heliocentrism it came only two hundred years later with the discovery of stellar parallax. It is thus easy for theologians to advise caution in accepting the new results while exasperating scientists, who see things clearly and so regard the theologians as reactionaries fighting a hopeless rearguard action.

Particularly after the Galileo case, there is now no doubt that the Bible should not be treated as a source of scientific knowledge. God is the author of the Bible and of the book of nature, and so we should expect both of them not only to be true but consistent and congruent with each other. We can expect them to cohere into a unified view, without a detailed concordance (Jaki, 1992, 1996, 1999a).

Pope John Paul II (1992, pp. 370–75) admitted that the theologians of the Church erred in their condemnation of heliocentrism and in their censure of Galileo:

> The error of the theologians of the time ... was to think that our understanding of the physical world's structure was in some way imposed by the literal sense of Sacred Scripture ... In fact the Bible does not concern itself with the details of the physical world. There exist two realms of knowledge, one that has its source in revelation and one that reason can discover by its own power ... The methodologies proper to each makes it possible to bring out different aspects of reality.

There are many Christians, particularly in the USA, who hold that the Bible is literally true in the direct verbal sense of the words. In the nineteenth century this led Archbishop Ussher to say that the world was created, essentially in its present form, about six thousand years ago. It was thus created in such a way that scientists would deduce from their observations that it had an immensely longer history. According to the creationists, the fossils of some fishes found in rocks do not indicate that many millions of years ago fishes lived in primeval seas. On the contrary, they believe that the rocks with fossil fishes inside them were directly created by God a few thousand years ago. Creationists who hold such views do indeed recognize the power of the creator, but do so in a way that is both radically unscientific and also insulting to God's integrity. Their secular opponents attack their belief in a creator, and the creationists respond by attacking science. Both have grasped one aspect of the truth but reject the other. It is vital to hold together both truths, namely the creation of all by God, and the scientific discoveries that have shown us how the world has developed over the ages (Kitcher, 1983).

The debates on theology and science often have hidden agendas and hidden motives. People argue strongly for or against a certain position on purely scientific grounds, but their motivation comes from entirely different considerations. Very often scientific theories are opposed, on scientific grounds, by people who are much more concerned with the possible theological implications, real or imagined, of that theory. Obviously, scientific problems must be tackled by scientific methods; it is only when this is done that it is legitimate to discuss implications. Scientific advances may well be initiated or stimulated by theological or philosophical beliefs, but they must be assessed solely by scientific criteria. This has been summed up by Duhem (see Jaki, 1984, pp. 113–14):

> If, therefore, we want to handle with competence and fruitfully the questions which are of the domain common to metaphysics and positive science, let us begin with studying the latter for ten, for fifteen years; let us study it, first of all, in itself and for itself; without seeking to put it in harmony with such and such philosophical assertion; then, as we have mastered its principles, applied it in a thousand ways, we can search for its metaphysical meaning which will not fail to accord with true philosophy. [Therefore] if Catholic theologians and philosophers had not become men with deep scientific knowledge, they must remain silent.

Does Science Lead to Faith?

To what extent can it be said that science implies, teaches or leads us to the acceptance of theological truths? At the simplest level, contemplation of mountains or the starry heavens have led many directly to God. The Psalmist declares that the heavens show forth the glory of the Lord. Similarly the intricate design of the natural world, from the symmetries of plants to the complicated interacting life cycles of plants and animals, can convince us that it all must have had a designer (Jaki, 1990).

The early Christians and the medievals were interested in the natural world as providing symbols of spiritual truths. Thus St Patrick used the shamrock to explain the doctrine of the Trinity, although this could easily be criticized as simplistic and indeed heretical, as it implies the identity of the three persons. St Augustine studied natural phenomena and wrote about their spiritual meaning. He was interested in nature primarily because it reveals God to an attentive observer, but in the process he gathered much useful scientific information. The pelican plucking her breast to draw blood to feed her chicks is a symbol of Christ shedding His blood for us. This was incorporated in a well-known hymn of St Thomas Aquinas to the Eucharist, and also appears in many coats of arms, including that of my own college, Corpus Christi College in Oxford. In this way the natural world was invested with layers of meaning that we should try to discover in order to enhance our spiritual life.

In the Renaissance this interest was continued. In encyclopedias such as Conrad Gesner's *History of Animals*, for example, animals were described together with the meanings of their names in every language, the proverbs associated with them and what they symbolize to Christians. Later writers such as Aldrovandi wove these associations into detailed webs that were described in huge volumes on birds, insects and animals. This emblematic view of nature came to a sudden end around 1650 when the new voyages of discovery brought back a whole range of previously unknown plants and animals that had no emblematic meaning. People became critical of the old stories and began to ask whether they were true, not what was their spiritual meaning. Francis Bacon summed up the new empirical attitude to nature, and rejected the idea that it is a complex of signs revealing God's plan, or a web with hidden meaning. Thereafter the main concern was to describe the natural world as accurately as possible, to seek what is true. This marks the difference between the medieval and the modern world view. Instead of arguing from general principles, scientists established the facts by observation and measurement.

Essential to scientific activity is the distinction between God's absolute and ordained powers. Everything is created by God, so He has absolute power over it. He can change or annihilate it at will; indeed without His conserving power it would immediately cease to be. He is the cause of everything, but sometime He acts directly and sometimes by what is called secondary causality (Davies, 1992). By this we mean that He delegates to material objects the power to cause, so that He now acts through them. In doing so He acts consistently, although He may for some particular purpose act otherwise. He orders everything 'in measure, number and weight' (Wisdom 16: 20) and 'determined His works for all time' (Ecclesiasticus 16: 25). 'The stability of nature is a sign of God's faithfulness' (Jeremiah 31: 35–36; 33: 25–26). This ordered behaviour of matter is the subject of science, so in normal circumstances we may speak of the behaviour of matter as determined by God. In this sense we can accept the uniformity of nature, while leaving open the possibility of miracles. This distinction between God's absolute and ordinary powers, or primary and secondary causality, is due to the medieval theologians Alexander of Hales, Albertus Magnus and Thomas Aquinas; it is to be sharply distinguished from the view of Muslim theologians such as al-Ashari (see Chapter 3) and the occasionalism of the French philosopher Malebranche, who held that God causes everything directly. As Davies (1992) remarks, God is the cause of both bat and ball, but it is still the bat that does the hitting. Apart from miraculous interventions, the physical world is thus a fully determined system, although it is impossible to prove or disprove this on the basis of science alone. These remarks apply to the physical world only, but not to human beings. Each of us is the union of a physical body and a spiritual soul, and God has given us free will. Without this we would be just an assemblage of molecules moving according to deterministic laws, and rational discussion would be impossible. We do not understand this union of body and soul, and discussion of the theories that have been proposed is beyond the scope of this book.

Internal and External Influences on the Development of Science

Does science develop according to internal criteria, unaffected by the beliefs and needs of the surrounding society, or do such external pressures influence or determine the way it develops? Should science be organized and controlled by the state to maximize the likely benefits to society, or should it be left entirely to the scientists themselves to decide what to do next? Many different views have been expressed. Following Marx, the Soviet historian Boris Hessen (1931) believed that the development of pure science is determined by the economic needs of society, and attempted to provide an example of this by a detailed analysis of Newton's *Principia*. The sociological roots of science were also studied by Zilsel (see Basalla, 1968). The Marxist physicist J. D. Bernal (1946) argued that the state should control scientific research. People have to be taxed to obtain the funds needed by scientists, so it seems only fair that the research topics should be chosen to bring the most practical benefits.

These ideas were vigorously opposed by Michael Polanyi (1958), G. P. Thomson, J. Baker (1942, 1945) and others, who founded the Society for the Freedom of Science. Polanyi (1958) pointed out, as an example, that the development of methods of illumination, from candles and electric light to fluorescent tubes and lasers, depends on a number of unconnected discoveries, all made by scientists who were solely interested in finding out about different aspects of the natural world. It would therefore have been quite impossible to plan and organize this development in advance.

There are numerous cases in the history of science of discoveries in pure science having quite unexpected applications. Thus Roentgen was studying electrical discharges in gases and discovered X-rays. He would never have done this if he had been told to improve methods of medical diagnosis. Hertz would never have discovered radio waves if he had been told to improve methods of communication. Madame Curie studied radioactivity and discovered radium: she would never have done this if she had been told to discover a way to treat cancer. Scientists cannot predict what they will find: Rutherford said in 1936 that he expected no more than small-scale applications of nuclear physics. Max Planck (1933, p. 137) emphasized that 'scientific discovery and scientific knowledge have been achieved only by those who have gone in pursuit of it without any practical purpose whatever in view'.

The lesson is clear: pure science must be allowed to develop in accord with its own internal criteria. When possible applications are found, it is then up to society to decide how to develop them. Any attempt to force the development of science to satisfy economic criteria is doomed to failure. Specification of required objectives may produce improvements, whereas pure science left alone produces revolutions. Inevitably, the social, cultural and economic state of society has some effects on the way science develops, but does not determine it.

Theological beliefs can have both internal and external influences on the development of science. The very possibility of science depends on definite philosophical and theological beliefs about the world, as described in Chapter 2. For science to develop, these beliefs must be held, at least implicitly, by society as a whole and by the scientists themselves. They are thus both internal and external. It may also happen that a particular scientific result contradicts some theological belief and then pressure may be put on the scientists concerned to stop their work and recant their conclusions. This again is both an internal and external constraint.

Considering the importance of theological beliefs for the development of science, it is not surprising that Jews and Christians have been prominent among the leading scientists from the Middle Ages onwards. They all share the beliefs necessary for science to develop. Thus, throughout all Planck's 'work and all that he has said or says there is always this golden thread of a living faith in the ultimate purposes of creation' (James Murphy in Planck, 1933, introduction, p. 39). It is not accidental 'that the greatest thinkers were always deeply religious souls ... Science furthers a love of truth' that displays 'itself in the constant endeavour to arrive at a more exact knowledge of the world of will and matter' (ibid.).

The Abbé Lemaître (see Weisskopf, 1991, p. 287) has suggested that

> perhaps the believer has the advantage of knowing that the enigma has a solution, it is in the final analysis the work of an intelligent being; so the problems posed by nature are here to be solved, and the degree of difficulty is without doubt appropriate to the present and future intellectual capacity of humanity. This will perhaps not give him greater resources for his investigations, but it will help to support this feeling of healthy optimism without which a sustained effort cannot be maintained.

Commenting on this, Pope John Paul II declared: 'I wish all of you this healthy optimism of which Abbé Lemaître speaks; it is an optimism that takes its mysterious but very real origin in God in whom you have placed your faith' (quoted by Weisskopf, 1991, p. 287).

The correlations between scientific achievements and Christians holding different theological beliefs are much less definite (Hall, 1975, 1983; Kneller, 1995; Davis and Winship, 2002). On the whole, it seems that there is not a strong correlation between scientific activity and theological beliefs that are not directly related to those underlying science itself. The existence of many non-Christian scientists shows that these beliefs need not be held explicitly.

The Presuppositions of Science

It is essential for the development of science that the beliefs about the material world mentioned above are firmly held, even though it is at a deep psychological level where they are implicit rather than explicit. This explains why it is so difficult to teach science in non-Christian countries. This difficulty is not immediately evident because technology is easy to convey, and this is frequently confused with or considered similar to science. It is easy to teach people in other countries how to set up and run manufacturing industries that provide them with their daily needs. On the contrary, it is exceedingly difficult to convey science, that is, to establish flourishing and fruitful research communities in such countries. It is of course easy to build and equip scientific laboratories, but it is almost impossible to fill them with really innovative indigenous scientists. It is not generally realized that the level of research in most non-Christian countries is very low. The few exceptions are those that have been for many centuries in contact with Western Europe; many generations have been taught in Westernized schools and so have absorbed the Christian presuppositions of science. Since Western education is often politically unacceptable, the situation is likely to worsen. Indeed, the decline in Christian belief in Western countries is likely to result in a slow decline of science. Already the falling numbers of aspiring students of physics is a sign of this decline.

To sum up, the principal interaction between theology and science is that Christian theology provided several of the beliefs on which science is based. On that basis, science can develop in accord with its own internal nature, without any further influences or external constraints. In particular, the detailed progress of science cannot be guided by theologians or by church decrees. Many popes have emphasized the freedom of science to search for the truth, so that

> basic research must be free with regard to political and economic authorities, which must co-operate in its development, without hampering its creativity or having to serve their own purposes. Like any other truth, scientific truth is answerable only to itself and to the supreme truth, God, the creator of man and of all things. (Pope John Paul II, 1979)

There is much discussion today about whether the advance of science, in particular of modern physics, can bring with it new theological truths. Certainly it can enhance our appreciation of the wonders of creation, but that wonder is not different in kind from what we feel when we look around us. It is also possible that science provides new concepts and ways of thought useful to theology, as Aristotle's philosophy made possible the medieval development of theology. This provides no new theological truths. Indeed, the provisional nature of scientific theories makes it impossible to use them as the basis of a new theology.

CHAPTER 2

The Judeo-Christian Contribution to the Development of Modern Science

Science in Ancient Civilizations

Viewed in the widest historical perspective, the explosive development of science in seventeenth-century Europe is one of the most astonishing events in the whole of human history. It makes that civilization unlike any other. For the first time people all over the world are joined together by rapid communications, easy travel and extensive trade. Why did this understanding of the detailed structure of the world that we call science develop and come to maturity just when and where it did? This is a question that can lead us to the heart of the relation between science and the Christian basis of our civilization.

It is usual to discuss the relation of science to religion as if they are two independent activities. We can then compare and contrast their objectives, their modes of procedure and the status of their conclusions. This is not without value, but it presupposes that they are two independent activities that have somehow to be related to each other. This directs attention away from the central point that is essential for the understanding of their relationship, namely that when seen in the perspective of history there is an organic connection between them. Science as we know it is based on certain definite beliefs about the world. Many of them were first formulated by the ancient Greeks but were not sufficient to establish science as a continuing enterprise. Modern science began only when they were reinforced and extended by the religious beliefs of the Hebrews and finally brought to completion by the theology of Christian Europe.

If we look at the great civilizations of the past, in China and India, in Babylon and Egypt, in Greece and Rome, we frequently find well-developed social structures, magnificent artistic and architectural achievements, imperishable drama and philosophy, but nothing remotely equivalent to modern science. We find great skill in the working of wood and metal, ingenious mechanical contrivances and perceptive philosophical speculations about the world, but not the detailed quantitative understanding of matter, from quarks to galaxies, expressed as the solution of a few differential equations, that is the hallmark of the more developed areas of modern science.

Most of the great civilizations of the past were able to provide all the material requirements for the growth of science. There was a leisured class, technical skills and systems of writing and mathematics. Obviously this by itself is not enough. What was lacking was the attitude towards the material world that is the essential precondition of science, and in some cases a social structure that allows new ideas to flourish.

What do we have to believe before we can hope to become scientists? We must believe that the world is in some sense good, so that it is worthy of careful study. We must believe that it is orderly and rational, so that what we find out one day will still be true on the next day. We must believe that this order is open to the human mind, for otherwise there would be no point in trying to find it. We must believe that this order is not a necessary order that could be found out by pure thought like the truths of mathematics, but is rather a contingent or dependent order that can only be found by making experiments.

In addition to these beliefs about the world itself, the development of science depends on moral convictions such as the obligation freely to share any knowledge that is gained. Furthermore, once it becomes clear that scientific understanding can be applied to grow more food and to cure diseases, then its further development is encouraged if we believe that we should do these things to help our fellow men.

These beliefs may seem obvious to us, but in the context of human history they are very special. They are not found in the ancient civilizations, and that is why science in the modern sense never developed among them. In some cases, particularly in ancient Greece, an impressive start was made by a few individuals of genius, but they lacked the support of a coherent set of beliefs shared by the whole community, and science never became a self-sustaining enterprise.

Why were these beliefs found in Christian Europe? Is there any connection between the medieval theology that formed the mind of Europe in the critical centuries before the birth of science? In each case we find that there is indeed such a connection. In order to see that this is so we have to look in more detail at the historical development of science.

The Origin of Science

Our present scientific and technical knowledge has been attained by a long, hard and winding road from the astronomical observations of the Babylonians to the quantum theory and supercomputers of today. Initially, science was not distinguished from philosophy and its roots are to be found in the early struggles to make sense of the world. Before answers can be found, we must ask the right questions. What methods should we use to understand nature? How can we know that our answers are right? Why do things change? Is there an unchangeable reality beneath the changes that surround us? Over the centuries these questions have been answered in different ways under the influence of the surrounding culture.

It was extremely difficult to get started. The early Ionian philosophers made some tentative speculations, but the first really systematic attempt was made by Aristotle. He took all knowledge for his province and proposed a vast rational structure embracing all fields of activity from mathematics, physics and biology to politics, art and music. He was an exceptionally acute observer, and many of his biological descriptions and discoveries were not surpassed until the invention of the microscope about two millennia later.

Aristotle was primarily concerned with the general principles of nature and with the qualitative relations among things, and not with precise quantitative analysis. He recognized that some natural phenomena such as optics and musical harmonies could be described mathematically, but he distinguished this from mathematics on the one hand and natural philosophy on the other.

Aristotle considered the world as an organism acting for a purpose. Every material body has a natural place and always moves towards that place. This may be seen most clearly in his discussion of motion, the most fundamental phenomenon that lies at the basis of physics and hence of all science. He distinguished between two types of natural motion: the circular motion characteristic of the celestial bodies, and linear motion characteristic of bodies on the earth. The celestial realm is changeless and incorruptible, and the planets must move in circular orbits because the circle is the most perfect curve. On the earth, bodies strive to reach their natural place, fire going upwards and heavy bodies downwards. Their rate of fall depends on their weights, as heavy bodies strive more strongly to reach their natural place; a body of a certain weight thus falls twice as fast as one of half its weight. Thus although Aristotle maintained that all knowledge come to us through the senses, he often preferred his deductions to the simplest observations. In this case a thought experiment suffices, as according to him two equal weights joined by a light rod should fall at twice the speed of the unconnected weights.

Aristotle analysed the concepts of space, time and motion, and came to the conclusion that the world is eternal. He also believed that time is cyclic, so that after a long time everything is repeated again and again, without end.

The Aristotelian world picture is a logically coherent structure that served as a framework for thinking for almost two thousand years. By its emphasis on purpose, a concept that has no place in physics, its over-optimistic belief that it is possible to intuit the structure of the world and its lack of understanding of the importance of quantitative measurement it prevented the development of genuine science. Other Greeks, notably Archimedes, Aristarchus and Euclid, made fundamental advances in geometry and the analysis of natural phenomena, but in spite of this heroic beginning Greek science never developed into a self-sustaining enterprise (Jaki, 1986).

To sum up, Aristotle believed in the eternity of the world, in a cyclic universe, and in a world of purpose, even in material things. He also believed that celestial matter, the world of the stars and planets, is incorruptible, unlike terrestrial matter that can undergo change. These beliefs prevented the development of science for two thousand years. Their stranglehold had to be broken before science could develop into its modern form.

A new beginning, a fresh style of scientific thinking, was made possible by the Judeo-Christian vision of the world. The God of the Hebrews is very different from the God of Plato or the Prime Mover of Aristotle. In sharp contrast, the God of the Hebrews freely created a world completely distinct from Himself, and His actions are inscrutable to men unless He freely chooses to reveal His plans.

The book of Genesis bears witness to the Hebrew belief in a transcendent creator from its opening phrases: 'In the beginning God created the heavens and the earth ... And God saw all that He had made, and indeed it was very good' (Genesis 1: 31). The Hebrew word translated as 'good' also means 'beautiful', and beauty is one of the most important characteristics of a scientific theory.[1] In contrast to the confused creation myths of the surrounding nations, the creation story in Genesis has a clear logical structure, expressed in poetic form. It clearly expresses belief in the absolute sovereignty, rationality and benevolence of God, who brings everything into being by His command and communicates His own goodness to them. Although not expressed in modern language, it contains the essential beliefs about the world that must be held if science is to flourish.

The earliest psalms tell us how God made the world and prepared it for man: He sets the heavens, the moon and the stars in their places, obeying a law that is fixed for ever (Psalm 148). He makes man the ruler over his works, ordering everything 'in measure, number and weight' (Wisdom 11: 20). In His reply to Job, Yahweh asks

> Where were you when I laid the earth's foundations?
> Tell me, since you are so well informed!
> Who decided the dimensions of it, do you know?
> Or who stretched the measuring line across it? (Job 38: 4–7)

God is all-powerful, and He alone is to be worshipped. The sun and the moon are not gods but parts of nature. The animist beliefs of the Egyptians and the Babylonians, the gods of the forest grove, the fates and furies, dryads and nereids, the belief in the divine earth-mother – are all totally rejected. In this way the natural world is desacralized, so that it becomes a proper object for scientific study.

Nothing comes into being, nothing remains in being, without being loved and willed by God:

> You made all that exists; you hold nothing
> of what you have made in abhorrence,
> For had you hated anything you would not have formed it.
> And how, had you not willed it, could a thing persist?
> how be conserved if not called forth by you? (Wisdom 11: 24–26).

The heroic mother of the seven martyred brothers in Maccabees (2 Maccabees 7: 22–29) likewise expressed her belief in creation when she exhorted her sons to stand firm, saying to them:

[1] The theoretical physicist Dirac remarked in 1963 that he always looked for beautiful mathematical equations. See Pais (2000), p. 69; Chandrasekhar (1979a and 1979b, p. 25). See also Jaki (1980), p. 26.

> I do not know how you appeared in my womb; it was not I who endowed you with breath and life. I had not the shaping of your every part. It is the creator of the world, ordaining the process of man's birth and presiding over the origin of things, who in his mercy will most surely give you back both breath and life, seeing that you now despise your own existence for the sake of his laws.

When it came to the last son, Antiochus tried to persuade him to abandon the traditions of his ancestors, and appealed to his mother to advise the young man to save his life. She finally agreed to persuade her son, but she fooled the cruel tyrant with the words:

> I implore you, my child, observe heaven and earth, consider all that is in them, and acknowledge that God made them out of what did not exist, and mankind comes to being in the same way. Do not fear this executioner, but prove yourself worthy of your brothers, and make death welcome, so that in the day of mercy I may receive you back in your brothers' company. (2 Maccabees 7: 22–29)

The faithfulness of God to Israel is compared with the reliability of natural phenomena (Jeremiah 31: 35).

> Your word, O Lord, for ever
> Stands firm in the heaven.
> Your truth lasts from age to age
> like the earth your creator. (Psalms 118: 89)

The order and stability of natural phenomena are taken for granted with the same quiet certainty as shown by the mother of the seven brothers:

> God's laws are permanently valid, and endure for ever:
> 'When God created His works in the beginning
> he allotted them their portions as soon as they were made
> he determined his works for all time
> from their beginnings to their distant future.
> They know neither hunger nor weariness,
> and they never desert their duties.
> None has jostled ever his neighbour,
> they will never disobey his word.' (Ecclesiasticus 16: 24–26).

Matter is entirely passive and it consequently endures, obedient to God's will. It is a perfect model for us.

In all these accounts of creation there is no distinction between the heavens and the earth, between the celestial and the terrestrial realms; both are made by God and are totally subject to His laws.

Thus according to Judeo-Christian beliefs the world is the free creation of God from nothing. The structure of the world cannot therefore be deduced from first principles; we have to look at it, to make observations and experiments to find out how God made it. This reinforces the Aristotelian principle that all knowledge comes through the senses, but requires it to be situated within a wider set of beliefs concerning the nature of the world that is implicit in the doctrine of creation. Aristotle's natural theology is thus transformed into the Christian notion of divine providence: God is not simply the Prime Mover or First Cause; He is the cause of the very existence of the world and its continuance in being.

We know that the world is rational because it was made and is kept in being by a rational God. It is contingent because it depends on the divine fiat: God could have chosen to make the world in a different way. There is here a delicate balance between the rationality and the freedom of God: tip the balance one way or the other and you have a belief in a necessary or in a chaotic world, both inimical to the growth of science. Finally, we are assured that the enterprise is a practicable one, that the world is open to the human mind, because God charged us to have dominion over it, and He does not command the impossible: 'Be fruitful, multiply, fill the earth and conquer it. Be masters of the fishes of the sea, the birds of heaven and all living animals on the earth' (Genesis 1: 28). Whatever wisdom we acquire, we must pass on to others: 'What I have learned without self-interest, I pass on without reserve; I do not intend to hide her riches. For she is an inexhaustible treasure to men, and those who acquire it win God's friendship' (Wisdom 7: 13).

The first study of the effect of the Hebrew theology of creation on Greek philosophy was made in the first century BC by Philo Judaeus of Alexandria. He accepted the Greek idea of unchangeable causality, but not the modes of causality proposed by Plato, Aristotle and the Stoics. Following Scripture, he argued that

> God did not act as Aristotle had maintained as an essentially passive first cause co-eternal with the world emanating by necessity from divine reason, that God did not make the world out of pre-existing matter as Plato proposed in the Timaeus, that God was neither material nor in the world as supposed by the Stoics, and that God is in no way necessitated, but that he had acted with entirely free omnipotence in creating *ex nihilo* a world separate from himself. (Crombie, 1994, p. 294)

He used the word *logos* to denote the rational pattern on which God modelled His creation, the immutable laws governing the world that shows God's power within it. They are often obscure to us, but they lie behind the motions of the stars and all natural phenomena. God is the absolute Lord of the universe; He has laid down its laws but can overrule them at will.

The Early Christian Centuries

The birth of Christ further ennobled the matter of the universe, and his teaching reinforced and enhanced the teaching contained in the Old Testament. The debilitating belief in a cyclic universe, held in all ancient cultures, was decisively broken by the Christian belief in the uniqueness of the Incarnation. Henceforth history was no longer an infinite series of dreary cycles, but a linear story with a beginning and an end. Inherent in Christ's teaching is a set of beliefs about the world that eventually led to the first viable birth of modern science in the High Middle Ages, and to its subsequent flowering in the Renaissance.

In the early Christian centuries several philosophers examined the cosmology of creation in the context of Christian theology. In the third century AD Lactantius rejected the Stoic belief that nature is animate and that God is within the world, and also the Epicurean belief that the world is simply the product of chance, without any providential design. He emphasized that God with infinite power created the world out of nothing, so that He is absolutely separate from His creation. Nature is designed by God ultimately for the benefit of man, and has no power of its own that does not come from God. This implies that nature is an inanimate mechanism operating according to fixed laws. In the fourth century AD Basil of Cappodocia insisted, contrary to Plato, Aristotle and other Greek philosophers, that nature is not animate, nor is it a living thing endowed with senses. When plants and animals grow, they do so following God's command and in accord with His laws.

The Christian beliefs concerning creation emphasize not only that the universe was created by God out of nothing and in time, but that the universe is totally dependent on God and totally distinct from God. The universe at any instant is sustained in being by God, and without this sustaining power it would immediately lapse into nothingness.

At that time there were passionate debates about the nature of Christ, and heresies abounded. To define the true nature of Christ was the task of a series of councils of the Church, and of these the Council of Nicea (325) formulated the creed that is widely held today:

> *Credo in unum Deum. Patrem omnipotentum, factorem coeli et terrae, visibilium omnium et invisibilium. Et in unum Dominum Jesum Christum, Filium Dei unigenitum. Et ex Patre natum ante omnia saecula. Deum de Deo, lumen de luminae, Deum verum de Deum vero. Genitum, non factum, consubstantialem Patri; per quem omnia facta sunt ...*

It is easy to recite these hallowed phrases without fully realizing their impact, and still more their importance for science. The beginning of the Nicene creed asserts the creation of the universe by God: '*Factorem coeli et terrae*'. One of the early heresies was pantheism, which failed to distinguish between God and His creation, holding that it is in some way part of God. In the Greco-Roman world the universe was thought of as an emanation from a divine principle that is not distinguished from the universe. Pantheism is explicitly excluded by the Nicene creed when it says that Christ is the only-begotten Son of God. Christ is begotten, not made. Only Christ was begotten and thus shared in the substance of God; the universe was made, not begotten. ('*Et in unum Dominum Jesum Christum, Filium Dei unigenitum ... Genitum, non factum*'.) Since pantheism was one of the beliefs preventing the rise of science in all ancient cultures, the

Nicene creed prepared the way for the one viable birth of science in human history.

Many ancient cosmologies held that the world is a battleground between the spirits of good and evil. This dualism is inimical to science because it makes the world unpredictable. Dualism is excluded by the Nicene creed when it says that all creation takes place through Christ ('*per quem omnia facta sunt*').

In his Epistle to the Colossians, St Paul says that in Christ all things took their being, and were all created through him and in him (Colossians 1: 15). He stressed Christ as the divine *logos* and the consequence that the creation must be fully logical and orderly. He referred to creation out of nothing when he praises God 'who restores the dead to life and calls into being those things which had not been' (Romans 4: 17) and promises that through Christ they would understand 'the breadth, the height and the depth' (Ephesians 3: 18).

Inherent in the Christian doctrine of creation is the belief that God freely chose to create the universe. He was not in any way constrained either to create or not to create it in the way that He did. It is therefore not a necessary universe in the sense that it had to be created or could not have been created otherwise. There is therefore no possibility of finding out about the universe by pure thought or by *a priori* reasoning. We can only hope to understand it by studying it and by making experiments. Thus the Christian doctrine of creation encouraged the experimental method, essential for the development of science.

The theology of St Augustine of Hippo encouraged the systematic study of the natural world, since he believed that its sacramental nature is symbolic of spiritual truths. He was a compulsive observer of natural phenomena, always on the lookout for anything that gave even a fleeting glimpse of the reason behind all things. The laws of nature are objective and inexorable, unalterable by us but not by God. He encouraged the study of nature and the search for its laws, to read the book of nature: 'Look above and below, note, read. God, whom you want to discover, did not make the letters with ink; he put in front of your eyes the things that he made.' Following Plato, he recognized the importance of mathematics, saying that the laws of nature are the laws of numbers. There is a rational pattern in nature which follows from the unchanging laws that govern its development through time. He was interested in nature primarily because it reveals God to the attentive observer. His philosophical reflections on the nature of time are still quoted as among the most profound ever written.

In the early Church, and subsequently throughout the Middle Ages, the natural world was studied primarily for the spiritual truths that it reveals. Science was seen as the handmaid of theology. Scientific knowledge for its own sake was without value, but it became valuable when it served a higher purpose. As an example, the regular movements of the heavenly bodies are used to show God's constancy and reliability in His relations to us. An additional reason to study nature is provided by its importance in scriptural interpretation. As Augustine emphasized, Scripture must be interpreted in a way that is not contradicted by established scientific conclusions. Thus when interpreting a passage that impinges on a scientific question it is necessary to determine first of all the relevant scientific knowledge, and then go on to interpret the passage. It is therefore incumbent on Christians to be familiar with contemporary science. Concerning scientific knowledge, Augustine remarks that 'it is a disgraceful and dangerous thing for an infidel to hear a Christian talking nonsense on these topics, and we should take all means to prevent such an embarrassing spectacle in which people see vast ignorance in a Christian and laugh it to scorn' (Augustine, 1982; Lindberg, 2002, p. 47).

In the early sixth century John Philoponus, a Christian Platonist who lived in Alexandria, wrote extensively on the material world, showing the influence of Christian beliefs on those of the surrounding pagan world, particularly those derived from ancient Greece (Sorabji, 1987). He commented extensively on Aristotle, whom he greatly admired, but when the teaching of Aristotle was contrary to Christian belief he did not hesitate to differ from it. This was particularly important in his commentary on Aristotle's physics, where he said, contrary to Aristotle, that all bodies would fall in a vacuum at the same speed, irrespective of their weight, and that projectiles move through the air not due to the motion of the air but because they were initially given a certain quantity of motion. This is a remarkable anticipation of ideas normally associated with Galileo, and shows a decisive break with Aristotelian physics. He was not the first writer in antiquity to break with Aristotle, but he did so more clearly and decisively.

The connection between his rejection of Aristotelian ideas and his Christian beliefs is to be found in the doctrine of creation. Addressing the question of motion, he asked 'could not the sun, moon and the stars be not given by God, their Creator, a certain kinetic force, in the same way as heavy and light things were given their trend to move?' He also believed that the stars are not made of the ether but of ordinary matter, thus rejecting Aristotle's distinction between celestial and terrestrial matter.

This shows very clearly that the Christian beliefs about the world are incompatible with the Aristotelian views on the divinity of celestial matter and the eternity of motion. It was thus inevitable that the spread of Christianity should lead eventually to the destruction of Aristotelian physics, thus opening the way to modern science. This is not to say, however, that Christian beliefs give any specific guidelines for the development of science, but the removal of obstacles is by itself no small service.

Philoponus was also the first to say that Genesis was written for spiritual and not for scientific instruction, a wise statement that was too far in advance of its time to be congenial to contemporary theologians. This theological boldness perhaps explains why Philoponus' ideas did not lead to further scientific developments. His ideas on motion are remarkably similar to those of Buridan and Oresme in the High Middle Ages, which did succeed in initiating the scientific enterprise. To be fruitful, ideas have not only to be right; they need to fall on fertile ground, in this case a society sufficiently developed to make full use of them, and this was lacking for Philoponus. There has been some speculation about whether the ideas of Philoponus were known to Buridan, but nothing seems to be established definitely on this question.

In the eighth century the Venerable Bede in Northumbria wrote not only his well-known *Ecclesiastical History of the English People*, but also a treatise 'On the Nature of Things' and two books on timekeeping and the calendar.

We are now on the threshold of the decisive breakthrough that led eventually to the rise of modern science.

The High Middle Ages

The High Middle Ages was a time of intellectual ferment. Schools, generally associated with cathedrals, and universities were being founded all over Europe, and the writings of the ancient Greeks were becoming available in translation. Christian theology was being re-thought using their unfamiliar but powerful concepts. The writings of Augustine and of others such as Philoponus were already forming new attitudes to the natural world.

In the early twelfth century, Adelard of Bath wrote his *Quaestiones Naturales*, which marks the dawn of medieval science. His nephew believed that the spontaneous appearance of life in a dish of dried soil was miraculous. At a time when there was a strong devotion to miracles, it would have been easy for Adelard to agree. Instead he drew a firm distinction between the action of the Creator and the natural workings of His creation: 'It is the will of the Creator that herbs should sprout from the earth. But the same is not without a reason either.' When his nephew persisted and pointed out that a natural explanation from the doctrine of the four elements was inadequate, he stuck to his point: 'Whatever is, is from Him and through Him. But the realm of being is not a confused one, nor is it lacking in disposition which, so far as human knowledge can go, should be consulted.' In other words, we should persist in seeking a natural explanation, and avoid attributing anything that we do not understand to the direct action of God. This advice, which is still worth heeding today, contains the essential attitude to the natural world that lies at the basis of science.

At the same time, Hugh of St Victor saw the study of the natural world as a twofold process, first the ascent of reason to the purely spiritual and then a descent to examine in this light the information provided by the senses. In so doing he expressed the mathematical rationalism of Plato and inspired his contemporaries William of Conches, Thierry of Chartres and Adelard of Bath, for whom reality was autonomous nature to be grasped by reason.

In the twelfth and thirteenth centuries there was a remarkable flowering of creativity in many areas of human activity. At the sociological level, this was largely due to the new concept of treating a group of people as a separate legal entity. This enabled them to act with considerable freedom, but always subject to the law. It came about as a result of what has been called the papal revolution, by which the Church asserted its freedom from the civil authorities (Huff, 1993, p. 125). Previously, it was usual for clerical appointments to be made by the civil authorities, but now the Church insisted that it alone had the authority to do this. This established the Church as a separate legal entity and put constraints on the power of the civil authorities. The most significant result was the creation of a separate legal system with its own area of jurisdiction. Once this idea was established, both Church and State became federations of many corporations, each with a measure of autonomy. Among these were cities, the first universities, the legal and medical professions, banks and business organizations, and later on, the scientific community itself.

In the High Middle Ages, many universities were founded by the Church to provide higher education for those educated in the monastic schools, to train future clerics and to facilitate the spread of learning. It was in these universities that the decisive breakthrough that led to the rise of modern science took place. The works of Aristotle and the other Greek philosophers were translated into Latin and were used by theologians to express the truths of the faith in more precise language, and by philosophers to refine their view of the natural world.

The two characteristics of the Western intellectual tradition that made science possible are the insistence on logical coherence and experimental verification. These were already present in a qualitative way among the Greeks, and the vital contribution of the Middle Ages was to refine these conditions into a more effective union. This was done principally by emphasizing the quantitative precision that can be attained using mathematics in the formulations of theories and then verifying them not by observation alone, but by precise measurements. This transition was achieved in the twelfth century, principally by Robert Grosseteste, who is regarded as the founder of experimental science. His work on experimental science owed much to Plato, who taught that the pure forms behind the appearances of things are mathematical in nature, so that our theories must also be mathematical, and the results of experiments expressed in numbers (Crombie, 1953).

Grosseteste elaborated his theory of the scientific method in some detail, although he did not himself carry out many experiments. He recommended the method of analysis and synthesis; namely that the problem is first resolved into its simplest parts and when these are understood the results can be combined to give the explanation of the whole. The observations and experiments may themselves suggest hypotheses and theories, and these in turn may be verified or disproved by comparison with further observations and measurements.

He first applied his method to the phenomenon of light. He believed that light is the most fundamental form, so that the laws of light must lie at the basis of scientific explanation. God first created light, and from that all things came. Light itself follows geometrical rules, in the way it is propagated, reflected and refracted, and this is the means whereby higher bodies act on lower. He studied the rainbow, and his criticism of Aristotle and Seneca were useful steps along the road to an adequate explanation. Although he emphasized mathematics, he was clear that mathematical entities have no objective reality but are simply abstractions from material bodies. Implicit in his work is insistence on quantitative measurement, and this in turn comes from the biblical insistence on the rationality of the Creator, who disposed everything in measure, number and weight.

Grosseteste's work on optics was continued by the Franciscan friar Roger Bacon, who also wrote extolling the value of science, and in particular predicted that man could make machines to travel on land, sea and in the air.

So great was the prestige of Aristotle that the philosophers of the medieval schools taught by commenting on his texts. Some of Aristotle's teaching, however, was inconsistent with the Christian faith, and the philosophers did not hesitate to differ from Aristotle when it seemed necessary. In 1215 the Fourth Lateran Council decreed that all creation, spiritual and material, took place out of nothing and in time. This is directly contrary to Aristotle's belief in the eternity of the world. There was intense discussion on a variety of topics, notably concerning the creation of the world and the motion of bodies. In 1277 the bishop of Paris, Etienne Tempier, found it necessary to condemn 219 philosophical propositions as contrary to Christian belief. His main purpose was to defend God's absolute power against any attempt by Aristotelian philosophers to set limits to it. Several of the condemned propositions set limits to God's power, saying for instance that He cannot make more than one world or move the world so as to produce a vacuum. Tempier thus reasserted the belief that God can freely create any world, just as He chooses.

There has been much discussion of the importance of this condemnation for the development of science. Any such action can have many unintended consequences. It was primarily aimed at Greek necessitarianism and the Aristotelianism of Averroës, but its affirmation of the omnipotence of God encouraged the theologians to consider as tenable several scientific and philosophical propositions previously deemed excluded by the very nature of things. In this way Christian theology 'facilitated, even in science, the opening of new perspectives' (Gilson, 1955). Certainly, 'the condemnation of 1277 does indeed signify or symbolise some critical turning point in the history of medieval thinking' (Emery and Speer, 2001, p. 3). Duhem saw it as the beginning of modern science, when the Church effectively condemned Aristotelianism and Neoplatonism, and thus opened the way to the new physics. His work on medieval science was extended by Dijksterhuis and Michalski. It was subsequently criticized by Koyré, Maier and Clagett, who maintained that there was less continuity between medieval science and modern sciences than Duhem supposed; Grant (1977) considered that Duhem's thesis was 'exaggerated and indefensible'. More recently, Duhem's thesis has been supported by the discovery of continuity between the work of the Parisian philosophers and Galileo. Further support was provided by Jaki, Gilson, and Arieu and Barker (see Murdoch, 2000, p. 23). Additional studies were made by Klaaren (1977), Grant (1981, p. 211), Murdoch (1991, p. 253) and Lindberg (1992, 2000, p. 259).

A serious defect of Duhem's work (1956, ch. IV) was his undervaluing the importance of medieval logic, especially as studied in the Mertonian school in Oxford. Many recent studies have shown its key role in the development of natural philosophy (Wilson, 1956). This attitude to the Mertonian school is not unconnected with Duhem's fervent French patriotism and his fulsome praise of French genius compared with the weak minds of the English physicists.

Although some of Aristotle's ideas were rejected as inconsistent with the Christian faith, he still retained immense prestige during medieval times. Following long-standing church tradition, ideas from the Greco-Roman world were welcomed as providing new tools for the understanding of Scripture and the development of theology (Grant, 2002, p. 34).

Aristotle believed that the world is eternal, but it has always been the Christian belief, following the opening phrases of the Old Testament and reiterated by the Fourth Lateran Council, that God created everything from nothing. One of the medieval philosophers, Jean Buridan, was particularly interested in the nature of motion. This is the most fundamental problem of physics, and so if science is to begin at all it must begin here. Impelled by his belief in creation, Buridan (quoted by Jaki, 1974, p. 233) wrote that 'God, when He created the world, moved each of the celestial orbs as he pleased, and in moving them He impressed on them impetuses which moved them without Him having to move them anymore except by the method of general influence whereby He concurs as co-agent in all things which take place'.

An eternal universe also requires God's creative and sustaining power, and Aquinas (see Baldner and Carroll, 1997) considered that we know only by revelation that the universe was created at the beginning of time. We do not know why God chose this way; perhaps it was because it makes it easier for us to deduce His existence. There are also philosophical arguments against an eternal universe, from Bonaventure (Gilson, 1955, p. 338; Baldner, 1989) to Craig and Smith (1993).

Buridan's concept of impetus reinterprets the dictum of Aristotle, who required the continuing action of the mover throughout the motion, by saying that the mover is now located within the body. Buridan also said that the impetus is proportional to the mass of the body and to its velocity, so it is equivalent to the concept of momentum; this insight became Newton's first law of motion. Buridan's works were widely published and his ideas became known throughout Europe, to Leonardo da Vinci and to the scientists of Renaissance times. Buridan's work thus played a key role in the transition from the qualitative and often erroneous speculations of Aristotle to the rigorous quantitative dynamics of Newton. This transition, and especially the degree of continuity between medieval and Renaissance concepts, is the subject of much scholarly study (Maier, 1949 in Damico, 2000, p. 41; Clagett, 1959; Truesdall, 1968; Weisheipl, 1976; Grant, 1981a and b; Barbour, 1989).

The Christian belief in the creation of the world by God also undermined Aristotle's sharp distinction between celestial and terrestrial matter. Since they are both created, why should they be different? Indeed, Buridan illustrated his concept of impetus with reference to the long jump; thus implicitly presupposing that celestial and terrestrial motions are similar. This made it possible for Newton to see that the same force that pulls an apple to the ground also keeps the moon in its orbit.

Belief in the Order of Nature

A vital component in the rise of science is the belief in the order of the world, that is the idea that every event is the precise result of preceding events. This implies that whatever measurements we make should correspond exactly, that is within the uncertainties of measurement, with our theories. A corollary to this is that if we want to test our theories, we should make the most accurate measurements we can. This insistence on precision is essential for the progress of science. An illustration of this is the work of Kepler on the orbit of the planet Mars. Some very accurate measurements had been made of its position by Tycho Brahe, probably the most accurate that could be made before the invention of the telescope. Kepler resolved to find the orbit. He believed, following Aristotle, that the orbit was circular, as befits incorruptible celestial matter. He found that indeed it is very nearly a circle, but however hard he worked, he could not make it fit Tycho's measurements. He could find a circular orbit that agreed with the measurements to about ten minutes of arc, but not to two, which was the accuracy of the measurements. Many people would have said that this was good enough, and gone on to do something else. But it was not good enough for Kepler, who believed that the fit must be exact, within the uncertainties of the measurements. So he toiled on and on for years, until he finally realized that he could never get the circle to fit. Then he tried an ellipse, and now the orbit could be fitted. This was a breakthrough that made possible Newton's work on the planetary orbits, when he showed from his theory of celestial dynamics that they must indeed be ellipses.

This vital stage in the development of science was made possible by the strong belief in the order of nature. This is what led Whitehead to say, in his Lowell lectures in 1925 (Whitehead, 1926, p. 17) that 'the Middle Ages formed one long training of the intellect of Western Europe in the sense of order'. This by itself is not enough, and he went on:

> I do not think that I have even yet brought out the greatest contribution of medievalism to the formation of the scientific movement. I mean the inexpugnable belief that every detailed occurrence can be correlated with its antecedents in a perfectly definite manner, exemplifying general principles. Without this belief the incredible labours of scientists would be without hope. It is this instinctive conviction, vividly poised before the imagination, which is the motive power of research:– that there is a secret, a secret which can be unveiled.

He went on to ask why this conviction was so vividly implanted on the European mind, and concluded: 'My explanation is that the faith in the possibility of science, generated antecedently to the development of modern scientific theory, is an unconscious derivative from medieval theology' (ibid., p. 17). One might indeed query whether unconscious is the right word, for many of the medievals explicitly saw their work as showing forth the works of the Creator.

The change from the medieval Aristotelian view of the world to that of modern science took place gradually over several centuries. Much is attributable to the unpredictable contributions of individuals of genius, but most is understandable as an inevitable historical development. Some changes were due to direct contradictions between Aristotelian physics and Christian revelation. Thus the unique Incarnation of Christ replaced the concept of eternal recurrence or circular time by linear time with a beginning and an end, and the belief that the universe was created in time forced the abandonment of Aristotle's view that the universe was eternal. Other changes were due to observations made by Galileo and other scientists. Some of these, such as the discovery of sunspots, the mountains on the moon and supernovae directly contradicted Aristotle's view of the immutability of the celestial realm. His theories of dynamics, and in particular his belief that objects fall with velocities proportional to their masses, were also disproved by Galileo. Other discoveries, such as that of the satellites of Jupiter and the phases of Venus, provided exceptions to Aristotle's belief that everything revolves around one centre, and supported the dynamical possibility that the planets all move around the sun. The whole process of discrediting Aristotelian physics was facilitated by the increased precision of the experimental apparatus and by the development of mathematics that enabled the new knowledge to be expressed more concisely and more easily related to other knowledge.

The transition from Greek to modern physics has been graphically described by Duhem (1956, pp. 3–4, quoted in Jaki, 1984, pp. 428–9; see also Duhem, 1985):

> From the start of the fourteenth century the grandiose edifice of Peripatetic physics was doomed to destruction. Christian faith had undermined all its essential principles; observational science, or at least the only observational science that was somewhat developed – astronomy – had rejected its consequences. The ancient monument was about to disappear; modern science was about to replace it. The demolition of Aristotelian physics was not a sudden collapse; the construction of modern physics did not take place on a terrain where nothing was left standing. From one to the other the passage took place by a long sequence of partial transformations of which each pretended to retouch or enlarge some piece of the edifice without changing anything of the ensemble. But when all these modifications of detail had been made, the human mind perceived, as it sized up with a single look all that long work, that nothing remained of that ancient palace and that a new palace rose in its place. Those who in the sixteenth century took stock of this substitution of one science by another were seized by a strange illusion. They imagined that this substitution was sudden and that it was their own work. They proclaimed that Peripatetic physics had just collapsed under their blows and that on the ruins of that physics they had built, as if by magic, the clear abode of truth. About the sincere illusion or arrogantly wilful error of these men, the men of subsequent centuries were either the unsuspecting victims or sheer accomplices. The physicists of the sixteenth century were celebrated as creators to whom the world owed the renaissance of science. They were very often but continuers and sometimes plagiarisers.

It was Duhem (see Jaki, 1984, 1991) who was primarily responsible for uncovering the evidence for the birth of modern science in the Middle Ages. He was a theoretical physicist working mainly in the field of thermodynamics, but had always been interested in the history of science. He was asked to write a series of articles on the history of dynamics, and easily wrote the first one on the ideas of the ancient Greeks. Like most historians of science at that time, he expected to pass rapidly over the Middle Ages to the giants of the Renaissance. But he was a careful man, not content to rely on secondary sources. He found obscure references to the work of Jordanus de Nemore and, following them up, primarily in the archives of the Sorbonne in Paris, he discovered the work of Buridan and his pupil Oresme, and of many other medievals who contributed to the origin of science.

Duhem subsequently wrote two volumes on the history of mechanics, three on Leonardo da Vinci, and then began a monumental account of the history of science in ten volumes, the *Système du Monde*. The first volume, devoted to the Greeks, was published in 1913, and was highly praised by the historian of science George Sarton, founder and editor of the journal *Isis*, who said that he looked forward eagerly to the second volume. When, however, he read the second volume, he realized that what Duhem had found was highly uncongenial to his secularist beliefs. Duhem left him in no doubt whatever. Writing on the Doctrine of the Great Year, the belief that history continually repeats itself in a series of unending cycles, he said:

> To the construction of that system all disciples of Hellenistic philosophy – Peripatetics, Stoics, Neo-Platonists – contributed; to that system Abu Masar offered the homage of the Arabs; the most illustrious rabbis, from Philo of Alexandria to Maimonides, have accepted it. To condemn it and to throw it overboard as a monstrous superstition, Christianity had to come. (Duhem, 1915, p. 390, quoted in Jaki, 1984, p. 403)

Sarton did not try to refute Duhem; that would have been impossible. Instead he used the one remaining weapon, that of silence. None of the following volumes were reviewed in *Isis*, and the name Duhem was hardly ever mentioned. In Sarton's own vast volumes on the history of science Duhem received very few mentions, whereas quite minor figures receive extensive discussion. The weapon of silence is still in use today in certain scholarly circles.

Tragically, Duhem died in 1916 when only five volumes of his *Système du Monde* had been published. Duhem left the text of the remaining five volumes in MSS, and the publisher was bound by the terms of the contract to publish them in successive years. The secularist establishment was, however, bitterly opposed to their publication, and succeeded in preventing this for forty years, despite the continuing efforts of his colleagues and of his daughter Hélène (Jaki, 1992). Only the death of his most determined opponent, and the threat of legal action, finally forced the publishers to act, and the remaining volumes were published in 1954–57.

Duhem is now recognized as the pioneer of the history of medieval science, and indeed as the founder of the history of science as a scholarly discipline. Clagett (1979, quoted by Truesdell, 1984, p. 175) has remarked that 'so rich were Duhem's investigations ... that ... the succeeding study of medieval mechanics has been largely devoted to an extension or refutation of Duhem's work'. His work on medieval science has been continued by many scholars, such as Alistair Crombie, J. H. Randall, Marshall Clagett, Anneliese Maier, Edward Grant, E. A. Moody, Charles Haskins and Dana Durand, who have generally confirmed his work, while correcting it in details. It is thus no longer possible to ignore the scientific work carried out in the Middle Ages that laid the foundations of modern science.

While Duhem's achievement in revealing the development of medieval science is beyond dispute, there remains the question of the contribution attributable to Christian theology. The medieval philosophers and theologians were themselves Christians, but it can be asked whether there is a connection between their personal beliefs and their scientific work.

The beliefs about the material world that form the essential basis of science came from the Greeks and the Hebrews, and these were later reinforced by specifically Christian beliefs. Modern science began in the High Middle Ages when for the first time in history there was a society permeated by these beliefs. It is thus plausible to see a connection between these events and, following Duhem, many writers have supported this thesis (for example Caldin, 1949; Foster, 1934–36; Hesse, 1954; Hooykaas, 1972; Jaki, 1974, 1978, 1984, 1988; Smethurst, 1955), while others have rejected it (Gruner, 1975).

Coincidence in time is insufficient to prove a causal relationship, and so many studies have been made of possible causal influences such as the link between the work of Buridan and the doctrine of creation already mentioned.

Account should also be taken of several aspects of Christian teaching that seem to militate against scientific study. Christianity teaches that the purpose of our lives concerns our spiritual destiny, and all else is frivolous distraction, to be avoided as perilous for our salvation. The natural world may be contemplated as the work of God, but not brutally assaulted by scientific experiments. Against this, one may argue that it may be our Christian duty to study the world, and for the scientist contemplation is not only thinking about God, but also thinking about His works in the light of present knowledge. This is the typical activity of theoreticians and leads to theories that can be tested by further experiments. For Aquinas, the active life follows from contemplation, but the active life is also a preparation for the contemplative life. This exactly parallels the interaction between theory and experiment that lies at the heart of scientific research.

Augustine was interested in the natural world mainly because it provided signs to spiritual truths, and he also realized that it is essential for Christians to be familiar with the science of the day so that they can meet attacks on the faith. Scientific studies lead to knowledge of the works of the Creator, and many scientists are motivated by this consideration. To believe that matter is evil would make science psychologically impossible: this is the Manichean heresy condemned by the Church. Scientific study must be undertaken for its own sake for it to be fruitful. Subsequently its results may be found to have practical applications that can be welcomed, but this possibility cannot be the initial motive power of research.

While it has happened historically that Christian beliefs contributed to the rise and development of science, it remains possible that the necessary beliefs could have been obtained in different ways. Neither can it be reasonably said that the Greek, Hebrew and Christian beliefs inevitably led to modern science. Modern science was reached by a rather narrow path that depended on a series of unlikely features of the world and also on the unpredictable genius of its founders.

Science in Eastern Christendom

This explanation of the rise of science in Western Europe during the High Middle Ages as due to the beliefs concerning the material world inherent in Christian theology raises the question why it happened in Western Europe and not in Eastern Europe, where Christianity also flourishes. One might indeed have expected science to arise first in the East, because it was the heir to the wisdom of ancient Greece, preserved and to some extent developed by Arab scholars. Thus from the eighth to the fourteenth centuries mathematics, astronomy, optics, physics and medicine were far more developed in Islamic countries than in Western Europe. In one vital area, for example, Arabic astronomers had so improved the Ptolemaic system that it was mathematically equivalent to the Copernican system, although it was still geocentric. And yet the lead was lost in one area after another as the West surged ahead and Arabic science decayed. This learning came to the West not via Eastern Christendom, but mainly through translations from the Arabic made in Spain. The Byzantine scientific tradition lacked originality, being content with the achievements of the Greeks and the Romans. Byzantine scientists were thus unable to develop technology and to apply their theoretical knowledge for practical purposes.

Could the explanation of the difference between the vitality of science in the West and its virtual absence in the East be due to a difference between Eastern and Western theologies, or are there other explanations, perhaps in terms of sociological factors, which themselves may or may not have their origin in theology?

The theological beliefs of Eastern and Western Christendom are essentially the same, but there are important differences at the conceptual and practical levels. These differences are difficult to describe, because there are many counter-examples to any general statement that can be made. Thus both attach high value to reason and to prayer, but the emphasis is different. In the West, scholarly work is itself considered to be a form of prayer. Orders of friars, such as the Dominicans, were founded to preach, and to teach in schools and in universities, and their times of prayer are regulated to allow time for study. Dominicans such as Thomas Aquinas taught in the universities and used reason to find out what they could about God, thus developing scholastic theology. In the monasteries of the East, the monks spend long hours in contemplative prayer and thus attain a knowledge of God, but as a result they inevitably have less time for study and for writing.

Of great importance for the origin of science is the concept of time. Before the advent of science our activities followed biological time, governed by the natural processes of night and day, the phases of the moon and the progression of the seasons. In contrast, scientific time is a regular sequence, and to each instant there corresponds a number, measurable to high accuracy. Monasteries need to have a way of marking the time to regulate the hours of prayer and work. Initially they followed biological time, supplemented by sand and water clocks. In the Western monasteries, clocks of high sophistication were developed as early as the twelfth century, whereas clocks, imported from the West, were not used on Mount Athos until the eighteenth century. Even now, the East has a more relaxed sense of time.

The use of biological time is associated with primitive technology, whereas more developed technology comes with scientific time. Thus the larger Western monasteries made many technological advances for domestic and industrial purposes, such as watermills and saws. This is of crucial importance for the development of science.

There are also several sociological reasons why science arose in the West and not in the East. It is essential for creative intellectual work that there are places where it can be carried on without external interference, so that the people there are free to think what they like and to follow wherever their reason leads them. Such opportunities are provided by universities, and many were founded in the West from the twelfth century onwards. The crucial steps that led to the birth of modern science took place in the University of Paris.

In the East, there was a spectacular intellectual and artistic revival in the ninth century after the end of the iconoclastic controversy, and the University of Constantinople attracted many distinguished scholars. There was, however, little interest in science or technology.

Byzantine society was rigidly authoritarian, with Church and State closely linked. The emperor was considered the viceregent of God, and as ruler of both Church and State his word was law. There was a highly centralized state organization with a well-developed civil service, so that practically all activities were controlled by the emperor. Trade and commerce were rigidly controlled, not to serve the interests of the merchants, but to subordinate economic life to the interests of the State. There were indeed schools, but they did not encourage independent discussion, and the static conception of life was not conducive to the development of science. In the West, on the other hand, the universities were centres of intellectual discussions, where novel views were expounded and discussed.

People speak and discuss freely when they are personally secure, when they know that they can say what they like without danger of any kind. This security can be provided by belonging to an organization, such as a university, which encourages free discussions, or by a society that respects the right of private property. In the West this is legally established, whereas in the East property was held subject to the will of the ruler, and might at any time be revoked. If one lives in perpetual fear that the ruler will suddenly take away one's house, one is hardly likely to indulge in any activity that may incur his wrath.

In the twelfth century the Crusaders caused consternation in Byzantium as they passed through on their way to the Holy Land, exacerbating the age-old tensions between East and West. These came to a head with the sack of Constantinople in 1204. Byzantium survived another two hundred years, but was fatally weakened and finally fell to the Turks in 1453.

Such sociological factors are sufficient to explain why science did not arise in Eastern Christendom, and it seems that these are more important than any theological differences.

An instructive example of the effect of sociological factors on intellectual activity is provided by the contrast between the English, French and Spanish colonies in North and Central America on the one hand, and the Dutch colony in South Africa on the other. In America, there was from the first a thriving intellectual activity, with printing presses and newspapers, and great colleges and universities were founded within a few decades of the arrival of the colonists. Mexico was conquered in 1521, and by 1553 had a university. In North America, the colonists arrived in 1619, and Harvard was founded in 1636. In South Africa, on the other hand, everything was controlled by the Dutch East India Company, and profit was the only motive. There were no printing presses, newspapers, colleges or universities. The Calvinist Church was also partly to blame for this situation, because it insisted that its ministers be trained in Holland, and was not willing to establish colleges in South Africa.

Conclusions

Modern science is the fruit of many historical developments over several millennia. It was made possible first of all by the revelation to the Jews, God's chosen people, then by the intellectual achievements of the ancient Greeks and also by the gradual formation of organized and civilized societies. The Jews were the first to recognize the one supreme God, creator of an ordered world that is open to the human mind. The Greeks asked the fundamental questions about the natural world and laid the foundation of the mathematical language that must be used to answer them. The growth of civilized societies provided the essential stability and order without which science is impossible. Yet all this, great and impressive though it is, was not enough to establish science as the ongoing self-sufficient activity that we know today. The destruction of the belief in eternal recurrence that prevented the rise of science in all ancient cultures was the unique achievement of Christianity. It was only in the Middle Ages, in a society permeated by Christian beliefs, that modern science was finally born. The Church founded the universities, where free discussion could take place, and fostered a culture that encouraged interest in the natural world. The pioneers of science were inspired to reveal God's world and thereby to give Him glory, and were conscious of the organic connection between their Christian beliefs and their scientific work. Their Christian beliefs furthermore encouraged them to apply the fruits of their work for the benefit of their fellow men. Modern science never developed in pre-Christian cultures, and it is stifled in cultures that have rejected or ignored their Christian heritage.

This brief survey shows that there are many factors of importance for the rise of science: material, sociological and theological. The material conditions are found in many civilizations, but on their own are not decisive. A very special set of beliefs about the material world is necessary before science can begin, and these beliefs are provided by Christian theology. For science to develop, society must encourage the freedom of thought, and this partly depends on sociological factors, which are themselves often determined by theological beliefs. In all these ways, Christian theology has proved decisive for the birth and development of modern science (see Templeton and Herman, 1989, p. 8).

It cannot be proved that modern science could not have developed in the absence of Christian beliefs about the material world. As it is, they played an important role in bringing about the transition from the science of the ancient Greeks to the physics of the modern world.