A. C. Crombie, *The History of Science from Augustine to Galileo*. 2 vol. New York: Dover, [1959, 1970, 1979] 1995.

2026—Complied by James D. Nickel

"Led by Voltaire, the rationalist historians of the 18th century discounted any possibility of a connexion between medieval philosophy and the triumph of scientific reason which they located in the period of Galileo, Harvey, Descartes and Newton" (1:23).

"It was the Greeks who invented science as we now know it. In ancient Babylonia, Assyria and Egypt, and in ancient India and China, technology had developed on a scale of sometimes astonishing effectiveness, but so far as we know it was unaccompanied by any conception of scientific explanation" (1:24).

"… it remained a characteristic of Greek scientific thought to be interested primarily in knowledge and understanding and only very secondarily in practical usefulness" (1:25).

"With the rise of Christianity, to this Greek rationalism was added the idea of nature as sacramental, symbolic of spiritual truths, and both attitudes are found in St. Augustine" (1:25).

"In Western Christendom during the early Middle Ages men were concerned more to preserve the facts which had been collected in classical times than to attempt original interpretations themselves. Yet, during this period, a new element was added from the social situation, an activist attitude which initiated a period of technical invention and was to have an important effect on the development of scientific apparatus" (1:25).

"The mathematics and logic of the Latin West rested on the work of the 6th-century Boethius … compiled elementary treatises on geometry, arithmetic, astronomy and music" (1:31).

"The gradual penetration of the barbarians into the Western Roman Empire from the 4th century had caused some material destruction and eventually serious political instability, but it was the eruption of the Mohammedan invaders into the Eastern Empire in the 7th century that gave the most serious blow to learning in Western Christendom" (1:32).

"That so much was preserved in spite of the gradual collapse of roman political organization and social structure under the impact, first, of Goths, Vandals and Franks, and then, in the 9th century, of Norsemen, was due to the appearance of monasteries with their attendant schools which began in eastern Europe after the foundation of Monte Cassion by St Benedict in 529 (here St Benedict had also established an infirmary. The care of the sick was regarded as a Christian duty for all such foundations). The existence of such centres made possible the temporary revivals of learning in Ireland in the 6th and 7th centuries, in Northumbria in the time of Bede, and in Charlemagne's empire in the 9th century" (1:32).

"Plato … eternal forms or ideas existed quite apart from any material object" (1:33).

"In general the learning of Western Christendom … was predominantly theological and moral" (1:34).

"… natural knowledge continued to be considered of very secondary importance during the early Middle Ages … The study of nature was not expected to lead to hypotheses and generalizations of science but to provide vivid symbols of moral realities" (1:35).

Adelard, "I do not detract from God. Everything that is, is from him and because of him. But [nature] is not confused and without system and so far as human knowledge has progressed it should be given a hearing. Only when it fails utterly should there be recourse to God" (1:45).

"With this remark the medieval conception of nature began to cross the great watershed that divides the period when men looked to nature to provide illustrations for moralizing from that in which men began to study nature for its own sake" (1:45).

According to Thierry of Chartes (d.c. 1150) in his *De Septem Diebus et Sex Operum Distinctionibus*, "it was impossible to understand the story of *Genesis* without the intellectual training provided by the *quadrivium*, that is without the mastery of mathematics, for on mathematics all rational explanation of the universe depended" (1:46).

"In St Augustine's writings, the demiurge had been replaced by the Christian God, and the forms given to the material world were reflections of the eternal ideas existing in the mind of God" (1:46).

Ptolemaic theory of the heavens: "each of the spheres had its own Intelligence or 'soul' which was the source of its motion" (1:49).

"In the field of mathematics the Arabs transmitted to Western Christendom a body of most valuable knowledge which had never been available to the Greeks, though here the Arabs were not making an original contribution but simple making more widely known the developments in mathematical thought which had taken place among the Hindus" (1:65).

"The Hindu mathematicians … had developed a system of numerals in which the value of a digit was shown by its position. They knew the use of zero, they could extract square and cube roots, they understood fractions, problems of interest, the summation of arithmetical and geometrical series, the solution of determinate and indeterminate equations of the first and second degrees, permutations and combinations and other operations of simple arithmetic and algebra. They also developed trigonometrical technique for expressing the motions of the heavenly bodies and introduced trigonometrical tables of sines" (1:65).

"The most important mathematical idea which the Arabs learnt from the Hindus was their system of numerals, and the adoption of this system in Christendom was one off the great advances in European science" (1:65).

"During the 13th and 14th centuries the knowledge of Arabic numerals was spread through Western Christendom by the popular almanacs and calendars" (1:67).

"St Thomas realized … that theology and natural science often spoke of the same thing from a different point of view, that something could be both the work of Divine Providence and the result of a natural cause. In this way they established a distinction between theology and philosophy which assigned to each its appropriate methods and guaranteed to each its own sphere of action. There could be no real contradiction between truth as revealed by religion and truth as revealed by reason" (1:78).

"Latin Averroïsts took their stand on the irrefutable rational truth of Aristotelian philosophy and accepted the consequence that Christian theology was irrational or even untrue" (1:76). This 'determinist' interpretation was condemned by Etienne Tempier, Bishop of Paris in 1277. With this condemnation "that Aristotle had said the last word on metaphysics and natural science, the bishops in 1277 left the way open for criticism which would, in turn, undermine his system" (1:78-79). Natural philosophers "because of the attitude of Christian theologians … were made free to form hypotheses regardless of Aristotle's authority, to develop the empirical habit of mind working within a rational framework, and to extend scientific discovery" (1:79).

re. C13, "The Western scholars were trying to make the natural world intelligible and they seized upon the new knowledge [the Greco-Arabic scientific system] as a wonderful, but not final, illumination of mind and as a starting-point for further investigation" (1:80).

"Mathematics, being an abstraction from change, could provide no knowledge of the *cause* of the observed events. It could merely describe their mathematical aspects" (1:83).

"Indeed, from one point of view, the whole history of European science from the 12th to the 17th century can be regarded as a gradual penetration of mathematics (combined with the experimental method) into fields previously believed [as per Aristotelianism] to be the exclusive preserve of 'physics'" (1:89).

"Aristotle's cosmology was founded on naïve observation and common sense and it had two fundamental principles: (1) that the behaviour of things was due to qualitatively determined forms or 'natures,' and (2) that the totality of these 'natures' was arranged to form a hierarchically ordered whole or cosmos" (1:89).

"All ancient and medieval systems of astronomy were based on Plato's dictum that the observed movements of the heavenly bodies must be resolved into uniform circular motions" (1:93).

"The completely heliocentric system of the 3rd century B.C. by Aristarchus of Samos was not known in the Middle Ages, although it was known, for example to Aquinas, that Aristarchus had taught such a system" (1:103).

"The astrolabe was the chief astronomical instrument of both the Arab and the Latin astronomers of the Middle Ages and was known as 'the mathematical jewel'" (1:104).

"During the first half of the 14th century an important school of astronomy grew up also at Oxford, in particular at Merton College. One of the results of the work there was the development of trigonometry … John Maudith (1310) and Richard of Wallingford (c. 1292-1335) are the initiators of Western trigonometry…. An important improvement in technique adopted by these writers was to use the Hindu-Arabic practice, already found in the tables of al-Zarqali and other astronomical tables in wide circulation, of basing plane trigonometry on sines instead of chords, as had been done in the old Greco-Roman tradition dating from Hipparchus" (1:110).

"Theodoric or Dietrich of Frieberg (d. 1311), whose work on refraction and on the rainbow is an outstanding example of the use of the experimental method in the Middle Ages" (1:122).

"One effect of this view of the special position of man in the universe was to emphasize the sacramental aspect of his scientific activities, to show that he, before all other creatures, was

in a position to worship the Creator of this great chain of being stretching above and below him, in which each thing existed to fulfil its own nature in its special place and all to praise the Lord" (1:181).

Vincent of Beauvais (C13 botanist and zoologist), *Speculum Majus*, prologue, chapter 6: "I am moved with spiritual sweetness towards the Creator and Ruler of this world, because I follow Him with greater veneration and reverence, when I behold the magnitude and beauty and permanence of His creation" (1:181).

"The free speculation which resulted led to radical criticisms of many of the fundamental principles accepted in the 13th century, even of propositions whose acceptance then seemed necessary to the Christian religion itself…; even, indeed, though radical views led to an occasional brush with ecclesiastical authority. Within natural science perhaps the most fundamental advance made as a result of these criticisms was in scientific method and the conception of scientific explanation, and this, together with the development of technology, formed the double track that led across the watershed of the 14th century and with many turns to the 16th and 17th century world" (1:182).

"It has often been pointed out that science develops best when the speculative reasoning of the philosopher and mathematician is in closest touch with the manual skill of the craftsman" (1:183).

"The practical arts were certainly despised by the majority of the most highly educated people in classical antiquity, and were held to be work for slaves" (1:183).

"… technics … more accurate measuring instruments and special apparatus" (1:184).

"… they had an abstract desire for power over nature such as Roger Bacon had expressed, but also that they were capable of getting the kind of knowledge that would lead to results useful in practice (e.g., spectacles in C14)" (1:186).

"An important result of this mathematical training received in medieval education was that it encouraged the habit of expressing physical events in terms of abstract units and emphasized the need for the standardization of systems of measurement. Without this habit of thought mathematical physics would be impossible" (1:190).

Polyphony (1:191-193).

Greek mechanical inventions (1:195).

"… it is characteristic of medieval Christendom that it put to industrial use technical devices which in classical society had been known but left almost unused or regarded simply as toys" (1:196).

Medieval Industrial Revolution (1:196-202).

"Perhaps because of changed economic conditions, perhaps because of the opposition of the Church, slave labour, which was the basis of classical industry, had become increasingly scarce in the early Middle Ages. The new methods of harnessing animal power, and the increasing exploitation of water- and wind-power, came to make slavery unnecessary" (1:203).

"The mechanical devices and instruments invented in classical times, pumps, presses and catapults, driving wheels, geared wheels and trip hammers, and the five kinematic 'chains'

(screw, wheel, cam, ratchet and pulley) were applied in the later Middle Ages on a scale unknown in earlier societies" (1:203).

"The combined crank and connecting-rod was a medieval invention. Though it is difficult to trace its later history, this mechanism had certainly come into general use by the 15th century. With the crank it became possible for the first time to convert reciprocating into rotary motion and *vice versa*, a technique without which modern machinery is inconceivable" (1:203).

"These were the strategic inventions in printing and with them the multiplication of books on a large scale became possible" (1:209).

Clock … "The adoption of this system [60 minutes to the hour, 60 seconds to the minute] of division completed the first stages in the scientific measurement of time, without which the later refinements of both physics and machinery would scarcely have been possible" (1:219).

"The foundation of large numbers of charitable hospitals for the relief of the poor and treatment of the sick was a product of Christian civilization" (1:241).

Medieval inventiveness … "Behind this inventiveness lay, without a doubt, the motive of physical and economic necessity; but, as Lynn White has pointed out in an article to *Speculum* in 1940, 'this "necessity" is inherent in every society; yet has found inventive expression only in the Occident.' Necessity can be a motive only when it is recognized, and among the most important reasons for its recognition in the West must be included the activist tradition of Western theology. By asserting the infinite worth of responsibility of each person, this theology placed a value upon the care of each immortal soul and therefore upon the charitable relief of physical suffering, and gave dignity to labour and a motive for innovation. The inventiveness that resulted produced the practical skill and flexibility of mind in dealing with technical problems to which modern science is the heir" (1:242-243).

Later Middle Ages and Aristotle, "The most important of these weapons were made by new ideas on scientific method, especially by new ideas on induction and experiment and on the role of mathematics in explaining physical phenomena" (2:17).

"The methods of multiplying and dividing used by the Hindus and Moslems had been very uncertain. The modern method of multiplication was introduced from Florence, and the modern technique of division was also invented during the later Middle Ages. This made division into an ordinary matter for the counting house, whereas it had formerly been a formidably difficult operation even for skilled mathematicians" (2:22).

C13 – "They began to form the conception of natural science as in principle *inductive and experimental as well as mathematical***,** and they began to develop the logical procedures of experimental inquiry, which chiefly characterize the difference between modern and ancient science" (2:23).

"Bur for one reason or another Arabic science failed to become thoroughly experimental in outlook [although some experimentation was made], though it was certainly the example of Arab work that stimulated some of the experiments made by Christian writers, for instance Roger Bacon and Theodoric of Freiberg…" (2:25).

"With Roger Bacon the programme for mathematicizing physics and a shift in the object of scientific inquiry from the Aristotelian 'nature' or 'form', to laws of nature in a recognizably modern sense, becomes explicit" (2:39).

"Scotus [John Duns, ca. 1266-1308) said that the certainty of the causal laws discovered in investigating the physical world was guaranteed by the principle of the uniformity of nature, which he regarded as a self-evident assumption of inductive science" (2:43).

"The effect on philosophy in general of this search for evident knowledge was to divert interest within the discussions of the schools away from the traditional problems of metaphysics to the world of experience. Ockhamite nominalism or, as it may more properly be called, 'terminism', went to show that in the natural world all was contingent and therefore that observations were necessary to discover anything about it" (2:48).

"Ockham himself firmly divorced theology from philosophy, the former deriving its knowledge from revelation and the latter from sensory experience, from which alone it took its origin" (2:48).

"Indeed, since the 14th century the stream of sceptical empiricism has flowed strongly in European philosophy, and it has done its work of directing attention to the conditions of human knowledge which has produced some of the most important clarifications of scientific methodology" (2:49).

"These discussions of infinity and other problems, such as the maximum resistance a force could, and the minimum it could not overcome, laid the logical basis of the infinitesimal calculus. Medieval mathematics was limited in range and it was only when humanists had drawn attention to Greek mathematics, and especially to Archimedes, that the mathematical developments which actually took place in the 17th century became a possibility" (2:56).

"The Christian Neo-platonist, John Philoponus of Alexandria, writing in the 6th century A.D., had also rejected both Aristotle's and the atomists' laws regarding falling bodies and maintained that in a void a body would fall with a finite velocity characteristic of its gravity, while in air this finite velocity was decreased in proportion to the resistance of the medium" (2:65). This theory has been claimed by Duhem to be "the origin of certain medieval conceptions that have been supposed in turn to have given rise to the modern conception of inertia, which was to be the basis of the revolution in dynamics in the 17th century (2:66). According to Crombie, the writings of Philoponus were not known in the Middle Ages (2:74).

"One of the most important changes facilitating the increasing use of mathematics in physics was that introduced by the theory that all real differences could be reduced to differences in the category of quantity … This change was what chiefly distinguished the mathematical physics of the 17th century from the qualitative physics of Aristotle. It was begun by the scholastics of the later Middle Ages. As with so many scientific concepts in the Middle Ages, the problem was first discussed in a theological context and then principles worked out there were later applied to physics" (2:97).

"… it is nevertheless possible to see in the 14th-century discussions the origins of some of the most powerful procedures of mathematical physics that became fully effective only in the 17th century. At the same time motion, where the statically conceived Greek geometry had been impotent, was first treated mathematically, thus leading to the foundation of the science of kinematics, that is, the analysis of movement in terms of distance and time" (2:100).

"The new methods of mathematical physics were developed in the first place in connexion with the idea of functional relationships. This is the natural complement of a systematic conception of concomitant variations between cause and effect; by expressing the

phenomenon to be explained (the dependent variable as we now call it) as an algebraic function of the conditions necessary and sufficient to produce it (the independent variables), it can be shown precisely how changes in the former are related to changes in the later. To be effective in practice the method depends on making systematic measurements, and these were few and far between before the 17th century … In the 14th century the idea of functional relationships was developed without actual measurements [exceptions: astronomy and refraction of light] and only in principle … (2:101).

"Two main methods of expressing functional relationships were developed. The first was the 'word-algebra' used in mechanics by Bradwardine at Oxford, in which generality was achieved by the use of letters of the alphabet instead of numbers for the variable quantities, while the operations of addition, division, multiplication, etc. performed on these quantities were described in words instead of being represented by symbols as in modern algebra (2:101).

"It was this conception of the relationship between the *intensio* and *extensio* of forms that gave rise to the second method of expressing functional relationships in the 14th century, a geometrical method by means of graphs" (2:103). This had been familiar to geographers and astronomers since classical times (2:103).

Intensio (latitude): *y*-axis (dependent variable: e.g., velocity or heat) or vertical straight line

Extensio (longitude): *x*-axis (independent variable: e.g., time) or horizontal straight line

The first to use this was John of Dumbleton (fl. ca. 1331-1349): "He began the analysis of some basic questions of optics that were only answered in the 17th century. He said that the intensity of illumination at a given point was directly proportional to the strength of the luminous source and inversely proportional to the 'density' of the medium" (2:104—very close to the photometric inverse square law formulated by Kepler in 1604, "intensity or illumination is proportional to the inverse square of the distance from the source" (2:104).

Oresme made striking advances in this area: He also "conceived the notion of fractional powers (later developed by Stevin) and gave rules for operating them. He anticipated Descartes in the invention of analytical geometry" (2:104).

Oresme introduced "into geometry … the idea of motion which Greek geometry had lacked" (2:105).

"The 14th century attempt to express the quantitative equivalent of qualitative differences led to genuine discoveries concerning both mathematics and physical fact. The latter were extended by the encouragement give to physical measurement, although here ideas were ahead of practical possibilities determined by the scope and accuracy of available instruments" (2:109).

"… the division of the hour into minutes and seconds was in use early in the 14th century" (2:110).

"Johannes Müller or Regiomontanus (1436-1476) "computed a table of sines (instead of chords) for every 10′ … and … wrote a systematic treatise on trigonometry which was to have a great influence, computing a table of sines for every minute and a table of tangents for every degree" (2:113).

"Many scholars now agree that 15th century humanism which arose in Italy and spread northwards, was an interruption in the development of science. The 'revival of letters' deflected interest from matter to literary style and, in turning back to classical antiquity, its devotees affected to ignore the scientific progress of the previous three centuries" (2:115).

"This literary movement performed some important services for science. Ultimately perhaps the greatest of these was the simplification and clarification of language, although this occurred mainly in the 17th century when it applied particularly to the French, but also, under the influence of the Royal Society, to English" (2:115-116).

Summarization of the principal original contributions during the Middle Ages to the development of natural science in Europe (2:117-120):

1. Scientific method (recovery of Greek idea of theoretical explanation especially the 'Euclidean' form of such explanations and its use in mathematical physics) raised the problems of how to construct and to verify or falsify theories. Developed the use of induction and experiment (imaginary and with equipment).
2. Extension of mathematics to the whole of physical science (in principle if not in fact) using quantitative measurement.
3. Radically new approach to the question of space and motion (Greek mathematics was the mathematics of static forms). Ideas that space might be infinite and void, and the universe without a centre, undermined Aristotle's cosmos with its qualitatively different directions and led to the idea of relative motion. The theory of impetus was used to explain many different phenomena, for instance the motion of projectiles and falling bodies, bouncing balls, pendulums and the rotation of the heavens or the earth. Discussions of the nature of a continuum and of maxima and minima began also in the 14th century.
4. Remarkable progress in technology: new methods of exploiting animal-, water- and wind-power, new machines were developed for a variety of purposes, often requiring considerable precision. Some of the inventions—the mechanical clock and magnifying lenses—were to be later used as scientific instruments. Astrolabe and quadrant were greatly improved as a result of the demand for accurate measurement. In chemistry, the balance came into general use.
5. Nature and purpose of science: (1) to gain power over nature useful to man, (2) neither God's action nor man's speculation could be constrained within any particular system of scientific or philosophical thought. This brought out the relativity of all scientific theories and the fact that they might be replaced by others more successful in fulfilling the requirements of the rational and experimental methods.

"Thus the experimental and mathematical methods were a growth, developing within the medieval system of scientific thought, which was to destroy from within and eventually to burst out from Aristotelian cosmology and physics. Though resistance to the destruction of the old system became strong among certain of the late scholastics, and especially among those whose humanism had given them too great a devotion to the ancient texts and those by who the old system had been too closely linked with theological doctrines, there can be little doubt that it was the development of these experimental and mathematical methods of the 13th and 14th centuries that at least initiated the historical movement of the Scientific Revolution culminating in the 17th century (2:120-121).

End of 14th and entire 15th century: interest and intellectual originality were directed towards literature and the plastic arts rather than towards natural science (2:121).

C17: "Did the "physico-mathematical Experimental Learning' of the early Royal Society spring unheralded from the heads of Galileo and Harvey and Francis Bacon and Descartes? … a more accurate view of 17th-century science is to regard it as the second phase of an intellectual movement in the West that began when the philosophers of the 13th century read and digested in Latin translation the great scientific authors of classical Greece and Islam" (2:121-122).

The printing press made the principal medieval scientific writings available to 17th century scientists (2:122).

"The central doctrines of medieval science developed almost entirely within the context of academic discussions based at some stage, near or far, on the books used in university teaching" (2:125).

"It is true that the application of academic sciences, such as of astronomy in determining the calendar and making proposals for its reform, or of arithmetic in the work of the exchequer and of commercial houses, or of anatomy and physiology and chemistry in surgery and medicine, were put into practice outside the universities. It is true also that in other fields outside the university system altogether, for example in technology of different kinds and in art and architecture with their increasing tendency to naturalism, developments took place that were to be of profound importance for science" (2:125).

"… it was within a general framework of philosophy closely bearing on theology, and specifically within the system of university studies run by clerics, that the central development of medieval science took place" (2:126).

"…. But medieval natural philosophers were *primarily* interested less in the concrete problems of the world of experience than in the *kind of knowledge* nature science was, how it fitted into the general structure of their metaphysics, and, if it extended so far, how it bore on theology" (2:127).

"It was through taking these seriously, through paying attention to the detailed facts of experiment and measurement and mathematical functions actually exemplified in nature, that the 17th century scientists were led to their radical revolution in the whole theoretical framework of physics and cosmology, where the medieval natural philosophers had only revised some limited sections" (2:129).

"Perhaps the most powerful feature of the medieval philosophy of science that remained strongly influential in the early 17th century was the Neoplatonic conception that nature was ultimately to be explained by mathematics" (2:129).

Scientific Revolution: "it came about by men asking questions within the range of an experimental answer, by limiting their inquiries to physical rather than metaphysical problems, concentrating their attention on accurate observation of the kinds of things there are in the natural world and the correlation of the behaviour of one with another rather than on their intrinsic natures, on proximate causes rather than substantial forms, and in particular on those aspects of the physical world which could be expressed in terms of mathematics. Those characteristics that could be weighed and measured could be compared, could be expressed as a length or number and thus represented in a ready-made system of geometry, arithmetic or

algebra, in which consequences could be deduced revealing new relations between events which could then be verified by observation" (2:131).

(2:132-134) Milieu of thrusts that produced the Scientific Revolution: interaction between motives, opportunities, technical skills, and intellectual changes (you cannot pin the thrust on one only; they all worked together and they all worked together in a *biblical* framework).

Algebra and geometry (2:138-139).

"In his use of 'thought experiments'—but not of impossible imaginary experiments – Galileo also carried on established practices. But he made one advance of the greatest importance. He insisted, at least in principle, on making systematic, accurate measurements, so that the regularities in phenomena could be discovered quantitatively and expressed in mathematics" (2:148).

"It was by his insistence on measurement and mathematics that Galileo combined his strictly experimental method with the second main characteristic of his new approach to science. This was to try to express the observed regularities in terms of a mathematical abstraction, of concepts of which no exemplaries need actually be observed but from which the observations could be deduced. From its consequences the hypothetical abstraction could then be tested quantitatively. Galileo's method of abstraction was explicitly an adaptation of the postulational method of Archimedes and Euclid. It was of revolutionary importance both for his own work and consequently for the whole history of science" (2:149).

"The faith that inspired nearly all science until the end of the 17th century was that it discovered a real intelligible structure in objective nature, an *ens reale* and not merely an *ens rationis*. Kepler believed himself to be discovering a mathematical order which provided the intelligible structure of the real world" (2:151).

"Plato had held that the physical world was a copy or likeness of a transcendent ideal world of mathematical forms; it was an inexact copy and so physics was not absolute truth but, as he put it in the *Timæus*, 'a likely story'. Galileo by contrast asserted that the real physical world actually consisted of the mathematical entities and their laws, and that these laws were discoverable in detail with absolute certainty" (2:152).

Copernicus, et al. (2:180-185).

Francis Bacon (2:290).

"In the *Advancement of Learning* Bacon declared the true end of scientific activity to be the 'glory of the Creator and the relief of man's estate'. Echoing this, the second charter of the Royal Society, which received the Great Seal on 22 April 1663 and by which the Society is still governed, laid down that the investigations of its Fellows 'are to be applied to further promoting by the authority of experiments the sciences of natural things and of useful arts, to the Glory of God the Creator, and the advantage of the human race'" (2:298). cf. Westminster Confession of Faith (1646).

"The Aristotelian system came into circulation accompanied by the Averroïstic doctrines that the universe was a necessarily determined [determinism] emanation from God's reason, instead of a free creation of his will as Christian theology taught; that the ultimate rational causes of things in God's mind could be discovered by the human reason; and that Aristotle had in fact discovered those causes, so that the universe must necessarily be constituted as he

had described it, and could not be otherwise. By means of the Christian doctrines of the inscrutability and absolute omnipotence of God, the 13th century theologians and philosophers liberated rational and empirical inquiry into laws that nature in fact exhibits from this absolute subjection to a metaphysical system" (2:318).

"The advance of science did in fact give rise to materialist metaphysics, naïve certainly but to become nevertheless influential in the 18th and 19th centuries, and by definition anti-theological. The God of the scientists, of Boyle, the 'intelligent and powerful being' praised by Newton in the *Principia*, when taken over by the 18th century Deists, no longer gave any primacy or uniqueness to Christianity among the religions. Most corrosive of all, the 'fictionalist' or 'conventionalist' policy adopted by Descartes and pressed forward by Berkeley, became in the hands of secular philosophers like David Hume (1711-1776), and of Immanuel Kant (1724-1804), the source of a doctrine that was anti-rational and anti-theological alike. Applied universally, as it inevitably was, it ceased to be a defence of theology against science and became a threat to all knowledge, whether rational or revealed. The way was open to the explicitly anti-theological and anti-metaphysical positivism of Auguste Comte (1798-1857) and John Stuart Mill (1806-1873), and to the agnosticism of T. H. Huxley, which became so characteristic a part of the philosophical ambience of science in the 19th century. This was a consequence of the influence of their intellectual careers in which neither Galileo nor Descartes would have any pleasure, yet in some degree both foresaw it" (2:320).

"Hume, the 18th century Ockham, went even further that Berkeley in claiming that science was irrational and that explanation was strictly speaking impossible" (2:330).

"Kant found himself able to admit Newtonian science as true only at the price of denying that it had discovered a real world of nature behind the world of appearance … scientific laws are dictated by the structure of our minds" (2:330).

"It was … an easy step from Kant's view that theories are read not in but *into* nature, to Auguste Comte's assertion that the real goal of science was and always had been not knowledge at all, but only power" (2:332).

"At the beginning of the European philosophical adventure, the search for the rational intelligibility of the world as we experience it, Hesiod's Muses announced darkly: 'We know how to tell many fictions that wear the guise of truth; but we also know how to declare the truth, when we will.' Lacking the gift of oracular understanding, the men who have in fact conducted the adventure since Greek times have themselves been able to make this philosophical distinction only by searching not only for the truth but also for principles for distinguishing truth from falsehood. Ever since the Greeks took the decisive step in cosmology of looking for explanations deductively connected with the means of prediction, then step by which they established the European scientific tradition as distinct for example from Babylonian astronomy in which there was a total logical disjunction between the highly developed technological predictions and the myths that did service for explanations, the problem of finding criteria for distinguishing true explanations from false has been a pre-eminent question in the growth of science. Seeking as they did knowledge as well as utility, the Greeks established European science as a philosophical activity different both from Eastern technology which largely knew no science and from Western technology which is science applied" (2:334).

"The creative processes of original discovery and invention, always mysterious, are as little open to direct inspection as the laws of nature themselves. It is part of the philosophical enlightenment provided by the history of science to discover that the thought of great innovators whose effectiveness we admire was organized on a patten in many ways so utterly different from our own, that they accepted a complex of non-empirical conceptions and 'regulative beliefs' that, alien though they are to us, nevertheless gave construction and form to theories of the great predictive and explanatory power" (2:334)

"Putting forward theories as true, but always submitting them to the experimental test, the intuition that has governed scitific traction has been characterized by Pascal in his Pensées (395: 'Instinct, reason.—Nous avons une impuissance de prouver invincible à tout le dogmatisme. Nous avons une idée de la vérité invincible à tout le pyrrhonisme. [We have an incapacity of proof, insurmountable by all dogmatism. We have an idea of truth, invincible to all scepticism.]' Balanced between intuition and reason, between imagination and experiment, philosophical opinion in relation to science has oscillated between the extremes of scepticism and rationalism according to whether the claims to have discovered ultimate reality, putting a stop to all further inquiry, or claims that no rational knowledge is possible at all, reducing science to an irrational technology, have presented most danger to the hopes of the moment. 'For who will prescribe bounds to man's intelligence and invention?' asked Galileo, the scientific realist, in 1615. 'Who will assert that all that is sensible and knowable in the world is already discovered and known?'" (2:334-335).