*Francis Bacon, an Essay on Its Development From 1603 to 1609 With New Translations of Fundamental Texts* (Liverpool, 1964)—neither the commentary nor the newly translated texts throw much additional light on Bacon's scientific ideas during this period; Kuno Fischer, *Francis Bacon of Verulam, Realistic Philosophy and Its Age,* John Oxenford, trans. (London, 1857), which is still a useful analysis of Bacon's method but, like most nineteenth-century works (except those of Ellis and Spedding), underestimates the significance of Bacon's doctrine of spirits; Thomas Fowler, *Bacon* (London–New York, 1881), which deals with Bacon's philosophy and scientific method and their influence; W. Frost, *Bacon und die Naturphilosophie* (Munich, 1927); Mary B. Hesse, "Francis Bacon," in D. J. O'Connor, ed., *A Critical History of Western Philosophy* (New York, 1964), pp. 141–152; C. W. Lemmi, *The Classic Deities in Bacon* (Baltimore, 1933), not always accurate on Bacon's science; A. Levi, *Il pensiero di F. Bacone considerato in relazione con le filosofie della natura de Rinascimento e col razionalismo cartesiano* (Turin, 1925), one of the first detailed accounts of Bacon's relation to his immediate predecessors; G. H. Nadel, "History as Psychology in Francis Bacon's Theory of History," in *History and Theory,* **5** (1966), 275–287; M. Primack, "Outline of a Reinterpretation of Francis Bacon's Philosophy," in *Journal of the History of Philosophy,* **5** (1967), 123–132; P. Rossi, *Francesco Bacone, dalla magia alla scienza* (Bari, 1957; English trans. by S. Rabinovitch, London, 1968), which interprets Bacon's science as being heavily indebted to the natural magic tradition and his logic as indebted to Ramist rhetoric; P. M. Schuhl, *La pensée de lord Bacon* (Paris, 1949); and K. R. Wallace, *Francis Bacon on Communication and Rhetoric* (Chapel Hill, N.C., 1943).

Recent general works with extensive references to Bacon are R. M. Blake, C. J. Ducasse, and E. H. Madden, *Theories of Scientific Method: The Renaissance Through the Nineteenth Century* (Seattle, Wash., 1960), ch. 3; C. Hill, *Intellectual Origins of the English Revolution* (Oxford, 1965), esp. ch. 3; R. H. Kargon, *Atomism in England From Hariot to Newton* (Oxford, 1966), which contains a good bibliography of recent scholarly articles on Bacon, pp. 150–153; R. McRae, *The Problem of the Unity of the Sciences: Bacon to Kant* (Toronto, 1961); and Margery Purver, *The Royal Society: Concept and Creation* (Cambridge, Mass., 1967), esp. ch. 2.

MARY HESSE

**BACON, ROGER** (*b.* England, *ca.* 1219; *d. ca.* 1292), *natural philosophy, optics, calendar reform.*

Apart from some brief references in various chronicles, the only materials for Roger Bacon's biography are his own writings. The date 1214 for his birth was calculated by Charles, followed by Little, from his statements in the *Opus tertium* (1267) that it was forty years since he had learned the alphabet and that for all but two of these he had been "in studio."[1] Taking this to refer to the years since he entered the university—the usual age was then about thirteen—they concluded that in 1267 Bacon was fifty-three and thus was born in 1214. But Crowley has argued that his statements more probably refer to his earliest education, beginning about the age of seven or eight, which would place his birth about 1219 or 1220. Of his family the only good evidence comes again from Bacon himself. He wrote in the *Opus tertium* that they had been impoverished as a result of their support of Henry III against the baronial party, and therefore could not respond to his appeal for funds for his work in 1266.[2]

After early instruction in Latin classics, among which the works of Seneca and Cicero left a deep impression, Bacon seems to have acquired an interest in natural philosophy and mathematics at Oxford, where lectures were given from the first decade of the thirteenth century on the "new" logic (especially *Sophistici Elenchi* and *Posterior Analytics*) and *libri naturales* of Aristotle as well as on the mathematical *quadrivium.* He took his M.A. either at Oxford or at Paris, probably about 1240. Probably between 1241 and 1246 he lectured in the Faculty of Arts at Paris on various parts of the Aristotelian corpus, including the *Physics* and *Metaphysics,* and the pseudo-Aristotelian *De vegetabilibus* (or *De plantis*) and the *De causis,* coincident with the Aristotelian revival there. In arguing later, in his *Compendium studii philosophie,* for the necessity of knowledge of languages,[3] he was to use an incident in which his Spanish students laughed at him for mistaking a Spanish word for an Arabic word while he was lecturing on *De vegetabilibus.* He was in Paris at the same time as Albertus Magnus, Alexander of Hales (*d.* 1245),[4] and William of Auvergne (*d.* 1249).[5]

The radical intellectual change following Bacon's introduction to Robert Grosseteste (*ca.* 1168–1253) and his friend Adam Marsh on his return to Oxford about 1247 is indicated by a famous passage in the *Opus tertium:*

> For, during the twenty years in which I have laboured specially in the study of wisdom, after disregarding the common way of thinking [*neglecto sensu vulgi*], I have put down more than two thousand pounds for secret books and various experiments [*experientie*], and languages and instruments and tables and other things; as well as for searching out the friendships of the wise, and for instructing assistants in languages, in figures, in numbers, and tables and instruments and many other things.[6]

Grosseteste's influence is evident in Bacon's particular borrowings, especially in his optical writings, but above all in the devotion of the rest of his life to the promotion of languages and of mathematics, optics (*perspectiva*), and *scientia experimentalis* as the essential sciences.

He was in Paris again in 1251, where he says in the *Opus maius*[7] that he saw the leader of the Pastoreaux rebels. This story and some later works place him there for long periods as a Franciscan. He entered the Franciscan order about 1257 and, soon afterward, he also entered a period of distrust and suspicion—probably arising from the decree of the chapter of Narbonne, presided over by Bonaventure as master general in 1260, which prohibited the publication of works outside the order without prior approval. Bonaventure had no time for studies not directly related to theology, and on two important questions, astrology and alchemy, he was diametrically opposed to Bacon. He held that only things dependent solely on the motions of the heavenly bodies, such as eclipses of the sun and moon and sometimes the weather, could be foretold with certainty. Bacon agreed with the accepted view that predictions of human affairs could establish neither certainty nor necessity over the free actions of individuals, but he held that nevertheless astrology could throw light on the future by discovering general tendencies in the influence of the stars, acting through the body, on human dispositions, as well as on nature at large. In alchemy Bonaventure was also skeptical about converting base metals into gold and silver, which Bacon thought possible.

Whatever the particular reasons for Bacon's troubles within the order, he felt it necessary to make certain proposals to a clerk attached to Cardinal Guy de Foulques; as a result, the cardinal, soon to be elected Pope Clement IV (February 1265), asked him for a copy of his philosophical writings. The request was repeated in the form of a papal mandate of 22 June 1266.[8] Bacon eventually replied with his three famous works, *Opus maius, Opus minus,* and *Opus tertium,* the last two prefaced with explanatory *epistole* in which he set out his proposals for the reform of learning and the welfare of the Church. It is reasonable to suppose that after twenty years of preparation he composed these *scripture preambule* to an unwritten *Scriptum principale* between the receipt of the papal mandate and the end of 1267. In that year he sent to the pope, by his pupil John, the *Opus maius* with some supplements, including *De speciebus et virtutibus agentium* in two versions[9] and *De scientia perspectiva,*[10] followed (before the pope died in November 1268) by the *Opus minus* and *Opus tertium* as résumés, corrections, and additions to it. The pope left no recorded opinion of Bacon's proposals.

Perhaps at this time Bacon wrote his *Communia naturalium* and *Communia mathematica,* mature expressions of many of his theories. These were followed in 1271 or 1272 by the *Compendium studii philosophie,* of which only the first part on languages remains and in which he abused all classes of society, and particularly the Franciscan and Dominican orders for their educational practices. Sometime between 1277 and 1279 he was condemned and imprisoned in Paris by his order for an undetermined period and for obscure reasons possibly related to the censure, which included heretical Averroist propositions, by the bishop of Paris, Stephen Tempier, in 1277. The last known date in his troubled life is 1292, when he wrote the *Compendium studii theologii.*[11]

*Scientific Thought.* The *Opus maius* and accompanying works sent to the pope by Bacon as a *persuasio* contain the essence of his conception of natural philosophy and consequential proposals for educational reform. He identified four chief obstacles to the grasping of truth: frail and unsuitable authority, long custom, uninstructed popular opinion, and the concealment of one's own ignorance in a display of apparent wisdom. There was only one wisdom, given to us by the authority of the Holy Scriptures; but this, as he explained in an interesting history of philosophy, had to be developed by reason, and reason on its part was insecure if not confirmed by experience. There were two kinds of experience, one obtained through interior mystical inspiration and the other through the exterior senses, aided by instruments and made precise by mathematics.[12] Natural science would lead through knowledge of the nature and properties of things to knowledge of their Creator, the whole of knowledge forming a unity in the service and under the guidance of theology. The necessary sciences for this program were languages, mathematics, optics, *scientia experimentalis,* and alchemy, followed by metaphysics and moral philosophy.

Bacon leaves no doubt that he regarded himself as having struck a highly personal attitude to most of the intellectual matters with which he dealt, but his writings are not as unusual as the legends growing about him might suggest. They have, on the whole, the virtues rather than the vices of Scholasticism, which at its best involved the sifting of evidence and the balancing of authority against authority. Bacon was conscious of the dangers of reliance on authority: Rashdall draws attention to the irony of his argument against authority consisting chiefly of a series of citations. Most of the content of his writings was derived from Latin translations of Greek and Arabic authors. He insisted on the need for accurate translations. When it was that he learned Greek himself is not certain, but his Greek grammar may be placed after 1267, since in it he corrected a philological mistake in the *Opus tertium*. He also wrote a Hebrew grammar to help in the understanding of Scripture.

One of the most interesting and attractive aspects of Bacon is his awareness of the small place of Christendom in a world largely occupied by unbelievers, "and there is no one to show them the truth."[13] He recommended that Christians study and distinguish different beliefs and try to discover common ground in monotheism with Judaism and Islam, and he insisted that the truth must be shown not by force but by argument and example. The resistance of conquered peoples to forcible conversion, such as practiced by the Teutonic knights, was "against violation, not to the arguments of a better sect."[14] Hence the need to understand philosophy not only in itself but "considering how it is useful to the Church of God and is useful and necessary for directing the republic of the faithful, and how far it is effective for the conversion of infidels; and how those who cannot be converted may be kept in check no less by the works of wisdom than the labour of war."[15] Science would strengthen the defenses of Christendom both against the external threat of Islam and the Tartars and against the methods of "fascination" that he believed had been used in the Children's Crusade and the revolt of the Pastoreaux, and would be used by the Antichrist.

Bacon's mathematics included, on the one hand, astronomy and astrology (discussed later) and, on the other, a geometrical theory of physical causation related to his optics. His assertions that "in the things of the world, as regards their efficient and generating causes, nothing can be known without the power of geometry" and that "it is necessary to verify the matter of the world by demonstrations set forth in geometrical lines"[16] came straight from Grosseteste's theory of *multiplicatio specierum*, or propagation of power (of which light and heat were examples), and his account of the "common corporeity" that gave form and dimensions to all material substances. "Every multiplication is either according to lines, or angles, or figures."[17] This theory provided the efficient cause of every occurrence in the universe, in the celestial and terrestrial regions, in matter and the senses, and in animate and inanimate things. In thus trying to reduce different phenomena to the same terms, Grosseteste and Bacon showed a sound physical insight even though their technical performance remained for the most part weak. These conceptions made optics the fundamental physical science, and it is in his treatment of this subject that Bacon appears most effective. Besides Grosseteste his main optical sources were Euclid, Ptolemy, al-Kindī, and Ibn al-Haytham (Alhazen). He followed Grosseteste in emphasizing the use of lenses not only for burning but for magnification, to aid natural vision. He seems to have made an original advance by giving constructions, based on those of Ptolemy for plane surfaces and of Ibn al-Haytham for convex refracting surfaces, providing eight rules (*canones*) classifying the properties of convex and concave spherical surfaces with the eye in various relationships to the refracting media. He wrote:

> If a man looks at letters and other minute objects through the medium of a crystal or of glass or of some other transparent body placed upon the letters, and this is the smaller part of a sphere whose convexity is towards the eye, and the eye is in the air, he will see the letters much better and they will appear larger to him. For in accordance with the truth of the fifth rule [Fig. 1] about a spherical medium beneath which is the object or on this side of its centre, and whose convexity is towards the eye, everything agrees towards magnification [*ad magnitudinem*], because the angle is larger under which it is seen, and the image is larger, and the position of the image is nearer, because the object is between the eye and the centre. And therefore this instrument is useful for the aged and for those with weak eyes. For they can see a letter, no matter how small, at sufficient magnitude.[18]

According to the fifth rule,[19] if the rays leaving the object, *AB*, and refracted at the convex surface of the lens meet at the eye, *E*, placed at their focus, a magnified image, *MN*, will be seen at the intersections of the diameters passing from the center of curvature, *C*, through *AB* to this surface and the projections of the rays entering the eye. As he did not seem to envisage the use of combinations of lenses, Bacon got no further than Grosseteste in speculating about magnifications such that "from an incredible distance we may read the minutest letters and may number the particles of dust and sand, because of the magnitude of the angle under which we may see them."[20]

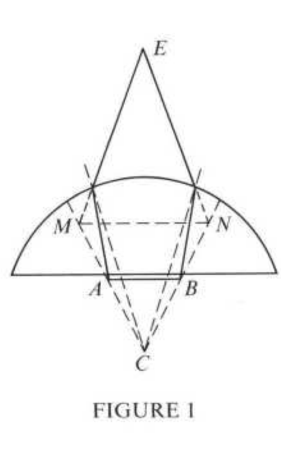


FIGURE 1

But he did make an important contribution to the history of physiological optics in the West by his exposition of Ibn al-Haytham's account of the eye as an image-forming device, basing his ocular anatomy on Ḥunayn ibn Isḥāq and Ibn Sīnā. In doing so, he seems to have introduced a new concept of laws of nature (a term found in Lucretius and numerous other authors more widely read, such as St. Basil) by his reference to the "laws of reflection and refraction" as *leges communes nature.*[21] His meaning is clarified by his discussion elsewhere of a *lex nature universalis*[22] requiring the continuity of bodies and thus giving a positive explanation, in place of the negative *horror vacui,* which he rejected, of such phenomena as water remaining in a clepsydra so long as its upper opening remained closed—an explanation comparable to one found in Adelard of Bath's *Natural Questions.* Universal nature constituted from these common laws, including those *de multiplicatione specierum,* was superimposed on the system of particular natures making up the Aristotelian universe—not yet the seventeenth-century concept but perhaps a step toward it.

"Having laid down the roots of the wisdom of the Latins as regards languages and mathematics and perspective," Bacon began Part VI of the *Opus maius,* "I wish now to unfold the roots on the part of *scientia experimentalis,* because without experience [*experientia*] nothing can be known sufficiently."[23] This science, "wholly unknown to the general run of students," had "three great prerogatives with respect to the other sciences."[24] The first was to certify the conclusions of deductive reasoning in existing speculative sciences, including mathematics. As an example he gave an investigation of the shape and colors of the rainbow involving both theoretical reasoning and the collection of instances of related phenomena in order to discover their common cause. The second prerogative was to add to existing sciences new knowledge that they could not discover by deduction. Examples were the discovery of the properties of the magnet, the prolonging of human life by observing what plants produced this effect naturally in animals, and the purification of gold beyond the present achievements of alchemy. The third prerogative was to investigate the secrets of nature outside the bounds of existing sciences, opening up knowledge of the past and future and the possibility of marvelous inventions, such as ever-burning lamps and explosive powders.

It is clear that Bacon's *scientia experimentalis* was not exactly what this term might now suggest, but belonged equally to "natural magic" aimed at producing astonishing as well as practically useful effects by harnessing the hidden powers of nature. His approach had been profoundly influenced by the pseudo-Aristotelian *Secretum secretorum,* of which he had produced an annotated edition variously dated between 1243 and sometime before 1257, but he also insisted that his new science would expose the frauds of magicians by revealing the natural causes of effects. The "dominus experimentorum" of the *Opus tertium,*[25] who may have been Pierre de Maricourt, the pioneer investigator of magnetism, is praised for understanding all these essential characteristics. In the *Opus minus,*[26] Bacon described possibly original experiments of his own with a lodestone held above and below a floating magnet, and argued that it was not the Nautical (Pole) Star that caused its orientation, or simply the north part of the heavens, but all four parts equally. It was in this work, and in the *Opus tertium,*[27] that he inserted his main discussion of alchemy, including the conversion of base metals into gold and silver. There is a further discussion in the *Communia naturalium,*[28] together with sketches of the sciences of medicine and agriculture. In the *Communia mathematica*[29] and the *Epistola de secretis operibus artis et naturae et de nullitate magiae,*[30] he described more wonderful machines for flying, lifting weights, and driving carriages, ships, and submarines, and so on, which he believed had been made in antiquity and could be made again.

Despite his occasional references to them, Bacon in his accredited writings deals with neither instruments nor mathematical tables in any but a superficial way. For this reason it is hard to measure his stature by comparison with that of his contemporaries whom we should call astronomers and mathematicians. We are not encouraged to set great store by the stories that while in Paris he constructed astronomical tables and supplied the new masters with geometrical problems that none of their audiences could solve.[31] His mathematics and astronomy were in fact almost wholly derivative, and he was not always a good judge of competence, preferring, for instance, al-Biṭrūjī to Ptolemy.

Bacon is often held to have achieved a deep and novel insight in regard to the role of mathematics in science, an insight that to the modern mind is almost platitudinous. In this connection it is easy to forget the large numbers of astronomers of antiquity and the Middle Ages for whom mathematics was an essential part of the science, and the smaller numbers of natural philosophers who had made use of simpler mathematical techniques than those of astronomy. It is more to the point to notice that Bacon argued for the usefulness of mathematics in almost every realm of academic activity. Part IV of the *Opus maius* is devoted to the usefulness of mathematics (1) in human affairs (this section was published separately as the *Specula mathematica*); (2) in divine affairs, such as chronology, the fixing of feasts, natural phenomena, arithmetic, and music; (3) in ecclesiastical affairs, such as the certification of faith and the emendation of the calendar; and (4) in affairs of state, under which heading are included geography and astrology. When Bacon sang the praises of mathematics, "the first of the sciences," "the door and key of the sciences," "the alphabet of philosophy," it has to be remembered that he used the word in an unusually wide sense. Bacon seemed to fear that mathematics would be dismissed as one of the blacker arts, as when arithmetic was applied to geomancy. He sought "per vias mathematice verificare omnia que in naturalibus scientias sunt necessaria"; and yet in the last resort, experience was still necessary, and in a sense supreme.[32]

So loud and long were Bacon's praises of mathematics that it is hard to avoid the conclusion that his love of the subject was unrequited. He could compose his *De communibus mathematice* and mention, in geometry, nothing beyond definitions, axioms, and methods. Apart from mathematically trivial results in such practical contexts as engineering, optics, astronomy, and the like, his works apparently contain not a single proof, not a single theorem; and we must take on trust the story of the difficult problems he devised for the young Paris masters. As for his analytical skills and his views on the citation of authority, rather than try to resolve the geometrical paradox of the doctrine of atomism—that it can make the hypotenuse and side of a square commensurable—he preferred simply to dismiss it as being contrary to Euclid.

The standard discussion of ratios in Euclid, Book V, did not include a numerical treatment of the subject, for which the standard medieval authority was the *Arithmetica* of Boethius. There the different species of ratio are tediously listed and subdivided, and the absence of a similar logical division of ratio in Euclid was complained of by Bacon in *Communia mathematica.*[33] He was not to carry out the program at which he might seem to have hinted, and not until Bradwardine's *Geometria speculativa* did the Schoolmen make any progress toward a numerical description of irrational ratios, except perhaps in some halting attempts to elucidate Proposition III of Archimedes' *De mensura circuli.*

As for the relation of logic to mathematics, Bacon inverted, in a sense, the logistic thesis of our own century: without mathematics, for instance, the categories were unintelligible.[34] Mathematics alone gave absolute certainty. Bacon was unusual in that he generally named his sources, citing such authors as Theodosius, Euclid, Ptolemy, Boethius, al-Fārābī, and—among modern writers—Jordanus de Nemore (*De triangulis* and *Arithmetica*) and Adelard. Despite his criticism of Jordanus, by any reckoning a better mathematician than Bacon, he had praise for "the only two perfect mathematicians" (of his time), John of London and Pierre de Maricourt. He also condescended to praise Campanus of Novara and a "Master Nicholas," teacher of Amauri, son of Simon de Montfort. In the last analysis, almost everything Bacon wrote under the title of mathematics is best regarded as being at a metaphysical level. His view that in mathematics we have perfect demonstration reinforced his theory of natural action. His philosophy of science, however, was inherently empiricist: rational argument may cause us to dismiss a question, but it neither gives us proof nor removes doubt.

It was held in the *Opus maius* that a more accurate knowledge of the latitudes and longitudes of places was needed for (1) knowledge of mankind and the natural world; (2) facilitation of the spiritual government of the world—missionaries, for example, would be saved from danger and from much wasted labor; (3) knowledge of the whereabouts of the ten tribes and even of the Antichrist. His geography was nevertheless a compilation of works on descriptive geography (in which he gave, as it were, an extended verbal map of the world) by such writers as Ptolemy and al-Farghānī, supplemented by the reports of Franciscan travelers, especially to the East.

In the *Opus maius*[35] he stated the possibility of voyaging from Spain to India. The passage was inserted, without reference to its source, in the *Imago mundi*[36] of Cardinal Pierre d'Ailly (*d.* 1420). Humboldt argued that this passage, quoted by Columbus in a letter of 1498 to Ferdinand and Isabella, was more important in the discovery of America than the Toscanelli letters. Thorndike suggests that Columbus probably did not read the vital work until his return from the first voyage of 1492.[37] It is immaterial, as Thorndike points out, whether Bacon was merely optimistically citing Aristotle, Seneca, Nero, and Pliny on the distance of Spain from India. In fact Bacon argued as cogently from such longitudes and latitudes as were available in the Toledan tables as he did from classical authors.

For the radius of the earth Bacon took a figure of 3,245 miles (al-Farghānī). He stated that the earth's surface was less than three-quarters water. In both cases he selected good figures from a great many authoritative but bad ones. It is clear, nevertheless, from his repetition of the method of determining the size of the earth—a method he took from al-Farghānī—that he had no appreciation whatsoever of the practical difficulties it involved.

Bacon appears to have sent a map to the pope with his *Opus maius*. Although it is now lost, from the description he gave it appears to have included the better-known towns of the world plotted by their latitudes and longitudes as found in many contemporaneous lists.[38] We have no knowledge of the projection adopted, but the description is compatible with the use of a rectangular coordinate system.

Bacon used the words "astronomia" and "astrologia" in a typically ambiguous manner, but there is no doubt that he believed in the reasonableness of what we would call astrology. In the *Opus tertium* he spoke of astrology as the most important part of mathematics, dividing it into a speculative, or theoretical, part, presumably of the sort included in Sacrobosco's *Sphere*, and a practical part, "que dicitur astronomia,"[39] concerned with the design of instruments and tables.[40] A remark in the *Opus maius*,[41] written in 1267, confirms a similar remark made four years later by Robertus Anglicus,[42] to the effect that conscious efforts were being made to drive what amounts to a clock (in Bacon's example the spherical astrolabe was to be driven) at a constant rate. This seems to confirm approximately the *terminus ante quem non* previously determined for the mechanical clock.

On many occasions Bacon emphasized at length that the two sorts of "astrology" were essential if man was to learn of the celestial influences on which terrestrial happenings depended. By reference to Ptolemy, Haly, Ibn Sīnā, Abū Maʿshar, Messahala, and others, he showed that the best astrologers had not held that the influence of the stars subjugated the human will, and that the Fathers who objected to astrology on these grounds had never denied that astrology could throw light on future events. It was possible to predict human behavior statistically but not with certainty in individual cases. Astrology might strengthen faith in the stability of the Church and foretell the fall of Islam and the coming of the Antichrist; and all these things "ut auctores docent et experiencia certificat."[43] On occasion he likened astrological influence to the influence of a magnet over iron.

In his main works Bacon did not discuss the technicalities of astronomy or astrology, but in both of the works ascribed to him with the title *De diebus creticis*[44] the standard medical astrology of the time is rehearsed. These works are not merely compilations of older authorities. Although technically they are in no sense new, they have a rational cast and even include the testimony of medical men of the time. The first of these two works is interesting because it incorporates the whole of the *De impressione aeris* attributed to Grosseteste and printed among his works by Baur. Little[45] suggests that Grosseteste (*d.* 1253) collaborated with Bacon. Internal evidence suggests a date of composition of about 1249. Some planetary positions quoted for that year are sufficiently inaccurate to suggest that the work was written before 1249 rather than after, and that the author was by no means as skilled as the best astronomers of the time.

The *Speculum astronomie,* of doubtful authorship (see below), is inconsistent with certain of Bacon's accredited writings. It is essentially a criticism of Stephen Tempier's decree of 1277 attacking 219 errors, several involving a belief in astrology. As already seen, Bacon's prison sentence was probably related to the bishop's decrees.

Bacon's astronomical influence was slight in all respects, although through Paul of Middelburg he is said to have influenced Copernicus.[46] His writings on the calendar were frequently cited.[47] Theologians treated the calendar with a respect it did not deserve, regarding it as a product of astronomy, while astronomers would have treated it with more disdain had they been detached enough to perceive it in a historical context. Here Bacon's skepticism was useful, and whatever the depth of his astronomical knowledge, he wrote on calendar reform with as much insight as anyone before Regiomontanus—Nicholas of Cusa notwithstanding. In discussing the errors of the Julian calendar, he asserted that the length of the Julian year (365 $\frac{1}{4}$ days) was in excess of the truth by about one day in 130 years, later changing this to one day in 125 years. The length of the (tropical) year implied was better than Ptolemy's, and indeed better than that accepted in the Alphonsine tables compiled a few years after the *Opus maius*. (The correct figure for Bacon's time was one day in a little over 129 years.) The Alphonsine tables imply that the Julian error is one day in about 134 years. There is no reason whatsoever to suppose, as many have done following Augustus De Morgan, that Bacon's data were his own. Thābit ibn Qurra made the length of the year shorter than the Julian year by almost exactly one day in 130 years, and according to a curious passage in the *Communia naturalium,* Thābit was "maximus Christianorum astronomus." In the *Computus,* however, Thābit is grouped with al-Battānī and others who are said to have argued for one day in 106 years, while Asophus (ʿAbd al-Raḥmān ibn ʿUmar al-Ṣūfī) appears to have been the most probable source of influence, with his one day in 131 years.[48]

As a means of reforming the calendar, Bacon seems finally to have recommended the removal of one day in 125 years (cf. the Gregorian method of ignoring three leap years in four centuries), and in connection with Easter, since the nineteen-year cycle is in error, the astronomical calculation of the feast; otherwise a lunisolar year like that of the eastern nations should be adopted. (Grosseteste had previously made this proposal.) He tempered this rash suggestion with the pious qualification that if an astronomical calculation of Easter was to be adopted, Hebrew astronomical tables should be used. His proposals may be compared with the much less radical ones of Nicholas of Cusa, who in his *Reparatio calendarii* (pre 1437?) merely suggested a temporary patching up of the calendar, eliminating a number of days to alter the equinox suitably (Gregorian reform, supervised by Clavius, took the same superfluous step) and changing the "golden number" so as to make the ecclesiastical moon correspond for a time with reality. These solutions were inferior to Bacon's, including fewer safeguards against a future state of affairs in which Church usage and the ordinances of the Fathers might differ appreciably. It is worth noting that Stöffler proposed to omit one day in 134 years (an obviously Alphonsine parameter), while Pierre d'Ailly followed Bacon explicitly in advocating a lunisolar cycle. Again, in connection with a proposal for calendar reform in England, we find that in 1582 John Dee commended Bacon to Queen Elizabeth as one who had "instructed and admonished" the "Romane Bishopp," who was now "contented to follow so neare the footsteps of veritye."[49] Judging by the speed of English legislation in the matter of calendar reform, it seems that Bacon was a little less than five centuries ahead of most of his countrymen.

Little wrote in 1914, "The extant manuscripts of Bacon's works show that the 'Doctor mirabilis never wanted admirers,'"[50] and cited as evidence the existence of twenty-seven manuscripts of the *Perspectiva*[51] alone, dating from the thirteenth to the seventeenth centuries. Apart from his proposals for the calendar it was on Bacon's optics that most scientific value was placed, by his contemporary Witelo as well as by Francesco Maurolico, John Dee, Leonard Digges, Hobbes, and the first editors of his works. At the same time his accounts of alchemy and natural magic gave him more dubious fame, varying from the sixteenth to the nineteenth centuries with current popular prejudices.

*NOTES*

1. *Opus tertium,* Brewer ed., p. 65.
2. *Ibid.,* p. 16.
3. *Compendium studii philosophie,* Brewer ed., pp. 467–468.
4. *Opus minus,* Brewer ed., p. 325; *Opus tertium,* Brewer ed., p. 30; *Compendium studii philosophie,* p. 425.
5. *Opus tertium,* Brewer ed., pp. 74–75.
6. *Ibid.,* p. 59.
7. *Opus maius* (1266–1267), Bridges ed., I, 401.
8. Brewer, p. 1.
9. Cf. *Opus maius,* Bridges ed., pt. IV, dist. ii–iv; and *De multiplicatione specierum,* Bridges ed.
10. Cf. *Opus maius,* pt. V.
11. Rashdall, pp. 3, 34.
12. *Opus maius,* VI, 1.
13. *Ibid.,* Bridges ed., III, 122.
14. *Ibid.,* II, 377.
15. *Opus tertium,* Brewer ed., pp. 3–4.
16. *Opus maius,* Bridges ed., I, 143–144.
17. *Ibid.,* p. 112.
18. *Ibid.,* V.iii.ii.4 (Bridges ed., II, 157).
19. Figure 1 is redrawn and relettered from *Opus maius,* V.iii.ii.3, British Museum MS Royal 7.f.viii, 13th cent., f. 93r.
20. *Ibid.,* Bridges ed., II, 165.
21. *Opus tertium,* Duhem ed., pp. 78, 90; *Opus maius,* Bridges ed., II, 49.
22. *Ibid.,* I, 151; *De multiplicatione specierum, ibid.,* II, 453; *Communia naturalium,* Steele ed., fasc. 3, pp. 220, 224.
23. *Opus maius,* Bridges ed., II, 167.
24. *Ibid.,* p. 172.
25. Brewer ed., pp. 46–47.
26. *Ibid.,* pp. 383–384.
27. Little ed., pp. 80–89.
28. Steele ed., fasc. 2, pp. 6–8.
29. Steele ed., fasc. 16, pp. 42–44.
30. Brewer ed., p. 533.
31. *Opus tertium,* Brewer ed., pp. 7, 36, 38.
32. See, e.g., *Opus maius,* Bridges ed., II, 172–173.
33. Steele ed., fasc. 16, p. 80.
34. *Opus maius,* Bridges ed., I, 102; cf. *Communia mathematica,* Steele ed., fasc. 16, p. 16.
35. Bridges ed., I, 290 ff.
36. *Imago mundi* was first published at Louvain in 1480 or 1487.
37. *A History of Magic and Experimental Science,* II, 645.
38. Bridges ed., I, 300.
39. Cf. *Communia mathematica,* Steele ed., fasc. 16, p. 49.
40. Brewer ed., p. 106. Since in ch. XII of the same work he seems to have used the word "tables" to refer primarily to almanacs, i.e., ephemerides, and to have spoken of instruments only as a means of verifying tables, it is probable that here he meant to refer only to the astrolabe and the equatorium.
41. Bridges ed., II, 202–203.
42. See L. Thorndike, *The Sphere of Sacrobosco and Its Commentators* (Chicago, 1949), p. 72.
43. *Opus maius,* I, 385.
44. Steele ed., fasc. 9, appendices ii and iii, ed. Little.
45. Little, *ibid.,* p. xxx.
46. Bridges ed., I, xxxiii, 292.
47. See bibliography. Note that the same passage occurs, word for word, in *Opus tertium,* Brewer ed., pp. 271–292; and in *Opus maius,* Bridges ed., I, 281. Notice, however, that the *Computus,* written 1263–1265, does not contain any passage from either of these works, and that it acknowledges Arabic, rather than paying lip service to Hebrew, sources.
48. Steele ed., fasc. 6, pp. 12–18.
49. Corpus Christi College, Oxford, MS C. 254, f. 161r.
50. Pp. 30–31.
51. *Opus maius,* pt. V.

*BIBLIOGRAPHY*

I. Original Works. A number of Baconian problems must remain unsolved until there is a complete critical edition of his works: see the bibliography by Little in *Roger Bacon: Essays* (Oxford, 1914), pp. 375–426; compare

G. Sarton, *Introduction to the History of Science,* II (Baltimore, 1931), 963–967; and L. Thorndike and P. Kibre, *A Catalogue of Incipits of Mediaeval Scientific Writings in Latin* (2nd ed., Cambridge, Mass., 1963).

The earliest of Bacon's authentic works to be printed was the *Epistola de secretis operibus artis et naturae* (*De mirabili potestate artis et naturae*) (Paris, 1542; Basel, 1593); in the *Opera,* J. Dee, ed. (Hamburg, 1618); in French (Lyons, 1557; Paris, 1612, 1629); in English (London, 1597, 1659); in German (Eisleben, 1608); and other eds. After this appeared the *De retardandis senectutis accidentibus et de sensibus conservandis* (Oxford, 1590; in English, London, 1683); and *Specula mathematica* (part of *Opus maius* IV); *in qua De specierum multiplicatione earumdemque in inferioribus virtute agitur* and *Perspectiva* (*Opus maius* V), both ed. J. Combach (Frankfurt, 1614). There were other early eds. of the doubtful *Speculum alchemiae* (Nuremburg, 1541; in French, 1557; English, 1597; German, 1608; with later reissues) and the collection *De arte chymiae scripta* (Frankfurt, 1603, 1620).

The 1st ed. of the *Opus maius* was by S. Jebb (London, 1733), followed by an improved ed. (Venice, 1750), both including only pts. I–VI. Pt. VII was included in the new ed. by J. H. Bridges, 2 vols. (Oxford, 1897), with a supp. vol. (III) of revisions and additional notes (London, 1900). This ed. was trans. into English by R. B. Burke (Philadelphia, 1928). Pt. VII of the actual MS sent to the pope has been ed. by E. Massa, *Rogeri Baconi Moralis philosophia* (Zurich, 1953). The eds. of Jebb and Bridges (Vols. II and III, pp. 183–185) both include *De multiplicatione specierum,* a separate treatise forming part of a larger work; a further section of this has been ed. with a discussion of its date and associations by F. M. Delorme, "Le prologue de Roger Bacon à son traité De influentiis agentium," in *Antionianum,* **18** (1943), 81–90.

The 1st eds. of the *Opus minus* and the *Opus tertium,* together with the *Compendium studii philosophie* and a new ed. of the *Epistola de secretis operibus,* were by J. S. Brewer in *Fr. Rogeri Bacon Opera quaedam hactenus inedita* (London, 1859). Further sections of the first two works have been ed. by F. A. Gasquet, "An Unpublished Fragment of Roger Bacon," in *The English Historical Review,* **12** (1897), 494–517, a prefatory letter and other parts of *Opus minus;* P. Duhem, *Un fragment inédit de l'Opus tertium de Roger Bacon* (Quaracchi, 1909), on optics, astronomy, and alchemy; and A. G. Little, *Part of the Opus tertium of Roger Bacon,* British Society of Franciscan Studies, IV (Aberdeen, 1912). The last two items include Bacon's *De enigmatibus alkimie.* For further parts of the *Opus minus,* including discussions of alchemy, still unpublished, see A. Pelzer, "Une source inconnue de Roger Bacon, Alfred de Sareshel, commentateur des Météorologiques d'Aristote," in *Archivium Franciscanum historicum,* **12** (1919), 44–67.

Other works have been ed. by E. Nolan and S. A. Hirsch, *The Greek Grammar of Roger Bacon, and a Fragment of His Hebrew Grammar* (Cambridge, 1902); H. Rashdall, *Fratris Rogeri Baconi Compendium studii theologii,* British Society of Franciscan Studies, III (Aberdeen, 1911); S. H. Thomson, "An Unnoticed Treatise of Roger Bacon on Time and Motion," in *Isis,* **27** (1937), 219–224; and in *Opera hactenus inedita Rogeri Baconi,* R. Steele, ed. (unless otherwise stated), 16 fasc. (Oxford, 1905–1940): (1) *Metaphysica: De viciis contractis in studio theologie* (1905); (2–4) *Communia naturalium* (1905–1913); (5) *Secretum secretorum cum glossis et notulis* (1920); (6) *Computus* (1926); (7) *Questiones supra undecimum prime philosophie Aristotelis* (*Metaphysica,* XII) (1926); (8) *Questiones supra libros quatuor physicorum Aristotelis,* F. M. Delorme, ed. (1928); (9) *De retardatione accidentium senectutis cum aliis opusculis de rebus medicinalibus,* A. G. Little and E. Withington, eds. (1928); (10) *Questiones supra libros prime philosophie Aristotelis* (*Metaphysica,* I, II, V–X) (1930); (11) *Questiones altere supra libros prime philosophie Aristotelis* (*Metaphysica,* I–IV), *Questiones supra de plantis* (1932); (12) *Questiones supra librum de causis* (1935); (13) *Questiones supra libros octo physicorum Aristotelis,* F. M. Delorme, ed. (1935); (14) *Liber de sensu et sensato, Summa de sophismatibus et distinctionibus* (1937); (15) *Summa grammatica, Sumule dialectices* (1940); and (16) *Communia mathematica* (1940). The *Chronica XXIV generalium ordinis minorum* (*ca.* 1370) was pub. in *Analecta Franciscana,* **3** (1897).

II. Secondary Literature. The best critical study of Bacon's life is T. Crowley, *Roger Bacon: The Problem of the Soul in His Philosophical Commentaries* (Louvain–Dublin, 1950). The pioneering study by E. Charles, *Roger Bacon: Sa vie, ses ouvrages, ses doctrines d'après des textes inédits* (Paris, 1861), is now mostly of historical interest. Essential general studies are A. G. Little, ed., *Roger Bacon: Essays Contributed by Various Writers* (Oxford, 1914), especially contributions by Little (life and works); L. Baur (Grosseteste's influence); Hirsch (philology); E. Wiedemann, S. Vogl, and E. Würschmidt (optics); Duhem (vacuum); M. M. P. Muir (alchemy); E. Withington (medicine); and J. E. Sandys (English literature); Little, *Franciscan Letters, Papers and Documents* (Manchester, 1943); L. Thorndike, *A History of Magic and Experimental Science,* II (New York, 1929), 616–691; S. C. Easton, *Roger Bacon and His Search for a Universal Science* (Oxford, 1952), with bibliography; and F. Alessio, *Mito e scienza in Ruggero Bacone* (Milan, 1967).

Studies of particular aspects are E. Schlund, "Petrus Peregrinus von Maricourt: Sein Leben und seine Schriften," in *Archivum Fransiscanum historicum,* **4** (1911), 445–449, 636–643; L. Baur, "Die philosophischen Werke des Robert Grosseteste," in *Beiträge zur Geschichte der Philosophie des Mittelalters,* **9** (1912), 52–63; and "Die Philosophie des Robert Grosseteste," *ibid.,* **18** (1917), 92–120; P. Duhem, *Le système du monde* (Paris, 1916–1958), III, 260–277, 411–442; V, 375–411; VIII, 121–168; A. Birkenmajer, "Études sur Witelo, i–iv," in *Bulletin international de l'Académie polonaise des sciences et des lettres,* Classe d'histoire et de philosophie (1920), 354–360; and "Robert Grosseteste and Richard Fournival," in *Mediaevalia et humanistica,* **5** (1948), 36–41; R. Carton, *L'expérience physique chez Roger Bacon, L'expérience mystique de l'illumination intérieure chez Roger Bacon, La synthèse doctrinale de Roger Bacon,* nos. 2, 3, 5 in the series

Études de philosophie médiévale (Paris, 1924); C. B. Vandewalle, *Roger Bacon dans l'histoire de la philologie* (Paris, 1929); G. Meyer, "En quel sens peut-on parler de 'méthode scientifique' de Roger Bacon," in *Bulletin de littérature ecclésiastique* (Toulouse), **53** (1952), 3–25, 77–98; A. C. Crombie, *Robert Grosseteste and the Origins of Experimental Science 1100–1700*, 3rd imp. (Oxford, 1969), pp. 41, 139–162, 204–207, 213–218, 278–281, with bibliography; and "The Mechanistic Hypothesis and the Scientific Study of Vision," in *Proceedings of the Royal Microscopical Society*, **2** (1967), 20–30, 43–45; M. Schramm, "Aristotelianism: Basis and Obstacle to Scientific Progress in the Middle Ages," in *History of Science*, **2** (1963), 104–108; and A. Pacchi, "Ruggero Bacone e Roberto Grossatesta in un inedito hobbesiano del 1634," in *Rivista critica di storia della filosofia*, **20** (1965), 499–502.

A. C. CROMBIE
J. D. NORTH

**BADĪ' AL-ZAMĀN AL-JAZARĪ.** See **al-Jazarī.**

**BAEKELAND, LEO HENDRIK** (*b.* Ghent, Belgium, 14 November 1863; *d.* Beacon, New York, 23 February 1944), *chemistry.*

Baekeland graduated with honors from the Municipal Technical School of Ghent in 1880, received the degree of Doctor of Natural Science from the University of Ghent in 1884, and stayed on to serve as professor of chemistry and physics at the Government Normal School of Science. In 1887 he received first prize in the chemistry division of a competition among the graduates of the four Belgian universities. Baekeland's travels took him to the United States in 1889, and he settled there, first as an employee of a photographic firm and then as the head of his own company, which manufactured a photographic paper he named Velox. This was a "gaslight paper" like that invented by Josef M. Eder for making, developing, and handling prints from negatives by artificial light. Baekeland perfected the process and sold it in 1899. He then became a consultant in electrochemistry and obtained patents on dissolving salt in spent electrolytes and on making more durable diaphragms from asbestos cloth treated with gummy iron hydroxides.

In 1905 Baekeland began his third enterprise, which he developed with great success and pursued until his death: the manufacture of condensation products from phenol and formaldehyde. This condensation had first been described in 1872 by Adolf von Baeyer. In a lecture before the American Chemical Society on 8 February 1909, Baekeland surveyed the previous attempts at industrial utilization of the reaction, which resulted in slow processes and brittle products; then he continued: ". . . by the use of small amounts of bases, I have succeeded in preparing a solid initial condensation product, the properties of which simplify enormously all molding operations. . . ." He distinguished three stages of reaction, with a soluble intermediate product. Manufacture of Bakelite resins started in 1907; by 1930, the Bakelite Corporation occupied a 128-acre plant at Bound Brook, New Jersey.

In 1914, Baekeland received the first Chandler Medal. During World War I, he was active in the National Research Council. He was elected president of the American Chemical Society in 1924 and received many other honors.

*BIBLIOGRAPHY*

Baekeland's writings include "The Synthesis, Constitution, and Uses of Bakelite," in *Industrial and Engineering Chemistry*, **1** (1909), 149–161; and "Some Aspects of Industrial Chemistry," in *Science*, **40** (1914), 179–198.

Further information on Baekeland and his work can be found in Helmut and Alison Gernsheim, *The History of Photography From the Earliest Use of the Camera Obscura in the 11th Century up to 1914* (London, 1955), pp. 284 ff.; see also J. Gillis, *Leo Hendrik Baekeland* (Brussels, 1965).

EDUARD FARBER

**BAER, KARL ERNST VON** (*b.* Piep, near Jerwen, Estonia, 28 February 1792; *d.* Dorpat, Estonia [now Tartu, Estonian S.S.R.], 28 November 1876), *biology, anthropology, geography.*

During the earlier years of his professional life, Baer concentrated his principal efforts on what is now known as embryology. He is known to Western biologists for his discovery of the mammalian egg in 1826 and for his treatise *Ueber die Entwickelungsgeschichte der Thiere, Beobachtung und Reflexion* (1828, 1837), the publication of which provided a basis for the systematic study of animal development. Baer was a professor in Germany when he carried out his embryological investigations. When he was about forty-two years old, he left Germany for Russia; there, during the remaining years of his long, active life, he devoted his attention primarily to anthropology, both physical and ethnographic, to geography, and, to a lesser degree, to archaeology. But this gives only a bare indication of how widely and how philosophically his mind ranged through nature.

Baer, whose complete style was Karl Ernst Ritter von Baer, Edler von Huthorn, was descended from an originally Prussian family. One of his ancestors, Andreas Baer, emigrated from Westphalia to Reval, Livonia, in the mid-sixteenth century; a collateral descendant of Andreas bought an estate in Estonia