ROGER BACON AS A SCIENTIST.

BY KARL E. GUTHE.

IN the history of science of the thirteenth century two commanding figures stand out among all the natural philosophers of their time, Albrecht von Bollstaedt and Roger Bacon. Both have been highly praised as great men, and both have been sneered at as charlatans. Certainly neither of them had a high opinion of the other. Nothing appears to be more difficult than to decide upon the characteristics of a great scientist. In his book entitled *Grosse Männer* Ostwald selected only investigators who had made some remarkable discovery as examples of this type. But to measure all men by such a single standard as Ostwald's appears to me unjust and wholly onesided. I would rather call each of Ostwald's heroes a scientific genius and not restrict the class of great men so as to shut out any one who in one way or another has had a profound influence upon the progress of civilization.

Roger Bacon cannot be credited with a single epoch-making discovery, and yet he deserves to be called a great man. He is one of those rare scholars who combine with a remarkably extensive knowledge and with an admiration for the majesty and mystery of this world a powerful conviction that a certain unity underlies the various phenomena in nature and that all sciences—in their widest sense—are dependent upon one another. Such men attempt to rise above mere details, to view the world as a whole, and then present in bold outlines a picture of the Cosmos as they see it. In many cases their efforts result in the production of a mere cosmic encyclopedia, but for really great thinkers the world of observation blends with the world which they build up in their imagination to a unified picture, though possibly distorted and unreal when viewed by later generations.

We seem to be unable to get at any one time a complete view of this world; in fact our view is constantly changing, and every attempt to chain down the Cosmos has been unsuccessful. In this

respect Roger Bacon achieved no more than others have before or after him. His works, like all similar attempts, should be entitled "Facts and Fancies." In view of the meager equipment of facts which the scientific world possessed at that time, fancies play an important rôle in Bacon's treatises. As a source of scientific information his writings are of little value, but as human documents describing the knowledge, beliefs and superstitions then existing, and showing the attitude of scholars towards scientific questions, they are of absorbing interest.

Man has not changed appreciably in 700 years. Much as we now discuss the value or uselessness of certain disciplines, so did men in Bacon's time. Just as at present we often consider any one an ignoramus who happens to disagree with us, and declare another a profound scholar whose views coincide with ours, so Bacon, who was a little more outspoken than is considered proper for a twentieth century professor, considered only one mental attitude towards important philosophic questions to be correct; and this indeed is the attitude which in the present scientific age is shared by many of us. Therefore we are liable to overestimate Bacon's importance in the history of science. He was not generally considered a great man in his own age and for some centuries afterwards, when the methods for searching after truth were different.

How was it possible that a man like Roger Bacon could arise in the thirteenth century? How could he have shaped for himself a world picture so different from that taught in the powerful University of Paris? I do not believe that even a master mind, such as he doubtless was, can create a great thought or state a fundamental truth without considerable preliminary work and study on the part of some predecessors who have at least felt it, though unable to express it as clearly. Indeed, Roger Bacon seems to me to be the product of a perfectly definite movement and—unfortunately for science—its last great exponent for the time being.

It was not until shortly before Bacon's time that Europe became acquainted with Arabian scholarship which itself was a product of the cultures of Greece and India. While the Arabs preserved and taught Greek philosophy, they were mainly interested in the purely scientific results of Greek scholarship and laid special emphasis upon the development of the mathematical sciences.

It seems that a revival of mathematics occurred first in England. Adelhard of Bath who had traveled among the Arabs for purposes of study, translated upon his return to England in 1130

the Elements of Euclid; Jean of Holywood wrote a book on arithmetic, and Robert Gross-tête, later bishop of Lincoln, was greatly interested in mathematics and the sciences. So was Adam de Marisco. The last two, Roger's teachers of whose learning he speaks always with the greatest respect, must have been powerful and original minds and must have made a lasting impression upon the younger scholar.

Bacon was thus a product of a school of mathematics and formed his world picture accordingly. While he acknowledges the value of the languages—namely in order to avoid mistranslations—he says of mathematics: "He who knows not mathematics cannot know any other science; what is more, he cannot discover his own ignorance or find its proper remedies. So it is that the knowledge of this science prepares the mind and elevates it to a well authenticated knowledge of all things."[1]

This statement which seems highly appropriate as applied to physical sciences, refers, however, not only to the sciences proper, but to theology as well, as he explains at length in his *Opus tertium*: "Without mathematics we can not fix the dates of sacred history nor can we see the true relations between celestial and mundane occurrences."[2] Without geometry we cannot get a clear idea of the shape of Noah's ark, or of the tabernacle. Without arithmetic we cannot understand the symbolic meaning of the Trinity. Since at his time mathematics included also the science of music, he adds as further argument, that without music we know nothing about hymns and invocations of spirits. A large portion of the *Opus tertium* is devoted to a discussion of the beneficial and elevating influence of music and rhythmical art. It may appear peculiar that Bacon places so much emphasis upon what might now be considered as trivial; but it should be remembered that these very things frequently formed the subject of highly learned disputations among Bacon's colleagues.

This man, so strongly convinced that mathematics forms the very foundation of all knowledge, went to Paris for further study; and what did he find? The far famed illustrious teachers of that

[1] *Opus majus,* pars IV ("Mathematicae in divinis utilitas," distinctio prima, ch. I): "Quoniam qui ignorat eam non potest scire caeteras scientias nec res hujus mundi, ut probabo. Et, quod pejus est, homines eam ignorantes non percipiunt suam ignorantiam, et ideo remedium non quaerunt. Ac per contrarium hujus scientiae notitia praeparat animum et elevat ad omnium certificatam cognitionem."

[2] *Opus tertium,* ch. XI: "Nam planum est quod sine mathematica non possunt sciri coelestia: et coelestia sunt causae rerum inferiorum, et causata non possunt sciri sine causis suis."

time—Albertus Magnus, Thomas Aquinas and others—were interested in entirely different things. In Roger's estimation they could not compare with his former teachers who according to him were perfect in divine and human wisdom. The shortcomings of the Parisians he could easily explain by asserting: "The neglect of mathematics for thirty or forty years has nearly destroyed the entire study of Latin Christendom."[3]

In disgust he turns away from his unsympathetic colleagues. He speaks in praise of only one person, and him indeed he calls a perfect mathematician. This man was a Picard by the name of Peter de Maharncuria. For many years historians have tried to identify him; Charles has shown him to be no other then Peter Peregrinus, the well-known writer of a letter on terrestrial magnetism and the compass.[4] This scholar was not a teacher in Paris, but an independent investigator, and apparently little known.

A man like Bacon would certainly be much interested in physical problems, and indeed he found great pleasure in the study of light which subject was at that time restricted to geometrical optics. In this field also he finds nothing in Paris. Twice there had been lectures in Oxford on light, but not once in Paris. Listen to his complaints about the conditions in the latter institution. "The man who pretends to be an authority in optics, knows nothing about its value, as clearly appears from his books; because neither has he written a treatise on this subject—and he would have done so, had he had the knowledge—nor has he said anything about it in other books." And then in his characteristic manner he closes with the words, "and therefor he cannot know any thing about philosophy."[5]

It is difficult to describe the peculiar charm which we find in the study of Bacon's works. We modern scientists are so accustomed—and I believe properly so—to eliminate our own personality from our work, that our world has become one without feeling, that it speaks to us only through experimental facts. In Bacon's writings it is all so different. Those old scientists took no interest

[3] *Opus majus,* pars IV, ch. I: "Et harum scientiarum porta et clavis est mathematica.—Cujus negligentia jam per triginta vel quadraginta annos destruxit totum studiûm Latinorum."

[4] A full account of this important work is given in Benjamin's *The Intellectual Rise in Electricity,* pp. 165-190.

[5] *Opus tertium,* ch. XI: "Haec autem scientia non est adhuc lecta Parisius, nec apud Latinos, nisi bis Oxoniae in Anglia; et non sunt tres qui sciant ejus potestatem: unde ille, qui fecit se auctorem, de quo superius dixi, nihil novit de hujus scientiae potestate, sicut apparet in libris suis, quia nec fecit librum de hac scientia, et fecissit si scivisset, nec in libris aliis aliquid de hac scientia recitavit.—Et ideo non potest scire aliquid de sapientia philosophiae."

in the game when they eliminated sentiment and animosity from their discussions. At times it is almost uncanny to feel the old monk sitting right by your side and pleading with you in such a personal and direct manner. One can not help fearing that one's estimate of his proper place in the history of science might become warped by sympathy for him. It is difficult not to be persuaded that the great Albert was after all an impostor, wholly unfit to be a professor in the great university. And yet, Bacon's estimate of his great scholastic contemporaries was certainly too harsh.

We must not forget that science had just been revived in the Christian world. In 1209 the study of the books of Aristotle was forbidden; in 1215 Robert de Courçon, a papal legate, renewed the prohibition, expressly including Aristotle's metaphysics; in 1231 a bull of Gregory IX modified this decision with the proviso that the prohibited books were not to be used until they were proved to be free of error; and only 13 years before Bacon wrote his *Opus majus* was the ban raised. It is therefore evident that considerable time was needed for the assimilation of the new knowledge and for a slow growing appreciation of its method.

A thousand years before Bacon, Eusebius said with regard to scientific questions: "It is not through ignorance of the things admired by them, but through contempt of their own useless labor, that we think little of these matters, turning our souls to the exercise of better things." The attitude of the church had not changed in the least, for Bacon says: "When the philosophers are told in these days that they ought to study perspective, or geometry, or the languages, they ask with a sneer: What is the use of these tings? insinuating their uselessness. They refuse to hear a word said with reference to their utility; they neglect and condemn the sciences of which they are ignorant."[6]

We can easily understand that a man of Bacon's temperament and independence had no use for Albertus Magnus who prided himself that he taught the ancient science in such a way that no one could recognize his own personal views. The animosity shown in the above quotation is a much more serious matter than a disagreement of two scholars would be at the present time. Not two men, but two schools of thought were battling with each other. Each had devised a method for the assimilation of the new knowl-

[6] *Opus tertium,* ch. VI: "Nam philosophantes his diebus, quando dicitur eis quod sciant perspectivam, aut geometriam, aut linguas, et alia multa, quaerunt cum derisione, 'Quid valent haec?' asserentes quod inutilia sunt. Nec volunt audire sermonemde utilitate; et ideo neglegunt et contemnunt scientias quas ignorant."

edge, and either school used all its influence to suppress the other. Personally I am convinced that Roger Bacon would not have hesitated a moment to silence the great Albert and his adherents, had he had the power to do so. At that time a compromise was impossible; freedom of thought had not yet been discovered.

If now we consider Bacon's actual accomplishments in science a little more closely we find nothing very remarkable, though we cannot help but admire his encyclopedic knowledge of details and the clear grasp of their interrelation.

In mathematics he has added nothing to knowledge, as far as we can see. No mathematical treatise which might form a part of his contemplated all-embracing work has ever been found. This is disappointing, for Roger states that the quadrature of the circle for which the ancients had searched in vain, had finally been accomplished.[7] It would have been interesting to compare his proof of this fallacy with that of Cusanus, 150 years later.

Bacon used his knowledge of astronomy to make an immense number of clever calculations, especially with a view of fixing the dates of occurrences mentioned in the Bible. Thus he proves to his perfect satisfaction that creation took place in the fall of the year,[8] and he knows the exact date when the flood began. He also calculated the size of the earth. This was a rather complicated problem. The decimal system was not in general use at that time and all the data which he had at his disposal were that the length of one degree on the earth's surface was fifty-six miles plus two-thirds of a mile plus twenty-seven ninetieths plus one six hundred and thirtieth of a mile. It needs real mathematical gymnastics to reach a solution. His final result was not very far from the truth; in fact, it was nearly as accurate as that on which 400 years later (in 1666) Newton according to tradition attempted to verify his law of gravitation with the result that he did not dare publish this fundamental law, until Picard 18 years later had made new and more accurate measurements.[9] Bacon found further that the diameter of the earth was $3\frac{2}{5}$ times the diameter of the moon, a value not bad as an approximation; but when he got farther away from

[7] *Opus majus, pars* I, ch. VI: "Nam quadraturam circuli se ignorasse confitetur, quod his diebus scitur veraciter."

[8] *Opus majus,* pars IV, (*loc. cit.*): "Nam multi voluerunt secundum sententiam vulgi, quod mundus fuerit creatus circiter aequinoctium vernale; sed alii apud aequinoctium autumnale; quia in veritate secundum Hebraicum veritatem, annus, quantum ad seriem temporis naturalem, incipit circiter aequinoctium autumnale."

[9] This is merely a tradition. Newton's difficulty seems to have been of an entirely different nature. See Cajori, *History of Physics,* p. 58.

mother earth he was less successful, for he found that the diameter of the sun was only 5½ times greater than that of the earth.

In spite of some mistakes of this sort, he was correct in many other calculations. He very earnestly and impressively urged a change of the calendar by showing clearly that Christian chronology did not agree with astronomical observations. Though he calls this error in itself *"horribilis,"* this is nothing in comparison with the fact that the whole order of ecclesiastic festivals is confounded. It seems to him inexcusable that in 1267 Lent began and ended a week too late and that therefore the infidels, Arabs, Hebrews and Greeks pointed with abhorrence at the stupidity of the Christians.[10]

Bacon was by no means the first to advocate an improvement of the calendar, though this is sometimes claimed by his admirers. He himself mentions Theophilus, Eusebius, Victorinus, Cyrillus, Beda and others who had before him labored for the same reform. Neither was Bacon successful. The necessary change was not made until more than 300 years later.

We should not blame Bacon for believing implicitly in astrology. All the best thinkers of his time did so and even his great namesake, three centuries and a half after Roger, had not abandoned it although the Copernican theory had at that time been accepted by the leading astronomers.

As we pass on to physics we find that in this science also Bacon's contributions of new facts are very meager. At his time physics consisted of the most elementary mechanics and what we call now geometrical optics. Very little was known of electricity and magnetism. While he was an admirer of Aristotle and claims to have read all his books, he was not a blind follower like Albertus Magnus. In fact he praises Robert of Lincoln for disregarding the writings of Aristotle and working out his theories independently. Besides large portions of the *Opus majus* (*"De scientia perspectiva"*) and *Opus tertium* devoted to optics his main work on this subject is *"De multiplicatione specierum."*

Roger Bacon knew the law of reflection and also that light may be refracted, though of course he was unacquainted with the law of refraction which was not discovered until 1621, by Willibrod Snell. He was much interested in the practical application of re-

[10] *Opus majus,* pars IV (*loc. cit.*): "Nam omnes literati in computo et astronomi sciunt haec, et deridentignorantiam praelatorum qui haec sustinent Atque philosophi infideles, Arabes, Hebraei, et Graeci, qui habitant inter Christianos ut in Hispania et Aegypto et in partibus orientis, et in multis aliis mundi regionibus abhorrent stultitiam quam conspicuunt in ordinatione temporum quibus utuntur Christiani in suis solemnitatibus."

flection by means of spherical mirrors, but did not know how to find their focus. Nevertheless he believed that by experiments in this direction much might be achieved. His friend Peter Peregrinus had already worked on such mirrors for three years and Bacon hoped that he would soon be able to perfect burning mirrors of great power. Of what enormous value would these be, he exclaimed. The armies of the Saracens and other enemies of Christendom could be burned at long distances by a dozen of such mirrors, attended to by a scientist and two helpers, and thus much bloodshed would be prevented.[11] What an elegant and inexpensive method of abolishing war and establishing universal peace!

Bacon's knowledge has been much overestimated. Some authors thought he invented the telescope. This is impossible. He did not even know that the greatest magnifying effect of a simple lens is obtained by holding it near the eye; for like Alhazen 200 years before him, he advised that the lens be laid upon the object to be viewed through the glass.[12] The great exponent of experimental work must have copied this mechanically without making independent observations. He knew, however, that the magnifying power depends upon the angle under which an object appears and he dreamed of the time when by a combination of lenses this angle might be increased so much that we might read the smallest script at incredible distance, that a boy would appear as a giant, that a small body of soldiers would be seen as a large army. By making the images of sun, moon and stars descend upon the heads of enemies, they would flee terror-stricken.[13] To distort this sentence

[11] *Opus tertium,* ch. XXXVI: "Certe si duodecim talia specula haberent Aconenses; et illi qui sunt ultra mare Christiani, ipse sine effusione sanguinis pellerent Saracenos de finibus eorum; nec oportet Dominum regem Franciae cum exercitu transire pro illa terra acquirenda. Et quando ibit, plus valeret ei habere illum magistrum cum duobus aliis, quam majorem partem exercitus sui, ne dicam totum exercitum."

[12] *Opus majus,* pars V, ("De scientia perspectiva," pars III, 2, ch. IV): "Si vero homo aspiciat literas et alias res minutas per medium crystalli vel vitri vel alterius perspicui suppositi literis, et sit portio minor spherae cujus convexitas sit versus oculum, et oculus sit in aere, longe melius videbit literas et apparebunt ei majores."

[13] *Ibid.,* ultima distinctio, ch. IV: "Nam possumus sic figurare perspicua, et taliter ea ordinare respectu nostri visus et rerum, quod frangentur radii et flectentur quorsumcunque voluerimus, ut sub quocunque angulo voluerimus videbimus rem prope vel longe. Et sic ex incredibili distantia legeremus literas minutissimas et pulveres ac arenas numeraremus propter magnitudinem anguli sub quo videremus, et maxima corpora de prope vix videremus propter parvitatem anguli sub quo videremus, nam distantia non facit ad hujusmodi visiones nisi per accidens, sed quantitas anguli. Et sic posset puer apparere gigas, et unus homo videri mons, et in quacunque quantitate—sic etiam faceremus solem et lunam et stellas descendere secundum apparentiam hic inferius, et similiter super capita inimicorum apparere et multa consimilia, ut animus mortalis ignorans veritatem non posset sustinere."

as meaning that Bacon actually knew a telescope or microscope, is rather daring. He merely stated a problem which he hoped might be solved by future generations.

It is this almost inspired presentiment of the coming development of science, this scientific instinct, which makes Bacon so interesting to later generations. While reading his optical works I found a most unsuspected treasure, namely what I believe to be the first appearance of the undulatory theory of light, in a rather crude form, it is true, but easily recognized. It is his theory of the propagation of species. The translators speak of Bacon's theory of propagation of "force," a word whose exact meaning as a physical quantity bothers us physicists even at the present time. But his species is not a force at all, but a quantity, as flexible and unreal as *our* much admired electromagnetic vibration of the ether. It is something caused by the acting body[14]—in the case of light, by the luminous body, from which the species proceeds into space in straight lines. While there may be a resemblance to the forms or replicas which according to Lucretius and the earlier philosophers proceeded from all luminous bodies, it would be an entire misapprehension of Bacon's views to identify these forms with his species. The species is not a part of the acting body, i. e., the body which we see; but it is generated in the surrounding medium. The luminous source acts on the first portion of the medium, stimulating its latent energy to the generation of the species. This portion, thus transmuted, acts on the part of the medium next succeeding, and so the action proceeds from point to point.[15] Species has therefore no bodily existence apart from that of the medium through which it passes, and light cannot be a material body.[16] Moreover each species lasts only an imperceptible time, since the medium has a nature opposed to the creation of species

[14] *Multiplicatio specierum*, pars I, ch. I: "Species autem non sumitur hic pro quanto universali apud Porphyrium, sed transumitur hoc nomen ad designandum primum effectum cujuslibet naturaliter."

[15] *Ibid.*, pars I, ch. III: "Quod non potest species exire nec emitti ab ipso agente, quia accidens non permutat subjectum, nec pars substantialis sine corruptione substantiae totius.—Sed species est effectus agentis naturalis, et naturaliter productus est, quare species ipsa debet de potentia materiae generari.—Unde forma ignis non alterat materiam vel alterius, ergo non potest species facta in prima parte patientis alterare illam partem ad alium effectum producendum in ea, sed partem secundam. Et ita quae fit in secunda alterabit tertiam, et sic ulterius."

[16] *Ibid.*, pars III, ch. I: "In primo consideratur an species sit corpus veraciter, sicut multi posuerunt. Quod vero non sit corpus probatur per hoc, quod non dividit latera continentis medii, quod est locum in alio occupare, ut omnes sciunt. Et ideo si species esset corpus secundum se, essent duo corpora simul, quod non est possibile."

and destroys it, but not until it has affected in a similar manner the surrounding medium. The luminous body must therefore cause one species after another in very rapid succession, but since they take place in time, it should be possible to count them.[17] Finally the propagation of species through space requires time, for otherwise light could be at once at the beginning of space, at its middle and at the end at the same time; which is a property of the Creator alone and not of any created thing.[18]

How much like the more modern undulatory theory of light this is. The species are periodic disturbances impressed upon the medium which due to its "contrary disposition" opposes them, but at the same time hands on the disturbance from point to point with a great, though finite, velocity. The carrier of the disturbances is an ether endowed with such physical properties as suited Bacon's purpose and as real as any of its many successors. The existence of a vacuum was to him an impossibility.[19] To find such a theory, even in a crude form in a work written six and one-half centuries ago, seems remarkable indeed. And still more. In his search after a unified view, Bacon extends the meaning of species to include the action of gravitational and other forces. It almost appears as if he had felt instinctively that there must be such a thing as that which we now call energy.

Personally I do not believe that Bacon was a sufficiently deep thinker to have originated the above theory, mixed up, as it is, with crude generalizations which are characteristically Baconian. His works show clearly a remarkable power of adaptation to Arabian scholarship, and I hope that further study may allow me to trace the "undulatory theory" back to an earlier author.

[17] *Ibid.,* pars VI, ch. I: "Dicto de generatione speciei et multiplicatione, nunc dicendum est de corruptione. Et patet eam esse corruptibilem, quia est generabilis.....Caeterum natura patientis specifica nata est ad contrariam speciei, si contarium habeat, vel ad dispositionem contrariam illi quae per speciem inducitur....et sic per consequens species lucis vel alterius corrumpitur per accidens per contrarium, etsi non per se."

Ibid., ch. III: "Deinde tertium consideratum est quod cum idem agens iterum redeat super eandem naturam patientis, facit impressionem seu speciem diversam numero a priore, et ideo effectus numeratur."

[18] *Opus tertium,* ch. XLII: "Iterum, nulla virtus agit in instanti; sicut probatur sexto Physicorum.....Iterum, nihil, potest simul et semel esse in diversis locis, nisi Creator. Sed si in instanti fieret tunc esset simul et semel in principio spatii, et in medio, et in fine, et per consequens in omnibus partibus spatii; ergo non esset creatura."

[19] *Opus majus,* pars V ("De scientia perspectiva," pars I, distinctio nona): "Sed si vacuum poneremus inter coelum et terram, nec esset densum nec rarum.....Atque vacuum non habet aliquan naturam, unde impediat speciem, nec unde resistat speciei, quia nulla natura est ibi....species enim est res naturalis et ideo indiget medio naturali, sed in vacuo nulla natura est."

Bacon was a man of great imagination, as every scientist ought to be. While our modern scientific dreams are checked on all sides by innumerable laws of nature which they must obey, *he* could give his fancy free rein. Listen to some of his prophecies:

"Ships will be built which, with a single man steering them, will move through rivers and the ocean with a greater speed than if they were filled with oarsmen. Carriages can be made to move with incredible speed without the help of any animals. Flying machines will be constructed so that one man sits in the middle of the apparatus, revolving some ingenious device by means of which wings beat the air after the manner of flying birds."[20]

In spite of all these speculations Bacon does not lay great emphasis upon them. In fact they are not found in his more serious work. Though he had quite a reputation as an alchemist and a magician, he holds all magic in contempt. In describing some astonishing experiment with the magnet, he says with fine humor: "Magicians make this experiment, mumbling incantations and believing that things happen by virtue of their songs. I have neglected chanting and have understood the marvelous work of nature."[21] He clearly recognized that a science, based upon superstition, speculation and arm-chair philosophy, cannot be of permanent value. But just this kind of science was taught at his time, disputations were held about the meaning of infinity, or in what language angels converse with each other, or how many angels can stand upon the point of a needle.

Bacon's fame does not rest upon any discovery he may have made, nor upon his actual knowledge of scientific facts, nor upon his more or less correct interpretation of human experiences, but upon the fact that more than any other of the early scholars he emphasized that none of the sciences could make any progress without the application of what he terms the *"scientia particularis,"* namely experimental science. "All sciences," he says, "are con-

[20] *De secretis operibus artis et naturae, et de nullitate magiae,* ch. IV: "Nam instrumenta navigandi possunt fieri sine hominibus remigantibus, ut naves maximae, fluviales et marinae, ferantur unico homine regente, majori velocitate quam si plenae essent hominibus. Item currus possunt fieri ut sine animali moveantur cum impetu inaestimabili; ut aestimamus currus falcati fuisse, quibus antiquitus pugnabatur. Item possunt fieri instrumenta volandi, ut homo sedeat in medio instrumenti revolvens aliquod ingenium, per quod alae artificialiter compositae aerem verberent, ad modum avis volantis. Item instrumentum, parvum in quantitate ad elevandum et deprimendum pondera quasi infinita, quod nihil utilius est in casu."

[21] *Opus majus,* pars VI ("Scientia experimentalis," ch. XII): "Et ideo magici utuntur hoc experimento, et dicunt carmina diversa, et credunt quod ex virtute carminum istud contingat. Et ego neglexi carmina et inveni opus naturae mirabile."

nected; they lend each other material aid as parts of one great whole, each doing its own work, not for itself alone, but for the other parts; as the eye guides the body and the foot sustains it and leads it from place to place."[22] "But above all these there is one, more perfect than any, which they all serve, namely experimental science. It alone can test their conclusions, which cannot be done by mere argument."[23]

"Experimental science has three great prerogatives among other sciences: First, she tests by experiment their noblest conclusions; next, she, the sole mistress of speculative sciences, discovers magnificent truth to which these sciences of themselves can by no means attain; her third dignity is, that she by her own power and without respect to other sciences investigates the secrets of nature."[24]

The examples which Bacon gives for these prerogatives are very curious and amusing. The first is a—for that time admirable—research as to the nature of the rainbow, though the moment he leaves the solid ground of experimentation he falls into error. For example, he says there can be only five colors in the rainbow, because five is a more perfect number than seven, the number which Aristotle had chosen.[25] While he experiments skilfully with reflection and refraction of light he reaches amusing conclusions: The direct ray is the most perfect, pertaining to the nature of God; then come the refracted rays corresponding to the vision of angels; while we poor mortals must be content with the weakest of them all, namely with a vision by reflected rays. For the apostle Paul says: Now we see through a mirror darkly, but then from face to face.[26]

[22] *Opus tertium,* ch. IV: "Nam omnes scientiae sunt connexae, et mutuis se fovent auxiliis, sicut partes ejusdem totius, quarum quaelibet opus suum peragit, non solum propter se, sed pro aliis: ut oculus totum corpus dirigit, et pes totum sustentat, et de loco ad locum deducit; et sic de aliis."

[23] *Ibid.,* ch. XIII: "Sed praeter has scientias est una perfectior omnibus, cui omnes famulantur, et quae omnes miro modo certificat; et haec vocatur scientia experimentalis, quae negligit argumenta, quoniam non certificant, quantumcunque sint fortia, nisi simul adsit experientia conclusionis, ut ostendo in tractatu de ista scientia. Et ideo haec docet experiri conclusiones nobiles omnium scientiarum, quae in aliis scientiis aut probantur per argumenta, aut investigantur per experientias naturales et imperfectas."

[24] See Whewell's *History of the Inductive Sciences,* Vol. I, p. 375.

[25] *Opus majus,* pars VI, ch. XII: "Quum enim Aristoteles dicit in Sensu et Sensato septem esse colores....sed quinque principales colores sunt per naturam distincti. Nam quinarius est melior numeris omnibus, ut Aristoteles dicit in libro Secretorum....Et quia numerus quinarius res certius distinguit et melius, ut dictum est, ideo natura magis intendit quinque colores."

[26] *Opus majus,* pars V: ("De scientia perspectiva," pars III, ultima distinctio, ch. II): "Aliter vero triplicatur visio secundum quod fit recte, fracte,

The examples of the second prerogative of experimental science are three: the art of making an artificial sphere which shall move with the heavens by natural influences, i. e., a *perpetuum mobile.* This was the great invention described by Bacon's friend, Peter Peregrinus. Secondly, the art of prolonging life, which experiment may teach, though medicine has no means of securing it, except by regimen. Thirdly, the art of making gold, finer than fine gold, which goes beyond the power of alchemy.

The third prerogative of experimental science, arts independent of received sciences, is shown by curious examples, many of them whimsical traditions. Thus it is said that the character of a people may be changed by altering the air. This refers to the answer which Aristotle is said to have given Alexander who wanted to know what he should do with certain barbarous nations. The reply was: If you can alter the air, permit them to live; if not, put them to death.

Arguments like these, should not, however, prejudice us against Bacon and the real service which he has rendered science. He outlines a definite method; he points to the only way in which progress may be achieved; and it is this service which entitles him to an honored place in history. It is true that there were experimental scientists before him, Ptolemy, Alhazen and many others, but none of them has spoken so clearly of the supreme importance of experiment, as he whose fanciful speculations appear childish in the better knowledge of to-day. In his appreciation of experimental demonstrations Roger Bacon was 300 years ahead of his time; he anticipated the scientific renaissance of the sixteenth century. Indeed, I place him in this respect far above the second Bacon though the latter managed to earn greater fame. But Roger Bacon was after all a child of his time. He was an astrologer and an alchemist, and his arguments did not differ to any marked extent from those employed by the despised teachers of the university of Paris. His own knowledge and accomplishments were advertised by him as unblushingly as by other learned men of his time. He could teach in three or six months all that he himself had learned in forty years of con-

et reflexe. Prima est perfectior aliis, et secunda certior est, tertia incertissima. ....nam rectitudo visionis Deo debetur; declinatio a rectitudine per fractionem, quae debilior est, anglicae naturae convenit: reflexiva visio, quae est debilior, homini potest assignari....Et homo habet triplicem visionem, unam perfectam, quae erit in statu gloriae post resurrectionem; aliam in anima separata a corpore in coelo usque ad resurrectionem, quae debilior est; tertiam in hac vita, quae debilissima est, et haec est recte per reflexionem. Secundum quod dicit apostolus 'videmus nunc per speculum in aenigmate, sed in gloria a facie ad faciem.'"

tinuous study; he would even undertake to teach Hebrew or Greek in three days.[27] Though his name was not mentioned in learned treatises of later times he must have had a number of secret admirers; for what better proof could we ask for than the fact that his writings have frequently been literally copied without any credit being given to him. Scientific plagiarism does not seem to have been a crime in those times, and I believe that *Francis* Bacon practised it cheerfully and extensively after some good fortune had made him acquainted with the works of the old monk, his namesake.

Not until the last century has Roger Bacon been shown to be the real author of much wisdom attributed formerly to others. Let me close with an interesting example. All that Christopher Columbus knew of Greek and Roman authors; all references of Aristotle, Strabo, and Seneca as to the proximity of Eastern Asia to the pillars of Hercules, references, which according to Columbus's son, Don Fernando, induced his father to look for the discovery of the East Indies—all this the admiral learned from the writings of cardinal Alliacus (Peter d'Ailly). He carried them with him on his travels; he translated in a letter from Haiti, addressed to the Spanish monarch a part of Alliacus's treatise *De quantitate terrae habitabilis.* Little did he know that Alliacus in his turn, had copied this, almost word for word, from the *Opus majus* of Roger Bacon.[28]

[27] *Opus tertium,* ch. XX: "Multum laboravi in scientiis et linguis, ut posui jam quadraginta annos postquam dedici primo alphabetum; et fui semper studiosus....et tamen certus sum quod infra quartam anni, aut dimidium anni, ego docerem ore meo hominem sollicitum et confidentem, quicquid scio de potestate scientiarum et linguarum....sed certum est mihi quod infra tres dies ego quemcunque diligentem et confidentem docerem Hebraeum, ut sciret legere et intelligere quicquid sancti dicunt....Et per tres dies sciret de Graeco iterum; et non solum sciret legere et intelligere quicquid pertinet ad theologiam, sed ad philosophiam et ad linguam Latinam."

[28] Humboldt's *Kosmos,* Vol. II.