THE EXPERIMENTAL METHOD IN THE MIDDLE AGES[1]

It is probable that since the beginning of civilisation there has never been a high culture without some kind of systematic study of matter. The Egyptians and Babylonians were metallurgists, architects, physicians, astronomers and mathematicians. The Greeks inherited some part of their tradition and transformed it from technique to philosophy. A scientific world-view emerged; theoretical systems of the sciences and natural histories, good and bad, expressed this view and the facts which it attempted to explain; and the corpus of Greek scientific writings remained as the chief inspiration and fountain of science until the seventeenth century, nor is its influence extinct to-day. Between 150 B.C. and 450 A.D. Greek science gradually died, but the record of it, preserved in Greek manuscripts, remained known to those who spoke that tongue. Thus in the sixth and seventh centuries there was considerable philosophical and scientific activity in Byzantium, Syria and Persia, and this later inspired the culture of Islam; but since very little had been translated into Latin, the knowledge of science in the Western world sunk to a low ebb.

Boethius and Cassiodorus recorded brief summaries of mathematics and the liberal arts. Dionysius Exiguus introduced the Christian era and a system of calculating the calendar: these and one or two slight medical treatises comprised most of the science known to the West. In the seventh century Isidore of Seville is the only light. His best work is a *De Natura Rerum* (P.L. 83, 965), dedicated to Sisebutus, king of the Goths from 612-621. In a condensed and lexicographic style he gives brief abstracts of the ancients' knowledge of astronomy, geography, meteorology and other sciences. This work and his better-known *Etymologies* were very influential and were quoted as authorities for nearly a millennium. In the early eighth century Bede writes in a fuller and more interesting way on scientific matters, but we cannot attribute to him any original observations. The same is true of that remarkable genius John Scotus Erigena, whose condemned work *De Divisione Naturae* shows a remarkable knowledge and critical understanding of Greek science.

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[1] The substance of a paper read at the Newman Association Congress, held at Ampleforth Abbey, August, 1944.

Beside that literary tradition was a practical one, manifest especially in medical works such as the Saxon leechdooms. These contain traditions from Greek science, and although they included old wives' spells and folk-remedies, they were at least practical medicine and made some contact with real things. Here are examples :[2]

> Against lice : pound oak-bark and a little wormwood in ale : give to the lousy one to drink : against lice : quicksilver and old butter : one penny weight of quicksilver and two of butter : mingle all together in a brazen vessel.
>
> In case a man be lunatic : take the skin of a mereswine or porpoise, work it into a whip, swinge the man therewith, soon he will be well. Amen.
>
> If thou be not able to stanch a blood-letting incision, take new horse-dung, dry it in the sun, rub it to dust thoroughly well, lay the dust very thick on a linen cloth; wrap up the wound with it.

The idea that a philosopher, as distinguished from a physician, should do anything with his hands begins to appear at the end of the first millennium of the Christian era. The first practical science we hear of is that of Gerbert, who, we may notice, had been in contact with Arab culture in Spain. We are told that 'with his own hands he constructed a clock which used water as motive power and whose movement was regulated by the pole-star,' which, we may suppose, means that he constructed a 24-hour clepsydra. In view of the alleged opposition of the Church to experimental science, we may remark that she enthroned Gerbert, its first exponent in the West, as Pope Sylvester II.

Perhaps it is this experimental tendency that appears in William of Malmesbury's account of his fellow-monk Eilmer, the first English aeronaut, who 'by some contrivance fastened wings to his hands and feet . . . and, gathering the breeze, on the summit of a tower, had flown for more than the distance of a furlong (*stadium et plus*); but agitated by the violence of the wind and storm, as well as by the consciousness of his rash attempt, he fell and broke his legs, and was lame ever after. He used to relate as the cause of his failure that he had forgotten to provide himself with a tail at the back.'[3]

The theoretical science of this early period showed little advance over that of the dark ages. There was, indeed, an interest in nature,

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[2] *Leechdoms, Wortcunning and Starcraft of Early England.* Cockayne. Rolls Series, 1865. Vol. II, pp. 125, 335, 341.

[3] *Gesta Regum Anglorum,* Lib. ii, §225 *ad fin.* (Rolls Series, Vol. I, p. 276: P.L. 179, 1206.)

but one that seems to the scientist of to-day most strange. The modern scientist asks ' How does the machine of the world work? ' the great scholastics asked ' How does the hierarchy of beings fulfil God's plan? ' but the natural philosopher of the eleventh and earlier centuries asked ' What does the outward show of the world signify? ' The function of nature was to act as a sign of something hidden; the world was an assemblage of symbols of divine truth.

The bestiaries are admirable examples of this attitude, but it may also be well seen in an author who was acquainted, though very imperfectly, with the elements of Aristotelian learning, namely Alexander Nequam or Neckam. He is interested in natural phenomena, but cannot describe any of them without explaining its symbolic significance. Thus:

LI. OF QUICKLIME.

> They say that quicklime contains a hidden fire, though it be cold to the touch, wherefore if water be poured over it, the hidden fire at once breaks out. Wonderful thing! After it has been burnt, it is set on fire by water (which is wont to put out fire) but is put out by oil. So also humility is well nourished by tribulation, but often perishes in prosperity.[4]

Neckam's information comes from many sources, including his own observation, but it has little or no reference to practical investigation, and is not systematised into science.

From about 1125 the scientific knowledge that the Arabs had borrowed from the Greeks began to enter Western Europe, and wherever there was contact with Arab learning we see science stimulated into rapid growth. The western scientist who was more than a copyist or a craftsman was an Englishman, Adelard of Bath, whose works cover the period from c. 1109-1145. He visited Palestine, learnt Arabic and studied the Arab Masters, as he called them. He wrote on arithmetic and astronomy, including treatises on the abacus and the astrolabe. From these we deduce his interest in instruments, and we have evidence that he made practical observations. His best known work ' On very difficult natural questions '[5] is in the form of a dialogue between himself and a nephew, who is as critical of the Arab Masters as Neckam is enthusiastic. The

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[4] *De Naturis Rerum*. Ed. Thomas Wright. (Rolls Series, 1863, p. 160.)

[5] *Quaestiones naturales perdifficiles Adelardi Bachonienses* (sic). Joh. de Paderborna. Louvain, 1480(?). *Quaestiones naturales*, ed. M. Müller, Münster in W. (B.G.P.M. xxxi, L.ii). *Dodi ve-nechdi* (uncle and nephew) . . . ed. with an Engl. tr. to which is added the first Engl. tr. from the Latin of Adelard of Bath's *Questiones naturales* by H. Gollancz; Oxford, 1920.

questions posed were mostly enquiries concerning the reasons for simple natural phenomena: Why is the sea salt? Why can one blow both hot and cool breath? Why do some animals chew the cud and not others? and the like. He gives somewhat ingenuous explanations, almost always based on the varying proportions of the four elements and their resultant tempering of the four qualities. He extols the power of reason in investigating such matters, but in fact his reason is mainly used in deciding what authority is to be followed.

Adelard appears not only to have visited Syria, but also to have spent some time in Spain and at the Norman court of Sicily, which, with Apulia, was the centre of science in the twelfth and early thirteenth centuries. Even before this time Sicily and Southern Italy has been a meeting-place of Greek, Arabic, Jewish and Latin culture. Salerno had for a century been a centre of medical learning, from which had emerged a number of remarkably clear and concise text-books. Sicily and Southern Italy, meeting places of East and West, were distinguished by a series of remarkable rulers, whose interests in the arts and sciences were scarcely to be paralleled before the time of the Renaissance. Roger of Sicily was primarily interested in geography, and consequently in astronomy, and it was for him that the Arab geographer Idrisi made his famous map of the world, the best for several centuries. The contact between the readers and writers of the different tongues led to an astonishing series of translations. Parts of Aristotle and Ptolemy, the *Optics* and *Catoptrics* of Euclid, and the *De Motu* of Proclus were translated from the Greek. The proportion of scientific works was high. This was not a revival of mere literary learning; rather was the object of the translator to make the craft, science and philosophy of Greece and Islam available to the Latins.

The most remarkable figure of the age, and the most notable exponent of practical science, was Frederick II of Hohenstaufen, Holy Roman Emperor, King of Sicily and Jerusalem, *Stupor mundi et immutator mirabilis*. Born in 1194, he succeeded to the throne of Sicily at the age of four. His political activities are too many, his private life too scandalous, to be narrated here. He lived very much as the Oriental despot—not for nothing was he known as the 'baptised Sultan of Sicily.' He consorted freely with Arabs, Jews, Greeks and Christians; and the effect of their religious differences was, it would seem, to make him a thorough sceptic in such matters. Yet, hardened, cruel and infidel as he became, his biographer Fra Salimbene could say 'I have seen him and at one time I loved him; in truth there would have been few rulers in the world like him, had he loved God, the Church, and his own soul.'

But, his personal defects aside, he must be hailed as scientist and patron of science. He has left us his great treatise on Falconry,[6] which is full of accurate first-hand descriptions of birds and is by far the most original work of its day. He neglected no source of information. Thus he employed Michael Scot to translate the works of Aristotle and Avicenna on animals; he sent questionnaires to the Arab potentates and their philosophers; he despatched messengers as far afield as Norway to enquire into the truth of alleged wonders of nature; and lastly he was himself in contact with the means and subjects of science. He collected instruments, and had an extraordinary menagerie of elephants, dromedaries, camels, lions, panthers, leopards and monkeys—even a giraffe, sent to him by the Sultan of Cairo. He certainly experimented with the hatching of ostrich eggs in the sun, and with the practice of artificial incubation. We may doubt the story of his investigation of the respective effects of sleep and exercise upon digestion by feasting two men, then sending one to hunt and the other to sleep, and later ripping up both of them; but the tale of his experiment of bringing up children in silence in order to discover what language they would speak is confirmed by its sequel, the death of both the children,—which is an anticlimax that would hardly have been invented. It is clear that the court of Frederick II was a home of science, and it may have been the chief source of the experimental science of its age.

The best piece of experimental physics that emerged from the four hundred years that preceded William Gilbert's *De Magnete* (1600) was the *Epistola de Magnete* of Peter Peregrine (Petrus Peregrinus, Petrus de Maharn-Curia, Pierre de Maricourt, which is a village of Picardy). This work, addressed to Siger of Brabant, was written in 1269 at the siege of Lucera, the former seat of Frederick II, where the Saracens had been in revolt; it is not easy to regard this as a mere coincidence, and it is at least likely that Sicilian science was the source of his knowledge. Peter Peregrine's Epistle[7] is a tiny work, but stands out far beyond anything of the time. He tells us the qualities of the man of science:

> But know, dearest friend, that the investigator in this subject must understand nature and must not be ignorant of the celestial

[6] *The Art of Falconry, the De arte Venandi cum avibus,* tr. and ed. by C. A. Wood and F. M. Fyfe. Stamford Univ., 1943.

[7] Pietro Peregrino di Maricourt e la sua epistola ' De Magnete.' P. D. Timoteo Bertelli, Barnabita. Rome, 1868. (Contains Latin Version).

Epistle of Peter Peregrinus of Maricourt to Sygerus of Foncaucourt. Silvanus. P. Thompson. London, 1902. (English Translation).

Peter Peregrinus de Maricourt and his Epistola de Magnete. Silvanus. P. Thompson. Proc. Brit. Acad. 1905-6, p. 377. (Contains bibliography).

> motions; and he must himself be very diligent in manual operations, to the end that through the operation of this stone[8] he may show wonderful results. For by his carefulness he will in a short time be able to come at an error, which he could not possibly correct by means of his knowledge of nature and mathematics, if he lacked carefulness in the use of his hands. For in hidden operations[9] we search out much by manual industry, and for the most part we can make nothing perfect and complete without it. Yet there are many things subject to the rule of reason which we cannot completely investigate by the hand.

And indeed his results were remarkable. He describes the poles of the loadstone, shows how to find them; he distinguishes the north and south poles; he shows that like poles repel and unlike attract each other, and that fragments of a magnet, broken so as to separate its poles, become complete magnets. He explains the process of making iron magnets and describes the making of graduated and pivoted compasses. All this is sound experimental work, and though his book is marred by the assumption that the supposed effect of the heavens on the magnet can bring about a perpetual motion, there is nothing like it between the Alexandrian Greeks and the scientists of the seventeenth century.

Roger Bacon (c. 1214—c. 1294) was acquainted with Peter Peregrine, and gives him such high praise that we may suspect that the Picard was his initiator into experimental science during his sojourn in Paris. Bacon calls him one of the only two perfect mathematicians. He speaks of optical experiments 'which none of the Latins can understand, save one, to wit, Master Peter' (*Opus Tertium*; cap. 13). Master Peter is making a burning mirror 'and by the grace of God he will soon come to an end of it, which none of the Latins knew how to do. . . . This mirror was made with great expense and labour, for its constructor had to pay a hundred Paris pounds and worked for several years.' In fine 'he was a master of experiments:[10] and therefore he knows by experiment natural history and physics and alchemy, and all things in the heavens and beneath them: indeed he is ashamed if any layman, or grandam, or soldier, or rustic knows anything that he does not know.'

That Roger Bacon was also an experimental worker is beyond question. 'For,' he tells Pope Clement IV, 'during the twenty years

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[8] The loadstone or natural magnet.

[9] Those of which the mechanism is not obvious to the eye or reason.

[10] *Experimentum*. Experience, trial—a wider term than our present *experiment*.

that I have specially laboured in the attainment of wisdom, abandoning the vulgar path, I have spent upon these pursuits more than 2000. *l*, not to mention the cost of secret books, of various experiments, languages, tables and the like; add to all the sacrifices I have made to procure the friendship of the wise and to obtain assistants skilled in the tongues, in geometrical figures, tables and instruments' (*Opus Tertium*; cap. 17).

The most interesting part of Bacon's admirable compendium of the sciences is the sixth part of the *Opus Majus* (Part vi, c.1), entitled *De Scientia Experimentali,* which 'Experimental Science,' he tells us, is the mistress of all that precede it. Experiment confirms the result of reading, and tests the truth of the assertions of authors.

He then gives an example of an experimental investigation, remarkably in the vein of the 'tables of instances' suggested by his great homonym, Francis Bacon, more than three centuries later. Thus he says (*ibid.,* Part vi, c.2) that Aristotle, Avicenna, Seneca, talk about the colours of the rainbow, but the experimentalist will consider all manner of visible things to discover colours ordered in this manner. Hexagonal quartz crystals held in a ray of light coming through a shutter into a dark room show these colours (did Newton read of this?): other stones with superficial striations show them, as does water dripping from oars and mill-wheels, dewy grass in the morning sun, and glass flasks filled with water. Rays passing obliquely through the oil in a glass lamp: the sun shining through the minute apertures of woven fabrics or the chink of the narrowed eyelids, likewise give rainbow colours. This passage shows remarkable powers of observation.

Bacon's prediction of the future utility of science, of the inventions of the telescope, mocroscope, automobile, and flying-machine, are obviously connected with this attitude. Science is to be investigated by instruments, and will issue in the improvement of instruments.

In Peter Peregrine and Roger Bacon, experimental science reaches its peak. During the Middle Ages many other authors made theoretical investigations, such as those so admirable anticipations of modern dynamics that have been recounted by Duhem, Gilson and others, but they do not appear to have applied to them the test of experiment. Meanwhile much scientific work was being done in astronomy, alchemy, pharmacy and medicine, but it was directed to the practical ends of astrology, calendar-computation, the making of gold, and the healing art. The use of manual operations for the speculative investigation of nature seems almost to have been confined to Peter Peregrine and Roger Bacon.

The only contemporary scientist who is at all comparable to these is St. Albert. It is difficult to compare their work because the former are primarily physicists, while the latter is biologist, mineralogist and chemist. St. Albert's scientific works are text-books of the subjects they treat, presented as commentaries on Aristotle. The latter received from him a degree of respect and authority which was not accorded him by the Oxford Franciscans. Thus Bacon says of Grosseteste :

> Master Robert, formerly Bishop of Lincoln, of holy memory, totally neglected the books of Aristotle and their ways, and by means of his own experience, and other authors, and other sciences, he busied himself with the matters in which Aristotle was expert, and knew and wrote the things of which the books of Aristotle speak, a hundred thousand times better than could be gathered in their incorrect translations. (*Compendium Studii,* cap. 8.).

St. Albert had a deep respect for tradition, and although he rejects a number of absurd tales about beasts and birds and stones, he does not submit all of his work to the test of experiment. He distinquishes what he has read from what he has seen, and he reports the latter most clearly and practically. He has the technical knowledge of a dog-fancier, a farrier, a miner and a metallurgist, he gives clear and vivid pictures of the birds and beasts he has encountered. He knows what is the object of natural science : thus in his treatise on minerals he says ' We do not here seek first causes of action and motion, which perhaps are the stars and their virtues and disposition, for this is the proper function of another science : but we seek the proximate efficient causes, which, existing in the matter, change the matter to something else ' (Lib. I. *Mineralium,* cap. 4). He knows that *experimentum* is the source of scientific knowledge, ' for at one time I was on my travels, going a long journey to mining districts in order to find out the natures of metals. For this reason I also investigated the alchemical transmutations of metals, so that they might to some extent make clear their natures and their proper accidents. For this is the best and most certain method of enquiry because the thing is then known through the cause of that particular thing, and there is the least degree of doubt about its accidents.' (Lib. III *Mineralium,* cap. 1). For all this, St. Albert's experimentum is further from our ' experiment ' than is that of Roger Bacon. The latter comes closer to modern science because, like Galileo, he sees the book of Nature as being written in the mathematical language. St. Albert's account of the world is wide, deep and human, but it is the less science because the less abstracted for quantitative reasoning.

St. Albert's great pupil, St. Thomas Aquinas, typifies the later scholastics, in that he understands the principles of science, is well acquainted with its findings, but is interested only in its general principles and not in its particular applications. St. Thomas puts the whole of science in its proper place among the philosophic disciplines, sketching from a conjectural cosmology a magnificent, but in part erroneous, picture of a hierarchy of creatures—minerals, plants, animals, men, planets, angels, rising to God Himself. But he is not interested, as far as we can see, in particular things, in elephants, dormice, vitriol and volcanoes; and thereby, for all his philosophic genius, he is less a scientist than Peter Peregrine, patiently fashioning his mirrors, filing his compass-needles and recording the seemingly trivial results which proved, in fact, to be the foundation of the science of magnetism.

What are we to think about this effervescence and subsidence of experimental science? It seems to have been quite contrary to the spirit of scholasticism and, indeed, of the western world in the Middle Ages. I would suggest that it was a phenomenon brought about by a peculiar set of circumstances. May we think that at the court of Frederick II, where Moslem, Jew, Greek and Latin met as equals, the opposing theological and ethical views that we know to have been mooted, effectively neutralised each other; and that it seemed to Frederick and his followers, as to the positivists of to-day, that the only certain knowledge was that of the properties of matter? This exaltation of material knowledge we may suppose to have spread to Frederick's University of Naples, and for a time to Paris and Oxford. Peter Peregrine, whose name shows him to have been a crusader and whom we know to have visited Apulia, had access to such sources. Roger Bacon was in contact with him. St. Albert mentions experiments he performed while studying at the University of Padua[11] and had observed an earthquake presumably in Southern Italy.[12] St. Thomas not only studied under St. Albert, but also received tuition in science at Naples from Peter of Hibernia.

The investigation of nature by observation and experiment was not, in fact, continued. The scholastic philosophers were interested in general principles, and desired only so much science as would enable them to construct a system. Science proceeds by investigation of minute particulars, and no man can discover for himself more than a very little, and that little only in a lifetime. It follows then that in the Middle Ages, when philosophy was far advanced but the

[11] *De Mineralibus*, II, tr. 3, c. i.
[12] *De Meteoris*, III, tr. 2, c. 12.

best account of science that could be given was confused and doubtful, the task of investigating nature seemed to be more difficult and less important than that of becoming a philosopher. In the seventeenth and eighteenth centuries science appeared to be simple, systematic, and not beyond the capacity of a philosopher, so that such men as Descartes, Leibnitz and Kant could acquire a mastery of both fields. To-day, science has grown to such a bulk and complexity that scarcely any scientist, let alone philosopher, has a clear view of its general outlines. Thus we have passed from mediaeval philosophers ignorant of science, through scientific philosophers of the seventeenth and eighteenth centuries, to twentieth-century scientists, ignorant of philosophy. Yet science in its researches into its own foundations is once more meeting the problems of metaphysics, and there is good hope that its own desires will cause it once more to seek a fertile union with divine Philosophy.

F. SHERWOOD TAYLOR.

THE PLACE OF SCIENCE IN MODERN CULTURE[1]

NATURAL science is concerned with understanding the working of material nature. The subject of this paper is the positive contribution which natural science, given its true place among the other activities of man, might make to the world. At the outset, it is essential to distinguish between science and the applications of science. When a certain knowledge of nature has been won, it is often possible to apply it to the control and manipulation of nature—to devise new techniques for handling matter. Modern industry is becoming more and more dominated by technology based in this way on applied science. The emphasis on the use of science in modern life is such that most of those who write on the 'place of science in society' are thinking primarily of the place of technics in society, and treat science only in relation to technics. But the question of the place of technics in society raises problems wholly different from

[1] From a paper delivered to the Newman Associatioon Conference at Ampleforth, August, 1944.