IV

THE PLACE OF FRANCIS BACON IN THE HISTORY OF SCIENTIFIC METHOD

FRANCIS BACON has been popularly accounted as the father of modern science and its method. Unfortunately, that sort of title has been given to many people. In fact, it must be remarked that on the tree of knowledge, considered as a family tree, many a "bar sinister" is hung; for it is rare in science that the son knows his own father. Even where parentage may be conceivable, an oblique descent is so much more the rule than the exception, that it is quite possible that we can find a more appropriate name for the relation which Bacon bore to the several scientific disciplines.

Let us spend a few moments in investigating this problem of paternity. The question is not one of the importance of Bacon, but rather more definite. It may be stated as follows: If there had been no Bacon, would the future of science have been essentially different, or would its development have been materially slower? I think we may give the negative answer to both these questions. Let us consider, therefore, the states of various modern sciences, and see if they may be traced back more or less directly to a source.

Probably we can all agree that up to the middle of the last century, at least, the most important body of natural science was that of physics and astronomy, with its mathematical systematization. Along this branch the lines of descent seem straighter than elsewhere. Two modern names are characteristic of it more than any others. Einstein is first, not only in Relativity, but also in Quantum Theory. Poincaré is the other name that I should give. If I were to add a third it would be Planck. The genesis of their ideas lies first, and very noticeably in the case of Einstein, in scientific and philosophical speculations which go back to antiquity; the principles which are enunciated may almost be called "final causes", and have a dignity which does not result from any mere induction. They pay tribute to all the philosophers from the time of Thales and Pythagoras, with the possible exception of those in the line from Bacon to Hume.

The more particular concepts in modern atomistic and relativistic theories lie on lines which have all passed through Maxwell. Here again, the ideas on electricity represent a cultivation of the broad ideas of Faraday by means of the mathematical plough forged by Lagrange and Laplace; for Faraday very largely succeeded in his task of systematizing that domain of knowledge which is concerned with electricity and magnetism. Tyndall says of him that he was recognized, probably without a dissentient voice, as the prince of physical investigators of his age.

The first researches of Faraday were concerned with theories that were already subjects of discussion at his time; for instance, that all forms of electricity were the same, whether they occurred in the battery, the fish, with magnetism, thermally, or in the electric machine, this being a theory which our own Franklin had helped to make definite with his kite. If we continue these researches forward they form a long chain of speculation suggested by experiment and experiment suggested by speculation—a single continuous thread which Faraday rapidly unrolled until nearly the time of his death. If we continue the same questions backward we find them derived from those beginnings which Gilbert, the contemporary of Bacon, disentangled from the fables of the Ancients.

The mechanical ideas of Poincaré and Maxwell go back to a contemporary of Bacon, namely, the great Galileo. This line passes through Lagrange and Laplace back to Newton, and thence to Kepler and Galileo. The methods of these scientists were more or less the same, and like that of Faraday; they were not afraid of following a slender thread of bold speculation; they turned repeatedly to experiments or calculations which might justify their theories, but only to follow the speculation itself further and with renewed enthusiasm.

Obviously this line of descent does not pass very closely to Francis Bacon. In fact, it is not merely in a figurative sense that students of science speak of Galileo as the first pupil of Archimedes. For when this great Italian, who was more proficient in playing the lute than in the study of medicine, to which he had been destined, turned to the mathematical and mechanical speculations which satisfied his curiosity and gave full scope to his imagination, he did so during time filched from Galen, by eavesdropping at one Ricci's lectures on Euclid, and by perusing the volumes of Archimedes. These, in the imperfect state in which they were transmitted by the Arabs, were not entirely intelligible to Europeans; but Galileo plunged into them, and reconstituted from them the methods which the modern world has only lately realized go back to Archimedes. One may instance the problem of the hydrostatic balance and the determination of pressures and centers of gravity. All this may be said in spite of the slow but continuous development of mathematical methods during the late Middle Ages and early Renaissance.

Given Bacon's neglect of mathematics, it is not surprising that these mathematical methods go back on a line which Bacon does not grasp. On this line stands the philosopher Leibnitz, in a fundamental sense. Leibnitz paid tribute to Francis Bacon, although he regarded him as overemphasizing the experimental side of knowledge. But it is most odd that it should be just on the mathematical side that there should be a connection from Bacon to Leibnitz. This ironical obliquity we pass over at present in order to have the opportunity of developing the scandal later, and more fully.

Of course we have not covered everything in this rapid survey. We have not mentioned that Boyle put numbers on the theories of Torricelli and Pascal; that mathematics is indebted to Descartes, to the superb Euler and many others; that Tycho Brahe resuscitated temporarily a theory of the solar system which combined the vices rather than the virtues of both Copernicus and Ptolemy; and that Cardinal Maffeo Barberini, later Pope Urban VIII, presented to his friend Galileo the attraction of the theory of relativity as a compromise with that of the Inquisition, only to be met temporarily with Galileo's super-Baconian attitude of deference to what he regarded as experimental fact.

Let us turn to other sciences as briefly. It is no new thing to offer homage to the prestige of Harvey in the fields of medicine and physiology. Harvey, however, was again a contemporary of Francis Bacon. He brought to England the tradition and methods of Vesalius and Fabricius, from their home in Padua. These men were the precursors of the science of anatomy.

In the field which is more particularly biology, four modern names are on the tongues of all men. These are Darwin, Wallace, Pasteur, and Mendel. We have been told that Darwin describes himself as having commenced his research in the true Baconian manner by collecting all the facts. However, we find that Darwin had in the back of his mind the theories and concepts of Malthus and that Wallace also pondered often on the "revolting ratios of Malthus". Evolution, as such, goes back, not merely to Lamarck but even to Thales and Anaximander; while Bacon expressly casts the idea aside.

Pasteur pursued one idea from chemistry to biology, and thence around the world. The chemists themselves had gradually found the threads to lead them from alchemy to the discovery and laws of chemical transformations. Francis Bacon, it is true, insisted that there was much humbug in alchemy, but it was the earlier Franciscan Friar Roger Bacon [1] who took the bigger step of actual accomplishment in separating part of the dross from the gold in that science.

Mendel was moved by an ideal quite different from that of Francis Bacon in introducing numbers essentially into the explanation of biological phenomena, and handing so much of it over into the dominion of the rebellious discipline which Bacon wanted always to keep in a minor rôle.

It seems clear that Bacon is not directly responsible for much of modern science, and that a great deal of the credit which he has acquired in this direction is due to the fact that he lived at the beginning of a scientific age which merges continuously into the present. But why does that age join continuously with ours? Why is it that the lively court of Frederick II, and the brilliant revivals of science

[1] CHRONOLOGY: Roger Bacon, 1214-1294; Leonardo da Vinci, 1452-1519; Copernicus, 1473-1543; Montaigne, 1533-1592; Gilbert, 1540-1603; FRANCIS BACON, 1561-1626; Galileo, 1564-1642; Kepler, 1571-1630; Harvey, 1578-1657; Descartes, 1596-1650; Torricelli, 1608-1647; Pascal, 1623-1662; Newton, 1642-1727; Leibnitz, 1646-1716.

typified by Roger Bacon, by Leonardo da Vinci, and by various Pre-Cartesians were all without sensible effect, while from the time of Francis Bacon onward Science flung itself forward by leaps and bounds, making conquests right and left, as ambitious and as successful as Cæsar's armies? We know that the effect of the scientific accomplishment of Spain was to give that country elsewhere the reputation of being the home of black magic, and that Roger Bacon's immense discoveries were garbled and distorted in the hearsay of succeeding generations until they became the possible products only of a man who sprouted the horns of the devil. And it is precisely for this reason that we cannot regard Roger Bacon or Leonardo as progenitors of modern culture.

The question is answered in the lives of two men, Galileo and Newton. It was Newton who took the work of Galileo and Kepler, and erected thereon the vast theoretical system whose ramifications extend through the whole structure of our material civilization. I am taking the emphasis on this idea from Whitehead, natural as I find it from my own point of view. Whitehead writes the following:[1]

"Archimedes left no successor. But our modern civilization is due to the fact that in the year when Galileo died, Newton was born. Think for a moment of the possible course of history supposing that the life's work of these two men were absent. At the commencement of the eighteenth century many curious and baffling facts of physical science would have been observed, vaguely connected by detached and obscure hypotheses. But in the absence of a clear physical synthesis, with its overwhelming success in the solution of problems which from the most remote antiquity had excited attention, the motives for the next

[1] Science and Civilization, edited by F. S. Marvin, Oxford University Press (1923).

advance would have been absent. All epochs pass, and the scientific ferment of the seventeenth century would have died down. Locke's philosophy would never have been written; and Voltaire when he visited England would have carried back to France merely a story of expanding commerce and of the political rivalries between aristocratic factions. Europe might then have lacked the French intellectual movement. But the Fates do not always offer the same gifts twice, and it is possible that the eighteenth century might then have prepared for the western races an intellectual sleep of a thousand years, prosperous with the quiet slow exploitation of the American continent, as manual labor slowly subdued its rivers, its forests and its prairies."

Whitehead remarks that the result might possibly have been happier, since the chariot of Phœbus is a dangerous vehicle. Indeed, we have seen in the last few years how reckless Phæthon narrowly escaped dumping us all in the ditch. Nor are we sure that war is the only kind of ditch. That, however, is not now our concern. Our present interest lies in seeing the methods of science emerge from insecure ground, where they were surrounded, and perhaps on the point of being overwhelmed again, by the interest in the past and the authority of the ancients.

Manifestly, as we have portrayed this development, we cannot say that Bacon, whatever he may stand for as a symbol in the popular mind, is the father of science. It is equally evident from the scientific societies which were founded in his name and his eminence as it was portrayed in the first lecture of this series, that he has an acknowledged position. Am I merely flippant if I call him possibly *the step-father of the sciences?*

Before we consider various scientific methods more in detail, let us point out one or two instances where the ideas of Bacon have born direct fruit. In the first place, we have the subject of law, where we were told by the second lecturer how much the modern legal practice and point of view derives from Bacon. We learned that the domain of Equity, as distinguished from Common Law, is Bacon's province: his conquest, if not his discovery.

A second instance comes from Bacon's emphasis on what he calls *prætergenera,* that is to say, the sports or monsters or freaks of nature. His idea is that by studying these abnormal things, experimenting on them and comparing them with the more usual ones, we can better come to an understanding of the normal process or situation. This is exactly the method which, we are told, Pinel used, at the end of the eighteenth century, in investigating mental phenomena; an investigation of insanity led to an understanding of many processes of the normal mind. Similarly, psychologists investigate sleep through hypnosis. Another classic example is the method of the kindergarten, which arose through the treatment of the subnormal child. It is, perhaps, natural to investigate the unusual and striking situation, for that is what awakens curiosity. But it is at least Bacon's merit to have focused attention on it as a key to nature.

The third instance that we give is that far-fetched one to which I have already alluded in mentioning Leibnitz. Among the scientists who founded the Royal Society, the project of a universal language was much discussed. Its prominence was undoubtedly due not merely to the ever-present need of secret codes in the unfriendly intercourse between princes and diplomats, but also to the fact that Bacon expounded their nature at some length in that extensive and systematic survey of the field of knowledge which he calls "De Dignitate et Augmentis Scientiarum". Wilkins (1614-1672), Bishop of Chester, published a manual of secret correspondence. It suggested a second attempt, better and more scientific, which was made in 1661 by Delgarno. The latter essay may be described, in modern terms, as a sort of index by letters to Roget's Thesaurus. It consisted in dividing concepts into seventeen main categories, each designated by the initial letter of a corresponding word. Each class was again divided into subclasses by a second letter, and so on. The sequences of letters thus built up could be used to form code messages. Wilkins took up the matter again, and amplified the main classification to forty concepts, so that letters would not suffice, and he had to use conventional symbols.

Leibnitz in the year 1671 became actively interested in the problem with the idea of making the symbolic language truly ideographic, and thus more universal and of more philosophical interest. In other words, if one concept be defined in terms of others, the symbol for that concept should be a direct and definite combination of those others. The invention of symbols might be carried out in some such way as this: When any finite number of concepts were analyzed, they could be explained in terms of some sub-group of them, until finally ideas should be arrived at which were simple concepts, and could not further be reduced. That is, they could not be explained or defined except in a vicious circle. What would be more natural then than to represent these primary ideas by numbers which could not further be reduced, *i.e.*, by prime numbers? The composite ideas would then be represented by composite numbers whose factors corresponded to the primary ideas involved.

For example, if we take *animal* as a primary concept (of course, that is not necessary), and represent it by the prime number 2, and similarly if we represent *rational* by 3, we must represent *man* by 6, so that the equation

$$6 = 2 \times 3$$

indicates the statement:

Man is a rational animal.

May I suggest that you reflect on the question as to whether 3×3 is 9 or merely 3, and 6×14 is 84 or merely 42?

This sort of representation is more than a mere code. It is also more philosophical than a *merely* ideographic language. Thus when the Chinese represent "peace" by a symbol which portrays a woman in a house, and "discord" by the addition of another woman symbol under the same roof, the graphic representation appeals to the cynic in all of us, but does not really analyze the concept.

To Leibnitz it seemed desirable to translate his numbers into words, by means of a simple correspondence, so that they might be easily and systematically spoken. He even had a vision of poetry in his universal language. But what is noteworthy is that he recognized the difficulty of his project, and held to its importance all his life. He saw that the construction of such a language required the analysis of existing concepts in a great encyclopedia, that it demanded the progress of theoretical knowledge in all directions, and at the same time made that progress more feasible by means of a direct method for synthesizing concepts. But he was confident that the loyal coöperation of a few men for a few years would yield a substantial increase in science by means of such an investigation. He sought for many years, but in vain, to interest the Royal Society in the project. I am afraid, had he succeeded, one of the practical results would have been to afford the Gladstones of various times and localities an opportunity to regard the registration at the Court House of fresh synthetic concepts, or of new primary ideas (for incorporation into the Official Encyclopedia) as a capital means for collecting fees or taxes.

Given the difficulty of the task, Leibnitz made various compromises. Thus he invented a new Latin, gradually purging it of its grammatical difficulties in a systematic manner, and enriching it with new concepts, thereby devising a scheme of construction for international languages which has become most prominent in recent times.[1] But shall we say that the original, more thoroughly philosophic attempt is devoid of fruit? In answer, we have only to think of the modern extensive development of the algebra of logic and the possible relation of that algebra to its arithmetic. Moreover, Leibnitz himself made a contribution to his language by a systematic analysis of geometry—an analysis which is again being prosecuted at the present time from new points of view. The most striking instance, however, is that Leibnitz's invention of the symbols now used in differential calculus—which, in fact, really make a *calculus* out of Newton's theory of fluxions—was a direct and conscious contribution to an ideographic language.

Thus developed by Leibnitz, the secret code becomes a universal logical language, which involves a general science, or at least a general scheme of theoretical science, and an encyclopedia of concepts. Nevertheless the result is truly a direct descendant of that Baconian discussion of secret codes. It must be remarked that if Bacon could be confronted with his offspring, he would very promptly disinherit it.

[1] Those who desire to pursue this subject will be led to Couturat's La logique de Leibnitz, Paris (1901), and, for the less philosophical languages, to Guérard's Short History of the International Language Movement, New York (1921).

In order to understand now, in more detail, the place of Francis Bacon in the history of scientific method, let us begin with the great sceptic Montaigne (1533-1592), whose essays served as one model for Bacon. Impressed by the turbulence and conflict amid which he lived and dismayed by the intolerance and uncompromising belief which he saw on every hand and in every sect, yet at the same time conscious of the real world about him and imbued with the literature of ancient ages in many ways superior to his own, it is not surprising that Montaigne regards dogmatism as a presumptuous vanity. He also laughs at the efforts of science, which hardly even serves to convince us of our own ignorance. Philosophy is a sterile conflict of variable opinions. He puts man, an animal, down on the same stage as the other animals, playing their parts as cruelly and as ineffectually. What are the exploits of conquerors? Their armies, furious monsters of myriad arms and heads, are merely angry ant-heaps, which may at any time be annihilated through a contrary gust of wind or the misstep of a horse.

Reason is to him a dangerous tool, and he who uses it loses himself along with his dogmatic enemies. It is well to keep the multitude under the subjection of law and tradition, and he himself obeys the police regulations, municipal and ecclesiastical, although he has carried himself along the road of doubt so far that to his mind all the human faculties are discredited. This does not prevent him, however pessimistic, from making extensive and acute observations, nor his soul from being a source of kindness and gentility. He is no hero, and no Macchiavellist.

Francis Bacon believes that he provides the way of putting in order the universe which Montaigne has left in such an unhappy state. He devises a method which he thinks will be easy to apply and will increase the domain of science enormously and rapidly. With this, incidentally, the logic of Aristotle will be seen to be mere mental gymnastics. He makes a grand survey of knowledge. In this survey he forms first a main division of knowledge into three parts which he calls History, Poesy, and Science or Philosophy; these are the branches which correspond respectively to what were regarded as the three mental faculties of memory, imagination, and reason. Then these principal divisions are cross-divided under the captions Natural and Civil (the latter including ecclesiastical) and finally redivided according to subject so that the classification becomes more and more minute.

In Natural History should be contained an account of the Generations, which are the phenomena of nature working freely, the Pretergenerations, which are the abnormalities and errors of nature of which we have already spoken, and finally the History of the Arts or Mechanic History, in which would eventually be included, for example, the modern engineering arts. By this means a table may be constructed of things still wanting as well as of those already obtained.

Bacon tends to diminish the importance of the imagination in arriving at scientific truth; that is necessary, from Bacon's point of view, since imagination is a most variable quality in men, and must be put in a minor place if, as he hopes, the advancement of science is to be the coöperative effort of many ordinary minds. What interests Bacon in poesy is the fable or myth which he regards as a first essay, but of minor utility, in arriving at scientific truth. In these allegories the mind puts together things according to desire, without much respect for reality. What is to be the real method of turning natural history into science is the systematic use of the reason in the way which Bacon explains in the "Novum Organum".

This systematic method is an induction with the help of experiment. According to Bacon's idea it is possible to arrive at a scientific theory by a process of exclusion, more or less as an argument by *reductio ad absurdum* is used in mathematics, but the process this time is to be carried out by interrogating the facts of nature, normal, monstrous or constrained by art. In other words, hypotheses are to be eliminated successively with reference to fact or experiment until only the hypothesis which must be true remains.

The famous Galileian controversy is a case in point, for Galileo already had the same idea with regard to exhaustion by experimental tests. He felt that it was demonstrable by appeal to the facts of nature that the Copernican theory was the only one which would "save appearances"—*i.e.,* account for all the facts—and must therefore be the true one. But could such a position ever be justified? Cardinal Barberini asks Galileo if it would not be possible for God to arrange and move the orbits and planets in some other manner than the Copernican, so that all the phenomena evident in the skies could be accounted for. If this were not to be the case it would be necessary for Galileo to prove that these phenomena could not be obtained by any system except the Copernican, since God would have the power and the corresponding knowledge to accomplish anything that was not in contradiction with his other acts. And otherwise Galileo would have no right to reduce Divine Power and Wisdom to the system which he had conceived.[1] In fact, even if the Ptolemaic system could be demonstrated to be false by reference to experiment, the system of Tycho

[1] P. Duhem, Essai sur la notion de théorie physique de Platon à Galilée, Paris (1908), p. 135.

Brahe, which made the Earth the centre of motion but let Venus and Mars move in orbits about the Sun, would have sufficed at the time of Galileo to explain all the known phenomena.

In other words, no matter what hypotheses are successively eliminated by experiment, there is no single hypothesis that remains. We cannot say that the given set of facts of experience will contradict necessarily every other hypothesis that might be imagined. To state the matter paradoxically, progress in the science of nature consists in proving that theories are not true.

Galileo in his celebrated dialogue of 1632 offered lip service to this reasoning by pointing out that it was open to God to move the system of the world in whatever complicated manner He chose, although the simple manner was quite evident. This did not meet the issue either logically or theologically. The argument for relativity failed to impress the uncompromising scientist, and the equally uncompromising theologians felt that their only recourse was the *argumentum ad hominem*.

The difficulty is aggravated instead of diminished in the general Baconian method, for in the general situation the hypotheses to be chosen are themselves lacking. If a hypothesis already at hand cannot be demonstrated by this method, is it possible to arrive at one and prove it at the same time? It is for this reason that Couturat and other logicians say that no scientific result was ever obtained by the Baconian method, and none ever will be. This does not mean that important results cannot be won merely by a systematic experimentation without any new theory; and perhaps such methods may be regarded as derived from Bacon. Thus in organic chemistry, when one hopes for a certain property, one may eliminate one compound after another until by good luck such a property may be obtained; and then one may number it in the six hundreds or the nine hundreds to indicate the industry rather than the science by which the result has been achieved. It is, however, the obtaining of theoretical results which is Bacon's idea.

If the carrying out of this idea were possible, it would be necessary, in order to clear the way for the formation of true principles, to guard against prejudices. Bacon attempts to do this systematically by listing them in three classes of fallacies of false appearances: Idola Tribus, Idola Specus and Idola Fori, he calls them, prejudices "of the tribe", due to the general nature of mankind, "of the cave", due to the narrow bounds of each mind, and "of the market-place" respectively. That is to say, men tend to imagine that nature acts as men do, and they make themselves a rule of nature (so that all idealistic philosophy for Bacon would be Idola Tribus), or secondly, they see too narrowly from the prisons of their own minds and bodies, or finally, they accept the tacit implications of mere words.

In such ways Bacon expected that attention should be focused on the facts, and that generalizations or theories should be obtained step by step, by induction from the facts, making sure that each step should be solidly placed. Is it a question whether these so systematic, laborious and uninspired processes would ever, as compared with the more imaginative methods, give the rapid advancement of learning which Bacon anticipated? That question was surely answered by Newton.

Another way of resolving the universal skepticism of Montaigne, diametrically opposite to the plan of Bacon, was developed by Descartes. He also thought that he could make the progress of science and philosophy sure and rapid, and that the mind could be provided with a tool which would give it the power to jack itself up from one truth to another by easy stages, and thus to answer gradually one after another the difficult questions of physics and metaphysics. His method consisted briefly, first, in a hypothetical skepticism: nothing to be assumed but what was presented so clearly and distinctly to his mind that he could not doubt it. Secondly, he was to divide any of his difficulties into as many small parts as possible. Thirdly, he was to conduct his ideas in orderly fashion commencing with the simplest and easiest to know, in order to mount stepwise to the most complicated subjects. And finally, he would make such numerous and general reviews that nothing would be omitted.

"Those long chains of reasoning, quite simple and easy, which geometers are accustomed to employ in order to achieve their most difficult demonstrations, gave me cause to think that all things which might fall under human knowledge might follow from each other in the same fashion (*Idolon Specus!* comments Mahaffy), and that provided only we take care to receive nothing as true which may not be so, and preserve the proper order to deduce one truth from another, there would be none so remote that we could not finally reach it, nor so hidden that we could not discover it." Descartes then instances his own discovery of analytic geometry as an illustration of his method.

One may criticise this effort, which endeavors to proceed so logically on the basis of a few axioms, from almost the same angle as that of Bacon, who tries to arrive at theories by conclusive experiments. Neither allows enough place for the imagination. Knowledge is to be advanced by the invention of new concepts. But what makes a concept significant? Why did Descartes do for analytic geometry what Euclid did not do? It is easy to see concepts after they are there, but only the Galileo, the Newton or the Darwin can build up those tremendously significant ones out of their personal reactions to nature.

In general, in a causal series, as Leibnitz points out, every event is caused by a previous one, and so on to an infinite regression; hence no one of the events contains the explanation of the entire series; for that explanation *one must go outside the series.* It is brilliance of imagination which makes the glory of science.

I hope I may be pardoned for turning finally to the rôle in Bacon's method of the discipline in which I am most interested. Mathematics for Bacon occupies an important position but not a thrilling one. He sees in it merely the means of stating formulæ or putting in convenient shape results which are, in their essential causal relations, already obtained. The mathematical work in astronomy, he would say, was an assistance in navigation but told nothing that satisfied him as a scientist. Perhaps that view is still held rather commonly. It is not inconsistent with Bacon's view of induction by experiment, but, on the other hand, it is not a necessary consequence of such a view. We see this fact clearly if we turn again to Galileo, who as we have pointed out, had the same view of exhausting all possibilities by experiment. Mathematics plays an essential part in the development of his theories, as it does later with Newton, for between them they bring the science of mechanics into being.

Moreover Galileo, whether or not you say it is possible, actually does get new ideas about space out of mathematics. Mathematics for him is a field of discovery; he sees novel relations there which he tries to prove, as mathematicians now meet striking relations in the theory of numbers, which Bacon's method would hardly suggest and Descartes' method has not yet proven. Thus Galileo sees a line or curve as infinitely divisible, and thinks to prove it by devising an experiment by means of which a small circle is made to roll along with a larger concentric circle. The only way that the small circle can be made to keep up with the large one is for its circumference to contain an infinite number of vacua. *Ipso facto* the circumference is infinitely divisible.

Nowadays we should hardly accept Galileo's reasoning in this case (which of course I have not given), although to a mathematician it is most suggestive. This type of reasoning, which generally leads to true results, gives that combination of novelty and truth which Kant, later, also regarded as characteristic of geometry, and which led him to regard space as a form of intuition.

The modern view of mathematics, as we find it say in Russell or Whitehead, is rather a development of that of Leibnitz at which I have hinted; that mathematics is a universal logical language, ideographic in that the combination of its symbols corresponds to the combination of the designated ideas, and with a syntax of operations which provides a calculus of deductive reasoning. We do not altogether agree with the positivistic philosopher who says (as Bacon might well have said explicitly) that by mathematics you get out at one end no more than you put in at the other; we do not agree, even if he states it in the more amiable form that it is worth while to have something by means of which you can get out at one end the implications of what you put in at the other. Moreover, it is the mathematician who has the task of deciding what ideas he wants to get out and what ideas he has to put in, and since that is an essential part of his task which no one else will undertake we may as well call it an essential part of mathematics. Would you call a man an author if he spent his time putting all possible words in all possible combinations, like some that Gulliver met in his travels?

Let me not seem to want to diminish the glory of Bacon by my criticisms. His influence for several centuries has been so vast that there is no question of his greatness. In what direction was he great? He manifestly was not a scientist, since his scientific work is hopelessly insignificant, even in terms of his own day. There is no question of his standing beside his contemporaries Galileo, Kepler, Gilbert, and Harvey. He cannot stand beside the practically minded Benjamin Franklin, with whom one is tempted to compare him.

His theory of knowledge also is insufficient; but, on the other hand, whose is not? We must not throw him aside on that ground. The philosophers Gassendi, Leibnitz, Locke, Hume, and Kant held him in high repute; and substantial portions of most books on logic are devoted to his treatment of induction. He was not merely a popularizer or a bally-hoo; Leibnitz and Kant had no need of such. If then these eminent philosophers found him estimable, was he not therefore great in philosophy? In that part of philosophy which deals with scientific method his comprehensive and systematic expositions and his daring un-Baconian generalizations have earned him a high place.

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