IV

BACON AND THE EXPERIMENTAL METHOD

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I WILL begin by giving you a very brief sketch of Bacon's life, so that you may have some idea of the kind of man that he was and the society in which he moved. He was born at York House, Strand, London, in January 1561, i.e. about two years after Queen Elizabeth came to the throne. His father was Nicholas Bacon, who held the office of Lord Keeper; and his mother was Anne Cook, whose father had been tutor to Edward VI. So we may say that Bacon's family belonged to the higher ranks of the civil service. Bacon was a very bright precocious boy, and Queen Elizabeth used to enjoy talking to him. He was sent to Cambridge as an undergraduate of Trinity College at the extremely early age of thirteen, and he left two years later. He then took up the study and practice of law, which became his profession. The Queen employed him much in legal and political business, but she seems not to have really liked him or trusted him, and he held no important office under her reign. After the accession of James I in 1603 Bacon's advancement was rapid, for the King greatly admired him. He became Lord Keeper, Lord Chancellor, and in 1620 Viscount St. Albans. He was now a very wealthy man, but a tragedy was approaching. He had always been careless with money and extravagant in his mode of life, and he had followed the common practice of his day in

taking presents from suitors, though he always asserted that he had not allowed this to influence his legal judgments. However that may be, he was tried on a charge of corruption, pleaded guilty, was condemned, and had to pay a fine of £40,000 (an immense sum in those days), lost his office, and was banished from the court. This happened in 1621. Bacon lived on for another five years, a broken man. He died in April 1626. His last illness is said to have been caused by his getting out of his carriage in freezingly cold weather in order to try the experiment of stuffing the carcase of a fowl with snow to test the preservative effects of a low temperature.

Though Bacon was an able, and up to a point successful, lawyer and politician, his heart was not in that work. His one fundamental interest was to discover and propagate a general method by which men might gain scientific knowledge of the ultimate laws and structure of matter, and might thus acquire ever-increasing practical control over nature. He saw that, in order to collect the data from which the laws of nature were to be extracted by his methods, a huge organisation of research would be needed. Vast numbers of men and women, at various levels, would have to be employed, and expensive buildings and apparatus would be required. All this would be very costly. The only hope of getting adequate supplies of money and sufficient authority and prestige to start and continue such a scheme was for Bacon himself to become a rich and prominent man and for him to persuade the King and powerful noblemen and churchmen to back it. In order to do this he must be ready to turn a blind eye to their vices and follies, to humour their whims, and to play upon their weaknesses by flattery. Bacon was nothing if not thorough, and he analysed and practised with his usual acuteness and assiduity the arts of worldly success. I believe that, like many other clever idealistic men, he started by seeking wealth and power wholly, or at any rate mainly, as a means to a high impersonal end, but gradually slipped into pursuing them for their own sake. I suspect also that, as often happens with such men, *he* was not quite so clever, and those whom he used and despised were not quite so stupid as he imagined, and that

he was seen through and distrusted much more than he realised.

If we are to appreciate Bacon's originality, farsightedness and breadth of vision and to be fair to his limitations and mistakes, we must see him against the background of the science of his own day and not against that of ours. The fundamental science of dynamics, for instance, did not exist. It was founded during Bacon's life-time by Galileo (1564–1642), who also invented the telescope and noted with it the spots on the sun and the irregularities on the moon's surface. In astronomy it was still generally held that the earth is the fixed centre of the universe, and that the sun and the planets revolved about it, the latter in complicated epicyclic orbits. The discovery of the three fundamental laws of planetary motion was made in Bacon's life-time by Kepler (1571–1630). It was not until long after Bacon's death that Newton provided the first example of a scientific theory on the grand scale and in the modern sense, by explaining those laws and correlating them with the phenomena of falling bodies through his hypothesis of universal gravitation. Bacon's older contemporary Gilbert (1540–1603) had discovered some elementary facts about natural magnets, but the existence of electricity was unknown and its connexion with magnetism was unsuspected. Chemistry, as a science and not a mere set of recipes, did not come into existence for another hundred and fifty years. Learned men commonly accepted without question the Aristotelian theory that earthly bodies are composed of the four elements, earth, air, fire and water, and that heavenly bodies are fundamentally different, being composed of a superior fifth element, called the *quintessence*.

Corresponding to this lack of scientific knowledge was a lack of power over nature. The only available devices for obtaining mechanical energy were clockwork, waterwheels, and windmills. All land transport was on foot or by horse, and all water transport by rowing or sailing. Men were constantly at the mercy of local and seasonal food shortages and gluts, and were periodically decimated by epidemics, whose causes they did not understand and which they had no rational means of combating. Bacon was impressed by

this impotence and its evil consequences, and he could not be expected to foresee, what we have learned since, that men can bring even greater evils upon themselves by abusing the power which science gives them than they suffered when they were powerless in face of natural forces.

Now Bacon was completely convinced that the ignorance of nature and the consequent lack of power over nature, which had prevailed from the earliest times up to his day, were by no means inevitable. They sprang, not from any fundamental imperfection in the human mind, nor from lawlessness or inextricable complexity in nature, but simply and solely from the use of a wrong method. He felt sure that he knew the right method, and that, if only this could be substituted and applied on a large enough scale, there was no limit to the possible growth of human knowledge and human power over nature. Looking back after the event, we can see that he was right, and we may be tempted to think that it was obvious. But it was not in the least obvious at the time; it was, on the contrary, a most remarkable feat of insight and an act of rational faith in the face of present appearances and past experience.

What was wrong with the methods in use up to Bacon's time? The fundamental defects, as Bacon clearly saw, were the following. In the first place there was an almost complete divorce between theory, observation and experiment, and practical application. Plenty of experiments of a kind had been done, and a certain number of disconnected empirical rules or recipes had been discovered. But the experiments were made in the main by men like alchemists and quack-salvers. These were often, though by no means always, charlatans or half-crazy enthusiasts. But, even when they were honest and sensible men, they did their experiments with some immediate practical end in view, such as turning lead into gold or discovering a universal medicine for all diseases. They were not guided by any general theory; they did not seek to discover the all-pervading laws and the minute structure of matter; and they worked in isolation from each other, keeping their results secret rather than pooling them. Bacon valued science both as an end in itself and for the immense power over

nature which he believed that it could give. He thought that the failure of contemporary physics to have any useful practical applications was a sign that it was on the wrong track. But he was firmly convinced that it is fatal for scientists to work shortsightedly at the solution of this or that particular problem. Let them concentrate, he thought, on discovering by suitably designed experiments and appropriate reasoning the fundamental laws and structure of nature. Then, and only then, could they make innumerable practical applications with complete certainty of success. Anyone who reflects on how our modern applications of electromagnetism, of chemistry, and of medicine depend respectively on the theoretical work of Faraday and Maxwell, of Dalton and Avogadro, and of Pasteur, will see how right Bacon was in this.

The second defect which Bacon found in the science of his time was on the theoretical side. During the twelfth century, when Europe had reawakened from barbarism and men had again begun to take a scientific interest in external nature, it happened that the works on physics of the Greek philosopher Aristotle were re-discovered. It happened also that the greatest and most influential thinker of the Middle Ages, St. Thomas Aquinas (1226–1274), became an enthusiastic disciple and advocate of Aristotle. Now St. Thomas was a daring innovator who had to face strong opposition. But Aristotle's physics and logic were so much better than anything else available at the time, and St. Thomas was so much abler than his opponents, that the Aristotelian methods and concepts scored a complete triumph. Thenceforth they were accepted uncritically and handed down from one generation to another. Scientists decided all questions, not by investigating the observable facts, but by appealing to the infallible authority of Aristotle, just as present-day Communists appeal to that of Marx, and Engels and Lenin. Now this would have been disastrous, even if Aristotle's physics had been sound. But although he was a very great man, his strength lay in natural history and in certain branches of deductive logic. He was no mathematician, and his theories of physics and astronomy were much inferior to those of certain other Greek philosophers.

Bacon rightly accused the learned men of his time of accepting on authority sweeping general principles, which Aristotle himself had reached by hasty and uncritical generalisation from a few rather superficial observations. Using these as premisses, they proceeded to deduce conclusions about nature and to hold elaborate wrangles with each other by means of Aristotle's favourite form of reasoning, which is called the 'syllogism'. The following argument is an example of a valid syllogism: All metals are good conductors of heat, and all good conductors of electricity are metals; therefore all good conductors of electricity are good conductors of heat. Some arguments in syllogistic form are valid and others are not. Aristotle formulated the rules for distinguishing between valid and invalid syllogistic arguments. That was a very considerable achievement, but, to put it familiarly, it rather 'went to his head', and made him overestimate the importance of the syllogism. What he failed to do was to suggest any method for establishing generalisations, like 'All metals are good conductors of heat', which are needed as premisses before any syllogistic argument can get started.

Bacon saw that syllogistic reasoning, however well it may be adapted for tripping up an opponent in the law courts or in Parliament, is utterly useless for discovering the laws of nature and for applying them to the solution of practical problems. What was wanted was a method by which we could slowly and cautiously rise from observed facts to wider and deeper generalisations, testing every such generalisation at each stage by deliberately looking out for possible exceptions to it, and rejecting or modifying it if we actually found such exceptions.

That process is called 'induction'. Of course, as Bacon quite well knew, men have always been practising it to a certain extent in an unconscious and unsystematic way. What Bacon did was to abstract and exhibit the general principles of such reasoning, so that in future men might perform it consciously with a full knowledge of what they were doing. Perhaps his greatest service here was to show the importance of testing every generalisation by devising and performing experiments which would refute it if the

result turned out in a certain way, and would confirm it if the result turned out in a certain other way.

Bacon realised that every man inherits or acquires certain mental kinks, of which he is generally quite unaware. These tend to lead us astray in our thinking, and we need to be put on our guard against them. Bacon calls these kinks by the quaint name of 'Idols'. Besides the tendency to accept on authority the dogmas of some prominent person or sect, which Bacon calls 'Idols of the Theatre', he enumerates three others. 'Idols of the Tribe' are certain unfortunate mental tendencies common to the whole human race: for instance, the tendency to notice facts which support one's beliefs and fall in with one's wishes, and to ignore or pervert those which do not. Then there are 'Idols of the Market Place'. These arise from the fact that many words and phrases embody the false beliefs and inaccurate observations of our remote ancestors, and are thus, so to speak, crystallised errors which we swallow unconsciously. Lastly, there are 'Idols of the Cave'. These are sources of error or bias which are peculiar to each individual, depending on his particular temperament and the special circumstances of his upbringing.

It is time for me to bring this chapter about Bacon to an end, though there is much more that I would like to tell you about him and his work. In conclusion I would say that he was not a practising scientist, and it would be quite unfair to judge him from that point of view. His service to science was to criticise the existing bad methods, to try to formulate the methods which should be substituted for them, and to paint a glowing picture of the power which men might acquire by such means over nature. Perhaps his main defect here was his failure to see the enormously important part which mathematics was to play in the development of science. But in other respects he showed great insight and most remarkable foresight, and he clothed his thoughts in a garment of wit and wisdom which makes his writings one of the glories of English literature.