Francis Bacon and Scientific Method.¹

By Dr. C. D. BROAD.

II.

THE natural history, selected, arranged, and recorded by the rules described in the previous article, forms the basis on which scientific knowledge must be built. Bacon's next task was to construct a logical instrument by which a knowledge of general laws can be erected on this basis. Plainly the kind of reasoning which is needed is inductive. But Bacon objected both to the order and the form of reasoning which he found in current inductive arguments. Those who use them jump directly from particular facts to extremely sweeping generalisations, and they then deduce propositions of medium generality from these generalisations by means of syllogistic reasoning. Now Bacon's view is that there should be a very gradual ascent from particulars through principles of slowly increasing generality to the widest generalisations. Conversely, there should be a very gradual descent from the widest generalisations through principles of slowly decreasing generality to new particular facts. In the ascending scale each stage covers all the facts below it and extends very slightly beyond them. We then deduce observable, but not hitherto observed, consequences from the hypothesis and see whether they are true. If they are found to be so we can accept the hypothesis and go on to generalise it a little further. Thus the descending scale serves to test the stages in the ascending scale.

Bacon's objection to the form of reasoning employed in current induction was that it made no use of negative instances. It simply argued in the form: "All observed S's have been P, therefore all S's will be P." Now Bacon's view is that the cause of a given effect cannot be discovered by direct and positive means. It can be discovered only by gradually eliminating alternative possible causes until we are left with a single survivor, which can then be accepted with confidence as *the* cause. In order to discover the cause of a given kind of phenomenon, three sets of tables were to be formed, namely: (1) cases where this phenomenon is present; (2) cases where it is absent; (3) cases where it varies in degree. Now Bacon takes it as axiomatic that what he calls the 'formal cause' of a phenomenon is such that (1) it cannot be absent when the phenomenon is present; (2) it cannot be present when the phenomenon is absent; and (3) it cannot be constant when the phenomenon varies, or conversely. He knows then that the cause must be present in all the cases in the first table. He need not consider, therefore, any factor which is absent from any of these cases. Again, he need not consider any factor that is present in the cases in the second table, for the cause must be absent from all of them. Lastly, he can reject any factor which is constant throughout the cases in the third table. By this method of rejection, and by it alone, Bacon thought it possible to discover with certainty the causes of given effects.

This is Bacon's method in the barest outline. What kind of fact did he hope to discover by it? He tells us that the ultimate aim of theoretical science is to discover 'the forms (or formal causes) of simple natures,'

and that the ultimate aim of applied science is to use this knowledge to 'induce on bodies the form of any nature that we may desire it to have.' He draws a sharp distinction between the 'formal cause,' on one hand, and the 'material' and 'efficient' cause, on the other. He assigns the study of material and efficient cause to 'Physics,' and their practical use to 'Mechanics'; whilst he assigns the study of formal causes to 'Metaphysics,' and their practical employment to what he calls 'Natural Magic.' But he recognises that he is here using 'Metaphysics' in an unusual sense. The meaning of all this is the following. By a 'simple nature' Bacon means some perceptible generic physical property, such as colour, temperature, etc. By the 'form' or 'formal cause' of a simple nature he means that which this property is in things themselves apart from their relation to sensitive organisms. Thus, violent and irregular molecular motion would be the 'form' of the 'simple nature' called 'temperature.' Again, periodic variation of electro-magnetic intensity would be the 'form' of the 'simple nature' called 'colour'; and so on. So the Metaphysics of Forms is what we should call Microscopic Theoretical Physics. The propositions of 'Physics,' in Bacon's sense of the word, are what we should call 'empirical laws,' e.g. 'if amber be rubbed with flannel it becomes electrified.' Here the 'material cause' is amber and flannel, whilst the 'efficient cause' is the process of rubbing the two together.

Now of course we may know of various practical methods of inducing heat or electricity on bodies when we know nothing of the form of heat or the form of electricity. But Bacon sees that so long as we have merely this rule-of-thumb kind of knowledge our practical control over Nature will be very limited. If, on the other hand, we know the form of a given nature we know that *any* means of inducing this form will induce this nature, and that nothing else will do so. Thus by knowledge of forms, and by that alone, we may be able to produce profound modifications at will in the properties of bodies. This is what Bacon means by 'Natural Magic'; and the syntheses of new substances in organic chemistry would be an example of what he had in mind.

Bacon holds that there is a part of physics and mechanics which is closely connected with metaphysics and natural magic, and constitutes the transition from the former to the latter. This he calls the study of the 'Latent Structure' and the 'Latent Processes' of bodies. He recognises that bodies have an inner microscopic structure too small for our unaided senses to perceive, and that many of their perceptible characteristics depend upon this. He also recognises that what we call the efficient causes of given effects are only isolated outstanding features in processes which are continuous and in the main imperceptible. If we are to understand and control Nature we must turn our attention from the gross structure and changes of bodies to their minute components and processes. Bacon particularly insists that, whilst both of these

¹ Continued from p. 488.

subjects have been neglected, the latter has been more neglected than the former; and yet the dynamical aspect of Nature is even more important than its statical aspect.

It will be interesting at this point to consider Bacon's views about mathematics, for they exhibit his peculiar weakness and strength in a clear light. It is evident that Bacon was no mathematician. He has no theory of mathematical reasoning; he seems to be contemptuous of pure mathematics; and he was evidently unacquainted with the progress which was being made by both pure and applied mathematics in his time. It is noteworthy that in his remarks about Plato, with whom he is not altogether unsympathetic, he never thinks of Plato and his school as mathematicians but always as theologians and moralists. Yet Bacon does repeatedly say that physics cannot progress far without mathematics; and some of his strictures on the excessive worship of mathematics in science are the negative side of an important positive demand. Thus he complains that optics and astronomy have fallen wholly into the hands of mathematicians. When this complaint is investigated it is found to mean that Bacon wants something more than mere geometrical optics and mere descriptions of the courses of the heavenly bodies. He wants a *physical* optics and a *physical* astronomy, which shall deal with the *nature* of light and the *substance* of the stars and planets. His own attempts to supply this want are of very little value, but the demand is a sound one.

Although Bacon held that the proper course for scientific reasoning to take is a gradual ascent from particulars to general laws and a gradual descent from these general laws to new particulars, he was prepared to admit as a subsidiary process the direct passage from one particular to other partly analogous particulars. This he calls *Instructed Experience* (*Experientia Litterata*). He distinguishes various forms of this, of which the following are the most interesting: (1) Varying an old experiment, either by applying it to different but partly analogous materials, or by applying different but partly analogous processes to the old materials, or by varying the quantities or intensities of the factors in the old experiment. (2) Repeating the original process on the product of the previous experiment, as in redistillation. Bacon is careful to point out that we must never assume that an increase in any factor will produce a corresponding increase in the effect, or that the repetition of a process upon its product will increase the effect. (3) Extending a process from Nature to art, from one art to another, or from one part of an art to another part of it. Bacon says that new and useful processes are most likely to be discovered when one or a few men learn to compare the processes of a number of different mechanical arts.

(4) Inverting one or more of the factors in an experiment; e.g. substituting great cold for great heat. (5) Making one factor gradually more or less intense until the characteristic effect just ceases to take place. (6) Coupling together two cause-factors, each of which has already been tried separately. Here again Bacon carefully points out that we have no right to assume that, because *a* in the absence of *b* gives *a*, and *b* in the absence of *a* gives *β*, therefore *ab* will give *aβ*. We may conclude this point of Bacon's doctrine with two highly characteristic quotations: "Though a successful experiment be more agreeable, an unsuccessful one is often no less instructive"; and "Experiments of Light" (i.e. those which throw light on the laws of Nature) "are more to be sought after than Experiments of Fruit" (i.e. those which lead to results that are of immediate practical use).

I will conclude by mentioning the seven cases in which the senses have to be aided and the kind of help which Bacon suggests. (1) If the object be very distant it must be joined to something which is perceptible at a distance, e.g. something that gives a flash or a noise. (2) If it be enclosed in an opaque envelope it must be judged by processes at the surface (e.g. feeling the pulse) or by what comes out from it (e.g. examination of urine). (3) It may be unable to affect the senses because of its intrinsic nature (e.g. colourless gases), or (4) because of its minuteness. The latter difficulty can be avoided by causing it to produce some effect of sensible magnitude (e.g. using an air-thermometer to indicate small changes of temperature). (5) Motion may be too slow or too swift to be perceived. In the former case it can be magnified by pointers and similar devices. Bacon does not know how to deal with the latter case. (6) The intensity may be too great for the senses to bear. In this case Bacon recommends the use of reflectors or semi-opaque screens. (7) The senses may be very rapidly exhausted. This happens only with taste and smell. Bacon suggests no remedy for this; but he says that where our senses fail us altogether we may use those of animals (e.g. dogs for scent).

Much of the merit of Bacon consists in minute detail, and is lost in a rapid sketch like the present. I think we may sum up his strength and weakness as follows. He was not a great scientist, either practically or theoretically. But he saw many of the essential factors in successful scientific procedure with great clearness, and stated them with admirable force. His method is admittedly incomplete; and no method could accomplish all that he expected of it. The nearest approach to a complete method would be a synthesis of the methods of Bacon and Descartes. But we must go far before we shall find another such combination of wide generalisation, strong common sense, balanced enthusiasm, and pointed eloquence as we find in Bacon.

The Tropical Cyclone.

By E. V. NEWMHAM.

THE cyclone season of the northern tropics is drawing to a close. The accounts of widespread damage to property and loss of life, both in the Gulf of Mexico and in the Far East, that have appeared recently in the newspapers, show that the storms that have already occurred will make this season a memorable one. It

is not intended here to deal with these recent events, but rather to present the salient facts about the tropical cyclones of both hemispheres, and to indicate the extent to which these phenomena are understood at the present time.

Like all meteorological phenomena, tropical cyclones