CHAPTER XV

Inductive Method

Section 1. It is necessary to describe briefly the process of investigating laws of causation, not with the notion of teaching any one the Art of Discovery, which each man pursues for himself according to his natural gifts and his experience in the methods of his own science, but merely to cast some light upon the contents of the next few chapters. Logic is here treated as a process of proof; proof supposes that some general proposition or hypothesis has been suggested as requiring proof; and the search for such propositions may spring from scientific curiosity or from practical interests.

We may, as Bain observes (Logic: B. iii. ch. 5), desire to detect a process of causation either (1) amidst circumstances that have no influence upon the process but only obscure it; as when, being pleased with a certain scent in a garden, we wish to know from what flower it rises; or, being attracted by the sound of some instrument in an orchestra, we desire to know which it is: or (2) amidst circumstances that alter the effect from what it would have been by the sole operation of some cause; as when the air deflects a falling feather; or in some more complex case, such as a rise or fall of prices that may extend over many years.

To begin with, we must form definite ideas as to what the phenomenon is that we are about to investigate; and in a case of any complexity this is best done by writing a detailed description of it: e.g., to investigate the cause of a recent fall of prices, we must describe exactly the course of the phenomenon, dating the period over which it extends, recording the successive fluctuations of prices, with their maxima and minima, and noting the classes of goods or securities that were more or less affected, etc.

Then the first step of elimination (as Bain further observes) is “to analyse the situation mentally,” in the light of analogies suggested by our experience or previous knowledge. Dew, for example, is moisture formed upon the surface of bodies from no apparent source. But two possible sources are easily suggested by common experience: is it deposited from the air, like the moisture upon a mirror when we breathe upon it; or does it exude from the bodies themselves, like gum or turpentine? Or, again, as to a fall of prices, a little experience in business, or knowledge of Economics, readily suggests two possible explanations: either cheaper production in making goods or carrying them; or a scarcity of that in which the purchasing power of the chief commercial nations is directly expressed, namely, gold.

Having thus analysed the situation and considered the possibility of one, two, three, or more possible causes, we fix upon one of them for further investigation; that is to say, we frame an hypothesis that this is the cause. When an effect is given to find its cause, an inquirer nearly always begins his investigations by thus framing an hypothesis as to the cause.

The next step is to try to verify this Hypothesis. This we may sometimes do by varying the circumstances of the phenomenon, according to the Canons of direct Inductive Proof to be discussed in the next chapter; that is to say, by observing or experimenting in such a way as to get rid of or eliminate the obscuring or disturbing conditions. Thus, to find out which flower in a garden gives a certain scent, it is usually enough to rely on observation, going up to the likely flowers one after the other and smelling them: at close quarters, the greater relative intensity of the scent is sufficiently decisive. Or we may resort to a sort of experiment, plucking a likely flower, as to which we frame the hypothesis (this is the cause), and carrying it to some place where the air is free from conflicting odours. Should observation or experiment disprove our first hypothesis we try a second; and so on until we succeed, or exhaust the known possibilities.

But if the phenomenon is so complex and extensive as a continuous fall of prices, direct observation or experiment is a useless or impossible method; and we must then resort to Deduction; that is, to indirect Induction. If, for example, we take the hypothesis that the fall is due to a scarcity of gold, we must show that there is a scarcity; what effect such a scarcity may be expected to have upon prices from the acknowledged laws of prices, and from the analogy of other cases of an expanded or restricted currency; that this expectation agrees with the statistics of recent commerce: and finally, that the alternative hypothesis that the fall is due to cheaper production is not true; either because there has not been a sufficient cheapening of general production; or because, if there has been, the results to be rationally expected from it are not such as to agree with the statistics of recent commerce. (Ch. xviii.)

But now suppose that, a phenomenon having been suggested for explanation, we are unable at the time to think of any cause–to frame any hypothesis about it; we must then wait for the phenomenon to occur again, and, once more observing its course and accompaniments and trying to recall its antecedents, do our best to conceive an hypothesis, and proceed as before. Thus, in the first great epidemic of influenza, some doctors traced it to a deluge in China, others to a volcanic eruption near Java; some thought it a mild form of Asiatic plague, and others caught a specific microbe. As the disease often recurred, there were fresh opportunities of framing hypotheses; and the microbe was identified.

Again, the investigation may take a different form: given a supposed Cause to find its Effect; e.g., a new chemical element, to find what compounds it forms with other elements; or, the spots on the sun–have they any influence upon our weather?

Here, if the given cause be under control, as a new element may be, it is possible to try experiments with it according to the Canons of Inductive Proof. The inquirer may form some hypothesis or expectation as to the effects, to guide his observation of them, but will be careful not to hold his expectation so confidently as to falsify his observation of what actually happens.

But if the cause be, like the sun-spots, not under control, the inquirer will watch on all sides what events follow their appearance and development; he must watch for consequences of the new cause he is studying in many different circumstances, that his observations may satisfy the canons of proof. But he will also resort for guidance to deduction; arguing from the nature of the cause, if anything is known of its nature, what consequences may be expected, and comparing the results of this deduction with any consequent which he suspects to be connected with the cause. And if the results of deduction and observation agree, he will still consider whether the facts observed may not be due to some other cause.

A cause, however, may be under control and yet be too dangerous to experiment with; such as the effects of a poison–though, if too dangerous to experiment with upon man, it may be tried upon animals; or such as a proposed change of the constitution by legislation; or even some minor Act of Parliament, for altering the Poor Law, or regulating the hours of labour. Here the first step must be deductive. We must ask what consequences are to be expected from the nature of the change (comparing it with similar changes), and from the laws of the special circumstances in which it is to operate? And sometimes we may partially verify our deduction by trying experiments upon a small scale or in a mild form. There are conflicting deductions as to the probable effect of giving Home Rule to Ireland; and experiments have been made in more or less similar cases, as in the Colonies and in some foreign countries. As to the proposal to make eight hours the legal limit of a day's labour in all trades, we have all tried to forecast the consequences of this; and by way of verification we might begin with nine hours; or we might induce some other country to try the experiment first. Still, no verification by experiments on a small scale, or in a mild form, or in somewhat similar yet different circumstances, can be considered logically conclusive. What proofs are conclusive we shall see in the following chapters.

Section 2. To begin with the conditions of direct Induction.–An Induction is an universal real proposition, based on observation, in reliance on the uniformity of Nature: when well ascertained, it is called a Law. Thus, that all life depends on the presence of oxygen is (1) an universal proposition; (2) a real one, since the 'presence of oxygen' is not connoted by 'life'; (3) it is based on observation; (4) it relies on the uniformity of Nature, since all cases of life have not been examined.

Such a proposition is here called 'an induction,' when it is inductively proved; that is, proved by facts, not merely deduced from more general premises (except the premise of Nature's uniformity): and by the 'process of induction' is meant the method of inductive proof. The phrase 'process of induction' is often used in another sense, namely for the inference or judgment by which such propositions are arrived at. But it is better to call this 'the process of hypothesis,' and to regard it as a preliminary to the process of induction (that is, proof), as furnishing the hypothesis which, if it can stand the proper tests, becomes an induction or law.

Section 3. Inductive proofs are usually classed as Perfect and Imperfect. They are said to be perfect when all the instances within the scope of the given proposition have been severally examined, and the proposition has been found true in each case. But we have seen (chap. xiii. Section 2) that the instances included in universal propositions concerning Causes and Kinds cannot be exhaustively examined: we do not know all planets, all heat, all liquids, all life, etc.; and we never can, since a man's life is never long enough. It is only where the conditions of time, place, etc., are arbitrarily limited that examination can be exhaustive. Perfect induction might show (say) that every member of the present House of Commons has two Christian names. Such an argument is sometimes exhibited as a Syllogism in Darapti with a Minor premise in U., which legitimates a Conclusion in A., thus:

A.B. to Z have two Christian names;
A.B. to Z are all the present M.P.'s:
.'. All the present M.P.'s have two Christian names.

But in such an investigation there is no need of logical method to find the major premise; it is mere counting: and to carry out the syllogism is a hollow formality. Accordingly, our definition of Induction excludes the kind unfortunately called Perfect, by including in the notion of Induction a reliance on the uniformity of Nature; for this would be superfluous if every instance in question had been severally examined. Imperfect Induction, then, is what we have to deal with: the method of showing the credibility of an universal real proposition by an examination of some of the instances it includes, generally a small fraction of them.

Section 4. Imperfect Induction is either Methodical or

Immethodical. Now, Method is procedure upon a principle; and if the method is to be precise and conclusive, the principle must be clear and definite.

There is a Geometrical Method, because the axioms of Geometry are clear and definite, and by their means, with the aid of definitions, laws are deduced of the equality of lines and angles and other relations of position and magnitude in space. The process of proof is purely Deductive (the axioms and definitions being granted). Diagrams are used not as facts for observation, but merely to fix our attention in following the general argument; so that it matters little how badly they are drawn, as long as their divergence from the conditions of the proposition to be proved is not distracting. Even the appeal to "superposition" to prove the equality of magnitudes (as in Euclid I. 4), is not an appeal to observation, but to our judgment of what is implied in the foregoing conditions. Hence no inference is required from the special case to all similar ones; for they are all proved at once.

There is also, as we have seen, a method of Deductive Logic resting on the Principles of Consistency and the Dictum de omni et nullo. And we shall find that there is a method of Inductive Logic, resting on the principle of Causation.

But there are a good many general propositions, more or less trustworthy within a certain range of conditions, which cannot be methodically proved for want of a precise principle by which they may be tested; and they, therefore, depend upon Immethodical Induction, that is, upon the examination of as many instances as can be found, relying for the rest upon the undefinable principle of the Uniformity of Nature, since we are not able to connect them with any of its definite modes enumerated in chap. xiii. Section 7. To this subject we shall return in chap. xix., after treating of Methodical Induction, or the means of determining that a relation of events is of the nature of cause and effect, because the relation can be shown to have the marks of causation, or some of them.

Section 5. Observations and Experiments are the material grounds of Induction. An experiment is an observation made under prepared, and therefore known, conditions; and, when obtainable, it is much to be preferred. Simple observation shows that the burning of the fire depends, for one thing, on the supply of air; but it cannot show us that it depends on oxygen. To prove this we must make experiments as by obtaining pure oxygen and pure nitrogen (which, mixed in the proportion of one to four, form the air) in separate vessels, and then plunging a burning taper into the oxygen–when it will blaze fiercely; and again plunging it into the nitrogen–when it will be extinguished. This shows that the greater part of the air does nothing to keep the fire alight, except by diminishing its intensity and so making it last longer. Experiments are more perfect the more carefully they are prepared, and the more completely the conditions are known under which the given phenomenon is to be observed. Therefore, they become possible only when some knowledge has already been gained by observation; for else the preparation which they require could not be made.

Observation, then, was the first material ground of Induction, and in some sciences it remains the chief ground. The heavenly bodies, the winds and tides, the strata of the earth, and the movements of history, are beyond our power to experiment with. Experiments upon the living body or mind are indeed resorted to when practicable, even in the case of man, as now in all departments of Psychology; but, if of a grave nature, they are usually thought unjustifiable. And in political affairs experiments are hindered by the reflection, that those whose interests are affected must bear the consequences and may resent them. Hence, it is in physical and chemical inquiries and in the physiology of plants and animals (under certain conditions) that direct experiment is most constantly practised.

Where direct experiment is possible, however, it has many advantages over unaided observation. If one experiment does not enable us to observe the phenomenon satisfactorily, we may try again and again; whereas the mere observer, who wishes to study the bright spots on Mars, or a commercial crisis, must wait for a favourable opportunity. Again, in making experiments we can vary the conditions of the phenomenon, so as to observe its different behaviour in each case; whereas he who depends solely on observation must trust the bounty of nature to supply him with a suitable diversity of instances. It is a particular advantage of experiment that a phenomenon may sometimes be 'isolated,' that is, removed from the influence of all agents except that whose operation we desire to observe, or except those whose operation is already known: whereas a simple observer, who has no control over the conditions of the subject he studies, can never be quite sure that its movements or changes are not due to causes that have never been conspicuous enough to draw his attention. Finally, experiment enables us to observe coolly and circumspectly and to be precise as to what happens, the time of its occurrence, the order of successive events, their duration, intensity and extent.

But whether we proceed by observation or experiment, the utmost attainable exactness of measurements and calculation is requisite; and these presuppose some Unit, in multiples or divisions of which the result may be expressed. This unit cannot be an abstract number as in Arithmetic, but must be one something–an hour, or a yard, or a pound–according to the nature of the phenomenon to be measured. But what is an hour, or a yard or a pound? There must in each case be some constant Standard of reference to give assurance that the unit may always have the same value. "The English pound is defined by a certain lump of platinum preserved at Westminster." The unit may be identical with the standard or some division or multiple of it; and, in measuring the same kind of phenomena, different units may be used for different purposes as long as each bears a constant relation to the standard. Thus, taking the rotation of the earth as the standard of Time, the convenient unit for long periods is a year (which is a multiple); for shorter periods, a day (which is identical); for shorter still, an hour (which is a division), or a second, or a thousandth of a second. (See Jevons' Principles of Science, ch. 14.)

Section 6. The principle of Causation is the formal ground of Induction; and the Inductive Canons derived from it are means of testing the formal sufficiency of observations to justify the statement of a Law. If we can observe the process of cause and effect in nature we may generalise our observation into a law, because that process is invariable. First, then, can we observe the course of cause and effect? Our power to do so is limited by the refinement of our senses aided by instruments, such as lenses, thermometers, balances, etc. If the causal process is essentially molecular change, as in the maintenance of combustion by oxygen, we cannot directly observe it; if the process is partly cerebral or mental, as in social movements which depend on feeling and opinion, it can but remotely be inferred; even if the process is a collision of moving masses (billiard-balls), we cannot really observe what happens, the elastic yielding, and recoil and the internal changes that result; though no doubt photography will throw some light upon this, as it has done upon the galloping of horses and the impact of projectiles. Direct observation is limited to the effect which any change in a phenomenon (or its index) produces upon our senses; and what we believe to be the causal process is a matter of inference and calculation. The meagre and abstract outlines of Inductive Logic are apt to foster the notion, that the evidence on which Science rests is simple; but it is amazingly intricate and cumulative.

Secondly, so far as we can observe the process of nature, how shall we judge whether a true causal instance, a relation of cause and effect, is before us? By looking for the five marks of Causation. Thus, in the experiment above described, showing that oxygen supports combustion, we find–(1) that the taper which only glowed before being plunged into the oxygen, bursts into flame when there–Sequence; (2) that this begins to happen at once without perceptible interval–Immediacy; (3) that no other agent or disturbing circumstance was present (the preparation of the experiment having excluded any such thing)–Unconditionalness; (4) the experiment may be repeated as often as we like with the same result–Invariableness. Invariableness, indeed, I do not regard as formally necessary to be shown, supposing the other marks to be clear; for it can only be proved within our experience; and the very object of Induction is to find grounds of belief beyond actual experience. However, for material assurance, to guard against his own liability to error, the inquirer will of course repeat his experiments.

The above four are the qualitative marks of Causation: the fifth and quantitative mark is the Equality of Cause and Effect; and this, in the above example, the Chemist determines by showing that, instead of the oxygen and wax that have disappeared during combustion, an equivalent weight of carbon dioxide, water, etc., has been formed.

Here, then, we have all the marks of causation; but in the ordinary judgments of life, in history, politics, criticism, business, we must not expect such clear and direct proofs; in subsequent chapters it will appear how different kinds of evidence are combined in different departments of investigation.

Section 7. The Inductive Canons, to be explained in the next chapter, describe the character of observations and experiments that justify us in drawing conclusions about causation; and, as we have mentioned, they are derived from the principle of Causation itself. According to that principle, cause and effect are invariably, immediately and unconditionally antecedent and consequent, and are equal as to the matter and energy embodied.

Invariability can only be observed, in any of the methods of induction, by collecting more and more instances, or repeating experiments. Of course it can never be exhaustively observed.

Immediacy, too, in direct Induction, is a matter for observation the most exact that is possible.

Succession, or the relation itself of antecedent and consequent, must either be directly observed (or some index of it); or else ascertained by showing that energy gained by one phenomenon has been lost by another, for this implies succession.

But to determine the unconditionality of causation, or the indispensability of some condition, is the great object of the methods, and for that purpose the meaning of unconditionality may be further explicated by the following rules for the determination of a Cause.

A. Qualitative Determination
I.–For Positive Instances.

To prove a supposed Cause: (a) Any agent whose introduction among certain conditions (without further change) is followed by a given phenomenon; or, (b) whose removal is followed by the cessation (or modification) of that phenomenon, is (so far) the cause or an indispensable condition of it.

To find the Effect: (c) Any event that follows a given phenomenon, when there is no further change; or, (d) that does not occur when the conditions of a former occurrence are exactly the same, except for the absence of that phenomenon, is the effect of it (or is dependent on it).

II.–For Negative Instances.

To exclude a supposed Cause: (a) Any agent that can be introduced among certain conditions without being followed by a given phenomenon (or that is found without that phenomenon); or (b) that can be removed when that phenomenon is present without impairing it (or that is absent when that phenomenon is present), is not the cause, or does not complete the cause, of that phenomenon in those circumstances.

To exclude a supposed Effect: (c) Any event that occurs without the introduction (or presence) of a given phenomenon; or (d) that does not occur when that phenomenon is introduced (or is present), is not the effect of that phenomenon.

Subject to the conditions thus stated, the rules may be briefly put as follows:

I. (a) That which (without further change) is followed by a given event is its cause.

II. (a) That which is not so followed is not the cause.

I. (b) That which cannot be left out without impairing a phenomenon is a condition of it.

II. (b) That which can be left out is not a condition of it. B. Quantitative Determination

The Equality of Cause and Effect may be further explained by these rules:

III. (a) When a cause (or effect) increases or decreases, so does its effect (or cause).

III. (b) If two phenomena, having the other marks of cause and effect, seem unequal, the less contains an unexplored factor.

III. (c) If an antecedent and consequent do not increase or decrease correspondingly, they are not cause and effect, so far as they vary.

It will next be shown that these propositions are variously combined in Mill's five Canons of Induction: Agreement, the Joint Method, Difference, Variations, Residues. The first three are sometimes called Qualitative Methods, and the two last Quantitative; and although this grouping is not quite accurate, seeing that Difference is often used quantitatively, yet it draws attention to an important distinction between a mere description of conditions and determination by exact measurement.

To avoid certain misunderstandings, some slight alterations have been made in the wording of the Canons. It may seem questionable whether the Canons add anything to the above propositions: I think they do. They are not discussed in the ensuing chapter merely out of reverence for Mill, or regard for a nascent tradition; but because, as describing the character of observations and experiments that justify us in drawing conclusions about causation, they are guides to the analysis of observations and to the preparation of experiments. To many eminent investigators the Canons (as such) have been unknown; but they prepared their work effectively so far only as they had definite ideas to the same purport. A definite conception of the conditions of proof is the necessary antecedent of whatever preparations may be made f/or proving anything.