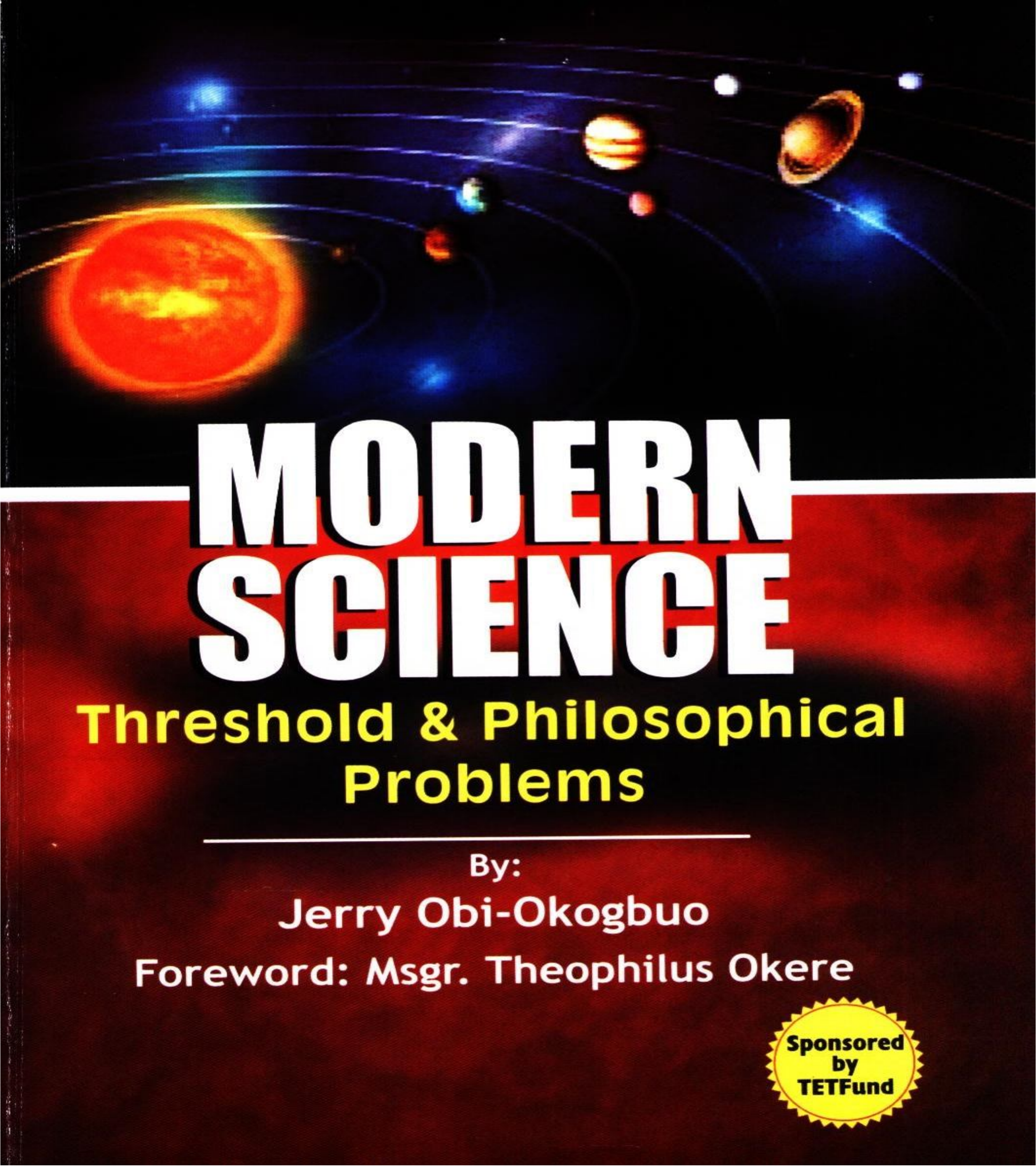
MODERN
SCIENCE
Threshold & Philosophical
Problems
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CHAPTER 2

THE METHOD OF SCIENCE

Three main goals of science are clearly identifiable. They are the theoretical goal: description and explanation; the practical goal: prediction and control; and the social goal: lucre and influence or prestige. However, central to the goals of science is explanation – making intelligible natural occurances or the multiple phenomena of our experiences. In this light, science is often said to be an account of why certain things are as they are. The account is sometimes called *explanans*, and the thing to be explained is called *explanandum*.[1] According to Irving M. Copi, "An explanation is a group of statements or a story from which the things to be explained can logically be inferred and whose assumption removes or diminishes its problematic or puzzling character."[2] For instance, the phenomenan of day and night are deducible from; that is, scientifically explained by, the rotation of the earth round the sun.

To analyze this kind of rational inquiry falls within the domain of the scientific method. When we talk about the scientific method, we are concerned to understand the thinking process of scientists; we want to know how the minds of scientists work when they are doing science; we want to see how scientists construct or come by the hypotheses – the general laws or principles that explain natural phenomena. In the analysis of the scientific method, we want to see the process taken by scientists when they invent; the step by step process of theory-construction; the logic of scientific discovery. In Einstein's expression we want to understand the "model of scientific thinking".

We have to warn, however, that there is no one single model of scientific thinking which every scientist must have to apply while doing science. Ernest Nagel expressly warns that when talking about the scientific method:

> It must not be understood to assert, for example, that the practice of scientific method consists in following prescribed rules for making experimental discoveries or for finding satisfactory explanations for matter of established fact. There are no rules of discovery and invention in science any more than there are such

> rules in the arts. Nor must the formula be construed as maintaining that the practice of scientific method consists in the use in all inquiries of some special set of techniques (such as the techniques of measurement employed in physical science), irrespective of the subject matter or the problem under investigation. Such an interpretation of the dictum is a caricature of its intents, and in any event the dictum on that interpretation is preposterous. Nor, finally, should the formular be read as claiming that the practice of scientific method effectively eliminates every form of personal bias or source of error which might otherwise impair the outcome of the inquiry, and more generally that it assures the truth of every conclusion, reached by inquires employing the method. But no such assurance can in fact be given; and no antecedently fixed set of rules can serve as automatic safeguards against unsuspected prejudices and other causes of error that might adversely affect the course of an investigation.[3]

What then is the scientific method? For we are sure that there exists, however elusive, something called the method of science. Answering this question Albert Einstein observes:

> If you wish to learn from the theoretical physicist anything about the methods which he uses; I would give you the following piece of advice: Don't listen to his words, examine his achievements. For to the discoverer in that field, the constructions of his imagination appear so necessary and so natural that he is apt to treat them not as the creations of his thoughts but as given realities.[4]

The scientific method is what the scientists do when they are doing science. It is the intellectual habit of investigating scientists. This is the spring of the creative aspect of the scientific enterprise. There is no device or mechanical method of achieving scientific cognition or of constructing a good hypothesis. Also it does not follow that because a man can do science, he can necessarily explain in abstract terms the nature of the scientific method. While explaining their methods, some scientists are influenced by the determination to make their reports acceptable to publishers of scientific journals and so on.

The main problem of the scientific method (of the experimental-scientific cognition) is to establish the interconnection between immediate experiences and those general laws which the investigator of nature has arrived at, and with whose help he has succeeded in explaining observable phenomena and predicting future events. That is, how is the language of the theoretician reducible to the language of the observer? How can we test the statements of the theoretician through empirical confirmation? This is a problem of the rational process, a problem of inference.

Charles Sanders Peirce (1839-1914) was the first person to categorize three different sorts of inference: deduction, induction, and retroduction (also referred to as abduction or the hypothetico-deductive method) and says that if there is any other kind of rational process, it is perhaps, analogy – a mixture of the other three.

It is not surprising, contrary to popular belief, that there is more than one model of scientific thinking. The reasons are simple, there is no one science, and there is no one single mode of knowledge, reality is enormously rich and different aspects of reality force on the human intellect different modes of study. While the natural sciences require patient observation of facts, mathematics is studied deductively starting with certain initial axioms, social sciences require a completely different method. Thus, a univocal notion of science and the scientific method is inadequate, not being appropriate to the diversity of the objects of science.

The Deductive Method: The deductive method is the model of scientific thinking in which the conclusion (explanandum) follows necessarily or logically from the explanatory premise. Deduction begins with a premise that is seen to be true in its own right without recourse to any other evidence then it proceeds to deduce other propositions. It is in the form of axiomatic system (the explanans). Deduction is from the Latin roots *de* meaning *from;* and *ducere* meaning *to lead*. Deduction is structured after Aristotle's *apagoge*. Aristotle is regarded as the inventor of deduction. The point of the deductive model of scientific reasoning is that the conclusion is necessarily or logically deduced from the premises; and as such if the premises are true, the conclusion must also be true. A deduction is either valid or invalid; consequently deduction is regarded as the ideal rational process or paradigm scientific explanation. Deduction is the hallmark of logic.

Deduction usually proceeds from a general premise to a particular conclusion. It can proceed from general to general, or even from particular to particular, with the only provisor that the premise provides sufficient and sometimes necessary warrant for the conclusion. This is why it is more satisfactory in modern times to call deduction necessary inference. A very good example is recorded by A. R. lacey:

All water heated at normal pressure to 100^{0C} boils;
this water was so heated.
These two premises explain why this water boiled.[5]

John Stuart Mill criticizes deduction of being a mere verbal "transformation" especially with regard to immediate inferences; or it is ultimately probable inference, that is, disguised induction. When Mill says deduction is mere verbal transformation, he is saying it is a circuitous reasoning. This implies that it does not increase our knowledge. It is trivial. Charles Sanders Peirce criticizes deduction of being a mere "colligation of premises". Francis Bacon says "deduction does not do more than render explicit the logical consequences of generalization derived from some external sources."[6]

The Inductive Method: The inductive method is the model of scientific thinking in which a generalized law-like conclusion (such as hypothesis or theory) is educed or abstracted from singular or particular observations or facts. A.R. Lacey defines it as "...any rational process where from premises about somethings of a certain king a conclusion is drawn about some or all of the remaining things of that kind."[7] In induction, one proceeds to make a claim about the whole of a class from the evidence of a sample. Regular co-occurrence is taken to be a sufficient and perhaps the legitimate basis for asserting the law-like generalization. Induction is from the Latin roots *in* and *ducere* meaning *to lead in*. It was first translated into Latin probably by Cicero (106-43 B.C.) from Aristotle's term *epagoge*. The point of the inductive model of scientific reasoning is that it proceeds from particular assertions to general assertions. Induction is the hallmark of science because general statements are based on accumulated observations of specific instances and scientific statements are based on the observation of facts. According to inductivists; inductive method demacates science and non-science.

Inductive thinking does not proceed from self-evident premises but from observational data; and the conclusion tells us something new, something not implicit in the premise. For instance, if a large number of ravens have been observed; and the observed ravens were black; then we can educe that all ravens are black.

The formal study of induction started with Aristotle (384-322 B.C.) Francis Bacon (1561-1626) was its modern chief theorist while John.S. Mill (1806-1873) came closest to working out the inductivist ideal. Galileo popularized its application. There are two kinds of induction: perfect induction, also variously called primitive, simple, strict, narrow or enumerative induction; and ampliative induction, also variously called wide or sophisticated induction. Simple or enumerative induction draws its conclusion directly in a single step. The conclusion rests on the knowledge of each instance covered. The conclusion does not go beyond the evidence. For instance, if all observed swans are white, then all swans are white. In ampliative or sophisticated induction the premises are mere samples of the class, while the conclusion is a generalization educed from the properties of the sample to the properties of the class.[8] The difference between the two is that sophisticated induction is broader. In a actual fact, it is based on the simple induction.

The Problem of Induction: This is also called the Humean problem after David Hume (1711-1776) who first pointed out the problem. The problem of induction is how to justify the inductive leap. In induction, there is a leap from particular observational statements to universal unobservable statement. R.D. Harre and E.H. Madden put it thus: the problem of induction is "the problem of the legitimacy of generalizing any result obtained in particular empirical investigation."[9]

Though Hume did not anywhere use the word induction, it is obvious that his analysis of cause and effect directly bears on induction. Hume critically observes:

> That there is nothing in any object considered in itself, which can afford us a reason to drawing a conclusion beyond it, and that even after the observation of the frequent or constant conjunction of objects, we have no reason to draw any inference concerning any object beyond those of which we have had experience.[10]

Hume is saying that, when we say that **A** causes **B**, we are merely falling back on our experience of contiguity, priority in time and constant conjunction. Contiguity means that **A** (the cause) and **B** (the effect) are always close together. Priority in time means that **A** always precedes **B**. Constant conjunction means that we always notice **A** accompanied by **B**. But our idea of causation goes beyond contiguity, priority in time and constant conjunction to the belief in the idea of "necessary connexion". But sadly, according to Hume, no matter how repeatedly an event, we are not rationally or logically entitled to believe in a "necessary connection" between cause or between observed particular instances and the general statement (laws or theories) inferred from them in induction. He says:

> Even after one instance or experiment where we have observed a particular event to follow upon another, we are not entitled to

> form a general rule or foretell what will happen in like cases, it being justly esteemed an unpardonable temerity to judge of the whole course of nature from one single experiment however accurate or certain.[11]

It follows that our belief in causation (induction or probable inference), according to Hume, is neither based on experience nor logical sequence but on "animal faith" or psychological disposition – the habit or custom of expecting effects. Consequently, from the point of view of logic, we cannot justify the inference from particular statements to universal ones. Inductive inference is inconclusive. No matter the number of white swans we have observed, we cannot logically conclude that all swans are white. In inductive inference then, we should not be speaking of the truth of its conclusion but rather of its probability. This probability is high or low depending on whether the experience it is based upon is high or low. In some instances the probability is so high that there is no conceivable chance of contradiction in the future. For instance, the probability that the sun will rise tomorrow is so high that we do not entertain any fear of contradiction and this strong belief is based on the many experiences we have had of the sun rising every morning. If induction has been reduced to a doubtful or probable edific, and induction is the foundation of the scientific edific, then science rests on doubtful or probable foundation.

Probability is from the Latin *probare* which means *to prove* or to *approve*. The Latin is a translation from the Greek *eulogen* which means *reasonable* or *sensible*. The term thus refers to the *likeliness of truth;* the likelihood of an event happening or of the truth of an event. While conclusions follow as of necessity in deductive inference (i.e nomological explanations are deductive), they follow as of probability in induction. (i.e. inductive explanations are statistical or probabilistic).

In modern times, probability theory has been developed into a very sophisticated study and many theories of it have emerged with some difficultly identifying a common meaning. E.H. Madden distinguished three types of probability statement: the classical, the frequency and the inductive theories of probability.

According to the classical theory of probability closely associated with Pierre Simon Marquis de Laplace, the probability of a thrown die turning up face 3 is 1/6. if a die is thrown, any one of its six faces might turn up and each of these events is equiprobable. That is, any face according to Laplace has as much chance as any other to turn up. We have no reason to expect one face to turn up more or less than others.

The frequency theory developed from statistical probability statement is associated with John Venn and Charles Sanders Peirce. According to this view, probability is "the measure of the relative frequency with which the members of a specified class of objects or events exhibit a certain property. For instance "the probability of a thirty year-old person living in the United States surviving his thirty-first birthday is 945. This means that an observation of the class of thirty-year-old men in the United States showed that for every 1000 men in this class 945 exhibit the property of surviving their next birthday.

The inductive theory of probability is simple, straightforward or highly complex. This theory measures probability in "weight or amount of evidence confirming a hypothesis, theory, or statement" That is, the use of probability is qualitative and unanalyzable. For instance, a theory with much evidence is highly probable; and a theory with some evidence is more or less probable; and theory with little evidence is improbable.

While some philosophers like Aristotle, Aquinas, Hobbes, J.S. Mill, Descartes and Kant insist that scientific (inductive) inference is valid, some other philosophers like John Venn, K. Popper, and Hans Reichenbach doubt its validity. Einstein speaking in his "autobiographical notes" of inductive inference which he calls "conjecture" says "by and by I dispaired of the possibility of discovering the true laws by means of constructive efforts based on known facts."[12] On his own part, Karl Popper, one of the greatest opponents of inductive inference says:

My own view is that the various difficulties of inductive logic here sketched are insurmountable. So also, I fear, are those inherent in the doctrine, so widely current today, that inductive inference, although not 'strictly valid', can attain some degree of 'reliability' or of probability.[13]

In this way, Popper denied both inductive inference and its fall out, the probability theory.

In spite of the "insurmountable" problem of induction, some attempts have been made to rescue induction from Humes devastating attack. These rescue attempts have been categorized as: the metaphysical justification of induction; the pragmatic vindication of inductions and the dismissal or dissolution of the problem of induction.

Metaphysical Justifications of Induction: This is the view that inductive inference follows logically or necessarily from inductive premises if the empirical evidence is supplemented with the metaphysical assumption or presupposition that *nature is uniform*. That is, the extrapolation of what the empirical evidence is telling us to all cases follows logically or necessarily if in an inductive inference we use as one of the premises the principle of the uniformity of nature. For instance:

> *X and Y have always occurred together;*
> *Nature is uniform;*
> Therefore X and Y will always occur together.

When philosophers say that nature is uniform, they mean that the regularities of nature are independent of space and time; the laws of science are independent of spatial and temporal location. It follows that what occurred in the past will also occur exactly the same way in the future. Another way of stating the metaphysical principle of the uniformity or homogeneity of nature is to say 'same cause, same effect'. If a cause occurs yesterday, today or tomorrow, it will have the same effect. This is called metaphysical assumption or presupposition of science because it purports to state a fact of our universe that is not empirically verifiable.

The objection to the principle of the uniformity of nature as an aid to the justification of induction is that it is circuitous. The validity of each induction presupposes the principle, yet the principle cannot be established as a final inductive conclusion of any induction.

The Pragmatic Vindication of Induction: The proponents of this view concede that there is no logical justification of induction even with supplementing the empirical evidence with the metaphysical principle of the uniformity of nature. There is no inductive justification of inductive inference – for this is circular. But they reject Hume's skepticism either. True it cannot be demonstrated that induction is sufficient condition of knowledge of the future, but it can be shown that it is a necessary conduction. Thus, since it can be shown that induction is at least a necessary condition of knowledge of the future, it is reasonable to adopt and follow it. Induction has proved successful as a tool of predication and explanation. This is called the practical vindication of induction. This contrasts with the logical justification which tries to show that induction is a sufficient condition for knowledge of the future.

Induction is also justified for being self-corrective in nature. Charles Sanders Peirce says: "The true guarantee of the validity of induction is that it is a method of reaching conclusions which, if it be persisted in long enough, will assuredly correct any error concerning future experience into which it may temporarily lead us."[14] That is, sampling helps us make predictions about the future. But if the future comes and does not conform to the prediction, then this sampling enlarges our data and thus corrects our prediction.

Dismissal or Dissolution of the Problem of Induction: This is a response to the problem of induction without recourse to either the metaphysical justification or the pragmatic vindication. There are a good number of philosophers who hold this view. They cannot easily be categorized. Sometimes they are called common-sense or ordinary language philosophers. They say that the denial of induction "is either self-contradictory, mistaken, or vacuous". The sceptic has no reason looking for any other justification of induction except the normal inductive process. Thus the so-called problem of induction is a pseudo-problem.

The Hypothetico-Deductive Method:

This is a model of scientific thinking which proceeds by first making empirical observations (noting problems), formulating a hypothesis that explains the empirical observation made and making deductive conclusions from the hypothesis; and then testing by observation or experiment whether or not these consequences occur in fact. If they occur then the hypothesis is confirmed, if they do not occur the hypothesis is rejected because brute fact must always win over beautiful hypothesis. The value of the hypothesis depends on its ability to deductively generate observation statements (consequences or conclusions) that turn out to be true and interesting. When a hypothesis is thus accepted, it may be called a theory and may lead to the statement of a principle. The hypothetico-deductive method starts with experience and ends with experience. It is a combination of the technics of empiricism (inductive logic) and rationalism (deductive logic). Robert Boyle joined the two and said: "I suppose that I have established forever a true and lawful marriage between the empirical and the rational faculty."[15]

The hypothetico-deductive method does not proceed in the classical model of Mill; that is by educing hypotheses from the set of individual observations (induction). This process, according to Enstein, is only "appropriate to the youth of science."[16] On the contrary, hypotheses are sometimes postulated, conjectured or is sometimes only a "supposition", "inspiration", "guess" or "hunch". It is therefore tentative until confirmed. There is no direct logical path from the observation experiences to the hypothesis. This is the innovative, constructive or speculative element of science. It is also a demonstration that theories are man-made. But Newton thought there was a direct link between experience and hypothesis that is why he says *hypothesis non fingo,* which could more adequately mean that we do not create the laws of nature we discover them.

The hypothetico-deductive method was applied by Newton though he did not anywhere categorically state that it was his method. If we examine what he did as a practicing scientist it becomes evident that it was his method. He made empirical observations like every other inductivist, such as Bacon. One of such observations was a falling apple. Then he formulated general hypothesis about the motion of bodies, (Now known as the law of gravity) to make sense out of the observations. The general hypothesis predicts what behaviour is expected in other areas of experience; for instance, the motion of the moon. Now to verify or confirm the hypothesis, Newton returned to experience or empirical observations. Ironically, the first time, the observed motion of the moon failed to confirm the hypothesis. Newton abandoned his work till much later when a French expedition made a more accurate measurement of the circumference of the earth. Newton now saw that his original calculation was based on a wrong conception of the earth. With the new calculation, the old observations of the moon agreed with the hypothesis. Thus Newton's method was a novel process, a mixture of experience and deductive logic, which is what we hereby call the hypothetico-deductive method.

The hypothetico-deductive method embraces both *abduction* and *retroduction*. *Abduction* is from the Latin *ab* meaning *away*; and *ducere* meaning *to lead*. *Abduction* is the rational process whereby hypotheses are generated moving from a particular case to a possible explanation of the case. Abduction is a probable mode of inference. It does not carry certainty. It has the following form recorded by Peirce:

> The surprising fact **F**, is observed
> If **H** were true **F** would be commonplace
> There **H** is (possible) true.[17]

On its part *retroduction* is the rational process that begins from the verification of the deductive consequences of the hypothesis. Comparatively, unlike *retroduction* the hypothetico-deductive method is founded on experience and unlike abduction, it terminates in experience.

Experimentation:

The essential feature of the modern scientific method is experimentation. The experimental method of science involves careful observation of facts and test of hypothesis to see whether or not predicated and actual consequences coincide. This must be public and repeatable. Therefore, in the dialogue with nature experimentation is central.

Modern science is the union of theory and practice; the constant endeavour to blend theoretical explanations (formulations) about the world with the brute facts of the world. Science is dialogue with nature. Modern scientists believe that nature is intelligible, simple, uniform (or homogenous). They believe that if nature is quizzed through the experimental method, it would speak. Nature responds to experimental interrogation, and its answers can be written in one language, the mathematical language. Since nature is homogenous, local experimentation will yield global truth. Richard Feynman compared nature to a huge chess game, the complexity is just apparent, if you know the rules it is simple. The rule is the experimental method. Subject nature to experimentation and it will speak. Galileo Says: "However partially nature is allowed to speak, once it has expressed itself, there is no further dissent: nature never lies."[18]

But how can we define the experimental method. For it is not just the faithful observation of facts as they occur nor is it the mere search for empirical connections between occurrences. It presupposes these and involves staging or manipulating physical reality so that it conforms as closely as possible to a theoretical description. That is, the phenomenon studied must be made to approximate some ideal situation or some conceptual scheme. But sometimes nature can say no to the questions posed to it. Or sometimes nature refuses to say what the scientist wants it to say.

The experimental method is an art. It is based on special skills and not on general rules. It is the art of choosing an interesting question and testing all the consequences of the theoretical framework thereby implied. The important feature of the experimental method is the control of variables and it is simple.[19] First recognize the problem and establish the facts by direct, frequent and careful observations. Collect all the possible relevant facts regarding the problem. Propose a solution or a hypothesis and deduce all the possible consequences or conclusions there-from. Then test them by relating many variables and noting what happens when only one is allowed to vary, the others remaining constant. Multiply the experiment as much as possible with utmost precision. Draw conclusions and express them in mathematical language if possible. Confront the new equations thus obtained with reality to see the facts they represent.

Significance of the Scientific Method: The significance of the scientific method is that it makes science a cooperative venture in spite of the fact that scientists may be working separately.

The scientific method makes truth less relative more objective and trustworthy. Any one can arrive at the same truth. And in short nothing is taken as scientific truth until collaborated or until checked and crosschecked in many ways. George Sarton writing about the significance of the scientific method says:

> It is the experimental method which has given to human reason its full potency, but at the same time it has clearly shown its limitations and provided means of controlling it. It has proved the relativity of truth, but at the same time has made it possible to measure its objectivity and its degree of approximation. Above all it has taught men to be impartial (or at least to try to be), to want the whole truth, and not only the part of it which may be convenient and agreeable.[20]

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