then deliberately selecting facts and principles tending to support it. This is the method sometimes used in debating. When two opposing debaters marshal the arguments on both sides of a question, each is likely to be more interested in winning the debate — proving his side right through the power of logic and eloquence — than in finding the true answer. But Bacon was being a little hard on Aristotle, for the latter seems to have insisted on the necessity of basing generalizations upon facts. The followers of Aristotle in the Middle Ages, however, undoubtedly neglected this part of his teachings and adopted the habit of deriving their conclusions from generalities and from statements of presumed authorities.

Bacon — and, for that matter, Leonardo da Vinci before him — stressed the need for basing general conclusions upon specific facts through direct observation. This, of course, is what we know as *inductive reasoning* — that is, going from the particular to the general, rather than, as in deductive reasoning, from the general to the particular. Bacon advised the scholar to ignore authorities, to observe nature closely, to experiment, to draw his own inferences, to classify his facts in order to reach minor generalizations, and then to proceed from the minor generalizations to greater ones. He especially warned against formulating any hypothesis (or probable solution) until all the facts have been gathered. This system of reasoning has been termed mechanistic, because every step of the process is based on provable fact rather than on speculation or logic.

The plain truth is that many scholarly problems cannot be solved by inductive reasoning alone, as Charles Darwin found when he attempted zealously to follow Bacon's advice. For years he collected fact after fact in his biological researches, hoping that the facts themselves would lead to an important generalization. Fact-gathering, however, proved as unproductive of results as gathering bricks for a house when there is no architectural plan for building it. Not until Darwin stumbled upon a possible solution to the problem of how evolution takes place and began to test it by making deductions from it was he able to see how his facts could be put together to form a workable theory. He describes this event as follows:

> My first note-book [on evolution] was opened in July 1837. I worked on true Baconian principles, and without any theory collected facts on a wholesale scale, more especially with respect to domesticated productions, by printed enquiries, by conversation with skillful breeders and gardeners, and by extensive reading. When I see the list of books of all kinds which I read and abstracted, including whole series of Journals and Transactions, I am surprised at my industry. I soon perceived that selection was the keystone of man's success in making useful races of animals and plants. But how selection could be applied to organisms living in a state of nature remained for some time a mystery to me.
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> In October 1838, that is, fifteen months after I had begun my systematic enquiry, I happened to read for amusement 'Malthus on Population,' and being well prepared to appreciate the struggle for existence which everywhere goes on from long-continued observation of the habits of animals and plants, it at once struck me that under these circumstances favourable variations would tend to be preserved, and unfavourable ones to be destroyed. The result of this would be the formation of new species. Here then I had at last got a theory by which to work. . . .[1]

In other words, having gathered a considerable body of data, Darwin made a shrewd guess (derived from reading Malthus) as to what the data might mean. He formulated in his mind a tentative explanation of the facts he already knew and then proceeded, with his theory (or hypothesis) as a guide for further investigation, to see whether his idea would be supported or proved wrong by the additional evidence which could be gathered. Thus Darwin used both inductive and deductive reasoning to arrive at his final conclusions. This is a good example of how modern research works.

The Scientific Method

The system Darwin used in seeking an explanation of biological evolution is often called the method of scientific inquiry. This method, of course, is effective not only for studies in the physical and biological sciences but for studies in any field.

Most modern research is conducted in accordance with the same method. Scientific inquiry as a method of learning new truth differs, as we have already seen, from the methods of chance, of trial-and-error, of generalization from experience, and of the syllogism. It also

[1] Francis Darwin, ed., *The Life and Letters of Charles Darwin*, 2 vols. (New York: D. Appleton and Co., 1899), I, 68.

differs from a way of learning often claimed by creative artists and by many scientists too — that of intuition. We should not rule out the possibility that valuable advances in knowledge may sometimes be the result of "unearned grants of insight," to borrow the phrase of Walter B. Cannon. Many an important idea has arrived as a flash of intuition, like Athena springing from the brow of Zeus. But these insights that overleap methods are most likely to come to the scholar who has worked long and hard on a project, and he will subject them to the rigorous tests of the scientific method before he accepts them as truth. Intuition must be regarded as a fortuitous glimpse of truth which comes as the result of no conscious effort or plan. Intuitive insight, moreover, cannot be relied on without careful consideration of its applications; it can be wrong as easily as it can be right. Since the intuitive recognition of truth cannot be objectively analyzed, and since it cannot be controlled, we shall not here discuss it in detail; our concern is with the conscious method or planned procedure that has proved most useful in modern research.

A great research institution recently described the process which is used for all studies made by its staff. The process consists of several very definite steps. These are: (1) identification of the problem to be investigated, (2) collection of essential facts pertaining to the problem, (3) selection of one or more tentative solutions of the problem, (4) evaluation of these alternative solutions to determine which of them is in accord with all the facts, and (5) the final selection of the most likely solution. In general, these are the steps most commonly followed in all modern research. They are discussed in considerable detail in later chapters of this book.

What are the distinguishing characteristics of this method? In the first place, it is based upon the belief that a natural explanation can be found for every observable phenomenon. It assumes that the universe is an ordered cosmos in which there is no result without a cause. Whereas primitive man ascribed anything unusual that he might see or hear to the special intervention of the gods, modern man looks for natural causes. Although there still remain many areas of knowledge that have resisted scientific investigation, we have had remarkable success in applying this fundamental assumption of the scientific method.

In the second place, this method rejects reliance upon authority and substitutes the idea that conclusions are valid only when supported by evidence. The modern scholar does not accept the word of Aristotle or anyone else as authoritative unless he has confirmed it by an inspection of the facts. This entails both direct observation and experiment. Galileo reportedly investigated the rate of acceleration of falling bodies by dropping cannon balls of various weights from the leaning tower of Pisa in 1589. He did not satisfy himself by merely *reasoning* or by consulting authorities on the matter, but actually studied the facts by experimental means. Until his time it had been commonly assumed by thinking men, following Aristotle, that a heavy object naturally would fall to the ground faster than a lighter object. This assumption appears perfectly logical and reasonable to anyone who thinks about it without taking the trouble to test it by experiment. Galileo refused, however, to accept either authority or logic as the basis for his conclusions and so learned, perhaps to his own surprise, that the cannon balls he dropped, except for minor differences caused by the resistance of the air, would all fall at the same rate of speed.

Galileo's experiment also illustrates a third way in which the scientific method is unlike others. This is in the substitution, wherever possible, of actual observation for logic. Ideas and facts, whether arrived at through logic or taken from some authoritative source, must be tested and shown to be either true or false.

What we have said in the preceding paragraphs does not mean, of course, that either logic or authority can be entirely dispensed with in research. The statements of experts upon some subject may be useful when other evidence is lacking, and especially when we have no contrary evidence. Yet reliance upon authority does not in itself constitute scientific investigation, and it may lead the investigator astray. We must also say that arguments advanced in the support of any conclusion should always be logical. In other words, the conclusion ought to be consistent with the evidence and with known facts and experience within the field of study. Logic may be thought of as the language of reasoning (relating to quality), just as mathematics is the language of measurement (relating to quantity or size). The use of logic, therefore, is essential to scientific inquiry.

Revolutionibus Orbium Coelestium and argued for a heliocentric or sun-centered theory of the universe. Much as Ptolemy was attacked by other scholars for heretical teaching in his day, so too Copernicus had to bear the label of heretic for seeming to dispute the accepted authorities. In the end, however, the new ideas were generally adopted because they proved more useful than the old and were apparently in greater accord with the observable facts. Acceptance of the heliocentric theory as proposed by Copernicus took about a century.

Ptolemy postulated a spherical earth entirely surrounded by a greater sphere in which the permanent stars are fixed. Thus as the outer sphere turns, the stars move slowly across the heavens at a regular rate of speed. The position of each of the fixed stars remains constant. The planets, Ptolemy observed, are not fixed in this outer circling sphere; each has an additional movement of its own which he described as an epicycle. Assuming the existence of such an epicycle (or smaller circle in which the planet moves, the center of which is on the surface of the outer sphere) explains what would otherwise appear to be irregular and erratic motion on the part of each of the planets. A separate epicycle must be assumed for every planet and its relative size determined by observation. The discovery of a new planet means the invention of a new epicycle to account for its movements. Copernicus, on the other hand, taught that, once the idea of a heliocentric rather than a geocentric universe is accepted, the motions of the planets can be calculated and accounted for without assuming the existence of epicycles and without having to invent new epicycles when a new planet is found. This amounts to a considerable simplification in theory.

Neither Ptolemy nor Copernicus conducted any experiments to test his hypothesis. Indeed, neither would have considered that any experimental work, when dealing with celestial bodies, was either necessary or possible. They both reasoned logically from the facts they observed. Thus we cannot say that Copernicus really had any *proof* to show his predecessor's theory false. He did so simply by supplying a less complicated and therefore more logical theory, that is, a "better" theory. In essence, what he did was to show that, if we are willing to assume a universe in which the earth moves around the sun (rather than one in which the sun moves around the earth), many facts can easily be explained which would otherwise need elaborate and complex explanations. In other words, the principal advantage of the Copernican theory, when compared with that of Ptolemy, lay in its relative simplicity—in its power to explain more of the facts with fewer modifications of the theory itself. Later it was also shown that the ideas of Copernicus were far more useful for predictive purposes. Early in the nineteenth century the planet Neptune was located largely as the result of conclusions based upon the Copernican theory. Such a discovery very likely would not have been made, except through accident, under the Ptolemaic system.

Nevertheless, it must be understood that the Ptolemaic theory did explain the movements of the planets (although not the reason for their movements) and was just as sound mathematically as the Copernican explanation of the same facts. Astronomers may be said to have had placed before them two rival theories of planetary motion, each of which competently accounted for the observable facts. If either theory would explain the facts, and if accurate calculations could be made according to either, why should astronomers have come to prefer one to the other? The answer is that one theory was much more simple and all-encompassing than the other; it explained more of the data with fewer complications in the theory itself. Later, of course, with the invention of better instruments it became possible to observe more and more facts which had been unknown to both Ptolemy and Copernicus and which gave further weight to the Copernican explanation.

The Marks of a Good Theory

The conclusion or theory resulting from any piece of thorough scholarly research can be judged and evaluated according to the success with which it meets the criteria of certain desirable characteristics. For instance, a satisfactory theory about anything must agree with and account for all the important observable facts in the case. To be sure, not every phenomenon can be satisfactorily explained, and then we sometimes merely make a guess, hoping that further study may reveal the proper explanation. Sometimes a theory will explain part of the evidence but fail to explain the rest of it, and such a theory must be regarded usually as incomplete. In general, no theory in any field of knowledge can be regarded as final and adequate unless it is able to explain all the data which have been observed.

Besides judging a theory on its ability to explain the facts, we may say also that the theory which has fewer complexities and assumptions — in a word, the simpler theory — is preferable to the more complicated one. As we have seen, greater simplicity was one of the advantages causing the acceptance of the Copernican theory. It requires no complicated system of epicycles to explain the planets' movements. As Isaac Newton so aptly phrased it, "Nature is pleased with simplicity." In different words, we may consider that theory best which explains the greatest number of observable facts without revisions of the theory. This idea has come to be known in scholarship as the Law of Parsimony.

Thus, a good theory ought to be capable of explaining all the known facts relating to any particular problem; and the more simply it can explain these facts, the better is the theory. Besides this, a theory may receive added weight if predictions based upon it actually turn out to be true. As a matter of fact, the success of a theory for predictive purposes constitutes one of the most useful criteria by which it may be judged. To elaborate on an instance already mentioned, the existence of the planet which later became known as Neptune could be predicted with certainty according to the principles of the Copernican theory (reinforced by Newton's ideas regarding gravitation) long before the planet itself was ever sighted through the telescope. Furthermore, astronomers for many years contended, without being able to secure exact measurements to test the idea, that if Copernicus was correct in arguing that the earth revolves around the sun, even a fixed star would have to appear in different positions if seen from two different points in the earth's orbit. That is to say, the revolution of the earth would cause changes in the actual distance between a star and any given point on the earth's surface. After a sufficiently powerful telescope had been developed, Bessel was able to verify this fact by observation in 1838 — a very difficult feat, indeed.

It should be said finally of the good theory in scholarship that it ought to be fruitful of new discoveries. It should suggest further

areas of knowledge to be investigated. One of the great achievements of the Copernican theory consisted in opening the door to the Newtonian mechanics upon which much of our modern technological development has depended. Probably the better the theory, the more new doors of knowledge it will unlock.

The Hypothesis as a Temporary Guess

As we have seen, the hypothesis may be looked at in two different ways. On the one hand, it may be regarded as a *principle* or *generalization* which has resulted from the careful and thorough study of a given problem. In this sense, the term *theory* or even *law* is often used, meaning a hypothesis adequately substantiated by evidence. On the other hand, in any study (particularly during the early stages) there may be one or more tentative hypotheses which really are nothing more than *temporary guesses at possible solutions* which the scholar makes to guide him in searching for further data and thus in reaching his final, correct conclusion. A scholar may test and reject any number of hypotheses in the course of a single research project.

When we speak of the hypothesis as a temporary guess or tentative solution of a scholarly problem, we find that it is arrived at and used much as follows:

1. The investigator, after a preliminary gathering of data or evidence which he believes to be related to the problem he is studying, employs inductive reasoning to reach a preliminary conclusion (or probable solution). This constitutes merely the first or trial hypothesis.

2. Having adopted this hypothesis temporarily as the most probable answer to the question he is investigating, the scholar next makes use of deductive reasoning to decide what kind of data he should expect to find if the hypothesis is true. In other words, he determines what should logically follow from the principle or generalization he is testing.

3. Having decided through his reasoning and previous knowledge exactly what kind of data to look for, the investigator then proceeds to test his hypothesis by gathering all possible data and considering whether the actual evidence and his hypothesis are fully in agreement.